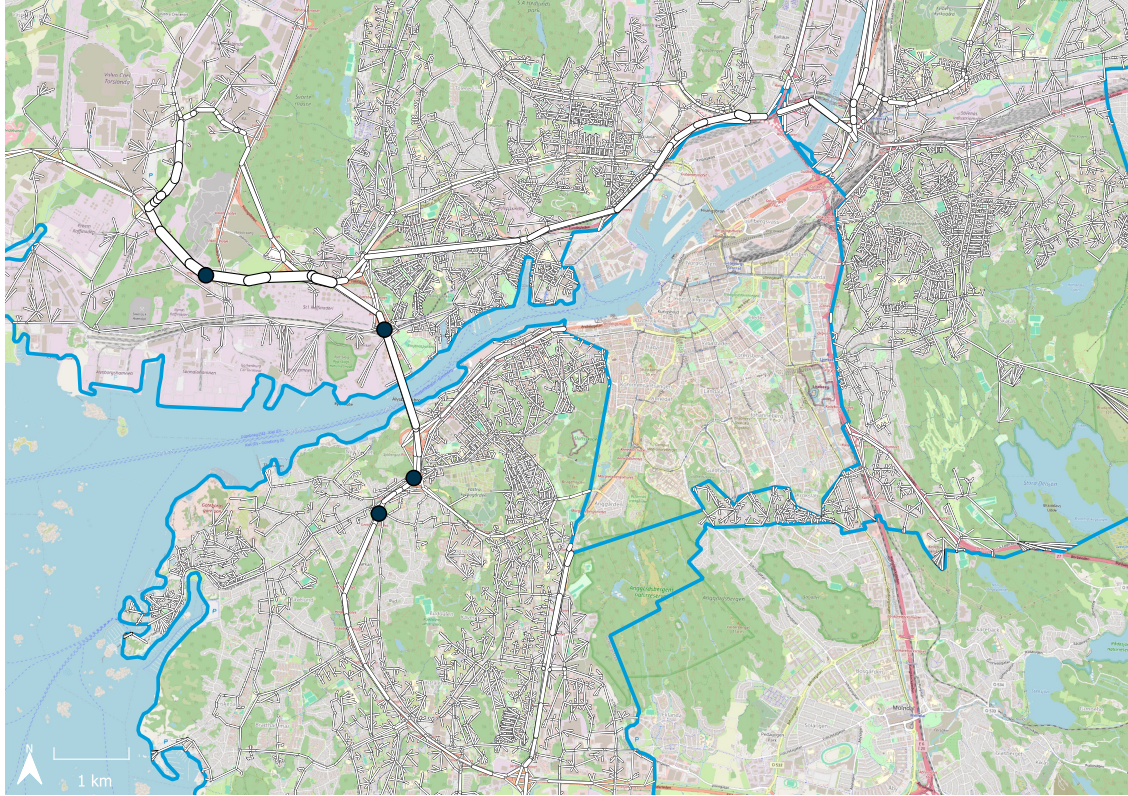




CHALMERS
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Data-Driven Mobility Hub Location Selection and Design

A GIS-Based Approach to Support Sustainable Travel Behavior

Master's Thesis in Infrastructure and Environmental Engineering

JULIA BORGSTEN & UNNI GRANFORS

DEPARTMENT OF ARCHITECTURE AND CIVIL ENGINEERING

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2026

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MASTER'S THESIS 2026

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UNNI GRANFORS

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Supervisors: Yinghao Chen & Xiaohan Liu, Department of Architecture and Civil Engineering. Anton Hammarsten & Pontus Sjöqvist, COWI.

Examiner: Kun Gao, Department of Architecture and Civil Engineering

Master's Thesis 2026
Department of Architecture and Civil Engineering
Division of Geology and Geotechnics
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

Cover: Zoomed in map showing the central area of Gothenburg with the four proposed locations for mobility hubs. The traffic flow segment use and the study area borders are also present. Background map provided by © OpenStreetMap contributors (2026).

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Abstract

Car dependency in urban areas remains a major challenge for sustainable transport planning, increasing the need for attractive alternative transport solutions, such as mobility hubs. Mobility hubs are strategically located and include private and shared transport modes with easy transfers, as well as the supporting services needed to simplify the daily life of its users. In this study, a location selection methodology is developed and presented in this study, along with design guidelines. The main objective of the study is to reduce car dependency for the commuting population by providing opportunities for multimodal travel along their current transport routes. Furthermore, factors that affect travel behavior in different sociodemographic groups and how they can be incorporated into the location selection process were of interest.

A literature review was conducted where topics such as drivers for car commuting, modal shift, sociodemographic factors, current mobility hub location selection processes and commonly included elements were researched. The findings were subsequently applied in QGIS, where synthetic traffic flow data, infrastructure connected to pedestrians, bicycles, cars, and public transport, and sociodemographic statistics are combined into a spatial scoring framework consisting of traffic flow, catchment potential, connectivity, and sociodemographic suitability. The findings include four specific locations within two corridors on major highways in western Gothenburg, indicating that intercepting commuters before entering the city center could contribute to reduced car dependency. The study highlights the importance of combining behavioral and sociodemographic factors with spatial accessibility when determining suitable locations for mobility hubs. The developed methodology can be adapted for use in other municipalities and planning contexts.

Keywords: Mobility hub, Modal shift, Spatial analysis, Synthetic population, Rule-based methods, Travel behavior

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Julia Borgsten & Unni Granfors, Gothenburg, May 2026

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1

Introduction

Sweden aims to reduce greenhouse gas emissions from the transport sector, where the use of private cars remains a significant contributor to the impact of greenhouse gas emissions, congestion, and inefficient land use (Naturvårdsverket, 2025). The transport sector accounts for 25% of greenhouse gas emissions and road transport accounts for approximately 71% of the transport sector (Europeiska rådet, 2025). In Sweden, the car remains the dominant mode of transport and accounts for just over half of all trips in 2024 (Trafikanalys, 2024). Supporting a shift towards more environmentally friendly transport modes, such as public transport and cycling, is therefore essential to achieving national and international climate targets, as well as promoting sustainable urban development. Measures that make sustainable travel easier and more attractive can reduce emissions, improve air quality, and contribute to more efficient use of urban space. To enable such a modal shift, an effective integration of different transport modes is required. This requires a good understanding of travel behavior, user preferences, and appropriate parking solutions for all modes of transport.

To address these challenges related to greenhouse gas emissions, congestion, and unsustainable commuter patterns, mobility hubs can support efficient intermodal transfers and encourage reduced dependence on private cars. A mobility hub can be defined as a strategically located node where multiple modes of transportation are integrated to allow sustainable travel choices and improve accessibility at both the local and regional levels (Schwarz et al., 2025). Well-designed mobility hubs can encourage commuters to combine modes, for example by cycling or driving to a hub and continuing their journey by public transport, thereby reducing emissions and supporting more sustainable commuting patterns. Despite the existence of numerous policies and strategies aimed at reducing greenhouse gas emissions, more concrete and operational solutions are required to achieve these targets in practice.

Previous research highlights the need for improved methods for planning and designing multifunctional mobility hubs. Studies indicate that current planning practices often lack systematic and evidence-based approaches to designing and dimensioning parking facilities for both cars and bicycles. For example, bicycle parking standards are commonly not based on actual demand, leading to under or oversupply (Kohlrautz & Kuhnimhof, 2024). Similarly, mobility hubs are often developed with limited guidance on how parking should be integrated to effectively support multimodal transfers (Krüger & Altrock, 2023). Furthermore, in conversations with traffic consultants at COWI, it is explained that there is no clear definition of what

a mobility hub is in a Swedish context and what it should contain, which indicates a need for concretization of the concept for the industry side. Regarding travel behavior, previous research shows that it is influenced by sociodemographic characteristics, the built environment, and factors related to the trip itself (C. Chen et al., 2016). Car ownership and use are strongly related to sociodemographic factors such as age, gender, income, residential location, accessibility, convenience, and travel time. However, the authors have not identified a clear connection with the location selection of mobility hubs, indicating a gap in research on the topic.

1.1 Aim

The aim of this master thesis is to develop and apply a GIS-based methodology to identify suitable locations and design principles for mobility hubs that facilitate multimodal travel and reduce car dependency in Gothenburg. The focus is on the hub itself and how it could improve the current network of bike, car, and public transport infrastructure, rather than suggesting improvements to the surrounding infrastructure.

Synthetic Sweden Mobility (SySMo) data will be analyzed with the purpose of identifying high-flow corridors and to characterize multimodal and private car commuter populations. The analysis will be integrated with a literature review of socioeconomic factors and determinants of travel behavior. The location of the proposed mobility hub will be determined by analyzing the connectivity of infrastructure for different modes, demand, and flow density, as well as factors influencing the probability that the hub will be used in practice by the surrounding population. Bike and car parking solutions, safety and comfort aspects for users, along with supporting services are reviewed in the literature and compiled into design guidelines which are applied to the selected hub location.

The analysis results in a proposed workflow to identify suitable locations for mobility hubs, as well as design considerations that are important to improve chances of usage. The findings are intended to support a reduction in transport-related emissions by facilitating the change of commute mode to more sustainable options through easy and comfortable mode changes. The workflow will be transferable to other major cities in Sweden with similar environmental goals and population diversity.

1.1.1 Research Questions

Based on the previously stated aim of the thesis, the main research question along with sub-questions have been formulated:

- How can mobility hubs be located and designed to encourage multimodal travel and promote sustainable commuting in Gothenburg?
- How can a GIS-based analysis of car traffic volumes and public transport accessibility be used to identify suitable locations and spatial design guidelines for mobility hubs?
- What spatial and functional guidelines should be considered in the planning of mobility hubs based on existing literature?

1.2 Scope and Limitations

In the context of this thesis, the intended users of the mobility hub will consist of citizens living and working in the City of Gothenburg who currently commute to work. The data used in the spatial analysis will therefore reflect the peak commuting hours during weekdays and the population that commutes between their home and workplace during those hours and days. The transport mode of the highest interest in this project is private cars, but also walking, biking on private or shared bikes, as well as public transport in the form of busses and trams. For time constraints, e-scooters, trains, and shared cars will not be included in spatial analysis, but due to their vital roles in the real commuting network, they will be considered in the design stage. A multimodal trip will be defined as a trip that contains more than one transport mode during one trip from the origin to the destination.

The literature will be reviewed in three areas: sociodemographic and economic mode choice determinants, mobility hub location selection, and the commonly used design of the hubs. The mode choice determinants will include factors such as age, gender, income, and car ownership, but not accessibility factors such as disabilities or digital skills related to mobility as a service (MaaS). The location selection and design and dimensioning will not consider the democratic participation process that usually is connected to the upgrading of the public transit network, economic constraints or competing land use interests. The analysis will focus on the design of mobility hubs in terms of types of mobility services and modes included, types of bicycle and car parking spaces and their safety and cost considerations, as well as supporting services. The final proposal will not be a detailed plan, but rather general guidelines and descriptions of the key parameters included. The impact of these limitations on the applicability and feasibility of the proposed location and design is discussed further in Chapter 6.

1.3 Disposition

The thesis starts with a background of Gothenburg and projects related to the topic of multimodal travel. A literature review follows, which outlines the factors that are related to mode choice, both cars and multimodal travel in general, as well as the process of selecting and designing mobility hubs in terms of demand, capacity, and user preferences. The main findings of the literature review act as the basis for spatial analyzes, which is described in the Methods sections, and design guidelines for the chosen mobility hub locations, which are presented in the Results section. Lastly, an analysis and assessment of the method and results is done before the conclusion of the thesis.

2

Mobility in Gothenburg

This master’s thesis focuses on the municipality of Gothenburg, Sweden’s second largest city, located in the south-west of the country, with a population of approximately 600,000 inhabitants (Smith & Sarasini, 2025). Figure 2.1 shows a map of the boundaries of the municipality and the area investigated in this report. The municipality of Gothenburg is called The City of Gothenburg, and therefore it is important to clarify that The City of Gothenburg includes the municipality in its entirety. However, in this master thesis, the archipelago and the congestion charging zone have been excluded from the study when searching for potential locations for new mobility hubs, which will be described in Chapter 4. This chapter will provide background information about mobility in Gothenburg and introduce the concept of mobility hubs in the municipality.

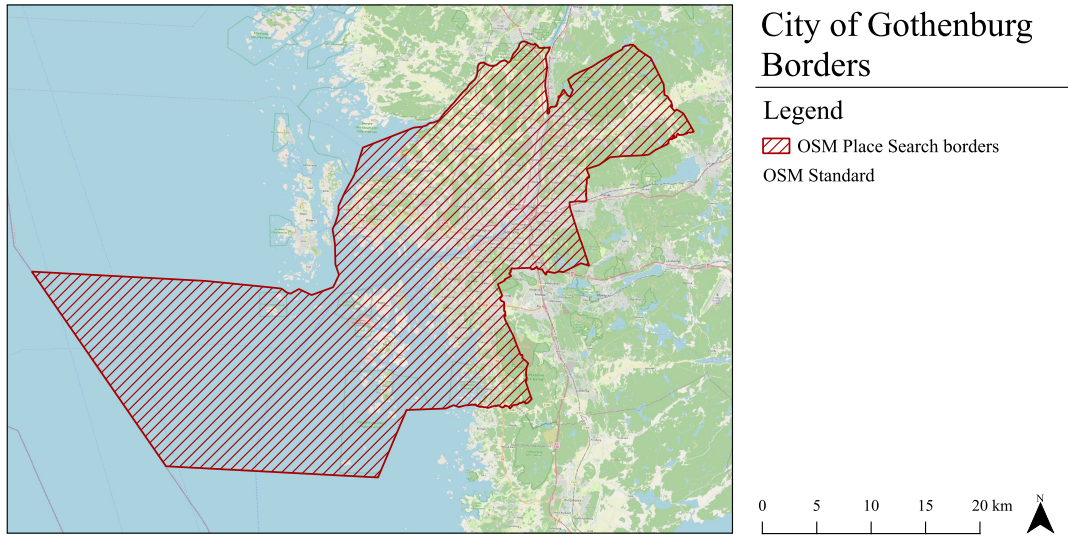


Figure 2.1: The municipal borders for the City of Gothenburg, according to the QGIS plugin OSM Place Search.

In Gothenburg, road traffic is the second largest source of greenhouse gas emissions (Göteborgs Stad, 2014). From a regional perspective, the private car remains the most widely used mode of transport in the Västra Götaland region, accounting for 57% of all trips, followed by public transport (27%), walking (7%) and cycling (8%). Work related trips represent the most common travel purpose, accounting for 34% of all trips (Västra Götalandsregionen, 2023). These patterns highlight the need for

transport-related measures aimed at reducing the dependency on cars and promoting other more sustainable modes of travel.

Gothenburg's transport policy focuses on sustainable accessibility by prioritizing walking, cycling, and public transport in traffic planning (Göteborgs Stads Parkering AB, 2018). The municipality aims to reduce the need for transports with cars while improving the efficiency of the system and creating safe, attractive, and well-maintained environments for pedestrians and cyclists, which are considered key enablers of a modal shift towards sustainable travel (Göteborgs Stad, 2014). In line with this ambition, Gothenburg seeks to create attractive mobility solutions that promote sustainable travel behavior. The municipality aims to expand and further develop services such as bicycle parking, bicycle pools, carpooling, public transport, and park-and-ride facilities (Göteborgs Stads Parkering AB, 2018).

Travel behavior in the region is documented through the Västra Götalandsregionen (2023) travel habit survey conducted in 2022/2023, which provides important information on mode choice, mobility needs, and user priorities. The survey indicates a strong public support for prioritizing public transport, walking, and cycling and identifies travel time, cost, perceived safety, and parking availability as key factors influencing travel behavior (Västra Götalandsregionen, 2023).

2.1 The Congestion Charging System

Another important factor to consider in the city center is the congestion charging system that The City of Gothenburg applies to reduce traffic congestion in the central city while simultaneously contributing to the financing of investments in transport infrastructure (Transportstyrelsen, 2026). The charge is based on vehicles entering or exiting the congestion zone on weekdays during peak and off-peak hours, fees varying by time of day, and a maximum daily charge of 60 SEK per vehicle. The congestion charging zone is defined by 37 fixed stations located on main arterial roads, bridges, and access routes that surround central Gothenburg, see Figure 2.2. These stations mark key transition points between peripheral areas and the city center and play an important role in influencing travel behavior.

From a mobility planning perspective, the congestion charge creates a financial motivation for drivers to avoid entering the city by car. Consequently, the mobility hubs in this study are preferably located outside of the congestion charging zone, allowing a modal shift before congestion charges apply. This supports both user cost savings and broader policy objectives by reducing car traffic within the city center and encouraging more sustainable travel patterns.

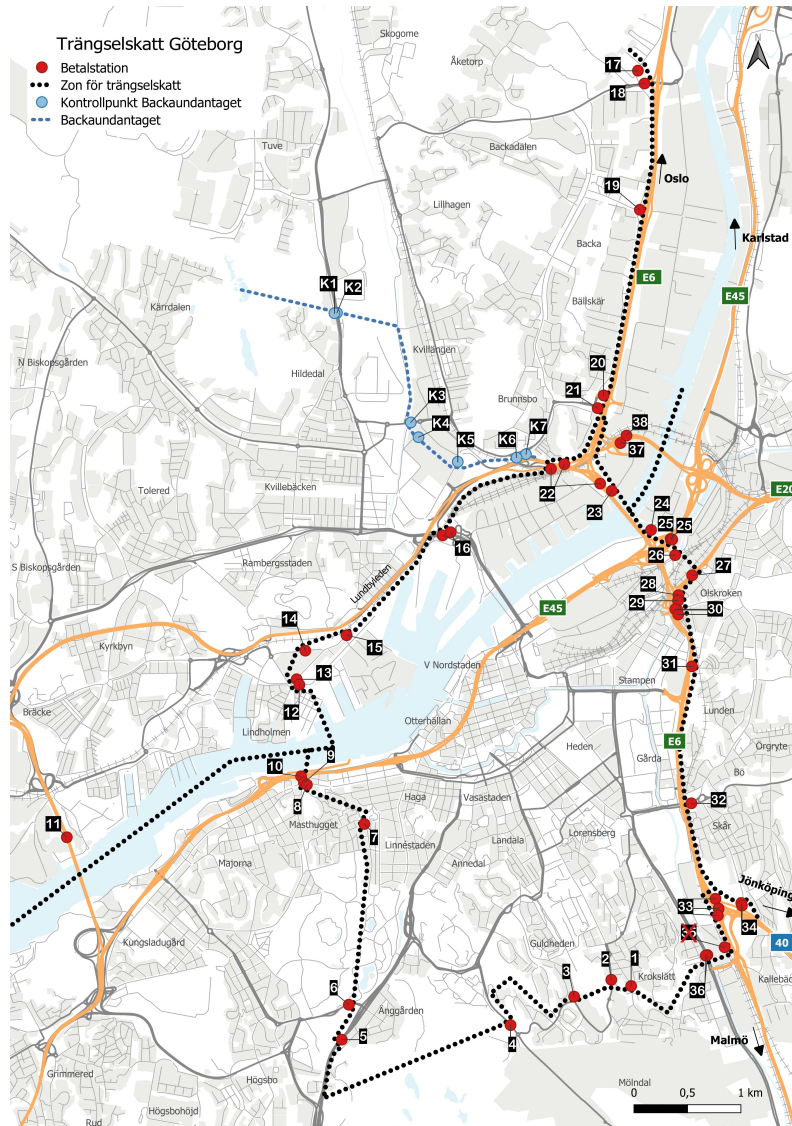


Figure 2.2: The congestion charging zones in Gothenburg (Transportstyrelsen, 2026).

2.2 Mobility Projects in Gothenburg

Gothenburg already has mobility hubs, commuter parking places, and important nodes for public transport. This section will describe already existing mobility hubs and relevant projects. For example, three pilot mobility projects in Gothenburg, located in Nordstan, Lindholmen and Klippan, were developed within the EU-funded MOVE21 project (2021 to 2025). MOVE21 aimed to strengthen the role of cities as nodes in sustainable transport systems by integrated passenger and freight mobility solutions in real urban environments (Göteborgs Stad, n.d.-b).

Gothenburg participated as a Living Lab, focusing on the development of mobility and logistic hubs designed to reduce emissions, optimize land use, and improve the coordination of transport services. The three locations were selected to represent

different urban contexts and mobility needs (Göteborgs Stad, n.d.-b). Within this framework, the Mobility Hotel in Nordstan was established as a central facility in the inner city, bringing together multiple actors to support green and emission-free transport. Services provided include bicycle delivery, electric moped battery replacement, and maintenance of bicycles and other electric micromobility vehicles (Nordstan, n.d.). In contrast, the Klippan site, located approximately two kilometers from the city center, was developed as a micromobility hub with Park-and-Ride and Park-and-Bike functions. The hub aims to reduce the use of private vehicles for inner city trips by enabling multimodal travel through the integration of public transportation and shared micromobility services, such as bicycles and e-scooters. Access to these services is facilitated through an existing parking application, reducing barriers for car users, and the mobility hub includes shared bike stations, a cargo bike pool, and improved wayfinding services (MOVE21, n.d.).

The City of Gothenburg shows a strong policy commitment to reduce private car dependency and facilitate a shift toward more sustainable travel modes. This master thesis aligns with these objectives by contributing knowledge relevant to the planning and implementation of sustainable mobility solutions in the city. Table 2.1 below summarizes the major public transport interchanges in Gothenburg, including their typology and the mobility services and components available at each location.

Table 2.1: Major public transport interchanges based on the Västtrafik tram and bus map.

Location	Bus	Tram	Train	Ferry	Kiosk	Bike sharing	Weather protected bicycle parking	Car parking	Service
Centralstationen	X	X	X		X	X	X	X	A lot of services/ restaurants in the building
Brunnsparken	X	X			X	X			
Hjalmar Brant- ingsplatsen	X	X			X	X	X		
Redbergsplatsen	X	X			X	X		X	On-street car parking
Gamlestadens torg	X	X	X		X	X	X		Indoor waiting area and a biking garage
Järntorget	X	X			X	X			
Korsvägen	X	X			X	X			
Marklandsgatan	X	X			X	X		X	
Stenpiren	X	X		X	X	X			Indoor waiting area
Lindholmen	X	X		X	X	X		X	Trams and car parking within walking distance
Klippan	X			X		X		X	Trams within walking distance

A project that is yet to be carried out is Metrobus, which is a BRT collaboration between multiple actors within the Västra Götalands region. The City of Gothenburg is planning to extend the public transport network by integrating a new Metrobus system with the goal of strengthening the public transport network and complementing existing modes, such as city busses, trams, and regional trains. This is because the municipalities of Gothenburg, Mölndal, and Partille anticipate a significant population and employment growth by 2035, which is expected to increase travel demand. The Metrobus is designed to improve connectivity, particularly for tangential travel along the inner ring and main access routes, with the aim of reducing travel times, reducing congestion in the city center, and supporting a more efficient and cohesive regional public transport system. Figure 2.3 illustrates the key interchange points between Metrobus and other public transport modes throughout the regional network, including end points outside the area where the infrastructure is analyzed and the cost assessed (Trafikverket & Västra Götalandsregionen, 2021).

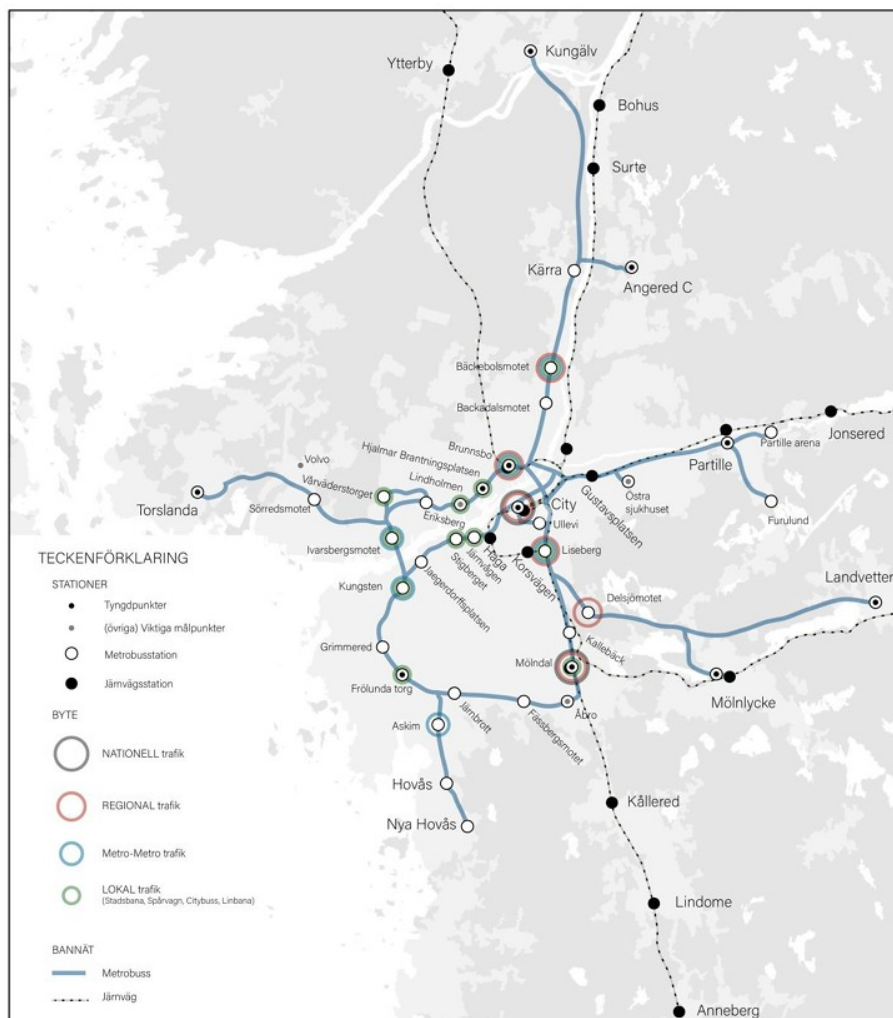


Figure 2.3: Key interchange points between Metrobus and other public transport modes (Trafikverket & Västra Götalandsregionen, 2021).

