



CHALMERS
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The relationship between operational profitability and social benefits of e-scooters

A case study of first and last-mile connections to public transit using e-scooters

Master's thesis in Architecture and Civil Engineering

Alexander Erlandsson

DEPARTMENT OF ARCHITECTURE AND
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ALEXANDER ERLANDSSON

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Department of Architecture and Civil Engineering
Geology and Geotechnics
Urban Mobility Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone: + 46 (0)31-772 1000

Cover:
Parked e-scooters
Department of Architecture and Civil Engineering
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ABSTRACT

E-scooters are a mobility service mainly used in urban areas for short distances. The primary purpose of using e-scooters is the fast and reliable aspect. They increase mobility and can be part of a multi-modal transportation solution. Surveys show that e-scooters have both substituting and complimenting effects on the transportation system. Mostly walking is replaced by e-scooters, followed by either car or public transit. Around one-third of the people in San Francisco use an e-scooter to connect to public transit. One concern about free-floating e-scooters is the parking aspect, as inappropriate parking negatively affects public spaces, authorities, and the passability of people with disabilities.

The relationship between the operational profitability and social benefits of e-scooters was studied in this thesis to investigate the effects of using e-scooters as a first and last-mile connection to public transit. A literature review was conducted to investigate the users' behaviour, focusing on the benefits of using e-scooters. The research focused on a study area in Gothenburg located outside the city centre, lacking access to the trunk and express public transit network. Computer tools helped investigate and simulate the first and last-mile connections considering the whole perspective. Data about the scooter's battery level, location and price were used to analyse the operational profitability. The goal was to generalise the conclusions to other areas with similar characteristics as the study area, solving the first and last-mile problem of public transit.

The result shows that e-scooters increase the catchment area of the trunk and express network compared to walking for five minutes. The entire study area is almost reached within eight minutes using an e-scooter, but five minutes is optimal for achieving the highest social benefits and profitability. First and last-mile trips with e-scooters to public transit are around seven minutes faster than walking but at a higher cost, considering the whole perspective of trips within Gothenburg's metropolitan area. Parking spots and racks help control the parking of e-scooters, and these spots must be placed within a specific acceptable walking distance, providing easy access to any site. The result also shows that e-scooters are operationally profitable in the study area.

Keywords: accessibility, bike, car, catchment area, mobility, mode, location, parking, reachable area, substitute, travel, trunk and express network, walking distance.

Table of Contents

1	BACKGROUND	1
1.1	Aims and objectives	1
1.2	Research question	2
1.3	Limitations	2
2	LITERATURE REVIEW	3
2.1	Mobility as a Service	3
2.1.1	E-scooters	3
2.2	First and last-mile services to public transit	4
2.2.1	The walking distance to e-scooters	5
2.2.2	Docked and dockless modes	5
2.2.3	Gothenburg's Public transportation programme	6
2.3	Substituting modes by e-scooters	7
2.4	Digital investments	8
2.5	Summary	8
3	METHODOLOGY	9
3.1	Research design	9
3.2	Data collection	10
3.3	Mapping the public transit and properties	12
3.4	Mapping the catchment and reachable areas	14
3.4.1	Converting the bicycling mode to fit e-scooters	15
3.4.2	Locations of e-scooters parking spots	15
3.5	Travel routes and modal splits	17
3.5.1	The speed of each mode	18
3.5.2	Impact of climb gradient and transit times on e-scooters trips	18
3.5.3	Travel costs	20
3.5.4	Route 1 - Ugglums school to Brunnsparken	21
3.5.5	Route 2 - Kvarnstensvägen 8 to Brunnsparken	22
3.5.6	Route 3 - Ugglums school 18 to Sahlgrenska Sjukhuset	23
3.5.7	Route 4 - Andra Tvärvägen 1 to Sahlgrenska Sjukhuset	23
3.6	Operational cost	24
3.7	Operating income	27
4	RESULTS	29
4.1	The transit network in Sävedalen	29
4.2	Accessibility to the e-scooters and the trunk and express network	32
4.3	Travel times and costs	35

4.4	Operational profitability	36
5	DISCUSSION	37
5.1	Social benefits and operational profitability	37
5.2	Regulating the parking of e-scooters	39
5.3	Fleet size and e-scooter parking spots	40
5.4	The e-scooter network	40
6	CONCLUSIONS	42
6.1	Further research	43
	REFERENCES	44
A.	APPENDIX – TRAVEL TIME MAPS	I
B.	APPENDIX – TRAVEL ROUTES	II
C.	APPENDIX – TRAVEL DISTANCES AND CLIMB GRADIENTS	XIII
D.	APPENDIX – TIMETABLES	XIV
E.	APPENDIX – OPERATIONAL PROFITABILITY	XVII

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Alexander Erlandsson, Gothenburg, May 2022

1 Background

As cities continue to grow in population, it stresses the transportation systems (Ramboll, n.d.). Future transportation systems need to be low-carbon, holistic and integrated to solve transportation challenges, such as congestion, air pollution and carbon emissions. E-scooters are a relatively new transportation mode in the cities, categorised as a micro-mobility mode (Trafikverket, 2019). They can solve the first and last-mile problem by increasing the public transit catchment area in areas lacking access to public transit. In most cases, e-scooters are free-floating mobility, allowing users to start and stop their travel anywhere, increasing flexibility. Free-floating mobility is challenging from an urban planning perspective. The availability to park e-scooters anywhere contributes to accessibility problems for people with disabilities, and local authorities can expect less control of the public space. In the US, many cities implemented e-scooters quickly without permits or consent, which led to banning e-scooters in some cities (Portland Bureau of Transportation, 2018b). There is an upcoming law proposal in Sweden that will forbid e-scooter parking on pavements and bike paths if there are no parking zones (Mattsson, 2022). Hence, the municipality could move incorrectly parked e-scooters and fee the companies of these e-scooters, which would pressure the companies to improve their parking regulations.

The benefits of using e-scooters as a micro-mobility service must outweigh the problems (Trafikverket, 2019; Wang et al., 2022). E-scooters need to have customers and be accepted by the local authorities to outweigh the negative aspects. Studies show that e-scooters substitute walking and short public transit trips in the city centres. E-scooters can provide a greater catchment area for public transit, reducing the need for cars (Trafikverket, 2019). E-scooters must be correctly distributed throughout the city to minimise congestion and inaccurate parking. Compared to cars and bikes, e-scooters require a smaller place for storage and parking, making e-scooters an efficient transportation mode with a small physical footprint (Wang et al., 2022). Furthermore, e-scooters should be placed where needed, such as near public transit stops, retail and service properties, and residential areas (Shu et al., 2019; Trafikverket, 2019). The usage pattern of e-scooters is, to some extent, already studied, but the operational profitability and social benefits of e-scooters are not investigated in detail (Engdahl et al., 2020)..

1.1 Aims and objectives

This master thesis aims to determine the relationship between the operational profitability and social benefits of e-scooters as a first and last-mile connection to public transit. The main goal is to determine if e-scooters can ensure faster and more convenient connections to public transit than other modes, where accessibility to public transit is lacking. Knowing the usage pattern and the actual profitability and social benefits of e-scooters is essential to solving the transportation challenges effectively

and correctly. This knowledge is valuable for companies, authorities, urban planners, engineers, municipalities, and users.

1.2 Research question

The following question determines if e-scooters can increase the catchment area where there is a lack of accessibility to public transit. The question answers the relationship between the operational profitability and social benefits of e-scooters as a first and last-mile connection to public transit.

- Is it profitable to use e-scooters in areas lacking access to public transit to bring social benefits?

1.3 Limitations

The study area is limited to Sävedalen in Gothenburg, where public transit connections are lacking. The connections are poor because the walking distance to the public transit stops often exceeds five minutes, which is unacceptable (Trafikverket & Sveriges Kommuner och Landsting, 2012). Sävedalen has minimal access to the trunk and express network by walking. The thesis limits the focus on connecting e-scooters to the trunk and express network to achieve the maximum benefits and profitability of e-scooters, as this network provides fast and frequent connections to key destinations, nodes, and cores in Gothenburg's metropolitan area.