2.3 Bike and Car Parking Guidelines

The City of Gothenburg together with Västtrafik provides two guidance documents regarding parking: a handbook for bicycle parking facilities in connection with public transport, and guidelines for commuter car parking. These documents are important to consider when implementing a new mobility hub, as they establish local standards and priorities for how parking should be planned and integrated with the transport system.

According to the handbook by Västtrafik (2014), bicycle parking should be prioritized over car parking. This prioritization is reflected both in location and in quality, as bicycle parking should be located closer to the public transport stop, be more attractive, and offer a higher standard compared to car parking. In this way, it becomes clear that bicycles are given higher priority than cars within the transport system. The demand for bicycle parking is influenced by several factors, including the use of public transport, the tradition and attitudes towards cycling, the density of the population and buildings. In addition, physical conditions such as the road network, topography, and climate also play a significant role (Västtrafik, 2014).

In terms of design, bicycle parking should be designed to meet the needs of each unique location with a focus on space efficiency, accessibility, and ease of use. Weather protected parking has been shown to have a positive impact and can increase the attractiveness of cycling, although such a solution requires a sufficient number of combined parking spaces to be cost effective, according to Västtrafik (2014). In commuter parking facilities, at least half of bicycle parking should be weather protected. Safety is another important consideration, and adequate lighting can be installed if necessary to ensure secure bicycle parking. Ideally, the parking areas should be positioned so that the general lighting of the area also covers the bicycle parking, while additional lighting can be installed if required. The specific lighting solution depends on the characteristics of each individual location (Västtrafik, 2014).

In addition to bicycle parking, the City of Gothenburg has developed 17 guidelines for the design of commuter car parking areas through Trafikkontoret (Göteborgs Stad, n.d.-c). These guidelines are also of importance for the planning of mobility hubs, as they address the role of parking in managing travel demand. The primary objective of commuter parking is to intercept private vehicles before they enter congested urban areas, thus reducing traffic pressure in the city center. For this reason, such facilities should be located in areas with high commuter flows and strong connections to the city center. High-quality public transport should also be essential and available in these locations, allowing travelers to continue their journey efficiently after parking their car. Furthermore, the guidelines consider the congestion charge zone in Gothenburg, which is located approximately within a 5-kilometer radius of the city center. Within this zone, the focus shifts to promoting cycling and local public transport rather than car use. This includes providing bicycle parking close to public transport stops to facilitate convenient transitions

between different transport modes, which is a key objective in the development of mobility hubs.

3

Literature Review

In this study, the concepts monomodality, multimodality, and intermodality are relevant when discussing travel behavior and mobility hubs. According to Nobis (2007) based on the definitions originally introduced by Chlond and Manz (2001), monomodality refers to the use of a single transport mode for a certain period of time. Multimodality refers to the use of several transport modes over a certain period of time, and intermodality refers to the use of several modes during a single trip. Since mobility hubs are designed to facilitate transfers between transport modes with the same journey, the concept of intermodality is of particular relevance to this study. However, since the terms intermodal and multimodal travel are often used interchangeably in the literature, both concepts are considered relevant throughout the thesis.

One way to understand the tolerance of new technology, such as mobility hubs, is through the Unified Theory of Acceptance and Use of Technology (UTAUT) framework, which identifies expected performance and effort, social influence, and facilitation conditions as four factors that affect the probability of using a technology (Marikyan & Papagiannidis, 2025). These four factors are moderated by individual factors such as age, gender, and experience (Venkatesh et al., 2003). The framework presented in Figure 3.1 has been adapted from the models developed by Jahanshahi et al. (2020) and Horjus et al. (2022) who adapted it to shared bike services in Iran and shared transport at a public transport stop, respectively. The authors formalized the influencing factors as transport barriers, and described them as specialized performance and effort categories along with the opinion of others, facilities at the stop, travel costs and feeling safe. Moderating factors are age, gender, income, education, physical ability, digital skills, and travel behavior. The framework used in this thesis is a simplification of its predecessors and is a summary of the topics that are reviewed in the literature.

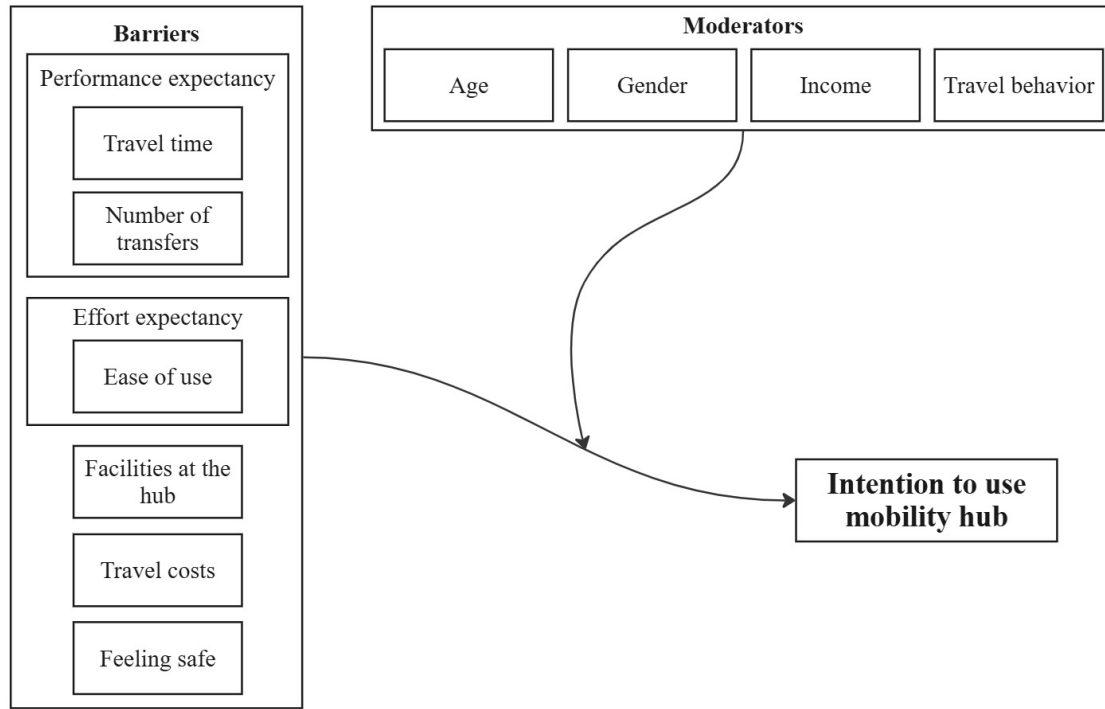


Figure 3.1: Theoretical framework of this thesis adapted from the UTAUT model.

The literature review addresses the main factors that influence travel behavior and the use and effectiveness of mobility hubs. It reviews the drivers of private car use, mode choice, and modal shifts, as well as the concept design and location of mobility hubs. In addition, aspects such as accessibility, physical integration, parking safety, comfort, and user needs are addressed. The review also highlights the importance of accessibility and travel time, as users are unlikely to use mobility hubs if the transfer significantly increases their travel time compared to traveling directly by car without stopping. In summary, the literature review examines how travel behavior, accessibility, and the location and design of mobility hubs influence their effectiveness, functionality, and attractiveness to users.

3.1 Drivers for Commuting with Private Cars

To reduce commuting by private car and encourage a shift towards more sustainable modes of transport, it is important to understand the factors that influence car use and travel behavior. This section further discusses the main drivers behind car usage and the factors that can support a modal shift towards more sustainable travel options.

Several behavioral and practical factors motivate people to use private cars for commuting. According to Gardner and Abraham (2007), five key motivations influence the use of cars: travel time and affect, effort, personal space, monetary costs, and desire for control. In interviews, respondents associated car travel with minimizing travel time and effort while maximizing positive affect, personal space, and flexi-

bility. Similarly, European Commission (n.d.) highlights that private cars play a significant role in personal control and independence of individuals. Sometimes, it is necessary to have a car in rural areas where public transportation coverage is lacking, and the elderly population might need a car due to limitations in bodily mobility (European Commission, n.d.). These perceived advantages make the car an attractive travel option compared to other modes of transport.

Socioeconomic characteristics also influence the ownership and use of cars. The relationship between income and car ownership is complex and depends on several factors, including household structure, income changes, and residential location (Blumenberg & Pierce, 2012). Life events such as changes in household composition, employment status, or income are also strong predictions of changes in vehicle ownership (Clark et al., 2016). For example, individuals may acquire a car when their employment status improves or when household responsibilities increase. The presence of children affects vehicle ownership patterns differently depending on the household situation. Clark et al. (2016) found that the probability of acquiring a car when having children increases for households that previously had no car, while the probability of selling a car increases among households that already own multiple vehicles. In contrast, people with lower incomes or weaker connections to the employment market are more likely to not own a car (Blumenberg & Pierce, 2012). Owning a car can also have positive income effects, such as improving employment opportunities, increasing working hours, and potentially leading to higher wages (A. E. Brown, 2017).

Spatial and accessibility factors are also important determinants of car ownership. Areas with poor access to public transport accessibility are associated with higher levels of car ownership, as residents rely more heavily on private vehicles to reach employment services (Clark et al., 2016). However, in neighborhoods with relatively good access to public transport, people without cars may still experience reduced access to employment opportunities (Grenge, 2010). This highlights the continued importance of car access for commuting in urban regions.

Car ownership also interacts with multimodal travel behavior. In Berlin, 54% of the intermodal population do not have access to a car, while the percentage is 34% for the monomodal population, according to Gebhardt et al. (2016). The authors present similar data for Hamburg, 53% to 24%, respectively. Cobbold et al. (2022) found that in Sydney, having a car resulted in having the tendency to travel multimodally. A similar weak relationship was found for the ownership of a bike, resulting in a reduction of 18% in inclination. Low-income households are more likely to travel by other modes other than the car (Blumenberg & Pierce, 2012).

In the travel habit survey conducted by Västra Götalandsregionen (2023), respondents who primarily rely on private cars reported that longer travel times and higher costs are the main barriers preventing them from switching to other modes of transportation. These findings highlight the importance of travel convenience and perceived efficiency in shaping commute behavior.

In general, the literature shows that car use is influenced by a combination of behavioral motivations, sociodemographic and economic conditions, spatial accessibility, and household characteristics. Understanding these factors is important when designing policies and mobility solutions that encourage commuters to switch from private cars to more sustainable transport alternatives.

3.2 User Profiles and Sociodemographic Factors

Car ownership and use have a strong relationship with sociodemographic factors such as age, gender, income, and where individuals live, for example, in the city center or outside of the city. The next section will explain this further and how it can be linked to peoples travel behaviors.

3.2.1 Age

Age is an important factor that influences travel behavior and the choice of transport modes. In general, younger individuals are more likely to use active and multimodal transport options, while these behaviors tend to decrease with age. For example, cycling is more common among younger age groups, particularly those aged 18-34 years, and gradually declines in older age groups (dos Santos et al., 2026; Fuller et al., 2011).

Age also plays a significant role in the use of shared and intermodal transport. Studies show that younger individuals are more likely to adopt shared mobility services, such as shared bicycles, scooters, and car sharing. Horjus et al. (2022) found that the willingness to use shared transport is highest among people aged 18-25 years as it decreases with age. Similar patterns are observed in intermodal travel behavior, where younger age groups show the highest levels of combined mode use in cities such as Berlin, Hamburg, and Sydney (Cobbold et al., 2022; Gebhardt et al., 2016). Although some studies indicate that middle-aged groups may also use combined travel modes under certain conditions, although this occurs less frequently and with lower variability in their travel patterns (Y. Liu et al., 2019; Susilo & Axhausen, 2014).

These age differences are also reflected in shared mobility systems such as bike-sharing where younger users dominate. For example, a bicycle sharing program in Mashhad found that users aged 20-44 years accounted for approximately 74% of all users (Jahanshahi et al., 2020). Similar patterns are observed in European and North American cities. In Lyon, most bike-sharing users are under the age of 30 years old (Raux et al., 2017), and comparable age distributions are reported in London and Washington (Buck, 2013; Ogilvie & Goodman, 2012). Overall, these findings indicate that shared bicycle services are currently most attractive to young urban populations.

Similar patterns appear in general travel behavior and mode choice. B. Liu et al. (2025) found that individuals aged 18-29 are more likely to prefer private cars, while

those aged 30-39 often combine car ownership with more frequent public transport use. Older individuals are less likely to own cars and more likely to rely on public transport. In addition, Hao et al. (2026) found that individuals aged 26-50 are more car dependent, while those over 50 are more likely to walk. These studies show that travel behavior varies with age, with distinct preferences for cars, public transport, walking and shared mobility across age groups.

These findings show that travel behavior varies with age, with different groups displaying distinct preferences for car use, public transport, walking and shared mobility. In general, younger individuals tend to be more open to flexible and multimodal transport options, while these patterns decrease with increasing age. At the same time, travel behavior is also influenced by life stages, lifestyle, and physical ability, which together shape mobility preferences between age groups.

3.2.2 Gender

Several studies indicate that gender differences play an important role in travel behavior and intermodal mobility. Gebhardt et al. (2016) found that women make up a slight majority of intermodal travelers in Berlin (55%) and Hamburg (53%), while Cobbold et al. (2022) found no significant gender differences in Sydney, suggesting that effects may be context specific.

Gender differences are also evident in mode choice and mobility constraints. Iturra (2025) observed that women generally use public transport more than men, although usage decreases with the number of children in the household, partly due to safety concerns when traveling with children. Similarly, McAndrews et al. (2017) found that women and young people are more likely to cycle in rural, and low-density areas, while Ghimire and Bardaka (2024) further showed that active travel is more common among low-income groups, particularly women, older adults, and households with children.

In terms of car use and variability in travel behavior, men are more likely to rely exclusively on the car as their main mode of transport (Heinen, 2018). Consistently, Susilo and Axhausen (2014) found that men and employed individuals show a lower variability in their travel mode combinations. In contrast, Garritsen et al. (2024) reported that women use mobility hubs less frequently and are also less likely to cycle, walk, or drive. Women also tend to travel less frequently and over shorter distances than men (Singh et al., 2025), with trips often being more local and shaped by household responsibilities, particularly in households with children and in suburban areas Balarezo et al. (2024).

Regional evidence supports these patterns. In Västra Götaland, women use public transport more frequently than men (Västra Götalandsregionen, 2023). Differences are also found in travel priorities: women place greater emphasis on safety, comfort, and affordability, while men prioritize travel time and cost (Davidich & Galkin, 2025).

Cycling behavior further highlights gender differences in relation to infrastructure quality. Giacomantonio et al. (2024) found that women cycle more frequently in areas with high-quality cycling infrastructure, whereas gender differences are minimal in areas without dedicated facilities. The same study shows that women aged 30-44 years, part-time workers or students, individuals with children, and those who combining multiple trips purposes are more likely to cycle at least once a week for commuting purposes.

In general, the literature highlights the importance of gender-sensitive transport planning. Differences in safety, accessibility, household responsibilities and infrastructure quality all influence mobility patterns and should be considered when designing inclusive transport systems.

3.2.3 Socioeconomic and Spatial Determinants

The relationship between income level and travel behavior is complex and context-dependent, with mixed findings from the literature. Some studies report no clear link between income and multimodality (Cobbold et al., 2022), while others find lower multimodality among higher income groups (L. Liu et al., 2026). In contrast, higher income has also been associated with greater likelihood of multimodal public transport use (Nobis, 2007), while low-income individuals are more likely to use carpooling (Yum, 2026). These findings suggest that income appears to influence how modes are combined rather than the overall level of multimodality.

Income interacts with other sociodemographic characteristics in shaping travel behavior. Buehler and Hamre (2015) found higher probabilities of multimodal car use among younger, male, higher-income individuals without children, especially in dense areas with rail access. In general, low-income populations are more dependent on public transport and active modes, while higher income groups are more dependent on cars and private bicycles (Garritsen et al., 2024). Heinen (2018) found that the low-income groups rely more on bicycles, while the higher-income groups rely more on private cars. High-income individuals are also more likely to access mobility hubs, while low-income groups tend to travel shorter distances and spend less time traveling (Giuliano, 2005; Y. Zhao & Stewart, 2025).

Cycling shows mixed income effects. Some studies do not find a significant relationship (Javaid et al., 2020), while others report higher cycling rates among higher income groups (Hudde, 2022). Bicycle ownership increases with income (Nobis et al., 2019), but cycling is also used as a cost-saving mode among low-income households who cannot afford cars (Chandra et al., 2017; Pooley et al., 2011). Consequently, low-income groups often walk or bike more frequently for financial reasons (Ghimire & Bardaka, 2023, 2024).

Residential location further shapes the travel behavior. Urban residents generally use more active modes than suburban and rural populations. High-income urban households show higher levels of active travel, while suburban and rural residents

are more car dependent (Ghimire & Bardaka, 2023, 2024). Within suburban areas, cycling is more common than walking, whereas low-income suburban car owners may rely more on walking (Ghimire & Bardaka, 2023). Residents who live in the central city are also more likely to use non-motorized modes compared to those who live outside of the city (Srinivasan & Rogers, 2005). Income and residential location are closely related, as lower income households are more likely to live in dense urban areas with better access to public transport, reducing the dependence on private cars (Maghelal et al., 2025). This aligns with McAndrews et al. (2017) who identified bicycling as the primary, although not exclusively, urban activity.

In general, the literature shows that socioeconomic and spatial factors together shape travel behavior. Income influences mode combinations rather than total multimodality, while the residential context strongly affects access to and reliance on different transport modes.

3.3 Reducing Car Dependency

Reducing car dependency is a complex challenge and requires a combination of infrastructure policy and behavioral measures. Previous research shows that travel behavior and mode choice are influenced by individual characteristics, social factors, and the quality of available transport infrastructure (Javaid et al., 2020). The process of changing travel behavior can be described using the MaxSumo approach, presented by Partnership for Urban Mobility (2019), which explains how individuals gradually transition from primarily using private cars to more sustainable modes of transport, such as walking, cycling and public transport. The study distinguishes between "hard" measures, such as infrastructure improvements, and "soft" measures, including information campaigns and behavior incentives.

Transport policies and urban planning also play an important role in reducing dependence on cars. Kuss and Nicholas (2022) identified several interventions that can contribute to a mode shift in urban areas, including parking charges at workplaces, mobility services for commuters, and workplace travel planning. These measures are often combined with economic incentives, such as discounted public transport or financial benefits for not commuting by car (Nichola & Billing, 2022). In addition, urban structure and transport accessibility influences travel behavior and car ownership. Clark et al. (2016) found that individuals living in areas with better access to public transport are less likely to own a car. This suggests that concentrating development on public transport nodes and improving accessibility can reduce car dependency over time.

3.3.1 Attractive Public Transport and its Time Considerations

Improving the quality of public transport is an important strategy to reduce car use. Factors connected to the service quality of public transport are reliability and

transfer quality, which both affect user satisfaction and thus mode choice. A well-functioning public transport system should provide punctual services, predictable travel times, good network coverage, and direct connections. Reliability, together with cleanliness, safety, and seating availability, strongly influences perceived service quality (Berggren et al., 2026; Xylia et al., 2024). Transfer-related factors such as waiting time, convenience, information, and accessibility also affect passenger satisfaction (Li et al., 2020). Well-designed transfer facilities with reliable connections, real-time information, amenities, and safe environments can reduce the burden of transfers and improve multimodal integration (Iseki & Taylor, 2009; Mahdi et al., 2025).

A survey study in Karlstad, Sweden, conducted by Eriksson et al. (2008) found that improved public transport and the possibility of working from home were the two most common reasons for reducing car use among commuters. Factors such as increased service frequency, shorter travel times, direct routes, reliability, and lower fares were identified as particularly important to encourage the use of public transport (Eriksson et al., 2008; Friman et al., 2001). Similarly, Chakrabarti (2017) found that public transport must offer exceptional service quality to compete with private cars. Important factors include travel time, frequency, reliability, and strong service along high demand travel corridors. The study also highlights the importance of solving the "last mile" problem through services such as bike sharing and car sharing services.

Two similar important concepts connected to travel time and quality are Value of Time (VOT) and Value of Travel Time (VTT), which often are used in transport research and cost-benefit analyses (Meunier, 2019). Y. Liu et al. (2019) defines VOT as "a traveler's willingness to pay for the savings in travel time" while VTT refers to the cost associated with time spent traveling. Traditionally, travel time has been viewed as non-productive time (Haubold, 2020). However, this perspective has changed with the increase in the use of mobile services and the possibility of user travel time for activities such as reading, working, or socializing. In addition, active modes of transport may provide health and environmental benefits that positively influence the perceived value of travel time (Kouwenhoven & de Jong, 2018).

More specifically, transfer time and quality of the trip are important factors that affect travel satisfaction and intermodal travel behavior. Ettema et al. (2016) found that overall travel satisfaction depends not only on the main transport mode, but also on the quality of access trips, egress trips, and transfers. Similarly, Goletz et al. (2020) identified attractive transfer points as an important factor promoting intermodality. Transfers are generally associated with additional time, effort, and inconvenience and, therefore, are often perceived negatively by travelers (Schakenbos et al., 2016). Waiting time is particularly important in multimodal trips involving public transport, as users tend to perceive waiting times as more burdensome than walking or in-vehicle time (Wardman, 2001). In addition, perceived waiting time can differ from objective waiting time, as users often experience waiting time longer than it actually is (Warman, 2014). According to Goletz et al. (2020), 78% of experts

considered long waiting times and poor connectivity to negatively affect intermodal travel. Reducing transfer times and improving transfer quality are therefore important for increasing the attractiveness of public transport.

The physical environment of transfer locations also affects perceived travel quality. Fan et al. (2016) found that features such as benches and shelters can reduce perceived waiting times, while perceived safety strongly influences the user experience. Female travelers in particular reported higher levels of perceived insecurity in waiting environments. This suggests that comfort, safety and station design are important aspects when planning mobility hubs and public transport interchanges.

According to Iseki and Taylor (2009), transfer quality can be evaluated through five main criteria: access, connection and reliability, information, amenities, and security and safety. Access could be improved with clear information on distances and directions to the boarding locations. Connection and reliability are also affected by the quality of information, but also by the scheduling of vehicles and the adherence to it. Comfort and convenience during transit can be improved by including amenities within the transit area, but what amenities would be suitable would preferably be site-specifically analyzed. Lastly, lacking security and safety can be detrimental for users' experience of transfers and is therefore, once again, of great importance to promote mobility hub usage.

3.3.2 High-quality Bicycle Infrastructure

Attractive cycling infrastructure is another important factor that supports sustainable and multimodal travel. User perceptions of safety, comfort, and infrastructure quality and design strongly influence cycling behavior. Hwang et al. (2026) found that bicycle lanes and perceived safety increase cycling activity, with protected bike lanes being especially effective in visually unsafe environments. Similarly, Berghoefer and Vollrath (2022) showed that separate cycling facilities are preferred, while high traffic volume and poor surface conditions reduce attractiveness. Cyclists also value separation from motor vehicles and pedestrians, as interactions with traffic are often perceived as stressful (Berghoefer & Vollrath, 2022; Desjardins et al., 2021; Gadsby et al., 2021). Greater separation from traffic is associated with greater comfort and willingness to cycle longer distances (Caviedes & Figliozzi, 2018; Vedel et al., 2017). In addition, smooth surfaces, connected networks, direct routes, and pleasant surroundings contribute to more attractive cycling conditions (Berghoefer & Vollrath, 2022; P. Chen et al., 2018; Gadsby et al., 2021). In general, high-quality cycling infrastructure is characterized by safe separation, good surface quality, efficient flow, and well-connected network.