2 Literature review

A literature review was conducted to understand the importance of mobility services and public transit for a sustainable, innovative, and integrated transportation system. First, the Mobility as a Service (MaaS) concept is explained, focusing on e-scooters. Second, the catchment area of the public transit is studied to see where e-scooters can act as a first and last-mile connection to public transit. In addition, to understand how public transit and mobility services can connect conveniently and quickly, the characteristics of e-scooters and public transit in Gothenburg were investigated. Last, the substituting modes by e-scooters and their complementing possibilities to public transit were reviewed to determine how and where e-scooters should be integrated into a multi-modal transportation solution.

2.1 Mobility as a Service

Mobility as a Service (MaaS) is a broad concept used to describe mobility services in the cities to reduce the demand for private cars (Holmberg et al., 2016). There are many definitions of MaaS, but they all have the same idea to provide easy, accessible, affordable, and convenient first and last-mile solutions that could force out the demand for private cars (E. Lund, n.d.). Public transit with high capacity is often seen as the central core of the MaaS system, which is served by either shared-vehicle or bike-sharing services to provide the citizens with enough mobility demand to solve first and last-mile problems.

2.1.1 E-scooters

E-scooters are a mobility service mainly used within the densely populated areas of cities for an average trip distance of around 1-2 kilometres (Engdahl et al., 2020). They are often parked along main streets in city centres, where many live and work. It is easy for the operators to pick up and return fully charged e-scooters to their parking spots from these locations. Some cities have e-scooters in the suburbs, indicating that e-scooters are also used in these areas. The average time travelled with an e-scooter is relatively short, with an average time of around 10-15 minutes. In addition, younger people use shared micro-mobility services more, and areas with high employment density have more weekly trips than other areas (Wang et al., 2018). Men use e-scooters more frequently than women, as women find them a more considerable safety hazard in traffic (Ramboll, 2021).

The utilisation rate is defined as the total time all e-scooters are used over the potential maximum usage time, which is 24 hours per day (Engdahl et al., 2020). It is found that the utilisation rate declines towards the autumn and winter in European cities with wintry conditions. The overall utilisation rate is low all year, around a few per cent, indicating that the e-scooters are parked more than used, but as high availability anytime is vital for e-scooter users, this issue is overlooked. High availability affects

the reliability of e-scooters positively in the long term. A study from the Portland Bureau of Transportation (PBOT) pilot program in the US shows that the primary purpose for using an e-scooter is the fast and reliable aspect (Portland Bureau of Transportation, 2018a). Many also answer that riding an e-scooter for their last trip was due to the fun aspect. Another study shows that e-scooters are used more in the afternoons and evenings, indicating that the primary purpose of using an e-scooter is for errands and evening activities (Engdahl et al., 2020). Stockholm, one of the four European cities studied, had a morning peak, indicating that e-scooters are also being used for commuting.

The speed of e-scooters is an essential factor to consider as the speed varies in different environments. E-scooters must be classified as bicycles with a maximum speed of 20 km/h and an engine power of less than 250 Watts in Sweden (Transportsyrelsen, 2021). The most common speed of e-scooters in Stockholm is about 12 km/h and varies between cities (Engdahl et al., 2020). Another study from Trondheim shows that the average speed is between 10-15 km/h (J. Lund & Jonsson, 2021). For hilly environments, the climb gradient does not affect the speed significantly; this may depend on the fact that the e-scooters have a speed limit and therefore have enough power to maintain high speeds for inclines. The e-scooter company, Voi Technology in Sweden, have a power of 250 Watts, as they follow the regulations of the maximum speed of e-scooter (Voi Team, personal communication, April 25, 2022). At a specific climb gradient, the e-scooters speed will be affected negatively. The limit is hard to predict, as the weight of the rider and the e-scooters' tiers affect the speed uphill, but most e-scooter can climb a gradient of up to 10 % (Wertheimer, 2020).

2.2 First and last-mile services to public transit

E-scooters can solve the first and last-mile problem in areas where the walking distance to public transit is far (Trafikverket & Sveriges Kommuner och Landsting, 2012). Each stop of the public transit network has a catchment area, a particular area around the stop or station where people can reach the public transit services convenient and fast. There are some guidelines for how far from the service the catchment area covers, but it is often referred to as 400 meters around the stop or station in urban areas. This corresponds to a walking time of five minutes. If the walking distance is above 400 meters, the importance of bicycling as a complementing mode to public transit increases for distances up to 1500 meters (Trafikverket & Sveriges Kommuner och Landsting, 2012).

Public transit with fast connections to other parts of the city can have a catchment area of up to 800 meters, corresponding to a walking distance of 10 minutes (Göteborgs regionen, 2009). People tend to walk longer for faster connections and are more willing to walk into areas with high services, activities, and tradings. Planning for well-connected and integrated bike and walk paths becomes vital to connect people conveniently, safely, and fast to public transit. Another crucial factor is that travellers

tend to walk to the stop or station in the same direction as their destination, even though the walking distance is longer (White, 2016).

A survey from a mid-pilot programme in the US shows that 34 % are using e-scooters to connect to public transit, and close to 28 % would not have used public transit if an e-scooter were not available (San Francisco Municipal Transportation Agency (SFMTA), 2019). Another pilot programme by PBOT shows that 39 % used an e-scooter to connect to public transit, with more than 12 % doing it weekly (Portland Bureau of Transportation, 2018b). The most common way to access an e-scooter is by walking. Interestingly, public transit nodes positively associate e-scooter usage (Wang et al., 2022). But people using e-scooters to reach public transit vary highly by city, technologies, regulations, and incentives.

2.2.1 The walking distance to e-scooters

To reach an e-scooter, people often need to walk a certain distance (Wincent, 2019). The users seem to prefer to walk a short distance to reach the service. One study by Voi Technology in Stockholm shows that the walking distance to e-scooters varies. Mainly the walking distance is relatively short, with a median of 88 meters, and people walk shorter distances in the mornings than in the afternoons. People also walk shorter distances on weekdays than at weekends. The walking time varies, with a median walking time of 3,47 minutes. The median value is more representative of finding the most common walking distance and time, as some people have walked long distances to reach an e-scooters, which affected the average value more. A walking time of 3,47 minutes is relatively long for walking 88 meters. This non-correlation behaviour between the walking distance and time depends on the fact that people may open their application earlier than they start walking the distance. But even the walking distance has uncertainties, as people may have picked up their application later considering their starting point, decreasing the walking distance.

The short walking distance could be explained from another point of view (Wincent, 2019). People may have used e-scooters services spontaneously by seeing the scooter visually rather than planning to use the service in advance as a first and last-mile solution. In addition, e-scooters have been available for only one year at the time of the study, which is a short time for the users to build a habit of using e-scooters for first and last-mile trips, which can motivate spontaneous behaviour.

2.2.2 Docked and dockless modes

There are some other mobility services, such as Station-Based Bike-Sharing (SBBS) and Free-Floating Bike-Sharing (FFBS) (Demaio, 2009; Du & Cheng, 2018; Pal & Zhang, 2017). SBBS has been studied more than FBBS, but there are many similarities. The only significant difference is that SBBS is limited to docked stations, which to some extent decreases the possibilities of solving the first and last-mile problem due to

less choice of pick-up spots. FBBS is a dockless mode which can be picked up everywhere, increasing the accessibility to public transit for underserved neighbourhoods. Studies have shown that docked infrastructure suits commuting better (Pal & Zhang, 2017; Reck et al., 2021). Using docked infrastructure on dockless modes, such as e-scooters, could strengthen the attractiveness of e-scooter as a first and last-mile solution, hence being an alternative to private cars. A survey shows that dockless e-scooters are more attractive than dockless e-bikes to act as a first-and last-mile solution to public transit (Wang et al., 2022). The distribution of e-scooters in the city remains a lot to the usage pattern of e-scooters, making the accessibility sensitive to changes in the usage pattern.