These factors are reflected in the concept of bikeability, which describes how attractive, and safe cycling infrastructure is perceived by users. In this study, bikeability is applied as a GIS-based measure of perceived cycling quality. Expanding shared mobility services together with safe cycling infrastructure can further support sustainable travel behavior. A. Brown et al. (2025) found that households without

cars but with access to shared mobility services made a large share of their trips by bicycle. Another earlier study by A. E. Brown (2017) concluded that strong public transport systems and safe walking and cycling infrastructure provide good alternatives to private car use.

In general, the literature highlights that high-quality cycling infrastructure and reliable public transport are key considerations for reducing car dependency by creating effective multimodal systems. Mobility hubs can support more sustainable travel behavior by enabling smooth and efficient transfers between modes. However, their attractiveness depends on factors such as infrastructure quality, accessibility, reliability, and coordination between services. The literature further suggests that reducing car dependency cannot be achieved through a single measure alone. Instead, it requires a combination of high-quality public transport, supportive policies, shared mobility services, improved accessibility, and safe infrastructure for walking and cycling.

3.4 Definition and Characteristics of Mobility Hubs

Currently, there is no clear singular definition of a mobility hub (Hachette & L'Hostis, 2024). However, mobility hubs are generally understood as places where multiple transport modes and shared mobility services are integrated to support sustainable and intermodal travel. Based on a review of 13 academic and planning definitions, K. Geurs et al. (2022) defined a mobility hub as "a physical location where different shared transport options are offered in permanent, dedicated and well-visible locations, and public or collective transport is available at walking distance". These are the minimum requirements, and the different shared transport options may vary between hubs. Some definitions analyzed included the availability of public transport, shared mobility, multiple modes, transfer between modes, and other services. Some definitions also focused on the digital, physical, visual and integration of the hub. Regardless of definition, the main objective of mobility hubs is to support more sustainable mobility patterns by reducing the dependency of private vehicles and encouraging changes toward sustainable transport modes (Hachette & L'Hostis, 2024).

The benefits of mobility hubs extend beyond the reduced environmental impact of transport and may also contribute to social and economic development (Arnold et al., 2023). Improved accessibility and transport equity are possible positive impacts of implementing mobility hubs in urban areas. By including services into the design, business opportunities arise, which help stimulate the economy. Aono (2019) summarizes the objectives into seven points, including the integration of sustainable transportation, improving the user experience, ensuring safety and security, creating a sense of place, introducing innovations to improve resilience, addressing equity and accessibility, and forming effective partnerships.

The transport modes included in a mobility hub depend on the local context, the surrounding infrastructure and the needs of users (Arnold et al., 2023). The most common modes to incorporate are busses, bicycles, and cars, but emerging modes

such as e-bikes and e-scooters are also often included. However, simply providing multiple modes of transport does not automatically create a successful mobility hub. The different modes must function as an integrated system through coordinated spatial layout, design, and timetabling. As a result, the scale function and the level of service of a mobility hub depend on its type and location (Hachette & L’Hostis, 2024). Several studies therefore classify mobility hubs according to their location, scale, and functioning, ranging from small neighborhood hubs to large regional or international hubs (Arnold et al., 2023; K. Geurs et al., 2022). The classification used in this study is presented in Table 3.1.

Table 3.1: Location and functional typology for passenger mobility hubs according to K. Geurs et al. (2022).

Type of mobility hub	Location, function, and size
Central urban hub	A large-scale mobility hub which is located in the city center with a high concentration of mobility services.
Urban neighborhood hub (small)	A small-scale mobility hub that serves a local area and is typically offering a limited number of shared services.
Urban neighborhood hub (large)	A larger neighborhood hub with a substantial number of shared mobility services.
Suburban/urban fringe hub	A mobility hub which is located near a motorway and/or a railway station at the edge of an urban area.
Rural hub	A mobility hub located in a rural area, typically providing basic mobility services.
(Inter)national hub	A major mobility hub serving long-distance and international travelers. Airports is also included here.
Other	It could be specialized hubs, for example a mobility hub located in a business park.

3.4.1 Common Components at Mobility Hubs

The literature emphasizes that mobility hubs should function as more than simple transfer points and instead operate as multifunctional nodes within the transport system. In addition to mobility services, Mobility hubs often include supporting infrastructure, digital services, and complementary urban functions (CoMoUK, 2019; K. Geurs et al., 2022).

The core components related to mobility typically include public transport services such as buses, trams, and rails, together with shared mobility services that include bike sharing, car sharing, cargo bikes, and other micromobility options. The supporting infrastructure may include bicycle parking, bicycle repair facilities, and electric vehicle charging. Digital services, such as real-time travel information, ticketing systems, and MaaS platforms, are also identified as important features that support intermodal travel. All these components of a mobility hub are summarized and categorized in Table 3.2.

Table 3.2: Common components of a mobility hub based on CoMoUK (2019) and K. Geurs et al. (2022).

Components	Services included
Public transport	Bus, tram, and rail
Non-public transport	Car and bike sharing, cargo bikes, and other micromobility options such as e-scooters
Mobility-related components	Electric vehicle charging, bicycle parking, bicycle repair facilities, and digital services (transport information, ticketing)
Non-mobility services	Parcel lockers, cafés, co-working spaces, play areas, and fitness facilities
Urban realm improvements	Seating, weather protection, greenery, and safe pedestrian crossings

In addition to transport-related mobility functions, several studies highlight the importance of complementary non-mobility services in improving the attractiveness and usability of mobility hubs (CoMoUK, 2019; K. Geurs et al., 2022). Examples include parcel lockers, cafes, co-working spaces, play areas, and fitness facilities, as well as improvements to the surrounding public area such as seating, lighting, weather protection, greenery, and safe pedestrian crossings. These elements contribute to comfort, convenience, and perceived safety, strengthening the role of mobility hubs as active urban places rather than technical transport infrastructure.

User oriented studies further demonstrate that complementary services can influence travel behavior and mode choice. Hachette and L’Hostis (2024) found that the perceived value of mobility hub services varies between user groups and transport modes. Similarly, Envall (2012) showed that many users would use bicycle services

or repair facilities if they were available at the stations, while Goletz et al. (2020) found that the ability to run errands while transferring between modes significantly supports intermodal travel behavior. The literature also suggests that flexibility and ease of access are important when implementing bicycle sharing systems. For example, Martens (2007) found that traditional bicycle leasing systems had limited success, while flexible bicycle rental systems at train stations contribute to increased bicycle and train use and reduced car dependency.

In general, the literature indicates that the success of mobility hubs depends not only on the integration of transport modes, but also on the inclusion of complementary services and high-quality public space. Together, these elements can support intermodal travel, improve accessibility and reduce the dependency on private cars.

3.4.2 Physical Integration and Inclusive Design

Physical integration is a key factor that influences the functionality and user experience of mobility hubs. K. Geurs et al. (2022) describe this through a hierarchical "physical integration ladder", where higher levels represent greater spatial integration, user orientation, and attractiveness. As mobility hubs move up the ladder, they become more interactive and better integrated with surrounding transport systems and urban environments.

Accessibility and inclusiveness are also important aspects of mobility hub design. According to SEStran (2020), mobility hubs should improve access for people with disabilities or mobility impairments, support users without private cars, and provide clear information on available travel options. Limited accessibility can contribute to social exclusion and reduced participation in daily activities (Ryan et al., 2023). Accessibility itself is a multidimensional concept influenced by land use, transport systems, time-related factors, and individual user characteristics (K. T. Geurs & van Wee, 2004). The transport component includes travel time, cost, and physical effort required to use a certain transport mode, which directly influences its attractiveness. For example, lower accessibility to public transport in suburban areas has been shown to reduce public transport use Cheng et al. (2020).

To address these challenges, universal and inclusive design principles should be integrated when planning a mobility hub. These principles aim to reduce physical and informational barriers for users, including older adults, people with reduced mobility, individuals with visual or cognitive impairments, and those without access to digital services. Complementary services such as stores, parcel lockers, and kiosks can further improve convenience and usability (K. Geurs et al., 2022).

K. Geurs et al. (2022) identified five levels of physical integration, ranging from no integration to fully integrated and user-oriented mobility hubs. Higher levels are characterized by visible and well-organized shared mobility services, short walking distances between modes, clear way-finding, complementary services, and the application of universal design principles. In this study, the highest level of integration is

used as a design target, requiring multiple shared transport modes, accessible information, complementary services, and fully implemented inclusive design principles. This highlights that successful mobility hubs depend not only on spatial integration, but also on their ability to meet diverse user needs in an accessible and user-friendly way.

3.4.3 Parking at Mobility Hubs

Parking is a central component of mobility hubs because it influences accessibility, intermodal transfers, and mode choice. Reductions in private car use can substantially decrease the demand for car parking while increasing the demand for bicycle, micromobility, and public transport related parking infrastructure (Silva et al., 2021). Parking strategies therefore involve not only reducing parking supply, but also reallocating urban space between transport modes.

3.4.3.1 Parking and Intermodal Mobility

Park-and-Ride (P&R) facilities are commonly used to connect private car travel with public transport and are typically located outside of urban centers (Nakamura et al., 2025). Studies show that P&R can reduce emissions and city center congestion when supported by high quality public transport and appropriate pricing strategies (Nakamura et al., 2025; Ortega et al., 2021). However, poorly integrated systems risk reinforcing car dependency.

Bike and Ride (B&R) systems are often considered a more space-efficient and more sustainable intermodal alternative. Bicycle access can improve first-and-last mile connections and increase the attractiveness of public transport (Martens, 2007; Ritveld, 2000). However, recent studies emphasize that successful bicycle parking systems depend not only on technical design but also on governance, funding structures, and institutional coordination. (Cannon et al., 2024; Smith & Sarasini, 2025).

3.4.3.2 Parking Design and User Experience

Parking design and accessibility strongly influence travel behavior and the attractiveness of sustainable transport modes. In the Västra Götaland region, approximately half of the respondents reported difficulties finding parking when traveling by car, while avoiding parking difficulties was identified as the most common reason for choosing public transport instead of private vehicles (Västra Götalandsregionen, 2023). Similarly, the quality of the route, walking distance, and comfort between parking facilities and public transport stops significantly affect the actual utilization of parking facilities (Martens, 2007).

For bicycle parking, walking distance and convenience are particularly important. Orozco-Fontalvo et al. (2024) found that most users are willing to walk approximately one block to bicycle parking, while UE (2010) suggested 150 meters as the maximum acceptable walking distance. Other studies reported preferred distances of 57 meters before cycling and 86 meters after dismounting (Mobility Secretary,

2019). Cyclists generally prefer parking close to station entrances, and inadequate or poorly located parking discourages cycling (Heinen & Buehler, 2019). These findings highlight the importance of convenient, accessible and high-quality bicycle parking in supporting cycling and intermodal travel.

Accessibility can also be addressed strategically through location planning. Ron-gen et al. (2022) proposed an ABC location framework, where parking locations are categorized according to accessibility and surrounding land use. A-locations are dense urban areas with high access to public transport, B-locations combine access to public transport and highways while C-locations are primarily car-oriented and located near motorway exits. Such location strategies can influence mode choice and support sustainable mobility patterns.

Safety and security are also important aspects of parking design. In Sweden, inadequate cycling infrastructure, poor signage, and conflicts with motorized traffic often discourage cycling (Balkmar, 2014; Konglin, 2013). Respondents to the Västra Götaland travel survey also reported feeling less safe when cycling compared to other transport modes (Västra Götalandsregionen, 2023). Secure and weather protected bicycle parking with anti-theft measures and proximity to destinations has been shown to increase both usage and user satisfaction (Envall & Lindberg, 2009; Heinen & Buehler, 2019; Martens, 2007; Pucher et al., 2010). However, studies also show that bicycle lockers can experience low utilization when cost is perceived as too high alternative to the risk of theft (Martens, 2007).

Examples from Gothenburg and Kungsbacka illustrate how secure and well-designed bicycle parking can support cycling. Facilities such as the bicycle garage in Gamlestaden and bicycle parking at Kungsbacka station provide weather protection, repair facilities, lighting, and secure storage to improve safety and convenience (Kungsbacka kommun, n.d.; SWECO, n.d.). In addition to the parking facility itself, the safety of walking and cycling routes to and from parking areas is also important, as poor accessibility and perceived insecurity may discourage users from choosing bicycles or public transport (Miao et al., 2024).

3.4.3.3 Parking Management and Demand

Pricing is an important tool for managing parking demand and influencing travel behavior. Static and dynamic pricing strategies are used to balance parking supply and demand by adjusting prices according to occupancy levels and time of use (Zhang et al., 2026). Research by Mo et al. (2021) showed that higher parking fees reduced parking demand and parking duration, while also improving perceived parking availability. However, the study also found that higher-income users were less sensitive to price increases.

In Gothenburg, parking fees were introduced in commuter parking facilities such as Radiomotet and Delsjömotet to reduce overcrowding, discourage long-term misuse, and encourage commuters to use public transport closer to home (Vårt Göteborg, 2024). Other pricing strategies have also been proposed to support intermodal mo-

bility. For example, Miao et al. (2024) suggested distance-based parking fees for Park-and-Ride systems, where users traveling longer distances by public transport receive lower parking fees. Such strategies can improve the attractiveness and efficiency of intermodal systems.

The price must be understood in a wider transport system. Although increased car parking fees can reduce demand, bicycle parking fees may discourage the use of bicycle facilities (Heinen & Buehler, 2019). Travel choices are influenced by a combination of cost, travel time, comfort, and convenience across all transport modes (Rodríguez et al., 2026). Parking should therefore be integrated with broader transport and mobility policies to support sustainable travel behavior.

Estimating parking demand remains a significant challenge in mobility hub planning. Parking demand depends on factors such as travel behavior, parking supply, pricing, congestion, and accessibility (Shoup, 2018; Zhang et al., 2026). Both insufficient and excessive parking supply can lead to negative impacts on the transport system. Limited parking availability increases cruising traffic, congestion, and emissions, while excessive parking supply can encourage additional car use (Arnott & Inci, 2006; Paidi et al., 2022; Shoup, 2018). Mobility hubs therefore require a balance where parking supports efficient transfers without reinforcing car dependency.

Traditional parking demand models often focus on variables such as land use, purpose of the trip, parking duration, price elasticity (Marsden, 2006). More recent studies also emphasize behavioral factors, including parking search time, perceived convenience, and attitudes towards new mobility services Rodríguez et al. (2026). Parking is increasingly viewed as part of the overall travel experience rather than only an end-of-trip activity. Emerging mobility trends and alternative parking strategies, such as remote parking or shared vehicle options may further influence parking demand (Rodríguez et al., 2026; Zhang et al., 2026). Additional factors such as walking tolerance, urban density, and access to public transport also affect parking behavior and demand (Guo & Ren, 2013).

In general, the literature highlights that parking demand in mobility hubs is dynamic and context dependent. Therefore, flexible and adaptive parking strategies is needed to manage uncertainty, support multimodal integration, and balance accessibility with sustainable mobility objectives.

3.5 Placement and Location of a Mobility Hub

The placement of a mobility hub is a critical factor influencing its performance, user base, and overall effectiveness. Key considerations include demand patterns, integration within the transport network, and the accessibility of the hub for different user groups. These aspects are closely related and determine how well the hub can support multimodal travel. This section examines the main factors that influence the location of mobility hubs, including spatial demand, network integration, user access, and existing evaluation approaches.

3.5.1 Demand and Spatial Context

The location of a mobility hub strongly influences both its user group and its overall success (SEStran, 2020). From a planning perspective, both at the municipal and regional levels in Sweden, it is relevant to place hubs in areas with high population or employment density, as they can also support sustainable commuting between municipalities by reducing the need for car-based regional travel. However, these locations typically already have great public transport access and mobility policies. The study suggests that mobility hubs in such locations may reduce walking and public transport trips instead of car trips. In contrast, lower-density areas may offer greater potential to influence travel behavior. In these areas, residents often rely on private cars due to the lack of public transport as a consequence of being given the second priority in mobility planning (Hachette & L’Hostis, 2024). On the other hand, K. Geurs et al. (2022) emphasizes that the suitable locations of mobility hubs should have a sufficient density of potential users. SEStran (2020) further suggests that areas with high travel demand, such as major transport hubs, city centers, and dense residential areas, seem to be suitable locations for mobility hubs. However, space constraints in dense urban environments can limit implementation, while suburban and rural areas often show greater spatial flexibility. This indicates that selecting an appropriate location requires balancing demand and potential with spatial feasibility and the opportunity to influence travel behavior.

3.5.2 Network Integration and User Access

A mobility hub must be well integrated within the transport network to enable efficient modal transfers and ensure high accessibility. One key concept is distance decay, which describes the reduced chance of traveling to destinations that require more time or effort to reach Verma and Ukkusuri (2025). This effect is influenced not only by physical distance but also individual factors such as income, physical ability, and access to private vehicles (Ryerson et al., 2022). As a result, poorly accessible mobility hubs are less likely to attract users and may limit overall system effectiveness.

Catchment areas provide a useful way to understand the spatial reach of a mobility hub. These areas represent the zone from which most users access a station without transferring (Lohmann Elkjær Andersen & Landex, 2009). Studies show that approximately 90% of public transport users access stations by walking (UITP’s Combined Mobility & Transport and Urban Life Committees, 2023). Catchment areas can be defined using simple radial distances or more advanced network-based approaches that account for real walking paths, barriers, and travel times. Incorporating time-based measures allows planners to consider different user groups, such as older adults or individuals with mobility impairments (Garritsen et al., 2024).

Acceptable walking distances to mobility hubs and public transport stops have been widely studied. What walking distances that are maximum and optimal from the users’ point of view have been researched extensively and are summarized by K. Geurs et al. (2022). The authors present the distances to vary between 125-250

meters (Bolger et al., 1992), 400-800 meters (CoMoUK, 2019), 500 meters (Mouw, 2020) and 400 meters (Blad et al., 2022). In addition, maximum walking time can be used as a measurement, where 5 minutes seems to be the general guideline (Blad et al., 2022; Indrakesuma, 2018; Luo et al., 2021). Burger (2021) found that regardless of the walking distance to a bus stop, the service attributes of the bus station were the most influential factor for the willingness to walk. Also, the pathways leading to the public transit stops are of importance, and if they are favorable to users, the amount of potential passengers can increase (UITP’s Combined Mobility & Transport and Urban Life Committees, 2023).

3.5.3 Rule-Based Methods: Distance to Mobility Hubs

The distances between users and mobility hubs are a critical factor that influences the attractiveness and effectiveness of multimodal travel. Some of the academic literature has examined acceptable access distances and travel times to mobility hubs and related facilities, highlighting variations depending on access mode, urban context, and sociodemographic characteristics.

Several studies assess access in terms of travel time rather than distance. An analysis of multimodal hub accessibility in Portland, Seattle, and Vancouver found that access times to the nearest hub typically range between 15 and 40 minutes, with notable differences between income groups (Tran & Draeger, 2021). In Portland, low-income households experienced access times of 20-40 minutes, compared to 25-30 minutes for higher income households. In Seattle and Vancouver, access times ranged between 15-20 minutes and 25-35 minutes, respectively. The study also showed that multimodal hub scenarios performed more efficiently when access times were limited to approximately 15-20 minutes. In terms of accessibility, the authors applied a 350-meter walk buffer between stations, which corresponds to roughly five minutes of walking in a normal adult pace.

Walking distance thresholds are frequently used to define the areas of interest in a location of a mobility hub. Multiple studies adopt network-based walking distances to approximately 300-400 meters as an acceptable maximum. For example, service areas defined by the 400-meter walk distance are commonly applied in transport network analyzes, based on empirical evidence of user tolerance for walking access (Aguilera-García et al., 2020; Arias-Molinares et al., 2023; Tran & Draeger, 2021; D. Zhao et al., 2021). This is also the case in Sweden, where a distance of 400 meters between public transport stops ensure uniform reachability (COWI, 2026). Similarly, several studies use a 300-meter buffer around stations to represent appropriate walking distances, both for access to public transport and to identify the characteristics of the surrounding streets relevant to cycling behavior (Faghih-Imani & Eluru, 2015). These distances align with findings that proximity within 300-meter residential areas, workplaces, amenities, and public transport stops have a significant positive effect on the generation and attraction of bicycle trips, while increases in travel length are associated with substantial reductions in travel frequency (D. Zhao et al., 2021).

The preference of users for bicycle-related facilities suggests even shorter acceptable distances in certain contexts. Surveys on bicycle pools and bicycle parking locations indicate that the preferred maximum distances to public transport range between 25 and 400 meters (Shaheen et al., 2013). The determination of optimal placement is shown to depend on multiple actors and contextual constraints, rather than on a single universal threshold.

In general, the literature indicates that while access distances to mobility hubs should remain with commonly accepted walking and cycling thresholds, overly strict proximity requirements may be counterproductive. Locating hubs slightly beyond immediate residential proximity can encourage intermodal travel behavior, such as park-and-ride, bike-and-ride, while remaining enough to support mode shifts.

3.5.4 Methods for Identifying Suitable Locations

Several approaches have been developed to support the identification of suitable locations for mobility hubs. Blad et al. (2022) propose a framework based on seven factors from the literature which are grouped into criteria related to operators, government, and users. These include demand indicators, accessibility, land suitability, existing parking conditions, and the potential to reduce congestion. Other approaches build on the concept of transport nodes as functional and spatial elements within the city. Aquilué Junyent et al. (2024) defined their six mobility hub criteria on the concept of transit nodes being both locations for transfer in a network and a place in the city, as described by Bertolini (1996). The criteria are mobility, compactness of the urban fabric, diversity in regard to land use, profile of potential users, spatial configuration, and environment and ecology. Each of these criteria has sub-criteria which are then weighed against each other and modeled in QGIS.

From the industry side, different public transport providers have their own idea of how mobility hubs should be included in their systems, and what is important to consider when placing and designing them. CoMoUK (2019) presents a list of factors to consider when deciding and evaluating mobility hub sites, including visibility of the area, sufficient density of residents or businesses and flows of passengers, enough modes to link together, accessibility for everyone, sufficient space, and support of local land use plans. SEStran (2020) analyzed the underlying demand for mobility hubs in South East Scotland with the following data as a basis: population density, workplace density, target mosaic population, access to services through car and public transport, car club locations, bike share locations, as well as stakeholder-proposed locations for mobility hubs. The result was maps showing areas with varying potential demand for mobility hubs. These approaches demonstrate that the selection of mobility hub locations requires a combination of data-driven analysis and strategic planning, taking into account demand, accessibility, spatial conditions, and policy objectives.

4

Spatial Analysis Framework

To investigate the potential location of mobility hubs from several points of view, numerous datasets from multiple sources had to be tied together and combined. The databases, extracted datasets, processes, and outputs are described in Figure 4.1 below.

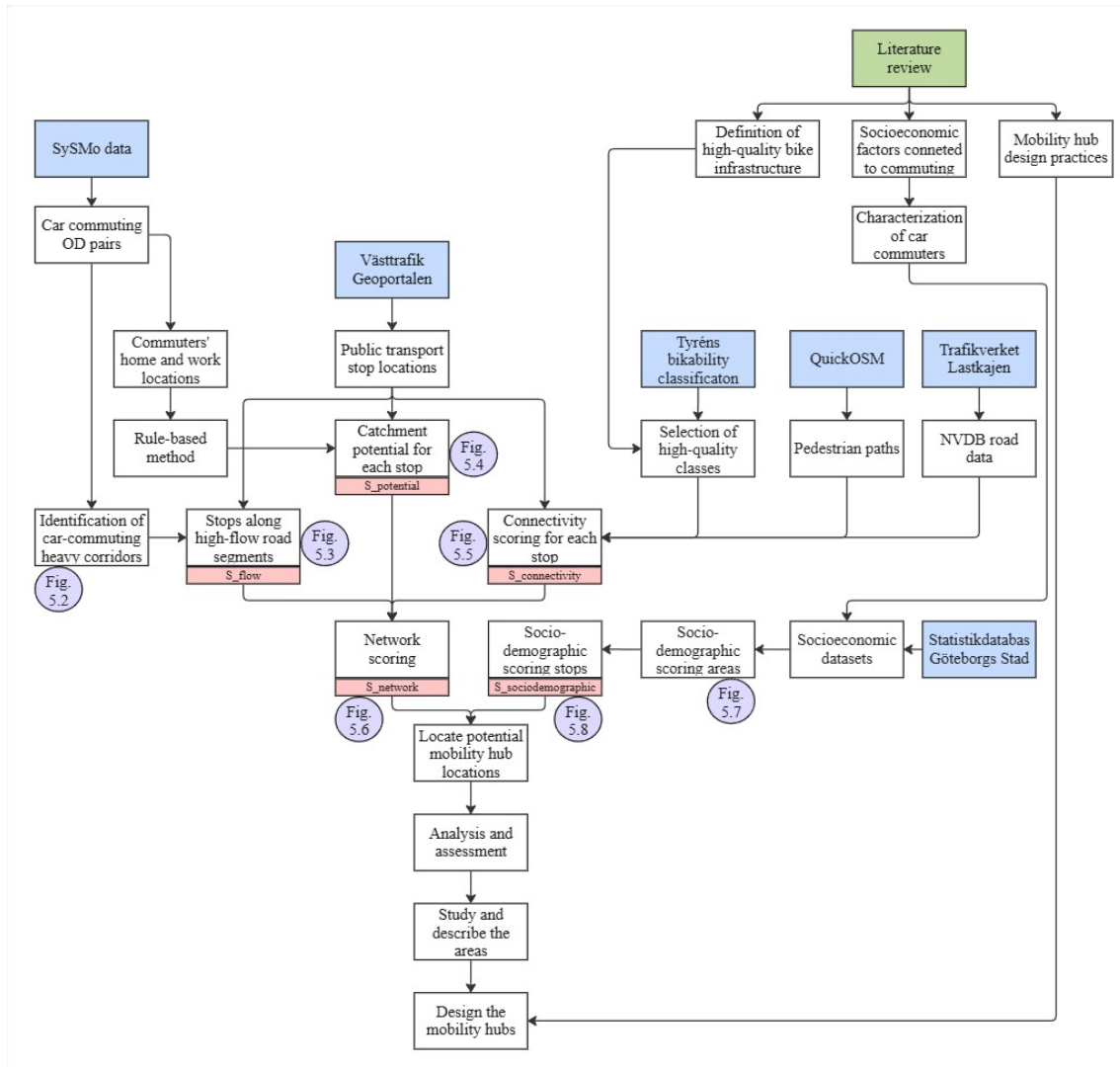


Figure 4.1: Framework for the location selection of the mobility hubs. Blue boxes represent sources of data, white boxes results and arrows are processes, purple circles are figure numbers, and pink boxes represent scores.