A survey from Beijing shows that the most attractive walking distance to SBBS at a public transit stop is less than 60 meters (Shu et al., 2019). For larger residential areas, the distance is less than 90 meters. The walking distance is short for all land use and most people prefer to walk less than 90 meters. Interestingly, people using SBBS frequently and for workout or leisure purpose could walk a longer distance to SBBS than people travelling for shopping or commuting purposes. This knowledge shows the importance of stations close to the entrances of shopping areas and public transit stops. Another survey from Beijing shows that the attractiveness of using the SBBS decreases with the distance, and here, most people walked 266 meters to the stations (Wincent, 2019).

2.2.3 Gothenburg's Public transportation programme

The design of the public transit network in Gothenburg is described by different Go-terms, where each Go-term serves different functions in the traffic system, see Table 2.1. Gothenburg's Public Transportation Programme (K2020) should help the region reach its goal of a 40% market share of public transit for all motorised trips by 2025 (Göteborgs regionen, 2009). 55% of all motorised trips should be made by public transit by 2035 (Göteborgs Stad, 2014). The latest data from 2011 showed that 34% of all motorised trips were made by public transit.

Table 2.1 *The characteristics of the public transit network in the Gothenburg metropolitan area.*

Go-term	Function in the traffic system
GoFast	Fast traffic between nodes Fewer stops Connects Gothenburg’s suburbs Trains and express buses
GoFrequent	Frequent and fast traffic between key destinations, nodes, and cores Densely populated areas Trams and trunk buses
GoClose	Connecting traffic Local lines connecting to the trunk and express network Local buses

The GoFast and GoFrequent terms define the central core of the public transit network in the Gothenburg metropolitan area (Kollektivtrafikprogram för Göteborgs- regionen, 2009). The central core of the public transit provides better options for travellers to reach key destinations, nodes, and cores in Gothenburg in terms of reliable, fast, and high-capacity public transit. This network contains trams, trunk buses, and express buses; therefore, called the trunk and express network (Göteborgs Stad, 2014).

The vision is that two random key destinations or cores should be reached within 30 minutes on public transit. The areas from which more than 50 % of the city’s workplaces are reached within 30 minutes on public transit are considered to have great accessibility. The 30-minute target is also a crucial limit to completing a trip within the city. Passability is vital in achieving reliable, fast, and high-capacity connections to other parts of the city (Göteborgs regionen, 2009). High passability is achieved by creating own public spaces for trams and buses, with priority in intersections. The other part of the public transit, the GoClose network, has less frequent traffic. This network aims to connect to the trunk and express network as a first and last-mile solution.

2.3 Substituting modes by e-scooters

Walking is the most common travel mode substituted by e-scooters, ranging from 30- to 60 % of all trips (Wang et al., 2022). Less than 10% of bike users use e-scooters instead, which still creates profitability for bike-sharing companies. E-scooters do displace more car trips in the US than in Europe, as the citizens of the US use more cars due to the low modal share of public transit. A pilot program in the US by the PBOT showed that 19 % of personal car trips are substituted by e-scooters (Portland Bureau

of Transportation, 2018b). 6% of the people did even get rid of their car in favour of e-scooter riders, and another 16% considered doing it as well.

In contrast, only a few per cent (3-5%) of car trips are displaced by e-scooters in Europe, such as Paris, Oslo, Munich, and Zurich (Wang et al., 2022). Instead, due to the high modal share of public transit, one-third of public transit trips are substituted by e-scooters, compared to a few per cent in the US. The average public transit trip in Europe is shorter than in the US. This is another explanation: one-third of the public transit trips are displaced by e-scooters in Europe, as e-scooters are mainly used for short trips. A study from three cities in France showed that around 30% of the local users would use e-scooters instead of public transit. The main reason for this is a more rapid way of travelling.

2.4 Digital investments

An application for paid subscriptions with all mobility services provides a better multi-modal transportation system for a large population and is the most suitable for planning and making door-to-door trips (Holmberg et al., n.d.). There is already an application that meets these prerequisites called Whim, invented in Helsinki, Finland, in 2016 (Ramboll, 2016). Today the application is available in six countries worldwide, and the goal is to operate in over 60 countries and 100 cities in only five years. With this application, users can purchase once or with a subscription plan for all available transportation options, reducing the need for private cars. Users can choose which mode to travel in the application, such as buses, trams, trains, shared bikes, e-scooters, taxis, and shared cars (Whim, n.d.). The application lets you plan, book, and pay for all trips, making the app easy to use for people. A combined mobility service application helps make everyday life easier for all citizens.

2.5 Summary

E-scooters can act as a first and last-mile connection to public transit. One factor confirming this is that 28% of the US e-scooter users in San Francisco would not have used public transit if no e-scooters available. In Europe, more public transit trips are displaced by e-scooters, whereas in the US, more car trips are displaced by e-scooters. E-scooters have complementing-and substituting effects on the transportation system, and differences depend on the modal share of transportation modes. The most substituted mode by e-scooters is walking, indicating that people already have the attitude to switch from walking to e-scooters. The walking distance to e-scooters is preferred to be short and varies for different land use. Today, there is a lack of information on the operational profitability and social benefits of e-scooters. Especially for areas with less access to public transit, as e-scooters are primarily used in city centres with good connections to public transit.

3 Methodology

This chapter describes the methodology to determine the operational profitability and social benefits of e-scooters as a first and last-mile connection to public transit. The research focuses on a study area in Gothenburg with less access to public transit.

3.1 Research design

The research design was conducted before to determine the overall approach of this thesis methodically. To determine the operational profitability and social benefits of e-scooters, quantitative and qualitative data about e-scooters were needed. Combining quantitative with qualitative data was essential to understanding the behaviour behind the numbers from the quantitative data. As e-scooter usage is a social phenomenon, specific numbers would not tell the whole truth about e-scooter usage and the potential to act as a first and last-mile connection to public transit. Both the quantitative and qualitative data were secondary data collected by someone else. The data were collected from reports, articles, and surveys using search engines such as Google, Google Scholar, Science Direct, and Chalmers library. In addition, the data were compared to other references to achieve validity and reliability in the research. Many references were peer-reviewed or from well-known authorities. Using peer-reviewed and authority-based references was vital in gaining validation and reliability, as the data needed to be accurate to achieve a correct result. Peer review references are a widely accepted method for research validation and reliability, and it improves the quality of this thesis (Science Direct, 2022).

The sampling of the e-scooters' operational profitability and social benefits was made for a specific study area, meaning that conclusions were based on the study area. However, the goal was to generalise the findings to a larger population with similar characteristics as the study area. The research design was fixed, meaning that the data collection plan was set before achieving higher validity and reliability when testing and making generalisations based on theory research. The research focused on understanding the current situation in the study area to solve the first and last-mile problem of public transit. Some computer programmes simulated and analysed the real-world environment of the study area considering public transit and e-scooters. The computer programmes provided a clear generalised picture of a real-world setting. However, the exact location was not set before, as some computer programs helped find the specific study area first. Despite that, the characteristics of a desirable study area were defined before; it should be an area with less access to public transit in Gothenburg's metropolitan area. In this context, less access to public transit was equal to a maximum walking distance of five minutes to the trunk and express network. Travellers need to reach key destinations, nodes, and cores fast and frequently, which the trunk and express network are excellent at providing.