The method of weighing datasets against each other is based on the methodologies described in Section 3.5.4. In summary, two scores are calculated, one based on network factors and one on sociodemographic factors. The network score is based on three scores based on traffic flow, catchment potential, and connectivity. The sociodemographic score is based on weighed-together statistics based on the literature review. The spatial analysis was performed in QGIS 3.40 Bratislava, which was chosen due to the authors' previous experience and knowledge in it, and the free access to the program. The starting point for location selection was the existing public transport stops within Gothenburg, which ensured good connectivity to the public transport network and allowed to narrow down the number of potential locations.

This chapter presents the method as a process from data collection, extraction, and processing to analysis of potential locations and selection of four options. Finally, the necessary elements, size, and design of the mobility hubs are determined. The latter is based on the literature review rather than the spatial analysis.

4.1 Data Collection

A large number of datasets were utilized in the spatial analysis to ensure a comprehensive location selection process. These include a synthetic population of the city of Gothenburg, and sociodemographic statistics of the city's real-life inhabitants. In addition, data regarding physical locations and characteristics of infrastructure elements connected to cars, bikes, pedestrians, and public transport were needed, and thus collected. All data were retrieved from open sources.

4.1.1 Definition of Study Area

To have a clear definition of the area to be studied, data was collected to create such a layer in QGIS. The OSM Place Search plugin was used to find the municipal borders of the city of Gothenburg as a base. To disregard the archipelago and Göta Älv completely, the map "Översiktskartan latest (shp)" ©Lantmäteriet from the Geodata Extraction Tool (GET) was used (Lantmäteriet, n.d.). The bridges and tunnels crossing the river were to be kept even though the layers did not necessarily include them, so the polygons had to be altered slightly to accommodate this. To exclude the central areas of Gothenburg, the congestion tax zone as described by Transportstyrelsen (2026) was added to QGIS for removal from the polygon layer. Several geoprocessing tools such as clip, union and difference were utilized in the process of finalizing the study area, which can be seen in Figure 5.1.

4.1.2 Infrastructure Elements and Characteristics

In QGIS, the four transport modes' infrastructure was of high relevance to both use on its own, and also to assign other data to. The networks meant for cars were downloaded from Trafikverket (n.d.) from the Swedish national road database (NVDB) as described by (Trafikverket, 2020a). For optimal QGIS application, this line layer was filtered to only be classified as car network. Categories for bike and

pedestrian networks were also included in the dataset, but were quickly disregarded due to a lack in quality. Other methods of finding such networks were instead utilized. For the sociodemographic analysis, NVDB data for the functional road class was utilized, as described by Trafikverket (2020b).

For the bike network, a dataset created by Jonas Hedlund at the consultancy firm Tyréns that both identifies and classifies bikeable infrastructure in Sweden was used. The process of creating this dataset is described in Hedlund (2022) and is retrieved from Hedlund (2025). For the pedestrian network, the QGIS plugin QuickOSM was used, with a quick query for line elements within the study area for key=highway and value=footway. In accordance with OpenStreetMap Wiki (2025), this search yielded "designated footpaths; i.e., mainly/exclusively for pedestrians". For the public transport aspect, Västtrafik (n.d.-a) was used as a source to retrieve the locations for all public transport stops within the study area. In QGIS, the stops were filtered to only be for ordinary line traffic, not taxi, flex, or local services.

4.1.3 SySMo: Synthetic Sweden Mobility

For the spatial analysis conducted in this study, a synthetic population was used, which is a simplified microscopic approximation of a real population constructed to be statistically representative at the aggregate level (Tozluoğlu et al., 2023). The dataset used in this study is Synthetic Sweden Mobility (SySMo), which provides a synthetic representation of more than ten million individuals in Sweden, including detailed information on household characteristics and individual activity-travel plans. The data set comes from the work of Somanath et al. (2024), who limited their analysis exclusively to Gothenburg. The objective of this study was to develop an end-to-end modeling framework to generate a synthetic population of Gothenburg residents, including corresponding activity schedules and mobility patterns for both present and historical populations. Table 4.1 shows the specifications of the SySMo dataset used.

Table 4.1: Specifications of the SySMo dataset, adapted from Somanath et al. (2024).

Specification	Description
Subject	Data Science and Engineering
Specific subject area	Activity-based synthetic modeling of active travel patterns in Gothenburg.
Type of data	Tabular data describing households and daily active travel schedules.
Data acquisition	Synthetic population generated using the SySMo model, representing mobility patterns of the Gothenburg population. The dataset consists of five relational tables: person, household, house, building and OD matrix.
Data format	Raw and processed data handled using Python.
Data source location	Primary source derived from the scientific report by Somanath et al. (2024).
Data accessibility	Repository: Zenodo Direct URL to data: https://doi.org/10.5281/zenodo.13882078 .

For this study, the main focus is on commute trips, so trips between home and work within rush hours were extracted. Only two out of five relational tables were used for relevance reasons, namely person and OD matrix. The extraction and processing of the Gothenburg specific dataset was carried out using simulations implemented in Google Colab. In this process, ChatGPT (GPT-5.3, OpenAI) was used as an aid in the coding process. The code is provided in Appendix A and the use of AI are further discussed in Chapter 8.

4.1.4 Sociodemographic Factors

To include the sociodemographic factors that were explored in the literature review into the location selection process, statistical data assigned to subareas within Gothenburg as described by Göteborgs Stad (n.d.-a) was used. The datasets of interest were the division of gender, share of commuter ages (45-64), car ownership and income levels. Areas where the population as of December 2025 are reported as less than 10 were filtered out to reduce statistical distortions caused by small population counts. This reduced the influence of outliers and therefore increased the reliability of the analysis.

4.2 Extraction of SySMo Car Commuting OD Pairs

The Gothenburg synthetic population dataset was narrowed down by applying certain filters. Since data processing is not the focus of this master thesis, as well as time constraints, it was decided that ChatGPT (GPT-5.3, OpenAI) would be used as an aid in the process of extracting the relevant data. The process consisted of trial-and-error prompting and coding, with the criteria listed in Figure 4.2 below as a basis. The criteria for the trips are related to the commuting in terms of trip purpose and trip start and end time. The code for this step can be found in Appendix A. The consulting firm COWI commonly defines the morning peak period as a span from 06:00 to 09:00 and the afternoon peak period from 15:00 to 18:00 (COWI, 2026). This broader definition reflects the observation that while work start times tend to be relatively synchronized in the morning, work end times in the afternoon are more dispersed. When a narrower defined peak hour is required for analysis, COWI typically focuses on the intervals from 07:00 to 08:00 in the morning and 16:00 to 17:00 in the afternoon. Due to the large dataset and its impact on RAM performance during subsequent data management and analysis, the time periods were restricted to 06:00–08:00 and 16:00–18:00. The resulting trips were exported in a geopackage file in ESPG:3006 (SWEREF 99 TM) to QGIS for further analysis.

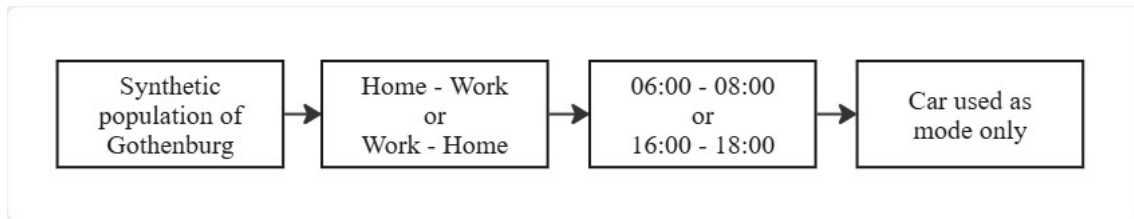


Figure 4.2: Framework for the extraction of OD commuting pairs.

Since the route assignment was already done in the OD matrix table in the SySMo dataset, there was no need to assign the trips to the road network. Instead, the data of interest was the aggregated traffic flows throughout the city. Due to the size of the dataset, it was determined that QGIS was not time-effective for this purpose, so Python coding in Google Colab with the help of ChatGPT (GPT-5.3, OpenAI) was once again done, after clipping the trips to be within the study area. The code can be found in Appendix B. The geopackage file containing only trips within the study area was exported and transformed into a Parquet file, keeping only route-relevant data. The routes for each trip are formatted as linestring containing any given number of points depending on the length of the route, which then was split up. The code processed 178,466 rows, kept 83,823 car trips which yielded 5,098,241 segments. These segments were then checked for identical ones, resulting in a count of how many times each segment was used during one day. The parquet file was then re-transformed into a geopackage file and put back into QGIS, where it was stylized using the graduated symbol with size as the differentiating method. The final network usage map can be seen in Figure 5.2.

The road network usage was then applied to the network of public transport stops

with the aim of identifying locations where car usage was high and the opportunity of taking public transport instead was possible. To be able to catch public transport stops close enough to the road network, buffers with a radius of 100 meters were drawn around the roads. Then, the tool "Join attributes by location (summary)" was used to assign values from the roads to the stops. In the case of several buffers overlapping one stop, the one with the largest flow was set as the designing value. The resulting point layer was then manually verified and edited as needed, since some routes in the SySMo dataset did not fully follow the road network. In some cases, different stop locations (e.g. A or B) for the same stop area were assigned different values, but the larger value was determined as designing later in the selection process. The network usage was classified into five equal categories and got assigned a score of 1 through 5 corresponding with the flow category. This score, S_{flow} was later used for the final calculation of the location selection. A map showing the scores for all public transport stops can be seen in Figure 5.3.

4.3 Characterization of Commuters

To analyze the sociodemographic factors that defined car commuters, ChatGPT (GPT-5.3, OpenAI) aided in a summarizing process of the main determinants. From the literature review, as well as available data columns in the extracted data, the characteristics presented in Table 4.2 were summarized. The purpose of this step was to validate the car commuting synthetic population to the car commuting population as described in literature review.

Table 4.2: The analyzed characteristics of the synthetic users of each transport mode.

Characteristic	Statistic measure
Age group	Percentage
Gender	Percentage
Car ownership	Percentage

The final Python code for user characterization can be seen in Appendix C, which works directly as a continuation of Appendix A. The comparison between the results of the characterization can be found in Chapter 6, while the maps showing the commute corridors per transport mode can be found in Chapter 5.

4.4 Rule-Based Methods

Rule-based methods are analytical approaches where predefined conditions are applied to transport data in order to classify or filter trips. These conditions are typically formulated as simple logical rules, where a trip is selected if it meets certain criteria. In transport analysis, rule-based methods are commonly used to identify trips that are suitable for mode shifts, intermodal travel, or the use of specific infrastructure such as mobility hubs. Such methods are well established in transport research, as several scientific studies use this approach. It could be a useful tool in the early stages of transport analysis, especially when the aim is to explore patterns rather than predict exact behavior (Ortúzar & Willumsen, 2011). Gigerenzer and Gaissmaier (2011) and Rashidi and Mohammadian (2011) showed that simplified decision rules are often sufficient to represent how people make daily travel decisions to classify the behavior of household travel and modal choices. Similarly, Breyer et al. (2021) applied geometric and speed-based rules to classify trips by travel mode, demonstrating that rule-based methods can effectively identify travel patterns while remaining transparent and easy to interpret.

In this study, rule-based scenarios are used to identify car trips that could be replaced by multimodal travel using mobility hubs. Based on previous research on multimodal travel behavior and acceptable access distances, three complementary scenarios are defined. Each scenario represents a different way of accessing a mobility hub and is used to assess whether a car trip can be shifted to a Walk-and-Ride, Bike-and-Ride or Park-and-Ride travel chain. The Ride part is equivalent to using public transport, which in this study is equivalent to bus or tram. The three scenarios and their times, distances and purpose are presented in Table 4.3 below.

Table 4.3: Rule-based scenarios for access to mobility hubs.

Scenario	Time	Distance	Purpose
Walk-and-Ride	5 min	≤ 400 m	Users access the mobility hub by walking, reflecting commonly accepted walking distances in urban areas.
Bike-and-Ride	3 min	400 m – 2 km	Users access the mobility hub by bicycle, allowing a larger spatial.
Park-and-Ride	15 min	2 – 5 km	Users access the mobility hub by car, considering medium access distances.

The three travel chains are based on three acceptable travel distances for each mode to a public transport stop. Several studies provide guidance on acceptable distances to mobility hubs and stations, Section 3.5.3. Walking commonly ranges between 300 and 400 meters, which corresponds to approximately 5 minutes of walking at a normal adult pace. For access to the car (Park-and-Ride), travel times of 15-30

minutes are commonly reported. Regarding the bicycle access, acceptable distances are larger, and therefore a value in between walking and biking is chosen, 400 meters up to 2 kilometers.

The distances summarized in Table 4.3 were added to QGIS with the help of the plugin "Multi Ring Buffer". Since the starting point of location selection is public transport stops, this was set as the middle point for all buffers. The distance for each buffer layer was defined as 400, 2000 and 5000 meters, respectively. It is worth noting that the distances are Euclidean and not network based, which is easier to model in QGIS but less connected to realistic travel behavior. The buffers symbolize the average acceptable distances that commuters can travel from their home location to a mobility hub with the three transport modes.

For each of the six buffer layers, the "Count points in polygon" tool was used to identify how many home and work locations were found within each buffer. Then, the tool "Join attributes by field value" was used to assign these six counts to the stops themselves. To be able to rank the stops from low to high potential usage, all six columns were classified into five quantiles and ranked 1 through 5. Two intermediate scores were calculated, one for home and one for work, where the three respective scores (1-5) were added up and divided by 3. This meant that for each public transport stop, the amount of home or work locations reached by foot, bike, or car was counted equal in the final scoring. The two scores were then added together and divided by 2 to ensure that the amount of both reachable home and work locations, regardless of mode, mattered equally. Below is an equation that describes the calculating process of all six scores to obtain one final catchment score.

$$S_{potential} = \frac{1}{2} \left(\frac{S_{walk,home} + S_{bike,home} + S_{car,home}}{3} + \frac{S_{walk,work} + S_{bike,work} + S_{car,work}}{3} \right) \quad (4.1)$$

A map showing the final potential catchment scores (1-5) for all public transport stops in the Gothenburg area can be seen in Figure 5.4.

4.5 Connectivity Scoring

The purpose of this study is to strengthen the connection between each transport mode and to simplify multimodal travel based on existing infrastructure. The idea was to determine a suitable distance from the car, bike, and pedestrian infrastructure to each public transport stop, and grade them based on how many modes they are connected to. The data utilized for this step was the three modes' networks as described in the data collection section earlier, and public transport stop locations. For the bike infrastructure, it was decided to only include the bikeability categories described as suitable for everyone and seasoned cyclists, and asphalt bike paths. All categories identified as unsuitable in the literature review were excluded, namely everything worse than not suitable for most, bike lanes, as well as gravel roads.

Six different distances were tested, namely 5, 12.5, 25, 50, 100, and 400 meters. 50 meters was an arbitrary distance used as a starting point, and the other distances were added to explore the general connectivity of public transport stops within the city of Gothenburg. A table summarizing the different results that all six distances yielded can be found in Chapter 5. The results yielded by the six different distances were analyzed, and it was determined that 50 meters should be used as the connectivity measure.

The methodology consisted of using the geoprocessing tool "Join attributes by nearest" and assigning the public transport stops to the pedestrian infrastructure network, with a maximum distance of one of the aforementioned meters. The same was done for the bicycle infrastructure network with the same maximum distance, and also for the car network. In the attribute table for the created layer, all stops located within 50 meters got a score of 1 for each mode, otherwise a score of 0 was reported, as described by Equation 4.2. A summary column added the three scores together and all modes were subsequently graded 0, 1, 2 or 3, depending on how many modes they were connected to, as shown in Equation 4.3.

$$C_m = \begin{cases} 1, & \text{if stop is within 50 m of mode } m \\ 0, & \text{otherwise} \end{cases} \quad (4.2)$$

$$S_{\text{connectivity}} = C_{\text{walk}} + C_{\text{bike}} + C_{\text{car}} \quad (4.3)$$

The calculated $S_{\text{connectivity}}$ was used to calculate the final score for all stops for the location selection. A map showing the scored for public transport stops can be seen in Figure 5.5.

4.6 Sociodemographic Analysis

Up until now, the focus has been on where the citizens of Gothenburg travel each day between home and work locations and how a mobility hub can facilitate more sustainable commuting. The idea was to find a location for a new mobility hub that would facilitate a shift of the sociodemographic group that is most likely to commute by car to one of the three aforementioned multimodal rule-based scenarios. Based on the literature review, the average car commuter is a man in the older working span with a high income living in an area with a high average car ownership number. Therefore, it was of interest to identify the areas where the chance of car commuting was the highest, in terms of the mentioned sociodemographic factors.

The income level data was only available at the primary area level, and the necessary disaggregation of the data into the smaller base areas introduces uncertainty. The population density of people aged 45-64 were of interest, as well as the proportion of men in each base area. The car per person ratio was calculated by dividing the number of private cars by the total number of citizens registered within all respective base areas. The process of combining datasets to retrieve relevant indicators can be found in Appendix D The four layers were then quintile classified, and were

then weighed together. It was determined that income level and car ownership would stand for 40% each of the final score, and that age and gender would account for 10% each. As found in the literature, car commuting relies heavily on the individuals owning a car, and that relies heavily on income level. It was therefore decided that those two indicators would have a stronger impact on the final score. The gender division is more or less 50/50 in most of the base areas which makes it less significant. Age considered to be heavily connected to income level since the older commuting population has a higher chance of earning more thanks to their longer career. A map showing the score for each base layer can be seen in Figure 5.7.

The analysis consisted of intersecting the layer with 5000-meter buffers around all public transport stops with the base area map. The area of all buffers that fell within all base areas was calculated using the \$area function in QGIS, which gives the area of certain polygons. To figure out the population that each stop reached within each area, the total population of the area was multiplied with the proportion of the base area covered by the buffer. This calculation is based on the assumption that the inhabitants are evenly distributed, which is not realistic but a necessary simplification of reality. The next step consisted of calculating a weighted score that multiplied the score of the zone by the population reached. Then, the values of each buffer were aggregated back to the public transport stops with the help of the "Join attributes by field value" tool. To summarize everything together, the "Join attributes by location (summary)" tool was used by comparing the layer to the original public transport stop layer and summarizing the weighted score and reached population. Now, every stop has gone from tens of rows to only one summary row.

To finalize the scoring of each stop, two scores were calculated and weighed equally against each other. The first is related to the quantity of the reached population, which is defined as the number of citizens within all the catchment areas. This is described in Equation 4.4, where P_b is the population of base area b , O_{sb} is the overlap area between the stop buffer and the base area, and A_b is the total area of the base area.

$$N_s = \left(\sum_b P_b \cdot \frac{O_{sb}}{A_b} \right)^{(q)} = \left(\sum_z R_{sb} \right)^{(q)} \quad (4.4)$$

The second score represents the quality of the citizens reached, and was calculated as the population-weighted mean of the sociodemographic score. It is described in Equation 4.5 where B_b is the car commuter likeliness score of the base area and R_{sb} is the quantity score described above.

$$Q_s = \left(\frac{\sum_b B_b R_{sb}}{\sum_b R_{sb}} \right)^{(q)} \quad (4.5)$$

Together, these two scores complement each other by presenting both the scale of the potential demand and its sociodemographic relevance. The two scores were quintile classified, added together and lastly divided by two as described in Equation 4.6.

$$S_{\text{sociodemographic}} = \frac{Q_s + N_s}{2} \quad (4.6)$$

This step ensured that both the size and characteristics of the reachable population were considered equally when identifying suitable hub locations. To ensure that users would not need to diverge from their original route to reach the mobility hub, it was decided a close distance to main roads to be considered suitable. For this purpose, the four main road classes (0-3) were extracted from the Functional Road Class dataset provided by Trafikverket (n.d.), which is described in Trafikverket (2020b). 100-meter buffers were created and dissolved along the roads and the intersect geoprocessing tool was used to find stops only located within them. The map shown in Figure 5.8 shows the final scores of the relevant public transport stops. The stops with the highest scores were qualitatively analyzed in regards of closeness to the city center and the subsequent effect on usage, large mobility nodes in the vicinity and spatial constraints. This can be seen in Chapter 5 in Table 5.5.

4.7 Location Selection

The location selection process ties together the SySMo car commuting flows, the rule-based method of mode shift potential, the connectivity scoring, as well as the sociodemographic analysis. The first step consisted of combining the first three scores in QGIS as described by Equation 4.7. Stops with a connectivity score less than 3 was filtered out, and then the traffic flow and catchment potential scores were weighed together equally. The final network scores varies between 1 and 5, and is only applied to well-connected public transport stops. This score is based strictly on network-related indicators and can be found in Table 5.5 in Chapter 5.

$$S_{\text{network}} = \frac{S_{\text{flow}} + S_{\text{potential}}}{2}, \quad S_{\text{connectivity}} = 3 \quad (4.7)$$

In addition to the network score, the sociodemographic score, $S_{\text{sociodemographic}}$ as described in Equation 4.6, was also considered when deciding on the most suitable locations for mobility hubs. Due to the differences in nature, the scores were examined in combination with each other, rather than only by combining them together. The stops with high network scores were of interest for the sociodemographic scores which can be found in Figure 5.6.

In continuation of the network and sociodemographic scoring, spatial constraints were also considered when determining the final mobility hub location. This ensured that locations with previously high rankings were also feasible in terms of available space and the existing urban environment. This assessment is qualitative and based on visual inspection in Google Maps and Google Street View. A summary of the calculated scores and the sociodemographic score and their respective components can be found in Table 5.5 and Table 5.6 and a description of them in Chapter 6.

5

Results

This chapter presents the results of the study, including a summary of the main findings in the literature review, design considerations for mobility hubs, as well as the spatial and demographic analyses.

5.1 Summary of Findings from the Literature Review

In this section, the main findings from the review of literature is presented in two tables. First, all the findings related to the mobility hub location and elements included are described. The focus is then shifted to the findings that affect the implications of the sociodemographic factors, specifically.

5.1.1 Mobility Hub Guidelines

This section presents guidelines for the mobility hub, which are based on the literature review, the network analysis, and sociodemographic factors. Together, these sources are used to turn theory and data into practical design principles. These principles guide both the location and the design of mobility hubs and are summarized in Table 5.1.

Table 5.1: Mobility hub guidelines based on the literature review, SySMo analysis and sociodemographic factors.