3.2 Data collection

The literature review provided quantitative and qualitative data about e-scooters and public transit travel. First, the walking accessibility considering distance was investigated for different land use, such as public transit stops, retail and service properties, and e-scooters, see Figure 3.1. The literature review provided unreliable results on the walking accessibility to e-scooters, see Section 2.2.1. Therefore, the walking accessibility to e-scooters was compared with docked modes to find an approximant walking distance to e-scooters. Second, the impact on speed considering the climb gradient for e-scooter trips was investigated, see Figure 3.1. Last, the travel behaviour was investigated considering the number of people who considered using an e-scooter to connect to public transit and which modes were substituted the most by e-scooters. The qualitative data consisted of statements regarding the commuting and parking of e-scooters and comparisons between station-based and free-floating services. In addition, the public transit system was investigated to understand travel behaviour.

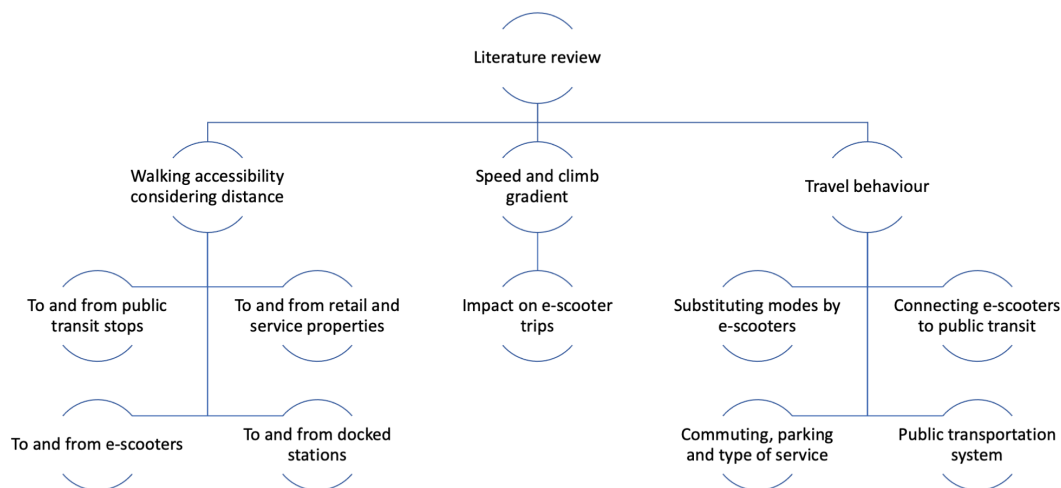


Figure 3.1 The overall data collection model using quantitative and qualitative literature.

The acceptable walking distance to public transit stops were equal to a catchment area of the public transit stops. The catchment area was best presented on a map. The locations outside the catchment area were the best for having e-scooters connecting to public transit stops considering profitability based on the literature review. One such place identified was Sävedalen, as described in Section 1.3. In the catchment area of the public transit stops, the walking distance was too short for achieving profitability and social benefits from e-scooters. The opposite applied to the catchment areas of e-scooters. Here, it was beneficial that the catchment area of e-scooters covered every

part of the study area to achieve profitability and social benefits. In addition, a reachable area was presented on a map to determine how well connected the public transit was to other parts of Gothenburg's metropolitan area. The reachable area was equalled to which parts of the city were reached within a specific time limit on public transit from Sävedalen. To verify that the trunk and express network provided fast connections to other parts, the reachable area was compared to the reachable area of the GoClose lines. If the trunk and express network offered fast connections, the reachable area should be more significant than the reachable area of the GoClose lines.

Understanding the whole perspective was also essential to determine if e-scooters were profitable and social benefiting. Therefore, travel routes from one point to another were analysed to determine how profitable and beneficial e-scooters were compared to other modes considering the whole perspective. The modes that were substituted by e-scooters were walking, public transit, car riding, and bicycling, as mentioned in Section 2.3. As e-scooters in this research were analysed as a first and last-mile connection to public transit, it was necessary to compare this part of the trip with feasible alternatives for connecting to public transit. Walking was the most substituted mode by e-scooters, making a comparison well-motivated. Bicycling and car riding were not motivated for a first and last-mile comparison, as a small percentage of these modes were substituted by e-scooters, especially car riding in Europe, see Section 2.3. Bicycling was, despite that, very similar to e-scooters for first and last-mile trips. Instead, these modes were compared considering the whole trip. To achieve reliability and validity in this research, four travel routes were analysed from various locations in Sävedalen to different key destinations, nodes, and cores in the Gothenburg metropolitan area. One route would not have been enough to ensure an accurate result, as the travel times and costs varied between routes affecting the conclusion. Instead, an average value of travel time and cost for all routes was calculated. In addition, to achieve more reliability and validity, the e-scooter trips to public transit were analysed for two different kinds of transit locations to determine where e-scooters suit first and last-mile trips.

One company's incomes and expenses were calculated to estimate the operational profitability of the e-scooters company. The income was based on the number of e-scooters and the average cost per e-scooter trip in the study area. The expenses were calculated by estimating the cost of buying and charging the e-scooters and the cost of collecting the depleted e-scooters in the study area, which needed to be charged. Most of the income, such as the cost of the e-scooter trips and the number of e-scooters in the study area, were average values and estimations based on the analysis of the users considering the profitability and social benefits. Information about the battery level and locations of e-scooters helped to calculate the expenses in Sävedalen. The data was provided through a text file by the research group Urban Mobility System at the Chalmers University of Technology and consisted of time, location, and battery information of around 1600 e-scooters in Gothenburg. The data was collected every two minutes on the 7th of November 2020 from Voi e-scooters'.

3.3 Mapping the public transit and properties

The computer programme QGIS was used to determine where e-scooters could work as a first and last-mile connection to public transit in Sävedalen. As e-scooters were best profitable and benefitted outside the catchment area of the trunk and express stops, some data on Gothenburg's public transit network was required. Ramboll Smart Mobility provided some data on the public transit network from 2018. The data contained all lines and stops within the Västra Götaland Region (VGR), where Gothenburg is located. First, the data was imported into QGIS to visualise the lines and stops. Making the QGIS analysis required a basic map, and this map was imported from OpenStreetMap by adding a vector layer. The map showed data about roads, bicycling paths, green areas, urban areas, and buildings.

To focus on the lines of Sävedalen, the remaining lines in VGR were sorted out from the map. This was done in the Layer Properties menu under Symbology with the Rule-based function. The Rule-based function defines the lines by "Line = X", where each line number in Sävedalen was written into the rule. The study area had seven lines, and each line was marked in different colours, see Figure 3.2. The same method was applied to the public transit stops in Sävedalen. The Rule-based function helped define the public transit stops in Sävedalen, but it was more complicated than the lines. Therefore, some changes were made to the attribute table. First, all GoClose stops in Sävedalen were marked on the map to be able to change the parameter of "Code" to 1. Second, the parameter of "Code" was altered to 2 for all stops of the trunk and express network in Sävedalen. Third, these new commands were written into the Rule-based function, which results in two labels, one for the GoClose stops and one for the trunk and express stops, see Figure 3.3. Having them separate made the whole research easier and even if this research focused on the trunk and express stops, some analyses were made for the GoClose lines. Mostly in comparing purposes considering the reachable area on public transit, as described in Section 3.2. Fourth, specific stops in the area were defined by the Rule-based function as "Stop = X", where the name for each stop was written into the rule. This was helpful for marking the analysed stops for the reachable areas and travel routes. Last, the retail and service properties were essential locations for e-scooters. Therefore, data about the retail and service properties were downloaded from the (Spatial Morphology Group, 2021) and imported into QGIS by adding a vector layer. The locations of the retail and service properties in Sävedalen were identified on the map and marked with a name label using the Rule-based function described above. The name label made it easy to recognise each property, see Figure 3.4.