Finding	Implication for Mobility Hub Guidelines
Determining the Location	
Proximity to public transport	Locate mobility hubs at or near existing public transport nodes to enable efficient transfers
Car traffic flow	Place hubs in areas with high car flows to intercept trips before entering dense urban areas
Cycling infrastructure	Ensure strong connections to existing cycling networks and high-quality bicycle infrastructure
Rule-based method	Apply catchment distances of 5 km for cars, 2 km for cycling, 400 m for walking

Continued on next page

Finding	Implication for Mobility Hub Guidelines
Sociodemographic Factors	
Age	Prioritize areas with a high proportion of car commuters in the 45-64 age group when selecting target locations
Gender	Account for higher car dependency among men when selecting potential locations
Income	Include areas with higher-income households, where car ownership is typically higher and residents may have the financial means to afford both car and public transport
Car ownership	Prioritize areas with higher car ownership, often associated with middle-aged, male, and high-income populations as well as in rural areas
Elements and Design Considerations	
Car parking	Calibrate parking supply to support modal shift without encouraging additional car use
Bike parking	Provide secure, safe, and weather protected bicycle parking facilities
Shared and supporting services	Include services such as parcel lockers, kiosks, bike repair stations, way-finding, and shared mobility options
Safety and comfort	Provide seating, lighting, weather-protected waiting areas, and safe pedestrian crossings

The results show that the location of a mobility hub should be closely connected to existing public transport nodes and positioned in areas with significant traffic flows, where car trips can be intercepted before entering dense urban areas. In addition, strong connections to existing cycling infrastructure are essential to support active mobility. Characteristics such as age, gender, income, and travel behavior must also be considered in the design process. This requires providing safe, accessible, and affordable mobility options that target a diverse range of users. A more thorough presentation can be found in the next section. Finally, the design and dimensioning of the hub should prioritize secure bicycle parking, carefully calibrated car parking, shared services, such as bike sharing and the inclusion of supporting services such as parcel lockers, a kiosk, and real time information systems. These elements are essential to improve usability and encourage modal shifts.

5.1.2 Sociodemographic Factors

The literature review identifies that travel behavior and car use are influenced by a combination of socioeconomic, demographic, and spatial factors. These findings form the basis for the design and planning of mobility hubs combined with the synthetic population SySMo analysis and the data from the city of Gothenburg.

A summary of key findings from the literature review and their implications for mobility hubs, as described in Table 5.1, are presented in Table 5.2.

Table 5.2: Summary of key findings from the literature review and their implications for mobility hub design.

Findings from Literature	Implications for Mobility Hubs
Car Ownership and Use	
Car ownership is influenced by income, life events, and accessibility	→ Car dependency can be reduced by improving alternatives
Higher income is linked to more car ownership	→ Target high-income users with strong alternatives
Lower income groups often depend on public transport and active modes due to constraints rather than preference	→ Ensure affordable and equitable mobility options
Cars provide flexibility, comfort, and control	→ Alternatives must compete in convenience and reliability
Poor public transport leads to higher car use	→ Improve public transport and integrate mobility hubs in accessible locations
Car access improves job opportunities	→ Ensure mobility solutions maintain accessibility to employment
Age	
Younger people travel more actively, multimodally and are more open to intermodal travel	→ Support intermodality and flexible travel options
Middle-aged people show higher car dependency	→ Focus on mode shift strategies for car users
Older people walk more and use shared mobility less	→ Ensure accessibility, simplicity and ease of use
Gender	
Women use public transport more frequently and are more sensitive to safety and accessibility	→ Strengthen public transport integration and ensure safe design
Men are more likely to rely on cars	→ Encourage behavioral change through improved alternatives

Continued on next page

Findings from Literature		Implications for Mobility Hub Design	
Travel with children affects mode choice	→	Include family-friendly design and facilities	
Women travel shorter distances	→	Focus on local accessibility and short-distance connectivity	
Socioeconomic Factors			
Low-income groups use public transport more and travel more actively due to constraints	→	Provide affordable and inclusive mobility options	
High-income individuals depend more on cars	→	Encourage shifts away from car dependency	
Travel behavior is often constrained rather than preference-based	→	Improve equitable access to transport options	
Cycling is used by both low-income (cost) and high-income (lifestyle) groups	→	Provide high-quality and attractive cycling infrastructure	
Spatial Factors			
Urban areas support more active and multimodal travel	→	Prioritize mobility hubs in dense urban areas	
Rural and suburban areas have higher car dependency	→	Focus on Park-and-Ride and transition hubs	
Good public transport access reduces car use	→	Integrate mobility hubs with public transport nodes	
Central residents walk and cycle more	→	Support last-mile connectivity and active travel	

The results show that car ownership is strongly associated with income, accessibility, and life events. Higher-income individuals are more likely to rely on private cars, while lower-income groups often depend on public transport and active modes due to constraints rather than preference. This indicates that mobility hubs must provide attractive and competitive alternatives to private cars while ensuring affordability.

Age is also a key determinant of travel behavior. Younger individuals are more likely to adopt multimodal and active travel, while middle-aged groups show higher car dependency. This suggests that mobility hubs should support flexible and multimodal options to attract different user groups. Gender differences further influence travel behavior. Women tend to use public transportation more frequently and are more sensitive to safe and accessible transport, while men are more likely to rely on cars. Finally, spatial context plays a critical role. Urban areas support active and

multimodal travel, while suburban and rural areas are associated with higher car dependency due to limited access to public transport.

In general, these findings highlight that mobility behavior is shaped by both individual characteristics and the built environment. As a result, the design of a mobility hub must address affordability, accessibility, comfort, and convenience to reduce the reliance on private cars.

5.2 Results from the Spatial Analyses

In this section, the maps created in QGIS will be presented in the order described in Chapter 4. This includes the study area, segment use, catchment potential, connectivity, and sociodemographic scores.

The study area defined for this thesis can be seen in Figure 5.1 below. The outer borders are based on the municipal borders of the city of Gothenburg, with the archipelago not being included. The congestion tax zone is also excluded, as can be seen as the central area being not marked in red.

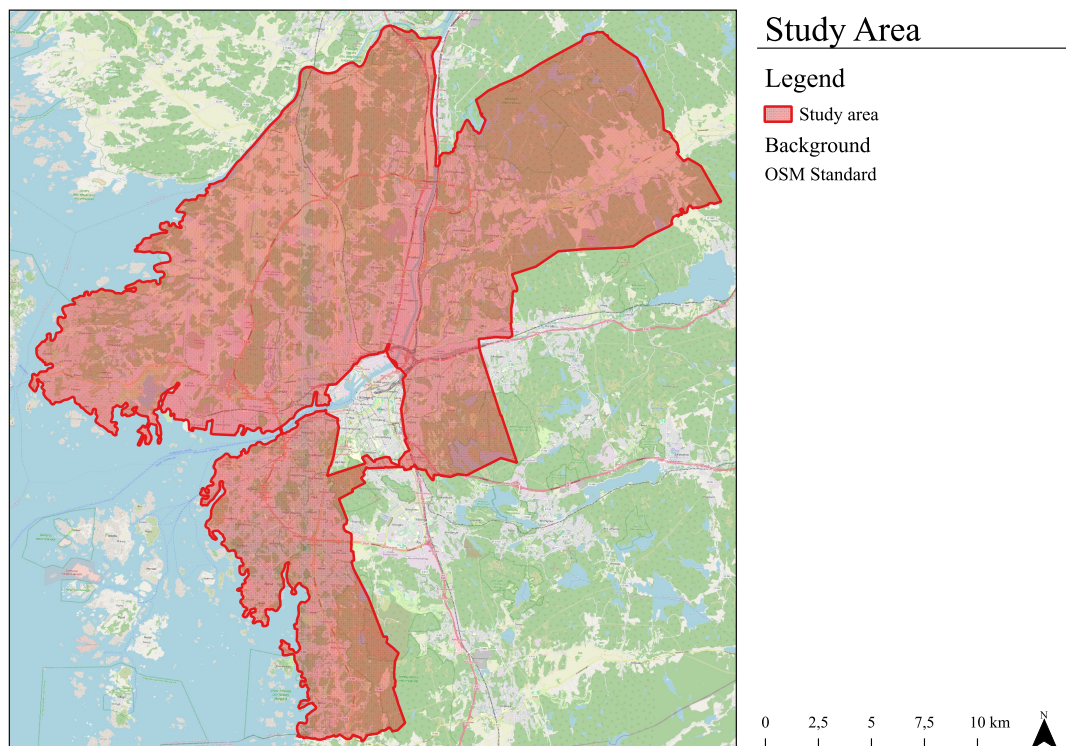


Figure 5.1: The area chosen for this study. It is based on the municipal border of the City of Gothenburg, with the archipelago and congestion tax zone excluded.

5.2.1 Network Scores

The car flows during the defined peak hours are shown in Figure 5.2. The majority of the road segments have less than 1,165 cars passing during the peak hours. The main roads, such as highways and trunk roads, naturally have higher flows than the smaller roads. The highest flows, according to the SySMo data, are on Hisingen close to the industrial areas. The majority of all road segments within the study area, however, fall within the smallest frequency category.

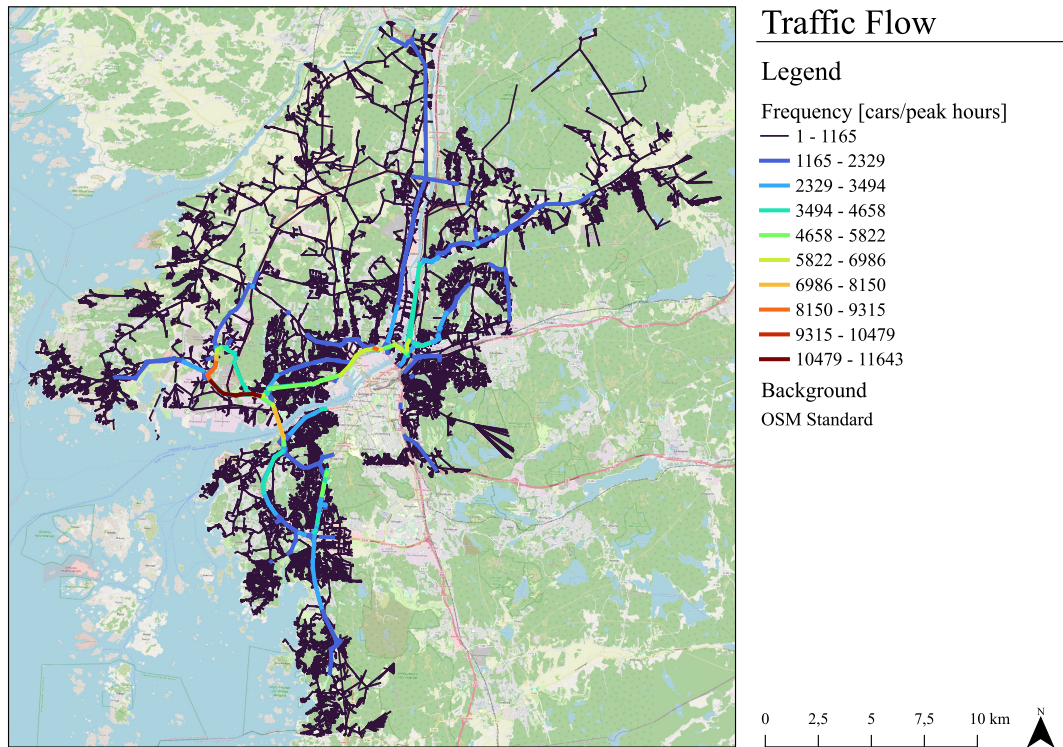


Figure 5.2: The segment use within the City of Gothenburg during peak hours, according to the SySMo data.

The aggregated car flows to public transport stops within 100 meters of the roads are shown in Figure 5.3. The majority of all stops fall into the lowest category. The higher scoring stops are generally located along major roads within the study area. Notable is the reduction in categories from 10 to 5, which was necessary to ensure the same scale for all scores going forward. S_{flow} is based directly on the five categories presented in the legend in Figure 5.3.

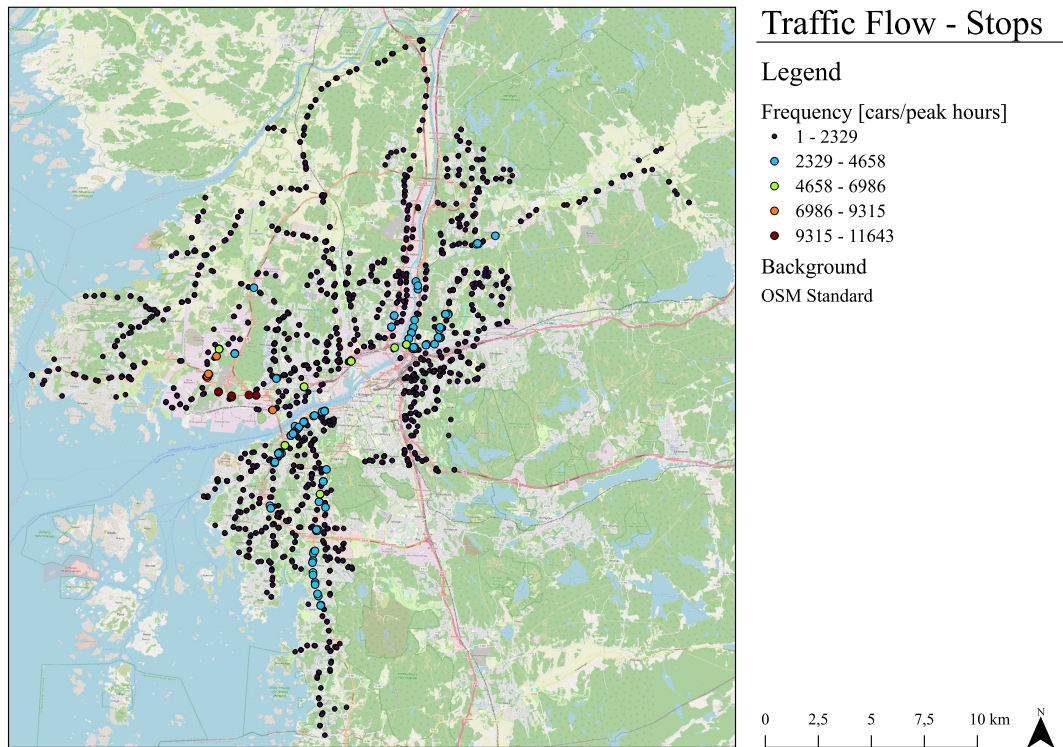


Figure 5.3: The SySMo peak hours segment use within the City of Gothenburg aggregated to stops.

The catchment potential of home and work locations for the three scenarios Walk-and-Ride (400-meter radius catchment area), Bike-and-Ride (2 kilometers) and Park-and-Ride (5 kilometers) can be seen in Figure 5.4 below. Note that the scores reported in the figure are not the final scores $S_{potential}$, but rather the raw scores before quintile classification. In general, it seems that public transport stops are closer to the city center and in certain parts of Hisingen report a higher catchment potential. The six scores that were weighed together to form Figure 5.4 can be found in Appendix E.

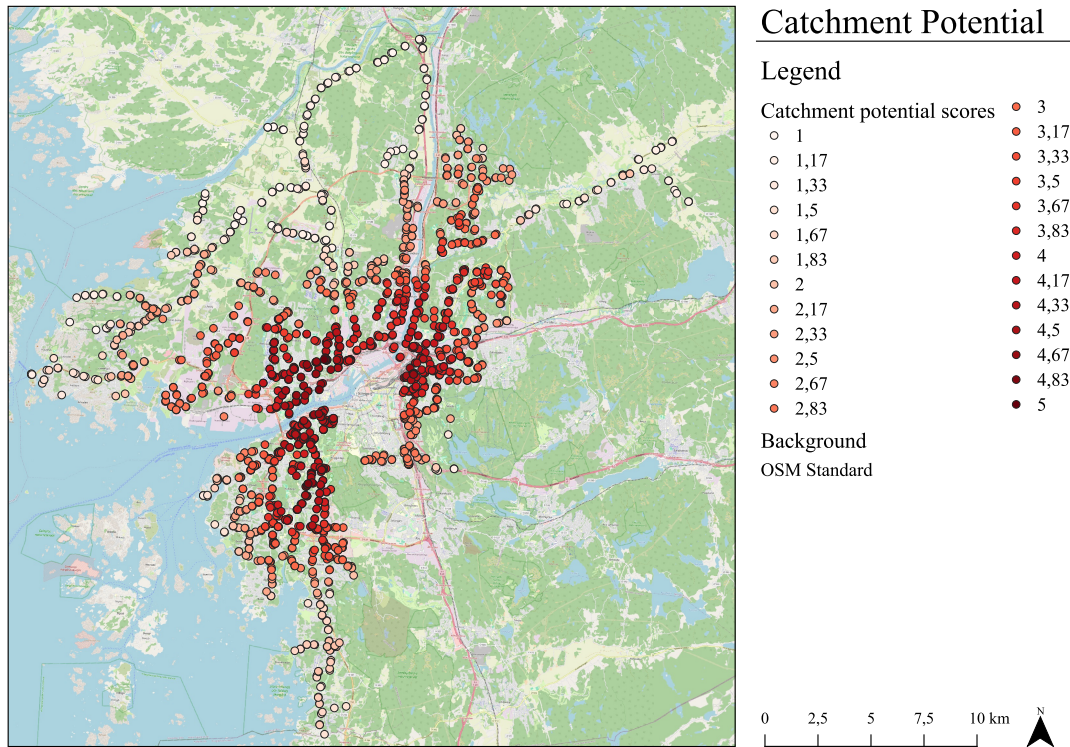


Figure 5.4: The catchment potential scores for public transport stops within the City of Gothenburg, before quintile classification.

Figure 5.5 shows the connectivity score for all public transport stops within the study area. As the map shows, the majority of the stops are well connected to the three modes' infrastructure. Furthermore, it seems that the connectivity generally disperses with increased distance from the city center. The chosen distance indicator for connectivity is 50 meters, but other distances were also analyzed, which can be seen in Table 5.3. For the calculation of $S_{network}$, only stops with a connectivity score of 3 are considered.

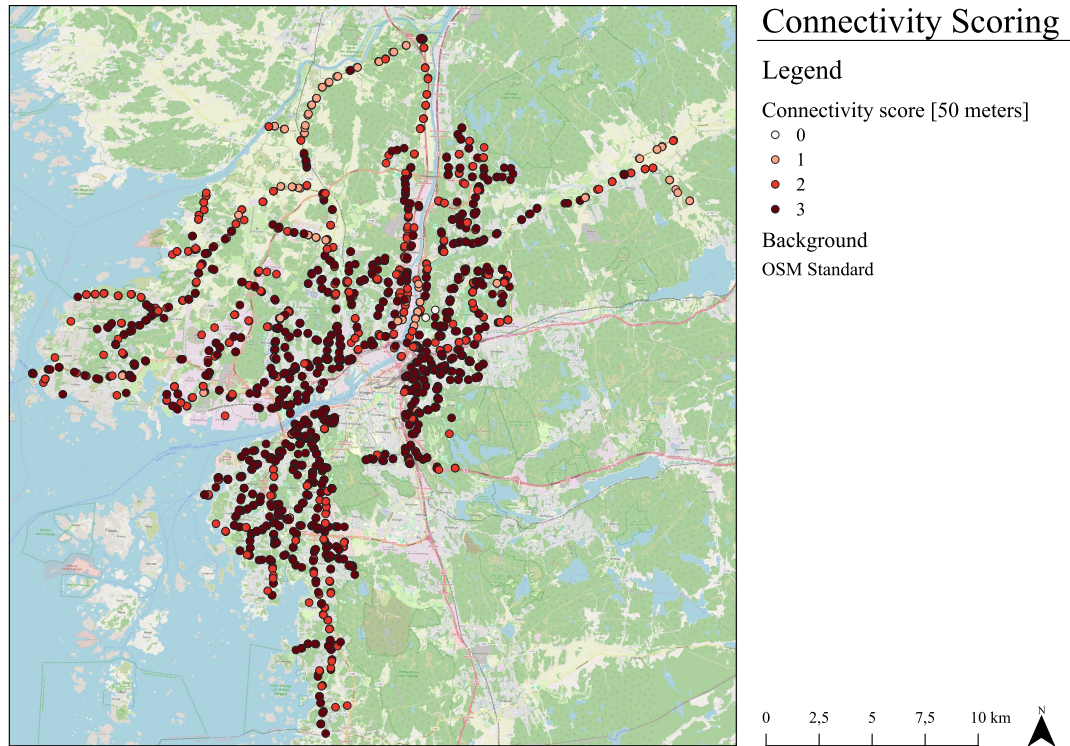


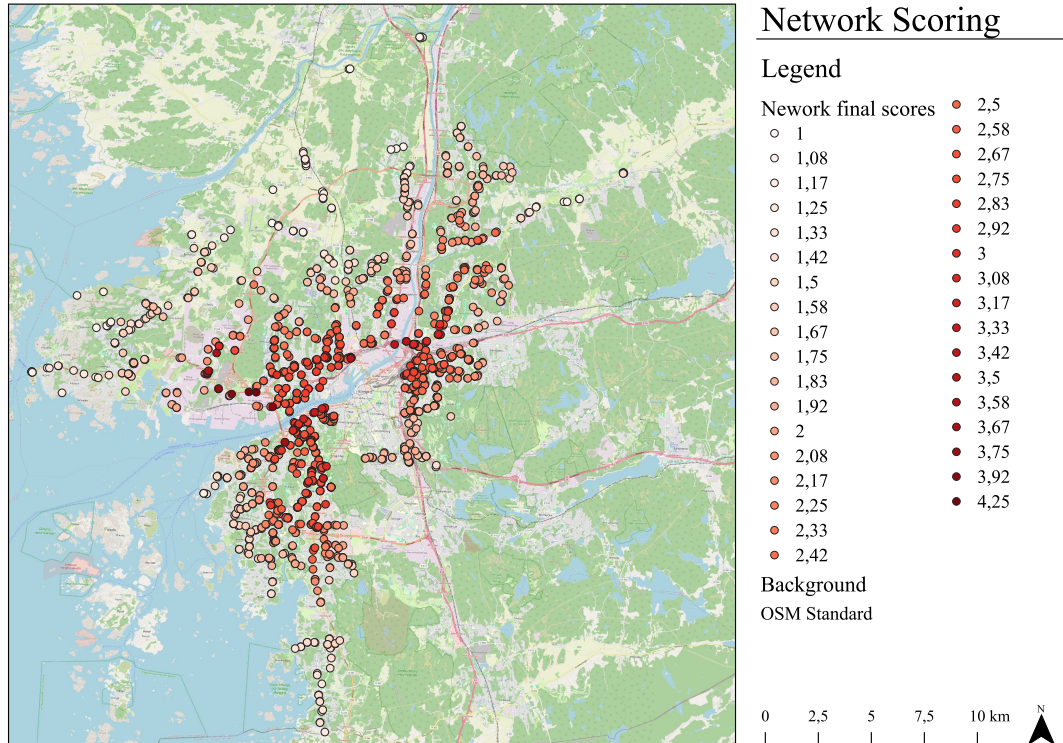
Figure 5.5: The connectivity scores for the public transport stops within the study area based on a proximity of 50 meters to the three infrastructures.

As Table 5.3 shows, the majority of the roughly 1800 public transport stops within the study area is located within 25 meters of car, bike, and pedestrian infrastructure. To allow more stops to be included in the final analysis, it was decided to increase the distance to 50 meters. The increase in numbers of scores of 3 per meter decline with an increase of distance, and almost all stops report a score of 3 for a distance of 400 meters, which is the general distance between public transport stops themselves. The decision of 50 meters as the distance is based on the plateauing of the increase in 3:s per meter, as well as the distance being the combination between strict and generous.

Table 5.3: The division of connectivity scores by distance within the study area.

Distance (m)	Division of scores			
	0	1	2	3
5	440	726	479	93
12.5	41	379	846	493
25	14	167	620	972
50	2	85	391	1,307
100	2	59	202	1,528
400	0	22	76	1,697

The final network-based score, $S_{network}$, for the relevant stops can be seen in Figure 5.6 below. Included in the calculation is, as described in Equation 4.7, traffic flow in the form of segment use (S_{flow}), catchment potential ($S_{potential}$) and connectivity score ($S_{connectivity}$). These are the scores presented Table 5.5 later in this chapter. Generally, the central areas of the study area report higher scores than the outer areas. The stops along the major highways on Hisingen have the highest scores.

**Figure 5.6:** The final $S_{network}$ scores for the public transport stops within the study area.

5.2.2 Sociodemographic Scores

The sociodemographic statistics for each base area the City of Gothenburg weighed together can be seen in Figure 5.7 below. The income and car ownership quintiles represent 40% each, and the gender and age quintiles are worth 10% each. The outer areas of Gothenburg generally report higher scores than the central areas, especially towards the coast in the west. The more central areas of the study area generally have lower sociodemographic scores. The higher the score, the higher the chance of its citizens using their private cars to commute to and from work.

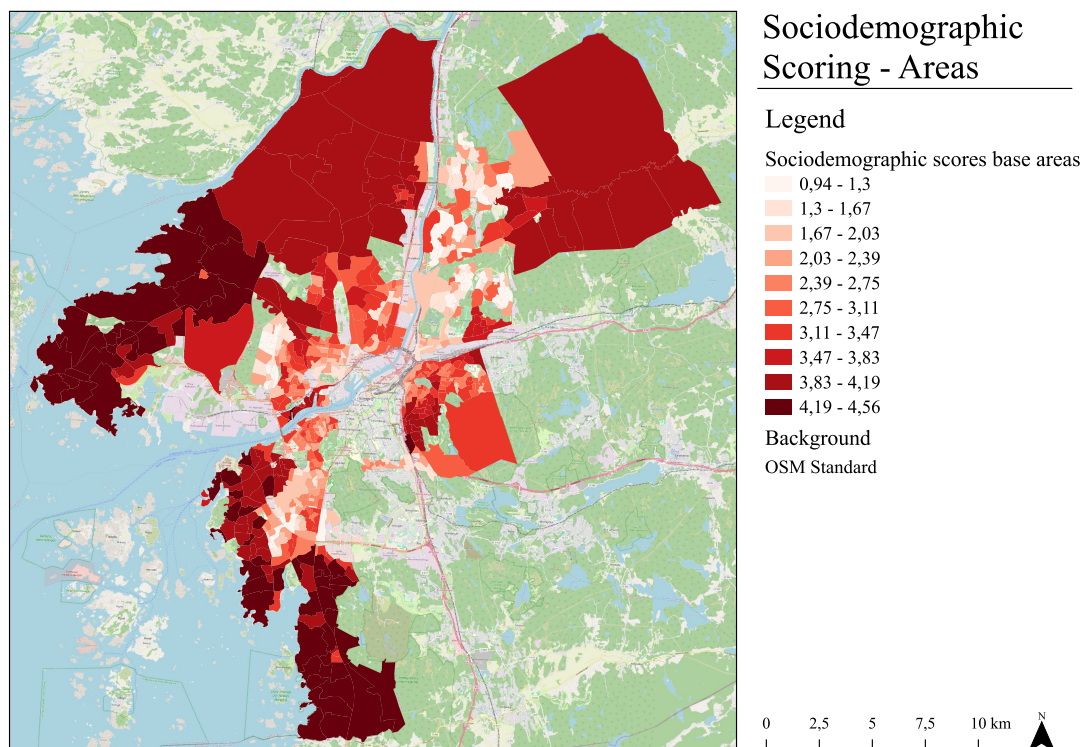


Figure 5.7: The sociodemographic scores for all relevant base areas.

Figure 5.8 shows the weighing together of the quality and quantity reached in terms of base area scores and their population counts. The highest scoring stops are around the central area, particularly near the lower-left side of the congestion tax zone. The lowest scores are generally located in the northeast zone of the study area. It seems like the majority of the stops report a score of around 3.

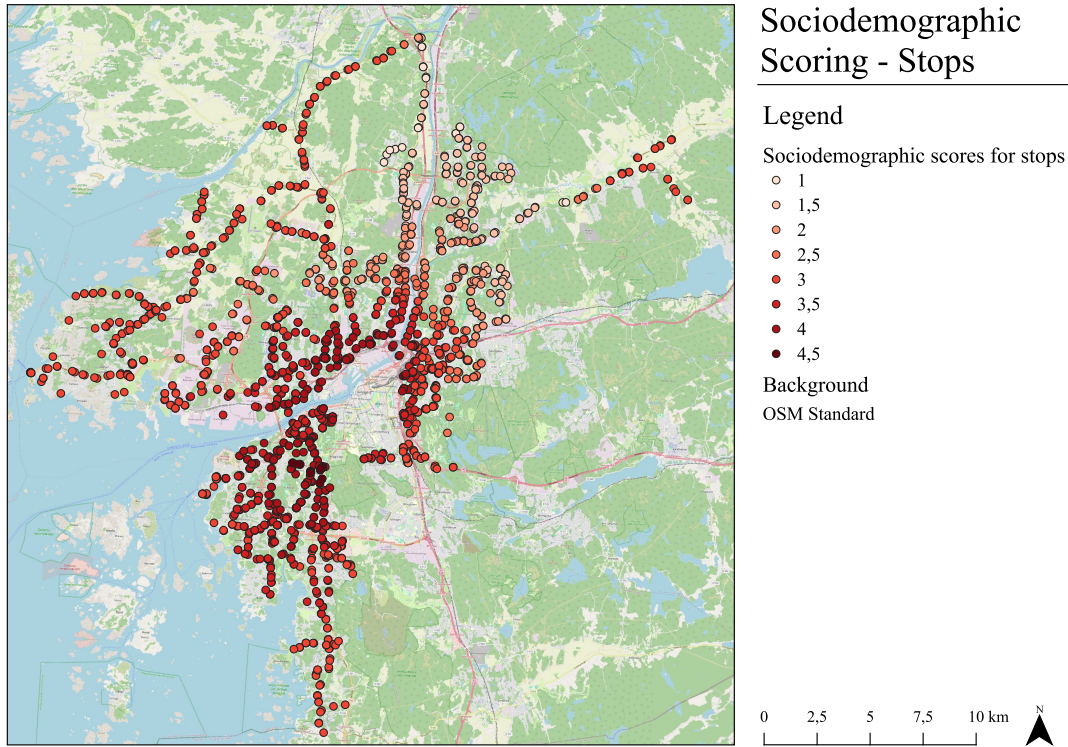


Figure 5.8: The sociodemographic scores for all public transport stops.

5.3 Validation of Commuter Characterization

The analysis of the SySMo dataset provides information on the characteristics of car commuters in Gothenburg. The results presented in Table 5.4 show that commuters with cars are predominantly between the ages of 25 and 64, men, and car owners. In addition, a higher proportion of car commuters are men (57.37%) compared to women (42.63%) and a majority of users have access to a car. The aspects of car ownership and gender are consistent with the review of the literature. However, the age aspect is not fully aligned. The age distribution is slightly younger than the literature review resulted in, even though the older working population still make out a large part. Overall, the alignment between simulated data and the main findings in the literature strengthens the validity of the assumptions used in the design of the nobility hub and supports the focus on targeting car users for modal shift.

Table 5.4: Division of sociodemographic characteristics of car commuters according to the SySMo dataset.

Category	Variable	Value
Age distribution (%)	19–24	2.59
	25–34	26.99
	35–44	22.58
	45–54	25.66
	55–64	20.96
	65–74	1.21
	75–84	0.01
Gender (%)	Women	42.63
	Men	57.37
Car ownership (%)	Owns no car	39.79
	Owns car	60.21

5.4 Mobility Hub Locations

The selection of mobility hub locations is based on network and sociodemographic factors from the QGIS data analysis. By combining these two approaches, it allows the identification of locations with high potential in terms of accessibility, demand, and spatial feasibility. Table 5.5 shows all potential locations and their network scores. Table 5.6 focuses on sociodemographic scores for the same locations. Table 5.7 summarizes the final scores $S_{network}$ and $S_{sociodemographic}$.

Based on the evaluation of network data, as seen in Table 5.5 below, several potential locations have been identified as suitable for the development of the mobility hub. Among these, Vädermotet achieves the highest score, followed by Bensingatan, and Ivarsbergsmotet. Other locations with relatively high scores include Ytterhamnsmotet, Arendalsvägen, Orustgatan, and Sörredsmotet.

Table 5.5: Evaluation of potential mobility hub locations and their network scores. $S_{potential}$ is S_{work} and S_{home} weighed together. The final score $S_{network}$ is S_{flow} and $S_{potential}$ weighed together.

Location	Traffic flow		Work (n reached within)				Home (n reached within)				Final scores	
	Cars passing/day	S_{flow}	400 m	2 km	5 km	S_{work}	400 m	2 km	5 km	S_{home}	$S_{potential}$	$S_{network}$
Vädermotet	11,643	5	4 (346)	5 (1,415)	5 (28,595)	4.33	1 (0)	3 (3,798)	4 (24,087)	2.66	3.5	4.25
Bensिंगatan	7,764	4	4 (95)	3 (1,904)	5 (29,672)	4	2 (42)	4 (6,032)	5 (27,362)	3.67	3.83	3.92
Ivarsbergsmotet	1,292	1	3 (35)	4 (2,110)	5 (29,726)	4	3 (145)	4 (7,035)	5 (27,051)	4	4	2.5
Ytterhamnsmotet	10,607	5	2 (10)	5 (3,759)	5 (27,922)	4	1 (0)	1 (460)	3 (19,038)	1.67	2.83	3.92
Arendalsvägen	10,622	5	1 (0)	5 (9,933)	5 (27,001)	3.67	1 (0)	1 (0)	2 (14,319)	1.33	2.5	3.75
Orustgatan	5,637	3	5 (298)	3 (1,322)	4 (14,278)	4	4 (245)	5 (7,748)	5 (28,791)	4.66	4.33	3.67
Kungsten	4,194	2	5 (232)	3 (1,221)	4 (14,446)	4	2 (47)	4 (5,911)	5 (26,850)	3.67	3.83	2.92
Nya Varvsallén	1,026	1	3 (35)	3 (1,500)	4 (14,247)	3.33	2 (55)	3 (2,640)	4 (25,316)	3	3.17	2.08
Dalavägen	3,720	2	3 (33)	3 (1,464)	4 (14,198)	3.33	2 (24)	4 (4,569)	5 (25,772)	3.67	3.5	2.75
Sörredsmotet	8,624	4	5 (611)	5 (17,487)	5 (25,530)	5	1 (0)	1 (0)	2 (11,183)	1.33	3.17	3.58
Radiomotet	3,539	2	5 (190)	5 (8,041)	2 (10,613)	4	3 (116)	4 (6,482)	3 (19,823)	3.33	3.67	2.83
Slupundsgatan	1,886	1	3 (35)	4 (2,101)	4 (14,558)	3.67	4 (384)	5 (8,377)	5 (27,094)	4.67	4.17	2.58
Bergkristallsgatan	3,410	2	5 (273)	3 (1,466)	3 (11,497)	3.67	4 (521)	4 (5,981)	4 (21,862)	4	3.83	2.92

Table 5.6: Evaluation of potential mobility hub locations and their sociodemographic scores. $S_{sociodemographic}$ is $S_{quantity}$ and $S_{quality}$ weighed together. $S_{quality}$ is the quintile of dividing sum of the zone weighted scores by the sum of the reached population.

Location	Quantity		Quality		Final score
	Reached population	$S_{quantity}$	Avg. zone score	$S_{quality}$	$S_{sociodemographic}$
Vädermotet	159,802	4	2.56	3	3.5
Bensingatan	183,087	5	2.52	3	4
Ivarsbergsmotet	182,451	5	2.52	3	4
Ytterhamnsmotet	134,523	3	2.69	4	3.5
Arendalsvägen	107,529	2	2.80	4	3
Orustgatan	200,683	5	2.50	3	4
Kungssten	188,878	5	2.58	3	4
Nya Varvsallén	174,401	4	2.64	4	4
Dalavägen	175,337	4	2.66	4	4
Sörredsmotet	80,809	2	2.89	4	3
Radiomotet	144,854	3	2.80	4	3.5
Sjupundsgatan	187,829	5	2.64	4	4.5
Bergkristallsgatan	149,240	4	2.85	4	4

The sociodemographic scores in Table 5.6 are presented for the stops with the highest network scores, with the highest being 4.5 for Sjupundsgatan. The other stops have sociodemographic scores varying between 3.5 and 4. Generally, the reached population quantity score is higher than the relevance quality score of the population.

Table 5.7: Summary of Table 5.5 and Table 5.6. The locations marked in bold are the ones which are chosen as the proposed locations suitable for mobility hubs.

Location	S_{network}	$S_{\text{sociodemographic}}$	Weighed together
Vädermotet	4.25	3.5	3.88
Bensingatan	3.92	4	3.97
Ivarsbergsmotet	2.5	4	3.25
Ytterhamnsmotet	3.92	3.5	3.71
Arendalsvägen	3.75	3	3.38
Orustgatan	3.67	4	3.84
Kungssten	2.92	4	3.46
Nya Varvsallén	2.08	4	3.04
Dalavägen	2.75	4	3.38
Sörredsmotet	3.58	3	3.29
Radiomotet	2.83	3.5	3.17
Sjupundsgatan	2.58	4.5	3.54
Bergkristallsgatan	2.92	4	3.56

Based on the combined evaluation of network and sociodemographic factors, four primary locations were selected for further design development: Ytterhamnsmotet combined with Arendalsmotet, Nya Varvsallén combined with Dalavägen, Orustgatan combined with Kungssten, Bensingatan combined with Ivarsbergsmotet. In Section 6.1, these locations are further analyzed and developed into mobility hub design proposals.

5.5 Mobility Hub Design

The design of the mobility hub is based on the integration of multiple transport modes and supporting services. The existing public transport infrastructure, including bus and tram connections, is already present on the site. The design will prioritize public transport, cycling, and walking, while limiting the dominance of private cars. The hub aims to provide effective transfers between modes with a focus on user comfort and accessibility. Table 5.8 shows a list of everything that should be included in the mobility hub.

Table 5.8: Design components of the mobility hubs proposed at the four locations.

Category	Elements Considered
Transport Modes	Walking
	Car
	Bike
	Bus
	Tram
Parking Facilities	Weather-protected bike parking
	Bike racks
	Cargo bike parking
	Car parking spaces
	Electric vehicle charging
Shared and Supporting Services	Bike sharing (Styr & Ställ)
	Cargo bike sharing
	E-scooters and E-bikes
	Parcel lockers
	Kiosk
	Bike repair station
	Bike air pump
	Real-time travel information
Safety and Comfort	Wayfinding
	Seating
	Lighting
	Greenery
	Weather protected waiting areas
	Safe crossings
	Wi-Fi and phone charging

5.5.1 Parking Design and Considerations

Parking is a key element in the design of a mobility hub, as it directly influences accessibility, modal choice, and the attractiveness of intermodal travel. The design prioritizes high quality bicycle parking in order to encourage cycling as a part of intermodal trips. The bike parking facility is designed to be safe, secure, and weather protected. All bicycle parking facilities are within 150 meters of the main transfer points to minimize walking distances (UE, 2010). The design follows the principles for dense urban areas (type A), ensuring close proximity to public transport and high accessibility (Rongen et al., 2022). The capacity of bicycle parking is determined by experienced demand and modal split, ensuring that sufficient spaces are available without creating unused capacity. All bicycle parking is provided free of charge to maximize usage. Parking spaces specifically for cargo bikes are also included in the design of the mobility hub.

Car parking is designed to support efficient transfers and changes to public transport and other more sustainable modes while minimizing space use and environmental impacts. The parking area is part of the mobility hub, but it does not dominate the space, and it is important to ensure that the parking facility is located close to the sustainable modes. The number of car parking spaces is calibrated to meet demand without encouraging additional car use. Some electric vehicle charging stations are also included in the parking area. The parking is primary intended for short-term use. In the Gothenburg region, 4 hours of free parking is standard and kept for this mobility hub to support Park-and-Ride functionality. Another pricing solution is to offer free parking between office hours 06:00 and 18:00 on weekdays and charge a higher fee for all the other hours to limit long term and overnight parking and to prevent cars blocking parking spaces for daily commuters. In conclusion, effective parking for cars and bicycles in mobility hubs requires a balance between safety, accessibility, convenience, and sufficient capacity, ensuring that parking supports sustainable mobility while avoiding car dependency.

5.5.2 Services and User Experience

The mobility hub includes a wide range of shared and supporting services designed to improve usability and enhance the overall user experience. Key services include parcel lockers, a kiosk, and additional services nearby. Indoor waiting areas and real-time travel information systems are also provided to improve comfort and usability. Furthermore, shared mobility services, such as bicycle sharing services, e.g. Styr & Ställ, are integrated into the hub to support flexible travel options. Additional facilities, including bicycle repair stations and air pumps, further support active mobility. Carpooling services are not included in this design, as this thesis focuses specifically on reducing the dependency on cars overall.

The quality of the surrounding urban environment plays a key role in the success of mobility hubs. Improvements such as seating, lighting, greenery, weather protected waiting areas, and safe pedestrian crossings contribute to user comfort and accessibility. In addition, the mobility hub should be designed according to universal

design principles to ensure accessibility for all user groups. The general concept of mobility hubs is guided by the physical integration ladder developed by K. Geurs et al. (2022), which describes the increasing levels of integration and quality in the design of mobility hubs. The lower levels are characterized by the basic co-location of transport services, while the higher levels include clearly organized interchange points, multiple shared mobility options, supporting services, and universally accessible design. The proposed hub aims to achieve a higher level of integration by combining public transport with active mobility, shared services, high quality parking facilities, within a safe, secure, and user-friendly environment.

6

Discussion

This chapter discusses the proposed mobility hub locations in relation to their feasibility, spatial characteristics, and potential role within the wider transport network. Although the analyses identified several locations with high scores, the final selection was not based only on the ranking results. Practical considerations such as available space, accessibility, and surrounding land use, as well as the existing transport network, were also taken into account. Therefore, some highly ranked locations were excluded from further considerations, while others were grouped into combined mobility hub alternatives. Finally, the applicability of the development framework is discussed, together with the limitations of the study and suggestions for further research.

According to Table 5.5, Vädermotet receives the highest network score. However, despite its high ranking, Vädermotet has significant physical and spatial constraints. The site is located along separated motorway lanes, which limits accessibility and makes it difficult to develop a mobility hub that serves users in both directions equally. Although cycling infrastructure is available, integrating a mobility hub into this environment would be challenging. For these reasons, Vädermotet is excluded from further considerations. In contrast, both Bensingatan and Ivarsbergsmotet are strong candidates due to their high scores, available space, and more favorable spatial conditions. Their proximity also creates opportunities for a combined mobility hub solution. Similarly, Ytterhamnsmotet and Arendalsvägen demonstrate high potential, offering available space and fewer physical constraints. Orustgatan, in combination with Kungssten, represents another strong option, as Kungssten offers connections to two tram lines to the city center and has available space for development.

The sociodemographic QGIS analysis identifies both overlapping and additional locations with high potential demand. Although there is considerable agreement between the two analyses, some differences are evident. For example, Sjöpundsgatan achieves a high score but was not considered a suitable location for a mobility hub due to its proximity to Marklandsgatan, which already functions as a well-established transport node. Similarly, Bergkristallsgatan faces challenges comparable to those of Vädermotet, as it is located in a highway dominated environment and quite close to the city center. Nya Varvsallén and Dalavägen both receive high scores and are located close together, making it reasonable to consider them as a combined alternative. However, the final selection focused on locations that consistently performed well in both analyses while also offering favorable conditions

for implementation. Kungssten is also located nearby and, together with Orustgatan, it forms another potential option for the mobility hub. Bensingatan and Ivarsbergsmotet are again confirmed as strong candidates in this analysis.

6.1 Potential Locations to Build Mobility Hubs

In this section, all four potential locations of the mobility hub are described, discussed, and further analyzed. The four locations are represented by pairs of nearby public transport stops: Bensingatan–Ivarsbergsmotet, Ytterhamnsmotet–Arendalsvägen, Orustgatan–Kungssten, and Nya Varvsallén–Dalavägen.

6.1.1 Bensingatan and Ivarsbergsmotet

The public transport stops Bensingatan and Ivarsbergsmotet are located on opposite sides of the highway at the northern entrance to Älvsborgsbron, see Figure 6.1 below.



Figure 6.1: A map showing the stop locations for Bensingatan and Ivarsbergsmotet, their surrounding environment, as well as their general location in Gothenburg. The background map is provided by Google Maps (2026), the Gothenburg map is provided by © OpenStreetMap contributors (2026) and the stop locations are based on Västtrafik (n.d.-b).

Bensingatan has several bus stop locations, but it is only marked with small guiding signs. Safe crossings for pedestrians and cyclists are available through signalized intersections. The stop achieves an overall SySMo score of 3.92 and a sociodemographic score of 4. Due to the high number of vehicles passing, the traffic flow score is 4 out of 5. In addition, accessibility to nearby residential areas and workplaces is favorable, contributing positively to the overall assessment. The overall cycling

infrastructure is well developed, indicating a strong potential for further improvement in the form of a mobility hub. In addition, there is sufficient available space to build a mobility hub and a parking facility in the area, for example, within the exit ramps off the highway.

On the other hand, Ivarsbergsmotet is more developed with bus shelters, seating, and bicycle parking provided at each stop. The location receives an overall SySMo score of 2.5 and a sociodemographic score of 4. However, its traffic flow score is only 1 out of 5, which is significantly lower than Bensingatan. Despite this, the accessibility to nearby residential and employment areas is comparable to Bensingatan. Although Ivarsbergsmotet demonstrates a somewhat stronger level of public transport stop infrastructure, a combined evaluation of both locations suggests considerable potential for integrated development.

Only one bus is currently stopping at Bensingatan, whereas four bus lines stop at Ivarsbergsmotet. This indicates that the public transport network in the area could be further developed. Therefore, a combined mobility hub at these locations could be an option. The high volume of car commuters passing through this area suggests a strong potential for a mobility hub, and both locations also have available space for parking facilities and the further development of public transport stops.

In terms of user groups, the southern locations are mainly suitable for residents in nearby western areas such as Långedrag, Frölunda and Högsbo who travel towards different parts of the city. The northern locations are more likely to serve both commuters from the Torslanda and island areas traveling into the city, as well as employees in surrounding industrial areas who may travel by public transport to the hub and continue by bike or other modes. Based on the typology proposed by K. Geurs et al. (2022), this location can be classified as a suburban/urban fringe hub because it is located near a motorway at the edge of an urban area.

6.1.2 Ytterhamnsmotet and Arendalsvägen

Ytterhamnsmotet is located along Torslandavägen, with a roundabout that provides access to and from the motorway, see Figure 6.2 below. This location shows strong potential mainly due to its overall high score, significant traffic flow, and proximity to workplaces. Two buses stop at this location. In the SySMo analysis, the score for workplaces within 2 kilometers and 4 kilometers reaches the maximum value of 5. In contrast, the score related to residential areas is relatively low, as the surrounding area is mostly industrial. The overall SySMo score for Ytterhamnsmotet is 3.92, while the sociodemographic score is 3.5. The location benefits from good existing cycling infrastructure and the roundabout allows cyclists and pedestrians to cross the road at multiple points. However, the spatial layout may lead to relatively long walking distances between public transport stops within the area. In addition, accessibility for cyclists is somewhat limited due to differences in elevation between parts of the site, which can cause inconvenience when biking and moving between the different locations at the bus stop. Although there is sufficient space available

for parking, careful planning is required to ensure that parking areas and other hub functions are placed close to each other and remain easily accessible.



Figure 6.2: A map showing the stop locations for Ytterhamnsmotet and Arendalsvägen, their surrounding environment, as well as their general location in Gothenburg. The background map is provided by Google Maps (2026), the Gothenburg map is provided by © OpenStreetMap contributors (2026) and the stop locations are based on Västtrafik (n.d.-b).

The bus stop Arendalsvägen is located close to Ytterhamnsmotet, but its public transport stop is located along Arendalsvägen, a smaller road that runs parallel to the Torslandavägen highway. This location offers additional opportunities, supported by nearby infrastructure, such as a gas station and existing cycling paths. A green area between the highway and the local road provides suitable space for development, particularly for parking facilities, although areas near the gas station could also be considered. Currently, only one bus stops at this location. In the SySMo analysis, Arendalsvägen has an overall score of 3.75, slightly lower than Ytterhamnsmotet but still relatively high. The socioeconomic score is 3. Similarly to Ytterhamnsmotet, the surrounding area is dominated by industries rather than residential buildings, resulting in lower scores related to residential proximity.

Taking advantage of their close proximity and complementary characteristics, a combined solution integrating Ytterhamnsmotet and Arendalsvägen is proposed. One limitation of this area is the lack of express bus services. To improve the attractiveness and overall functionality of the mobility hub, the introduction of an express bus stop should therefore be considered. Based on the typology proposed by K. Geurs et al. (2022), this location can also be classified as a suburban/urban fringe hub because it is located near a motorway at the edge of an urban area.

6.1.3 Orustgatan and Kungssten

Orustgatan is located along a smaller road near the Västerleden highway, see Figure 6.3 below. The cycling infrastructure in the area is good and there is an existing residential parking facility nearby, which could potentially be a combined parking space for residents and commuters. Currently, public transport stops include bus shelters and benches in both directions, but there is no dedicated bike parking. Two buses stop at this location. Compared to Ytterhamnsmotet and Arendalsvägen, Orustgatan has a lower traffic flow, with roughly half the number of passing cars. Despite this, the location still achieves an overall SySMo score of 3.67, and 4 for the sociodemographic analysis. One of the main strengths of this location is the proximity to residential areas, reflected in high scores (4-5) for home locations. The proximity to workplaces is also strong, particularly within 400 meters, where it reaches the highest score. In addition, the Otterklintsvägen commuter parking facility has a total of 21 parking spaces located near Orustgatan public transport stop, which makes the location even more suitable for a potential placement of a mobility hub. Orustgatan is well positioned between residential and employment areas, which gives it strong potential to build a mobility hub here.