- Legend
- Study area
 - ⊕⊕ Tram line 1
 - ⊕ Tram line 5
 - Busline 17
 - Black Express
 - Bus line 513
 - Bus line 514
 - Bus line 515

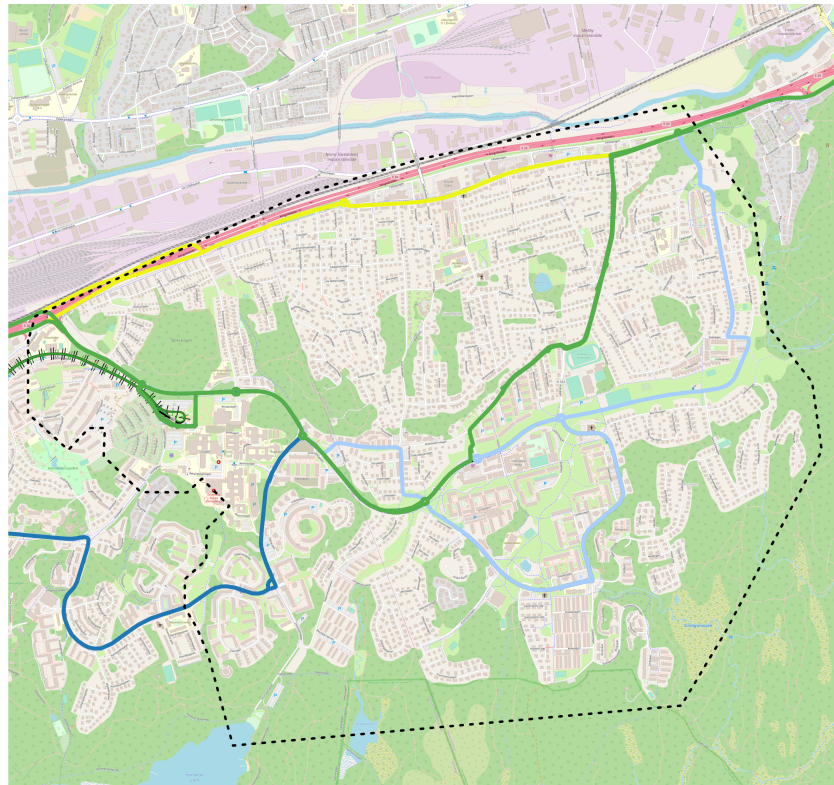
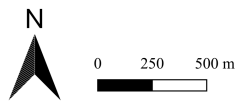


Figure 3.2 The public transit lines in Sävedalen.

- Legend
- Study area
 - Stops of the trunk and express network
 - Stops of the GoClose lines

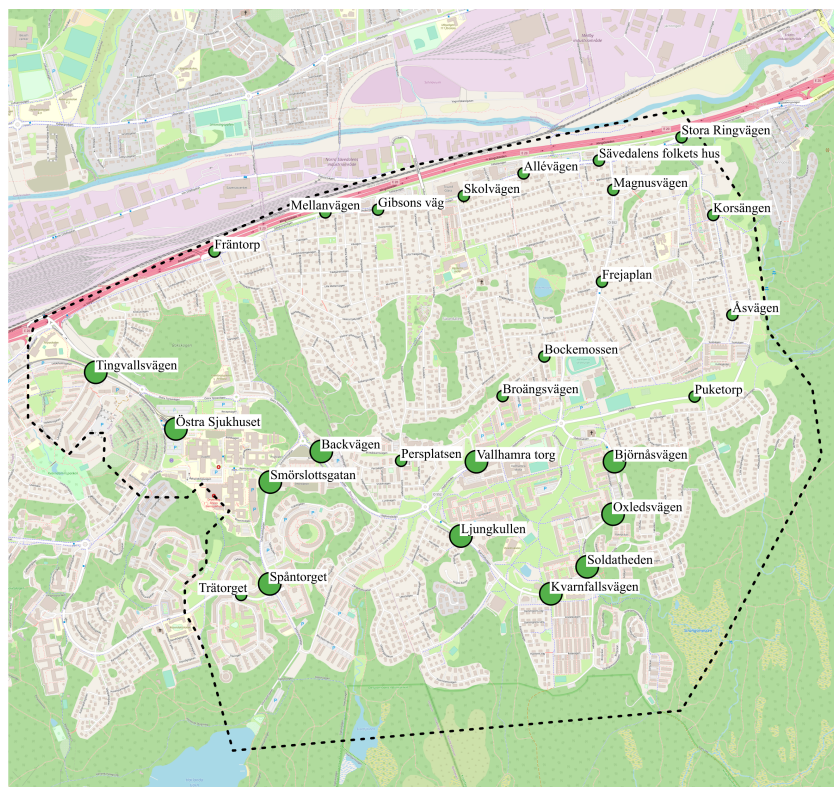
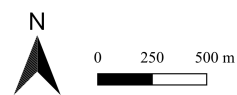


Figure 3.3 The public transit stops in Sävedalen, where the trunk and express stops and the GoClose stops are marked separately.

- Legend
- Study area
 - Retail and service properties

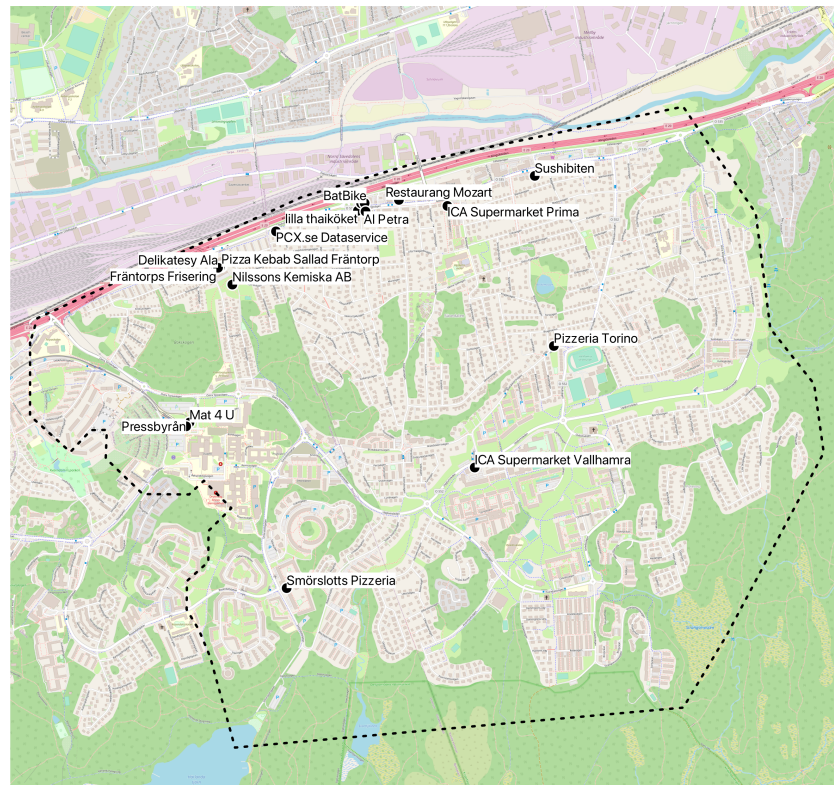
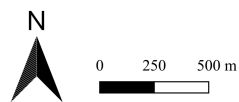


Figure 3.4 The retail and service properties in Sävedalen.

3.4 Mapping the catchment and reachable areas

Analysing the catchment area of the public transit stops and the e-scooter locations required a plugin in QGIS called Travel Time. Travel Time created a time map which symbolised the catchment or reachable area in the form of a polygon within a specific time and transportation mode (Travel Time, 2021). First, the catchment area of the trunk and express stops was analysed using a five-minute walking distance. A union polygon was created for all polygons of the stops. The union polygon corresponded to the area reached within five minutes of walking distance to and from these stops. Travel Time used an average walking speed of around 5 km/h (Travel Time, 2021). The speed was accurate to use even though the speed varied depending on weather and personal conditions. Second, the catchment area of the trunk and express stops was analysed using a five-minute e-scooter distance from these stops. As there is no transportation mode for e-scooters in Travel Time, the bicycling mode was motivated to use, see Section 3.4.1. Using the same time of five minutes for walking and e-scooter made it possible to compare the sizes of these catchment areas. Comparing the catchment areas helped determine the added social benefits and profitability of e-scooters as first and last-mile connections to public transit. The maximum social benefits and profitability for e-scooter users were determined to occur when the users reached the entire study area in less than five minutes from the trunk and express network stops. It was necessary to know the travel time required to reach the entire area by an e-scooter. The analysing time in Travel Time for e-scooters was changed to determine the travel time until the whole study area could be reached by an e-scooter from the trunk and express stops.