Figure 6.3: A map showing the stop locations for Orustgatan and Kungssten, their surrounding environment, as well as their general location in Gothenburg. Also, the commuter car parking Otterklintsvägen is shown in the north area of the map. The background map is provided by Google Maps (2026), the Gothenburg map is provided by © OpenStreetMap contributors (2026) and the stop locations are based on Västtrafik (n.d.-b).

Kungssten is located nearby and already functions as an established public transport node. It is served by several bus and tram lines, which makes it well connected to a wider transport network. Although it already functions well, there is still potential for improvement, particularly in terms of a commuter parking area and better

cycling accessibility. Kungssten is divided into two elevation levels, one higher up at Långedragsvägen and one for the tram lines in the lower levels of Västerleden. There is limited space to expand the public transport stop, but if designed effectively, it should be a great improvement to the already existing node. In terms of scoring, Kungssten has a relatively low SySMo score of 2.93 and a score of 4 for sociodemographic analysis. The lower traffic flow may reflect the fact that many users already rely on public transport in this area, rather than private cars. This could explain the lower score for passing traffic. However, both proximity to workplaces within 400 meters and accessibility to residential areas within 5 kilometers receive high scores, indicating a strong demand potential.

Taking advantage of their close proximity and complementary characteristics, Orustgatan and Kungssten together represent a promising location for a mobility hub, combining strong accessibility to both residential and public transport infrastructure. Based on the typology proposed by K. Geurs et al. (2022), this location can be classified as an urban neighborhood hub (large), as it is located in a larger residential area with potential for a substantial number of shared mobility services.

6.1.4 Nya Varvsallén and Dalavägen

Nya Varvsallén and Dalavägen are located on each side of Västerleden at Gnistängsmotet, see Figure 6.4 below. Nya Varvsallén has one tram line passing through meanwhile Dalavägen only has one bus stop. Therefore, a combination of them would be beneficial and it would be a good option to place a mobility hub in this area. Dalavägen has a higher traffic flow and better residential accessibility, as it scores higher compared to Nya Varvsallén. The overall score for the SySMo analysis is 2.75 and for Nya Varvsallén the score is 2.08. However, the proximity score of the work location is the same for both locations and they received a sociodemographic score of 4 out of 5.



Figure 6.4: A map showing the stop locations for Nya Varvsallén and Dalavägen, their surrounding environment, as well as their general location in Gothenburg. The background map is provided by Google Maps (2026), the Gothenburg map is provided by © OpenStreetMap contributors (2026) and the stop locations are based on Västtrafik (n.d.-b).

Both locations have great potential for developing a mobility hub in the area as there is available space for parking facilities and when combining a tram and a bus stop the attractiveness will improve. Currently, there are no bike or car parking facilities available near public transport stops, however, bus shelters and seating are available. Based on the typology proposed by K. Geurs et al. (2022), this location can be classified as an urban neighborhood hub (large), as it is located in a larger residential area with potential for a substantial number of shared mobility services.

6.1.5 Discussion of the Potential Locations of the Mobility Hub

All four locations demonstrate great potential for the development of mobility hubs. However, the sites differ in terms of surrounding land use, traffic flow, accessibility, spatial conditions, and integration of public transport. Each location may therefore support different mobility functions and user groups. Common strengths among the locations include good accessibility to major transport corridors, opportunities for intermodal connections, and available space for the further development of parking and mobility services.

An important factor influencing the suitability of the locations is the surrounding urban context. The locations in the Torslanda area, particularly Ytterhamnsmotet and Arendalsvägen, are strongly connected to industrial and employment areas. Their high traffic flows and proximity to workplaces indicate a strong potential for

commuter-oriented mobility hubs that improve access to major employment destinations. However, the limited residential density in the surrounding areas may reduce their function as local neighborhood hubs. In contrast, Orustgatan and Kungssten are located closer to residential areas and existing public transport infrastructure, making them more suitable for hubs that support daily multimodal travel for residents. These differences highlight that mobility hubs can serve different purposes depending on their spatial and functional context.

Another important aspect is the physical layout and topography of the sites. Several locations such as Ytterhamnsmotet and Kungssten include elevation differences that can create accessibility challenges for pedestrians and cyclists. In addition, some locations require relatively long walking distances between transport modes due to the spatial separation of stops within the area. These factors may reduce user convenience and should therefore be carefully considered during the design process. At the same time, most of the locations provide sufficient available space for the development of parking facilities, bicycle infrastructure, and complementary mobility services, creating favorable conditions for future expansion.

The existing level of public transportation integration also differs between locations. Kungssten already functions as an established public transport node with several bus and tram connections, while locations such as Bensingatan and Arendalsvägen currently have fewer public transport services. However, lower existing levels of existing transport infrastructure may also indicate greater potential for development. Combining nearby stops, such as Bensingatan with Ivarsbergsmotet or Ytterhamnsmotet with Arendalsvägen, could strengthen intermodal connectivity and improve the overall functionality of mobility hubs.

Future public transport investments further strengthen the potential of several locations. According to Trafikverket and Västra Götalandsregionen (2021) the public transport network should be extended in Gothenburg and therefore a Metrobus is going to be implemented. Kungssten, Ivarsbergsmotet, and Sörredsmotet will be new Metrobus stations, which means that these three locations are already confirmed as suitable locations for further developments. Integrating mobility hubs with planned public transport investments could therefore improve both long-term functionality and attractiveness.

Among the four evaluated areas, Bensingatan and Ivarsbergsmotet appear to be the most favorable option. One key advantage is the availability of space, which provides good conditions for developing a full-scale mobility hub with parking, shared mobility services, and improved public transport infrastructure. The location is also well positioned to serve surrounding residential areas such as Eriksberg, Bräcke, and Sannegården, which makes it relevant for a relatively large local population. In addition, its location near the entrance to Älvsborgsbron makes it strategically suitable for intercepting car traffic before it enters the city center. Combined with the fact that this location achieved the highest overall scores in the analysis, it emerges as the strongest candidate among the alternatives evaluated.

In general, all four locations demonstrate different strengths and challenges for the development of mobility hubs. Some locations are better suited to support commuting and access to workplaces, while others have stronger connections to residential areas and everyday public transport use. Among the alternatives, Bensington and Ivarsbergsmotet emerge as the most preferable locations if only one site is to be selected. Finally, mobility hubs should be adapted to the surrounding land use, accessibility conditions, and travel patterns of each location, rather than designed as standardized solutions.

6.2 The Importance of Complementary Network Measures

Although the implementation of mobility hubs can play a significant role in facilitating intermodal travel and reducing car dependency, their effectiveness is strongly dependent on the wider transport system and supporting measures. To create changes in citizens' travel behavior, mobility hubs must be combined with other actions that both reduce car use and improve sustainable alternatives.

An important approach is to make car use less attractive. This can be achieved by reducing parking in the city center, increasing congestion charges, or introducing car-free areas. For example, fewer parking spaces in central areas can discourage people from driving, while higher parking fees or congestion charges make car use more expensive. These measures can influence travel choices, especially in dense urban areas. At the same time, it is important to improve the attractiveness of alternative transport modes. If sustainable options are not convenient, reliable, and safe, people are unlikely to change their behavior. Therefore, high quality public transport is crucial. This includes frequent services, reliable travel times, and well-designed transfer points. Mobility hubs can support this by making transfers easier, but the overall quality of the public transport system remains a key factor. In addition, cycling and walking infrastructure also plays an important role. Safe and well-designed bike lanes, especially those separated from car traffic, can make cycling more attractive. It is particularly important to avoid situations where cyclists must share space with cars, as this is often perceived as unsafe. Good pedestrian environments and first- and last-mile connections are also necessary to ensure that people can easily access mobility hubs.

Urban structure and land use planning also influence travel behavior. In areas with high density and mixed land use, the distances between home, work, and services are shorter, making walking, cycling, and public transport more attractive. In contrast, low density areas often lead to higher car dependency, regardless of mobility hub implementation. Finally, behavioral and social factors should be considered. Travel habits, perceptions of safety, and convenience affect the choice of transport mode. Therefore, measures should focus not only on infrastructure but also on creating a transport system that feels safe, simple, and attractive for different user groups. A

balanced combination of "push" measures that discourage car use and "pull" measures that improve sustainable alternatives is necessary. Mobility hubs should be seen as one part of a larger, coordinated system. Their success depends on how well they are integrated with broader policies, infrastructure, and urban planning strategies aimed at reducing car dependency.

6.3 Applicability of Framework to Other Scenarios

It is of interest to evaluate whether the method developed in this study is applicable to other scenarios outside of the city of Gothenburg. For this discussion, the flowcharts presented in Figure 4.1 and Appendix D are considered. The overall method is rather simple to recreate for other applications, but adaptations might have to be made in the case of missing datasets for other cities. The SySMo dataset used is only available for the city of Gothenburg, but the original data that Somanath et al. (2024) used is available on a national scale, but without the route assignment and with less detailed individual data. In theory, the method described by Somanath et al. (2024) could be recreated for the mobility hub location purpose, but it might not be feasible for time and effort reasons. For the network analysis, other datasets could be used in place of SySMo, such as municipal or national traffic flow measurements in combination with home and workplace locations. In fact, this alternative might result in a result more connected in reality at the cost of the time needed to locate such datasets.

Regarding the sociodemographic analysis, the availability of such data may vary between municipalities in terms of quality and frequency. The method can easily be adopted to analyze traffic planning from other perspectives than the one explored in this study, so different sets of data would technically not be problematic. Naturally, the results would change in nature after such changes, but the method framework is still applicable. The final weighting of sociodemographic factors could also easily be changed if needed.

A key strength of the framework is that it is based on general planning principles rather than context specific to only Gothenburg. By combining network-related factors, such as accessibility and travel demand, with sociodemographic characteristics that influence travel behavior, the framework can be adapted to different cities and planning objectives. Although datasets and weighting factors may need to be adjusted to local conditions, the overall methodology remains applicable and can support mobility hub planning in other contexts.

6.4 Limitations and Further Research

The main limitation of the study is the quality and reliability of the data used. The SySMo dataset is a simulation of reality, which can never be fully correct due to

necessary simplifications and assumptions. By introducing more simplifications and assumptions in the methodology of this study, the results get further away from reality, even though the implications of the study can be insightful. The quality of the results is heavily dependent on the quality of the SySMo dataset and its simplifications, assumptions and limitations. The varied quality and method and time of collection of data, such as the the Tyréns bikeability index and sociodemographic statistics, further reduces the accuracy of the results compared to reality. The impact data quality has on the results is hard to measure, but when regarding them, it is important not to take them at face value, but rather as possible locations for mobility hubs according to the data used. One way to solidify the results would be to replace the simulated data with real-life measured data and compare the results to identify similarities and nuances.

Also, it is of high importance to consider the construction of the average car commuter from the literature being a man in the upper working age with a high income and high car ownership. Even though it was confirmed that the majority of car commuters within the SySMo dataset fit into these categories, it might not be of the highest importance from the city itself to focus on this population from an equity perspective. By focusing on benefiting one group, which statistically has the highest probability of car commuting, other groups are at risk for being excluded in the planning process. On the other hand, simply because this sociodemographic group needs to change their travel behavior the most, does not mean that they in practice actually will. Even though the design elements are considered with users of all ages, gender, income and transport mode in mind, the location selection is based on benefiting the car commuters the most. The method developed in this study might be suitable for identifying alternatives for hub locations, but it is vital to consider all sociodemographic and economic groups when choosing hub locations in a practical setting in the city of Gothenburg.

Another aspect that is important to consider when interpreting the results is that the population that would be able to use the proposed mobility hub is larger than the one extracted and included. For example, the municipalities of Mölndal and Partille are not considered at all, and due to their proximity to the city of Gothenburg the populations travel interchangeably over the borders. In practice, public transport is not the responsibility of single municipalities or cities, but rather the Västra Götaland region, which includes several municipalities. By focusing only on one of them, the bigger picture is missed, and the applicability of the solution is weakened. However, the developed method for mobility hub location selection could be used to analyze larger datasets, including several municipalities and more modes.

Moreover, a continuation of the study could be to explore the consequences on all modes' network flows after a theoretical construction of mobility hubs in the proposed locations. The starting point of this thesis was to consider only the existing infrastructure for cars, bikes, public transport, and walking. The four proposed mobility hub locations are all located along major commuting corridors and could therefore intercept car commuters before they enter more congested parts of the

city. If successful, this could reduce the traffic volumes on these corridors, decrease congestion, and increase the use of public transport and active modes. The best-case scenario in the context of this study is a decrease in car commuting and a shift towards public transport. To some extent, this would change the need for parking spaces for cars and bikes in the city center and the departures of public transport. The economical and spatial planning consequences of this are not within the scope of this thesis but of high interest from a societal point of view.

7

Conclusions

This study aimed to develop a new method for identifying suitable locations and designs for mobility hubs, the study area being the City of Gothenburg. The main objective was to reduce the dependency on cars for the commuting population by providing opportunities for multimodal travel along their current transport routes. The research questions aimed to explore the usability of a GIS-based program for this purpose, as well as investigate what factors affect travel behaviors in different sociodemographic groups.

The review of the literature resulted in a generalization of the car commuting population, being men of upper working age who have a higher income and own more private cars. Furthermore, citizens living further away from the city center were also more likely to use the private car. Regarding the location of mobility hubs, it was found that high car flows should be intercepted before entering urban areas, and proximity to already existing public transport and bicycle infrastructure is vital. Design elements include safe and secure parking for cars and bikes, shared mobility options, supporting services, and a feeling of safety and comfort for its users. All of these findings were applied to the QGIS spatial analysis which tied together four scores: traffic flow, catchment potential, connectivity, and sociodemographic. The highest scoring public transport stops are located close to each other, all along major highways and in the west of Gothenburg. The four final locations where mobility hubs would be suitable to establish are Ivarsbergsmotet, Ytterhamnsmotet, Kungssten and Gnistängsmotet, all with their own specific public transport stops. These stops generally got high scores in all categories, which indicates a high suitability. The authors' suggestion is not to construct mobility hubs at all four locations. Instead, establishing a single hub, or alternatively one on each side of Älvsborgsbron, may better align with the objective of this study.

Research has shown that car commuters of Gothenburg travel mainly on highways and it might be beneficial to intercept them before entering the city center. Most public transport stops are reachable with the three main transport modes analyzed in this study, pedestrians, bikes, and cars, but since the private car is used to such a great extent, other factors beyond connectivity and reachability seem to matter for commuters. This thesis has provided a deeper insight into the connection between travel behavior and the factors that influence them and the importance of considering such factors in infrastructure planning. The findings could be of interest for the City of Gothenburg or other municipalities with a strong aim of improving multimodal travel. The method developed could easily be modified to fit other datasets

or intentions.

Regarding the results of this study, both in terms of methodology and specific findings, there are limitations that need to be taken into account, as they influence the reliability and credibility of the results. Mainly, the quality and coherence of the data used, as well as the use of a synthetic population rather than real-life traffic flows, both affect the findings' accuracy. The study is also limited by the fact that it was restricted to only analyzing the City of Gothenburg, although citizens of neighboring municipalities naturally commute to and from the study area. Regardless of limitations, the developed method can work as a tool for municipalities to evaluate potential locations in terms of suitability to develop into mobility hubs. A natural progression of this work is to analyze the broader picture in terms of the study area, explore real-life measured data, and include more modes of transport.

The use of private cars cannot be reduced by only establishing a new mobility hub or two on the edges of the city center. Complementary and separate actions are needed to fully address the problem to ensure a modal shift that is sustainable in all respects of the term. Increased congestion taxes, reduced parking spots in the city center and economic incentives for multimodal commuters might be needed to reach the full potential of the mobility hub. Regardless, the first step in this process is to establish the mobility hub itself in a location that is well connected to infrastructure, can catch pedestrians, bicyclists and car users to and from their workplaces, is aimed at the citizens most in need of a modal change, and includes attractive design elements that simplifies daily life of its users. If strategically implemented, mobility hubs have the potential to reshape everyday travel behavior and become a key component in the transition towards a more sustainable, accessible, and less car-dependent urban future.

8

Responsible Use of AI

As mentioned briefly in Chapter 4, AI was used to generate Python code for data extraction for OD-pairs, identification of identical segments and car commuter characteristics. The model used was ChatGPT (GPT-5.3, OpenAI). In the authors' opinion, the use of generative AI reduces the reliability of the results of this study, but it was a necessary measure to ensure the project would be completed within the set time frame. Ideally, the code would be written by the authors themselves, but a lack of coding experience was the main obstacle for this. The coding itself was not the aim of this thesis, even though its results are significant for the proposed locations for mobility hubs.

To ensure high quality results regardless of the inclusion of AI, measures were taken throughout the coding process. The Python code that was generated was continuously tested in Google Colab to ensure that the extracted data was within the right filters and that the code was doing what ChatGPT said it would. Also, ChatGPT was prompted several times in different chats with the same objective of extracting data, with the aim of identifying nuances in the codes provided. The final codes presented in Appendix A, Appendix B or Appendix C are the result of back-and-forth prompting done in several chats. Regarding the aspect of data sensitivity in relation to AI, all data have been collected from open sources. No internal data has been acquired from COWI.

Furthermore, ChatGPT (GPT-5.3, OpenAI) was used throughout the thesis as an aid in structuring the contents of the report for improved readability. This was only done in terms of order and structure, and it was not used to generate or enhance the authors' texts. It was used in a brainstorming capacity in the beginning of the project, but has not replaced reasoning, or analytical and critical thinking. Lastly, ChatGPT was occasionally used for assistance in QGIS and LaTeX when experience and online forums were lacking. The method itself is developed by the authors, and the technically difficult parts of the spatial analysis were aided by AI to ensure time-efficiency throughout the process of the thesis. The authors take full responsibility for the contents of this report.

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A

Python Code for OD-Pair Extraction

```
1  #data for gothenburg: https://zenodo.org/records/13882078
2  !pip install gdown
3  !gdown 1-JPj8xmCwfWcWj8qack3qQZ-VXYaVjfe
4
5  import os, glob, zipfile
6
7  # --- Find the most recent ZIP in current directory ---
8  zip_candidates = sorted(glob.glob("*.zip"), key=os.path.getmtime,
   ↪ reverse=True)
9  if not zip_candidates:
10     raise FileNotFoundError("No .zip found in the current folder. Check
   ↪ what gdown downloaded with !ls")
11
12  zip_path = zip_candidates[0]
13  print("Using ZIP:", zip_path)
14
15  extract_dir = "extracted_dbs"
16  os.makedirs(extract_dir, exist_ok=True)
17
18  with zipfile.ZipFile(zip_path, "r") as z:
19     z.extractall(extract_dir)
20
21  # Find .db files
22  db_paths = sorted(glob.glob(os.path.join(extract_dir, "**", "*.db"),
   ↪ recursive=True))
23
24  print("Found database files:", len(db_paths))
25  for p in db_paths[:30]:
26     print(" -", p)
27  if len(db_paths) > 30:
28     print(" ...")
29
30  import sqlite3
```

```

31 import pandas as pd
32
33 out_db = "merged.db"
34 if os.path.exists(out_db):
35     os.remove(out_db)
36
37 def list_tables(conn):
38     return [r[0] for r in conn.execute("""
39         SELECT name FROM sqlite_master
40         WHERE type='table' AND name NOT LIKE 'sqlite_%'
41         ORDER BY name;
42     """).fetchall()]
43
44 def list_columns(conn, table):
45     return [r[1] for r in conn.execute(f"PRAGMA
46         ↳ table_info('{table}');").fetchall()]
47
48 def ensure_table(conn_out, table, cols):
49     col_defs = ", ".join([f'"{c}" TEXT' for c in cols])
50     conn_out.execute(f'CREATE TABLE IF NOT EXISTS "{table}"
51         ↳ ({col_defs});')
52
53 def ensure_columns(conn_out, table, cols_needed):
54     existing = set(list_columns(conn_out, table))
55     for c in cols_needed:
56         if c not in existing:
57             conn_out.execute(f'ALTER TABLE "{table}" ADD COLUMN "{c}"
58                 ↳ TEXT;')
59
60 conn_out = sqlite3.connect(out_db)
61
62 for i, src_path in enumerate(db_paths, 1):
63     print(f"\n[{i}/{len(db_paths)}] Merging: {src_path}")
64     try:
65         conn_src = sqlite3.connect(src_path)
66         tables = list_tables(conn_src)
67
68         if not tables:
69             print(" (no tables found, skipping)")
70             conn_src.close()
71             continue
72
73         for t in tables:
74             src_cols = list_columns(conn_src, t)

```

```

73         # Ensure table & columns exist in output
74         ensure_table(conn_out, t, src_cols)
75         ensure_columns(conn_out, t, src_cols)
76
77         # Align df to output schema and append
78         df = pd.read_sql(f'SELECT * FROM "{t}"', conn_src)
79
80         out_cols = list_columns(conn_out, t)
81         for c in out_cols:
82             if c not in df.columns:
83                 df[c] = None
84         df = df[out_cols]
85
86         df.to_sql(t, conn_out, if_exists="append", index=False)
87
88         conn_src.close()
89
90     except Exception as e:
91         print("    Failed on:", src_path)
92         print("    Error:", repr(e))
93
94     conn_out.commit()
95     conn_out.close()
96
97     print("\n Done. Created:", out_db)
98
99     import sqlite3
100    import pandas as pd
101
102    conn = sqlite3.connect("merged.db")
103
104    # --- Get all tables ---
105    tables = pd.read_sql("""
106    SELECT name FROM sqlite_master
107    WHERE type='table' AND name NOT LIKE 'sqlite_%'
108    ORDER BY name;
109    """, conn)
110
111    display(tables)
112
113    # --- Loop through tables ---
114    for t in tables["name"].tolist():
115
116        print("\n" + "="*80)
117        print(f"TABLE: {t}")
118

```

```

119     # Row count
120     n = pd.read_sql(f'SELECT COUNT(*) AS n FROM "{t}"', conn)["n"].iloc[0]
121     print(f"Rows: {n:,}")
122
123     # Column names
124     cols = pd.read_sql(f"PRAGMA table_info('{t}');",
125         ↪ conn)["name"].tolist()
126     print("Columns:", cols)
127
128     # First 20 rows
129     preview = pd.read_sql(f'SELECT * FROM "{t}" LIMIT 20;', conn)
130     display(preview)
131
132     conn.close()
133
134     # --- Install minimal deps ---
135     !pip -q install pyarrow geopandas shapely fiona pyproj
136
137     import os, re, sqlite3
138     import pandas as pd
139     import pyarrow as pa
140     import pyarrow.parquet as pq
141
142     from datetime import time
143
144     # Outputs
145     OUT_DIR = "outputs"
146     os.makedirs(OUT_DIR, exist_ok=True)
147
148     PARQUET_DIR = os.path.join(OUT_DIR, "trips_parquet")    # parquet dataset
149     ↪ folder
150     GPKG_PATH = os.path.join(OUT_DIR, "trips_filtered.gpkg")
151     GPKG_LAYER = "trips"
152
153     # Remove previous outputs if rerunning
154     import shutil
155     if os.path.exists(PARQUET_DIR):
156         shutil.rmtree(PARQUET_DIR)
157     if os.path.exists(GPKG_PATH):
158         os.remove(GPKG_PATH)
159
160     # --- Helpers ---
161     def list_columns(con, table):
162         cur = con.execute(f"PRAGMA table_info({table});")
163         return [r[1] for r in cur.fetchall()]

```

```

162
163 def pick_join_keys(od_cols, person_cols):
164     # Prefer uuid_person -> uuid (your described case)
165     if "uuid_person" in od_cols and "uuid" in person_cols:
166         return "uuid_person", "uuid"
167     # Fall back to common variants
168     candidates_od = ["uuid_person", "person_uuid", "uuid", "person_id",
169         ↪ "pid", "PIId"]
170     candidates_p = ["uuid", "uuid_person", "person_uuid", "person_id",
171         ↪ "pid", "PIId"]
172     for a in candidates_od:
173         for b in candidates_p:
174             if a in od_cols and b in person_cols:
175                 return a, b
176     raise KeyError("Could not detect join keys between od_matrix and
177         ↪ person.")
178
179
180 _time_re = re.compile(r"Start Time:\s*([0-9]{2}:[0-9]{2}:[0-9]{2}).*?End
181     ↪ Time:\s*([0-9]{2}:[0-9]{2}:[0-9]{2})", re.IGNORECASE)
182
183
184 def extract_times(series: pd.Series):
185     # returns two Series: start_time, end_time as strings "HH:MM:SS"
186     extracted = series.astype(str).str.extract(_time_re)
187     extracted.columns = ["start_time", "end_time"]
188     return extracted["start_time"], extracted["end_time"]
189
190
191 def in_peak_window(start_s, end_s):
192     # start and end must both be within 06-08 OR both within 16-18
193     # expects strings "HH:MM:SS"
194     def to_min(s):
195         if pd.isna(s):
196             return None
197         hh, mm, ss = s.split(":")
198         return int(hh)*60 + int(mm)
199     smin = start_s.map(to_min)
200     emin = end_s.map(to_min)
201
202     m06, m08 = 6*60, 8*60
203     m16, m18 = 16*60, 18*60
204
205     am = (smin.between(m06, m08) & emin.between(m06, m08))
206     pm = (smin.between(m16, m18) & emin.between(m16, m18))
207     return (am | pm)
208
209
210 def guess_epsg_from_xy(x, y):