The social benefits and profitability decreased if the study area was not covered within five minutes of using an e-scooter. The goal was to cover the entire area within five minutes using an e-scooter. However, ten minutes could still bring social benefits and profitability for the e-scooter users, see Section 2.2, but at a lower level.

The reachable area within 30 minutes of public transit from different stops in Sävedalen was analysed with Travel Time in QGIS. Thirty minutes was chosen according to the 30-minute target by Gothenburg's Public Transportation Programme (K2020). The departure time from the stops in Sävedalen was set between 07:30 to 09:30. This time was chosen because most people commute at this time; hence most people would use e-scooters to connect to public transit. The reachable area within 30 minutes on public transit was analysed from Östra Sjukhuset. Östra Sjukhuset was chosen because it was part of the trunk and express network and a key destination. Other stops that were analysed were Frejaplan, Åsvägen, and Skolvägen. These stops were part of the GoClose network in the area. Analysing the reachable area within 30 minutes of these stops gave an idea about which network was the most appropriate for reaching many parts of Gothenburg's metropolitan area within the time target. A walking distance of five minutes was also included within these 30 minutes. Therefore, the marked area on the map was equalled to the reachable area within a total travel time of 30 minutes.

3.4.1 Converting the bicycling mode to fit e-scooters

The bicycle mode was used because it was the most similar transportation mode in Travel Time to e-scooters. Using the bicycle mode was a simplified method based on assumptions that the default speed was 20 km/h (Travel Time, 2021). In real life in Sweden, it is unrealistic for e-scooters to maintain a maximum speed of 20 km/h during the entire trip, as the speed limit is 20 km/h, see Section 2.1.1. Sävedalen is a suburb with less traffic than Trondheim and Stockholm city centres and for these cities, the average speed was 10-15 km/h and 12 km/h, respectively, see section 2.1.1. With less traffic and urban conflicts, the average speed was expected to be higher than in these cities' centres. Therefore, the upper value of the interval 10-15 km/h was motivated to use. With these arguments, the default speed of 20 km/h in the Travel Time was changed to 15 km/h by lowering the analysed time by 25% to achieve the same distance for the slower speed.

3.4.2 Locations of e-scooters parking spots

To ensure a short walking distance to e-scooters in Sävedalen, a proposal for e-scooter parking spots has been made in QGIS. The parking spots should help operators return the e-scooters to these spots to ensure a short walking distance for the users. A short walking distance to the e-scooters was vital for achieving social benefits and profitability for the e-scooter users. The acceptable walking distance most people were willing to walk to reach mobility services was relatively new data and varied for SBBS, see Section 2.2.1 and 2.2.2. Therefore, an average value was calculated, see Table 3.1.

Table 3.1 The acceptable walking distance most people were willing to walk to reach different mobility services for all land use and the average acceptable walking distance for all mobility services.

Mode	Acceptable walking distance [m]	Source
E-scooter	< 88	(Wincent, 2019)
SBBS	< 90	(Shu et al., 2019)
SBBS	< 266	(Wincent, 2019)
Average	< 148	

An acceptable walking distance for e-scooters all land use was equalled to less than 148 meters. According to Section 2.2.2, the walking distance should less than 90 for residential areas. Sävedalen is a large area, and with less than 90 meters to the parking spots, the spots would have been too many, reducing the profitability for the operators. Therefore, the average value of 148 meters for all land use was better motivated. Using the average value was more accurate considering a real-world environment for achieving profitability. Equation 3.1 was used to estimate the walking time.

$$WT = \frac{AWD}{AWS} \quad (3.1)$$

$$\frac{148}{1,4} \approx 106 \text{ seconds}$$

$$\frac{106}{60} \approx 1 \text{ minute and } 46 \text{ seconds} \approx 2 \text{ minutes}$$

where:

WT is the Walking Time in seconds

AWD is the Average Walking Distance in meters

AWS is the Average Walking Speed in meters per second (approximately 1,4 m/s)

The location of e-scooters at public transit stops was arranged at the platform or beside it as a maximum walking distance of 60 meters was preferred, see Section 2.2.2. Therefore, every stop within the trunk and express network had parking spots for e-scooters. Even the retail and services locations had e-scooter parking spots beside the entrance or parking lots. For the residential area, there were some challenges considering the location of these parking spots, as there were no specific buildings or sites of interest, such as retail and service properties or public transit stops. Instead, these spots were placed randomly, following the street layout, so everyone had the shortest way to the e-scooters. One method was to place these locations in intersections, see Figure 3.5. Placing e-scooters in intersection gave a more effortless connection to all households and areas by having more than one way to choose from the intersections, increasing the connections in different directions. Sävedalen has many intersections between either road, walking or bicycling paths, which made the locations easy to

determine. Where there were leisure sites and terrace houses, the e-scooter was placed close to these locations, see Figure 3.5. Leisure locations were classified as sites of interest, and terrace houses has in general higher population density, which motivated to place parking spots here. The locations of e-scooter parking spots for the residential area were presented in QGIS. The other parking spots at the public transit stops and retail and services properties were not placed out, as these locations were already marked in QGIS. After placing out the locations of the parking spots in the residential area, the catchment area of the e-scooter parking spots was analysed using Travel Time, with a two-minute walking distance around every parking spot.



Figure 3.5 The method used for determining locations for e-scooter parking spots, where e-scooters were placed in intersections or close to leisure sites and terrace houses.

3.5 Travel routes and modal splits

Four travel routes were analysed from different locations in Sävedalen to other sites in Gothenburg's metropolitan area. To conduct the travel route analysis, the Travel Time analysis of the catchment and the reachable areas were first done to find appropriate locations in Sävedalen as starting points for the e-scooters trips. The purpose was to investigate the travel times and costs for different modal splits. The Google Maps function for directions was used for travel distance and time, whereas the fastest trip was chosen. This information was necessary to determine the travel costs, which depended on travel distance and time. Four modal splits were analysed for all travel routes with a departure time at 07:30 on weekdays, see Table 3.2.

Table 3.2 The different modal splits used for analysing the four travel routes.

Modal splits
E-scooter + Public transit
Walking + Public transit
Bicycling
Car

3.5.1 The speed of each mode

For the bicycling mode, the standard speed in Google Maps was 16 km/h, considering elevations (Google, 2022). It was accurate to use this speed as the bicycling speed varied between 12,5-26,5 km/h on bike paths (Eriksson et al., 2019). The same speed was applied for e-scooters, as there was no e-scooter mode in Google Maps. Using 16 km/h for e-scooters was accurate as it is impossible to maintain a maximum speed of 20 km/h during the trip, see Section 2.1.1. It was also motivated to use 16 km/h as it was only one kilometre per hour higher than the Travel Time analysis. One kilometre per hour higher speed does not affect the travel time on shorter distances, such as for e-scooters. The average walking speed was 5 km/h, the same as the Travel Time analysis (Google, 2021). For car trips, Google Maps had information about speed limits, real-time traffic, and historical traffic patterns for almost all roads (Wallin M, 2020). This information helped Google Maps estimate the travel time for car trips for the selected time. Therefore, a small-time range was given for car trips since it was impossible to calculate an exact time, as queues quickly can build up and affect the travel time. Google Maps used Västtrafik's current data of departure, arrivals, and travel time to determine the travel times for public transit (Google, 2022).

3.5.2 Impact of climb gradient and transit times on e-scooters trips

The elevation tool in Google Earth was used to determine how much the inclinations affected the speed of e-scooters (Google Earth Pro, 2022). The maximum climb gradient of 10% was a critical limit. As this research focused on e-scooters as a first and last-mile solution to public transit, the elevation profile was analysed for only the e-scooter trips. The height differences from the lowest point to the highest point of a slope were measured to calculate the climb gradient. Later this value was divided by the slope length, according to Equation 3.2.

$$\text{Climb gradient } [\%] = \frac{\text{Height difference } [m]}{\text{Length of slope } [m]} \quad (3.2)$$

This equation was calculated automatically in Google Earth's elevation profile by marking a section of a e-scooter trip with a significant inclination, see Figure 3.6. It was necessary to use the average value of the marked section, as temporary height differences over a small distance of a few meters resulted in very high inclination rates, which were not representable for the natural inclination, see Figure 3.6.

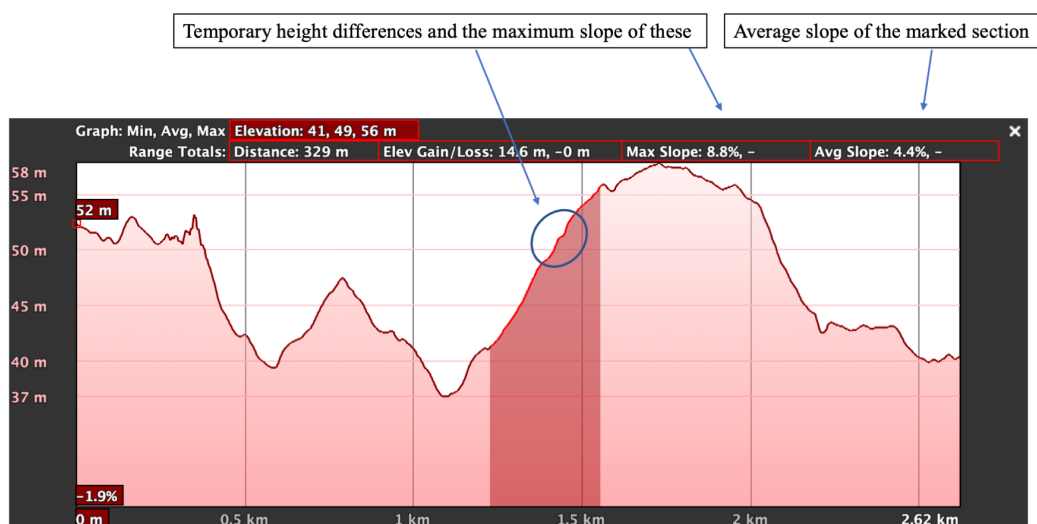


Figure 3.6 The elevation profile of a e-scooter trip with the temporary height differences and the maximum slopes of these, as well as the average slope of the marked section.

A very high climb gradient depended mainly on errors in the map, which were identified by checking the position of the extreme inclination rates and comparing them with a street view at the location. The errors were primarily trees or cars, which affected the actual elevation of the ground and hence the elevation profile. To use this elevation tool, the directions of the e-scooter routes were written into Google Earth, which created an elevation profile for the e-scooter trips.

A transit time was considered for the modal split between e-scooter and public transit. One minute was added to the total travel time considering ending the e-scooter trip and transit to public transit. This short time was accurate as the parking spots of e-scooters were located close, less than 60 meters to the public transit stops. In contrast, two minutes were added considering walking to the parking spots of the e-scooters in the residential area. This time was chosen because the e-scooter parking spots in the residential area were within a walking distance of two minutes. The transit location analysed between e-scooters and public transit was Östra Sjukhuset for all routes, as it is a key destination where all the trunk and express lines meet, see Section 2.2.3. But it was essential to analyse other transit locations between e-scooters and public transit closer to the starting point to determine if it was necessary to transit at a key destination, such as Östra Sjukhuset, or if it was enough to transit at a closer stop. A closer stop was

not always the nearest stop to the starting point, but it was the stop recommended by Google Maps for the fastest trip with public transit.

3.5.3 Travel costs

The travel costs depended on the distance travelled and the travel time. The cost of riding e-scooters was determined by checking the current kilometre- and starting prices in the applications of the existing operating e-scooter companies in Gothenburg in March 2022, such as Voi, Tier, and Bolt, see Table 3.3. Bolt was the only company without any starting fees, and this company was used for the first and last-mile trips, as it was the cheapest alternative for the users considering short trips.

Table 3.3 The cost of riding an e-scooter for different companies in Gothenburg's metropolitan area, considering a starting price and a kilometre price. The data is from March 2022.

Company	Starting Price [SEK]	Kilometre Price [SEK/km]
Voi	10	2,5
Tier	10	2,5
Bolt	0	2 < 15 min / 3 > 15 min

The prices of car riding were determined by checking the average energy efficiency among passenger cars, fuel prices, and congestion taxes for both Diesel and Gasoline 95 cars (Circle K, 2022; Naturvårdsverket, 2019; Transportstyrelsen, 2020). The average energy efficiency data was from 2019 and had stabilised the year before and was assessed to be accurate, see Table 3.4. The fuel prices had varied, but an average fuel price for January and February 2022 was used, see Table 3.4. The fuel price and energy efficiency were used to calculate the cost per kilometre for these cars, according to Equation 3.3 for each fuel sort. In addition, there was a congestion charge of 22 SEK for all car trips from Sävedalen to the destinations between 07:00 to 07:59 on all weekdays.

Table 3.4 The energy efficiency, the average fuel price, and the total fuel price for different fuel sorts.

Fuel sort	Energy efficiency [litre/100 km]	Average fuel price [SEK/litre]	Total fuel price [SEK/km]
Diesel	5,2	21,29	1,11
Gasoline 95	5,8	18,85	1,09

$$TFP = EE * FP \quad (3.3)$$

where:

TFP is the Total Fuel Price in SEK per kilometre

EE is the Energy Efficiency in litre per 100 kilometres

FP is the Fuel Price in SEK per litre

3.5.4 Route 1 - Ugglums school to Brunnsparken

This route was chosen because Brunnsparken is a node and core within Gothenburg's metropolitan area, with many workplaces (Göteborgs Stad, 2014; Göteborgs Stad: Trafikkontoret, 2013). Ugglums school was chosen because it is a local target point for students and workers in the study area. It was also a point in the middle of Sävedalen where the walking distance to all public transit stops exceeded five minutes of walking, see Figure 3.7. First, the transit location between e-scooters and public transit was Östra Sjukhuset, see the e-scooter trip in Appendix B, Figure B.1. From Östra Sjukhuset, the trunk and express network were used to Brunnsparken. Second, the transit location between e-scooters and public transit was Skolvägen, which were located closer to Ugglums School than Östra Sjukhuset, see the e-scooter trip in Appendix B, Figure B.4. From Skolvägen, bus line 513, part of the GoGlose lines, was used to reach Brunnsparken. Bus line 513 does not stop at Brunnsparken but at Polhemsplasten, located about six minutes walking from Brunnsparken. Therefore, an e-scooter to reach Brunnsparken was an alternative for a last-mile solution for this modal split, see the e-scooter trip in Appendix B, Figure B.6.