```

```

203     # crude heuristic: if values look like lon/lat -> 4326 else assume
204     ↪ already 3006
205     # lon ~ 10-20, lat ~ 55-70 (Sweden-ish)
206     try:
207         x0 = float(pd.Series(x).dropna().iloc[0])
208         y0 = float(pd.Series(y).dropna().iloc[0])
209     except Exception:
210         return 3006
211     if -180 <= x0 <= 180 and -90 <= y0 <= 90:
212         return 4326
213     return 3006
214
215 def find_route_wkt_column(cols):
216     # prefer a WKT/geom column if present (common names)
217     preferred = ["wkt_geom", "route_wkt", "geom_wkt", "geometry_wkt",
218                 ↪ "geometry", "geom", "wkt"]
219     for c in preferred:
220         if c in cols:
221             return c
222     # also accept columns containing both route+geom/wkt
223     for c in cols:
224         lc = c.lower()
225         if ("route" in lc and ("wkt" in lc or "geom" in lc or "geometry"
226                               ↪ in lc))):
227             return c
228     return None
229
230     # --- Download the geopackage ---
231     from google.colab import files
232     files.download(GPKG_PATH)

```

B

Python Code for Car Commuter Characteristics

```
1 import glob
2 import os
3 import pandas as pd
4 from collections import defaultdict
5
6 # ---- find parquet files ----
7 parq_files = glob.glob(os.path.join(PARQUET_DIR, "**", "*.parquet"),
8                               ↪ recursive=True)
9
10 # ---- accumulators for car mode only ----
11 sum_age = 0.0
12 cnt_age = 0
13
14 agegrp_counts = defaultdict(int)
15 sex_counts = defaultdict(int)
16 car_counts = defaultdict(int)
17
18 # ---- loop through parquet files ----
19 for fp in parq_files:
20     chunk = pd.read_parquet(fp, columns=["mode", "age", "age_group",
21                               ↪ "sex", "has_car"])
22
23     # keep only car rows
24     chunk = chunk.loc[chunk["mode"] == "Car"].copy()
25
26     if chunk.empty:
27         continue
28
29     # ---- age group distribution ----
30     agegrp = chunk["age_group"].dropna().astype(str).str.strip()
31     for k, n in agegrp.value_counts().items():
32         agegrp_counts[k] += int(n)
```

```
32     # ---- gender distribution ----
33     sex = chunk["sex"].dropna().astype(str).str.strip()
34     for k, n in sex.value_counts().items():
35         sex_counts[k] += int(n)
36
37     # ---- car ownership distribution ----
38     car = pd.to_numeric(chunk["has_car"],
39         ↪ errors="coerce").dropna().astype(int)
40     for k, n in car.value_counts().items():
41         car_counts[k] += int(n)
42
43     # ---- build one summary table ----
44     row = {"mode": "Car"}
45
46     # age group percentages
47     agegrp_total = sum(agegrp_counts.values())
48     for k in sorted(agegrp_counts.keys()):
49         row[f"age_group_{k}_pct"] = round(100 * agegrp_counts[k] /
50         ↪ agegrp_total, 2) if agegrp_total else float("nan")
51
52     # gender percentages
53     sex_total = sum(sex_counts.values())
54     for k in sorted(sex_counts.keys()):
55         row[f"sex_{k}_pct"] = round(100 * sex_counts[k] / sex_total, 2) if
56         ↪ sex_total else float("nan")
57
58     # car ownership percentages
59     car_total = sum(car_counts.values())
60     for k in sorted(car_counts.keys()):
61         row[f"has_car_{k}_pct"] = round(100 * car_counts[k] / car_total, 2)
62         ↪ if car_total else float("nan")
63
64     car_summary = pd.DataFrame([row])
65
66     display(car_summary)
```

C

Python Code for Segment Use

```
1 !pip install gdown
2 !gdown 1i7sNq_BgKd8TUWLVXWX6JVF5ccdfgBwD
3
4 import geopandas as gpd
5
6 gdf = gpd.read_file("trips_within_study_area.gpkg")
7
8 print("Number of rows:", len(gdf))
9 print("\nColumns:\n")
10 print(list(gdf.columns))
11
12 !pip install -q geopandas pyarrow
13
14 import geopandas as gpd
15
16 # read gpkg
17 gdf = gpd.read_file("trips_within_study_area.gpkg")
18
19 # save as parquet
20 gdf.to_parquet("trips_within_study_area.parquet")
21
22 print("Saved parquet file")
23
24 !pip install -q pandas pyarrow shapely fastparquet
25
26 import os
27 import pandas as pd
28 import pyarrow as pa
29 import pyarrow.parquet as pq
30 import pyarrow.dataset as ds
31 from shapely import wkt
32 from shapely.geometry import LineString
33
34 INPUT_FILE = "trips_within_study_area.parquet"
35 OUTPUT_PARQUET = "trip_segments_car_only.parquet"
```

```
36
37 keep_cols = [
38     "origin",
39     "destination",
40     "mode",
41     "origin_purpose",
42     "destination_purpose",
43     "route",
44 ]
45
46 keep_mode = "Car"
47
48 dataset = ds.dataset(INPUT_FILE, format="parquet")
49
50 if os.path.exists(OUTPUT_PARQUET):
51     os.remove(OUTPUT_PARQUET)
52
53 parquet_writer = None
54
55 total_in = 0
56 total_kept = 0
57 total_out = 0
58
59 def split_route_to_segments(route_wkt):
60
61     if pd.isna(route_wkt):
62         return []
63
64     try:
65         geom = wkt.loads(route_wkt)
66     except Exception:
67         return []
68
69     segments = []
70
71     if geom.geom_type == "LineString":
72
73         coords = list(geom.coords)
74
75         for i in range(len(coords)-1):
76             a = coords[i]
77             b = coords[i+1]
78
79             if a != b:
80                 segments.append(LineString([a,b]).wkt)
81
```

```

82     elif geom.geom_type == "MultiLineString":
83
84         for part in geom.geoms:
85
86             coords = list(part.coords)
87
88             for i in range(len(coords)-1):
89
90                 a = coords[i]
91                 b = coords[i+1]
92
93                 if a != b:
94                     segments.append(LineString([a,b]).wkt)
95
96     return segments
97
98 for record_batch in dataset.to_batches(columns=keep_cols,
99 ↪ batch_size=2000):
100
101     batch_df = record_batch.to_pandas()
102
103     total_in += len(batch_df)
104
105     # filter only Car
106     batch_df = batch_df[batch_df["mode"] == keep_mode]
107
108     total_kept += len(batch_df)
109
110     rows = []
111
112     for row in batch_df.itertuples(index=False):
113
114         segs = split_route_to_segments(row.route)
115
116         for seg in segs:
117
118             rows.append({
119                 "origin": row.origin,
120                 "destination": row.destination,
121                 "mode": row.mode,
122                 "origin_purpose": row.origin_purpose,
123                 "destination_purpose": row.destination_purpose,
124                 "route": seg
125             })
126
127     if not rows:

```

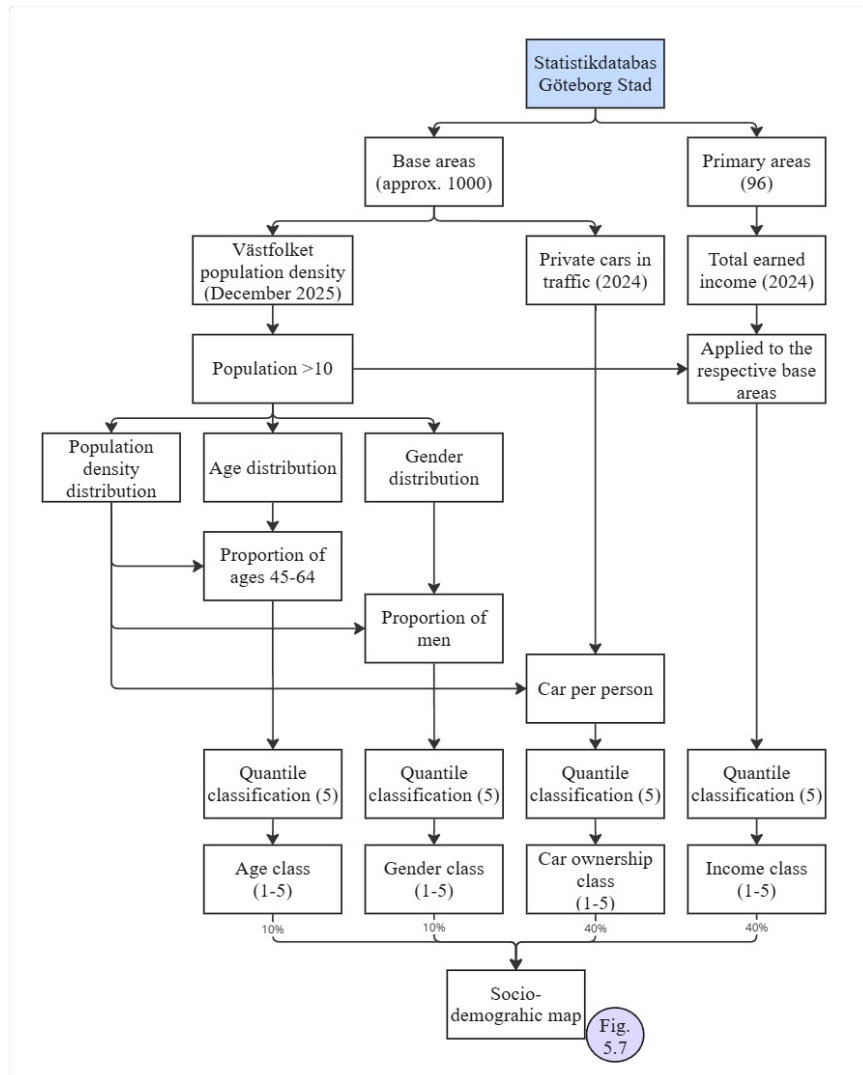
```
127         continue
128
129     out_df = pd.DataFrame(rows)
130
131     total_out += len(out_df)
132
133     table = pa.Table.from_pandas(out_df, preserve_index=False)
134
135     if parquet_writer is None:
136         parquet_writer = pq.ParquetWriter(
137             OUTPUT_PARQUET,
138             table.schema,
139             compression="snappy"
140         )
141
142     parquet_writer.write_table(table)
143
144     print(
145         f"Processed {total_in:,} rows → kept {total_kept:,} car trips → "
146         f"{total_out:,} segments"
147     )
148
149     if parquet_writer:
150         parquet_writer.close()
151
152     print("Saved:", OUTPUT_PARQUET)
153
154     import pandas as pd
155     import geopandas as gpd
156     from shapely import wkt
157
158     INPUT_SEGMENTS = "trip_segments_car_only.parquet"
159     OUTPUT_FREQ = "segment_frequency_car.gpkg"
160
161     df = pd.read_parquet(INPUT_SEGMENTS)
162
163     counts = (
164         df.groupby("route")
165         .size()
166         .reset_index(name="count")
167     )
168
169     counts["geometry"] = counts["route"].apply(wkt.loads)
170
171     freq_gdf = gpd.GeoDataFrame(
172         counts.drop(columns=["route"]),
```

```
173     geometry="geometry",
174     crs="EPSG:3006"
175 )
176
177 freq_gdf.to_file(
178     OUTPUT_FREQ,
179     layer="segment_frequency",
180     driver="GPKG"
181 )
182
183 print("Saved:", OUTPUT_FREQ)
184 print("Unique segments:", len(freq_gdf))
185
```

D

Workflow for Sociodemographic Statistics

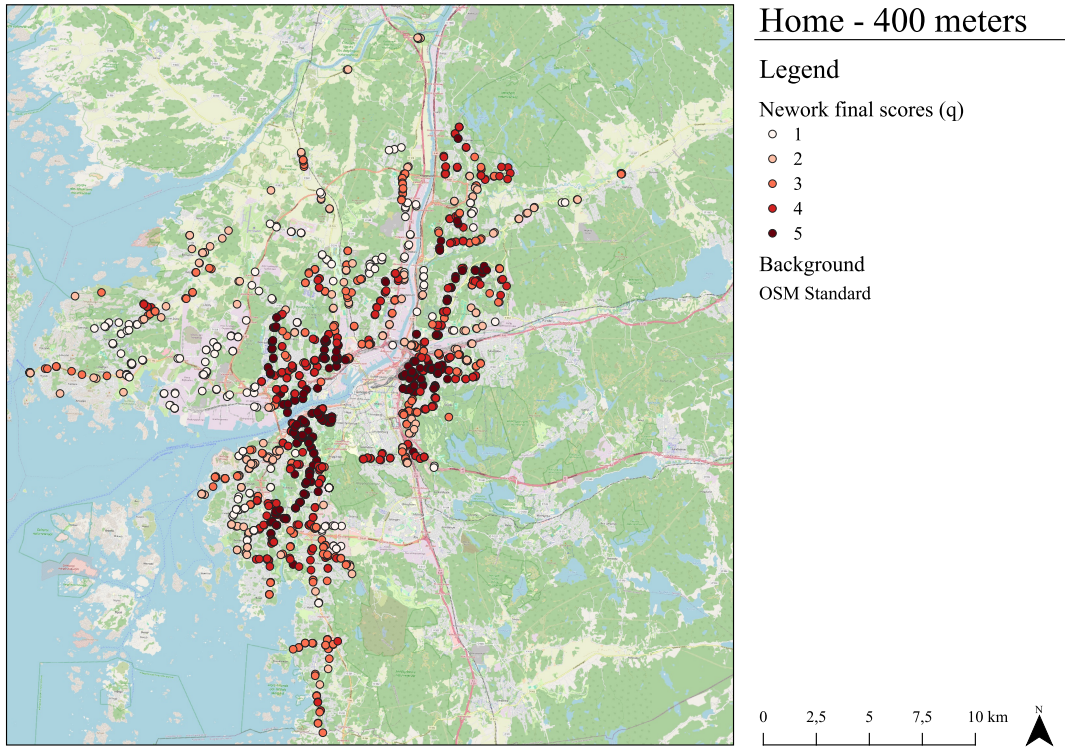
Appendix D shows the process of extracting, combining and analyzing sociodemographic data in QGIS as described in Section 4.6. The data source is the statistical database compiled by Göteborgs Stad (n.d.-d) and the final map can be seen in Figure 5.7.

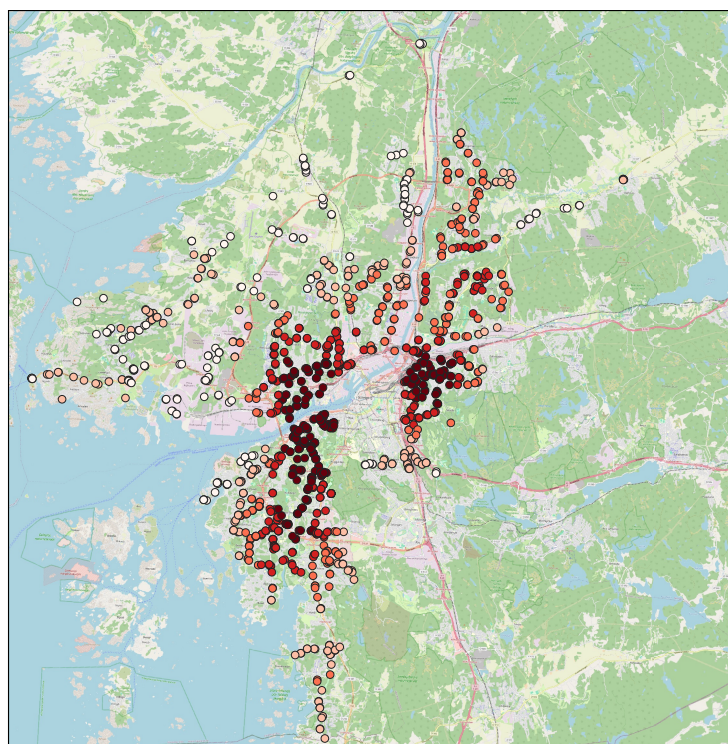


E

Components of $S_{potential}$

Here, the individual scores included in the calculation of $S_{potential}$ is presented, with the score $S_{connectivity}$ also in place, meaning only stops with a $S_{connectivity} = 3$ is included. All six scores are quintile classified as they are in the final calculation.





Home - 2000 meters

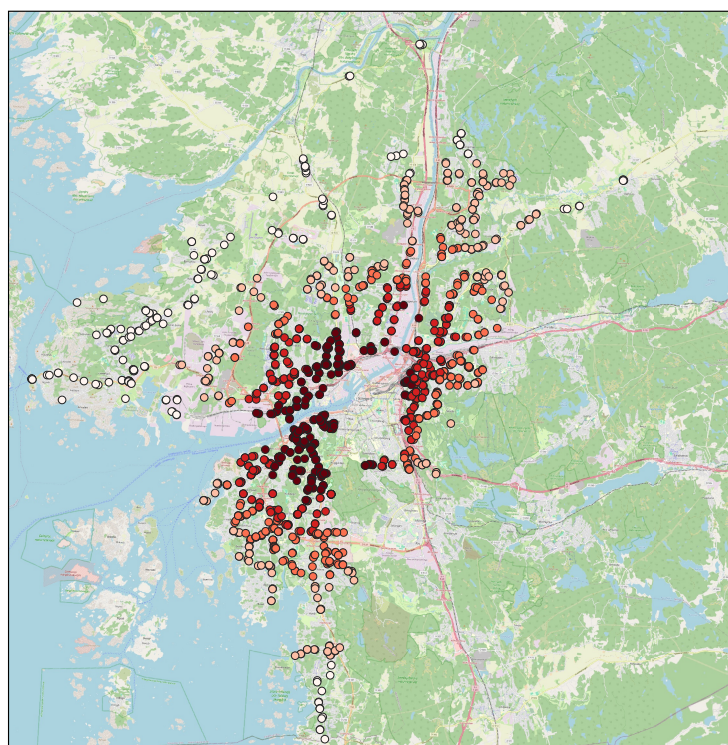
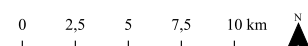
Legend

Nework final scores (q)

- 1
- 2
- 3
- 4
- 5

Background

OSM Standard



Home - 5000 meters

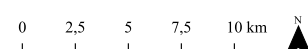
Legend

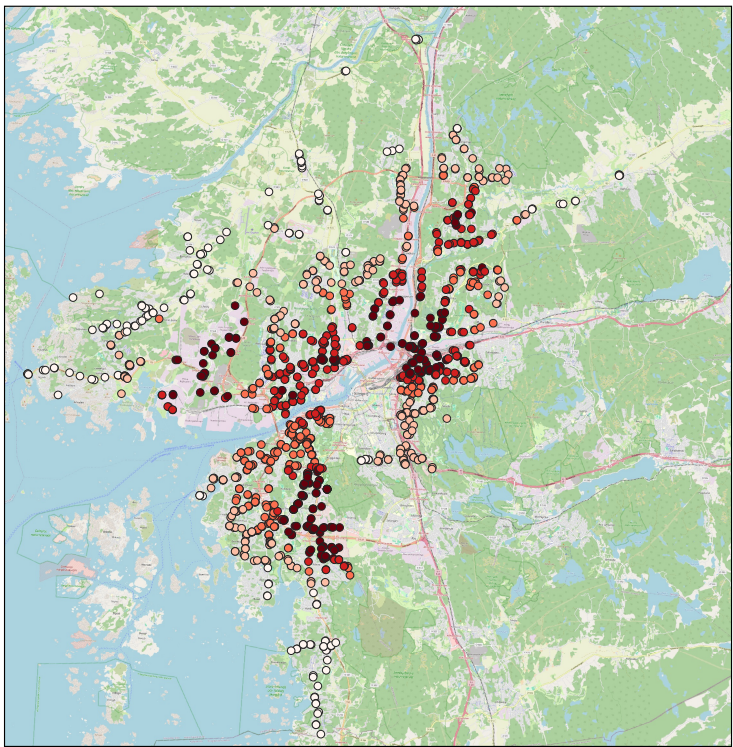
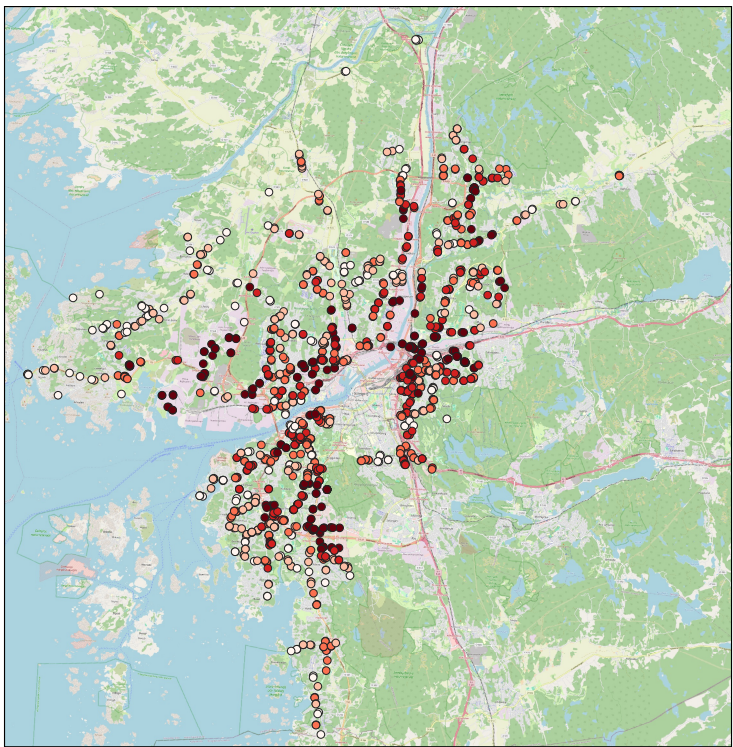
Nework final scores (q)

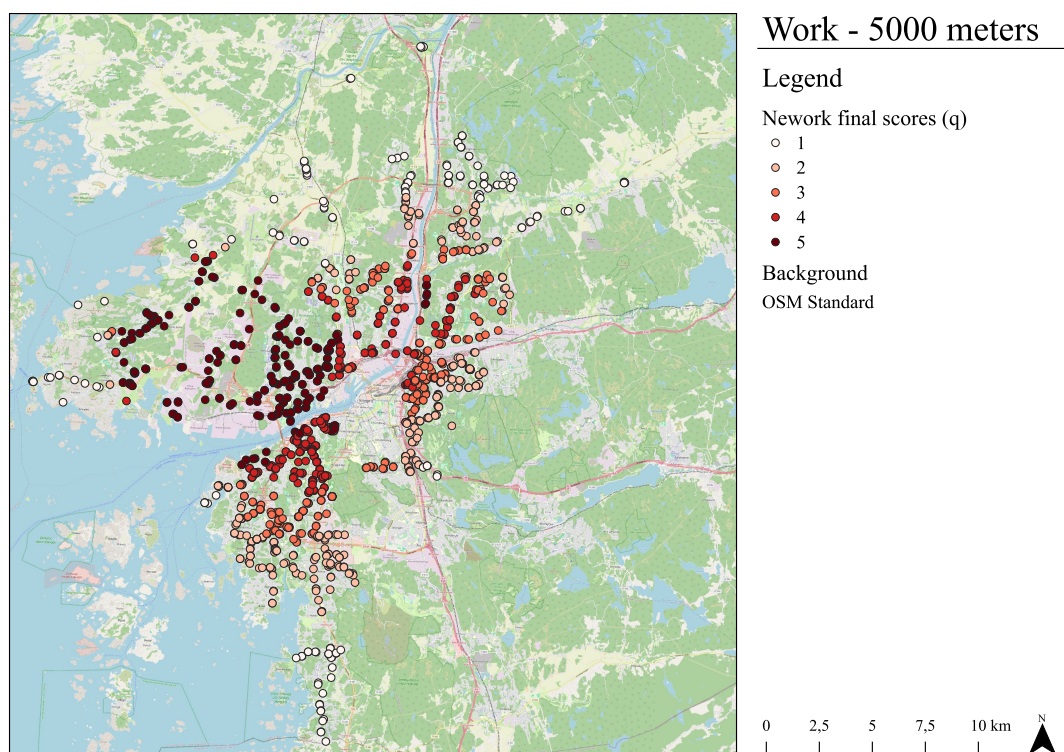
- 1
- 2
- 3
- 4
- 5

Background

OSM Standard







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Gothenburg, Sweden
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