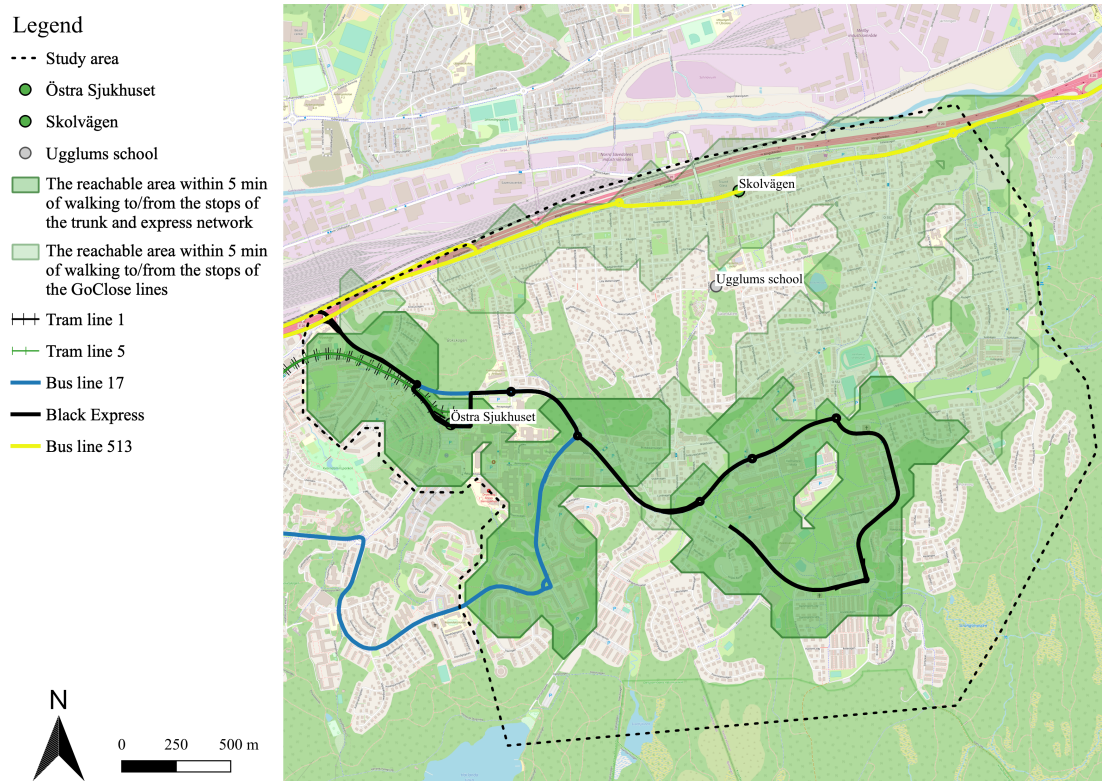


Figure 3.7 The location of Ugglums school, Östra Sjukhuset and Skolvägen, and the recommended lines that were used to reach Brunnsparken from Ugglums school. In addition, the catchment area of all public transit stops considering a five-minute walking distance to and from the stops.

3.5.5 Route 2 - Kvarnstensvägen 8 to Brunnsparken

This route had the same destination as Route 1, but another starting point was chosen. The starting point was Kvarnstensvägen 8, which were in another part of Sävedalen, where the walking distance exceeded five minutes to all public transit stops, see Figure 3.8. The closest public transit stop was the trunk and express network, not the GoClose stop as it was for Ugglums school. First, an e-scooter was used to transit to public transit at Östra Sjukhuset, see the e-scooter trip in Appendix B, Figure B.8. From Östra Sjukhuset, the trunk and express network were used to reach Brunnsparken. Second, the transit location between e-scooters and public transit was Kvarnfallsvägen, see the e-scooter trip in Appendix B, Figure B.11. From Kvarnfallsvägen, Black Express was used to reach Brunnsparken. The problem with this line was that the bus does not stop at Brunnsparken but at the Central Station. Hence required a last-mile connection to Brunnsparken and the route passed the square Drottningtorget in a crowded urban environment making e-scooter riding inconvenient. Therefore, walking was preferred, and the walking distance between the Central Station and Brunnsparken was around three minutes.

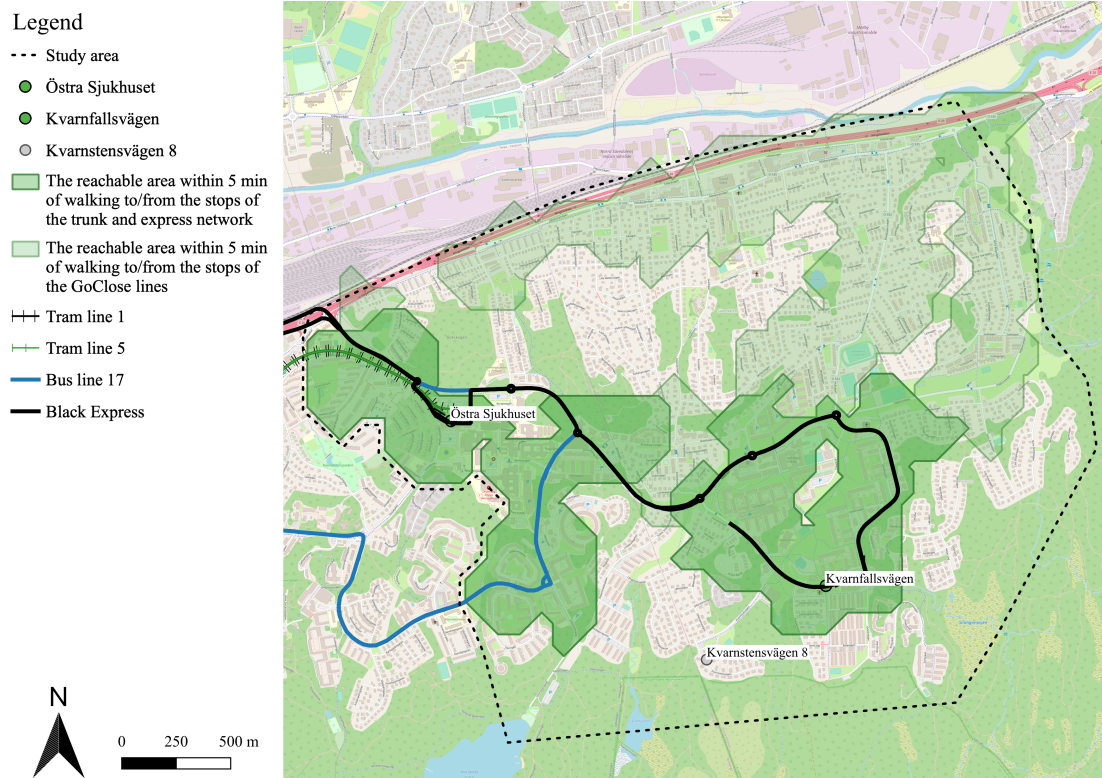


Figure 3.8 The location of Kvarnstensvägen 8, Östra Sjukhuset and Kvarnfällsvägen, and the recommended lines that were used to reach Brunnsparken from Kvarnstensvägen 8. In addition, the catchment area of all public transit stops considering a five-minute walking distance to and from the stops.

3.5.6 Route 3 - Ugglums school 18 to Sahlgrenska Sjukhuset

Instead of having Brunnsparken as the destination as in Route 1 and 2, Sahlgrenska Sjukhuset was chosen, as it is another central location for workers (Göteborgs Stad: Trafikkontoret, 2013). Ugglums school was selected as the starting point, as described in Section 3.5.4. The transit stops between e-scooters to public transit were the same as in Section 3.5.4.

3.5.7 Route 4 - Andra Tvärvägen 1 to Sahlgrenska Sjukhuset

For this route, Andra Tvärvägen 1 was chosen as a starting point. The destination Sahlgrenska was chosen as described in Section 3.5.6. The starting point was selected because it is far from the trunk and express network, and the walking distance exceeded five minutes to all stops, see Figure 3.9. First, the transit location between e-scooters and public transit was Östra Sjukhuset, see the e-scooter trip in Appendix B, Figure B.14. From Östra Sjukhuset, the trunk and express networks were used to reach Sahlgrenska Sjukhuset. Second, an e-scooter was used to reach Stora Ringvägen, see the e-scooter trip in Appendix B, Figure B.16. From Stora Ringvägen, bus line 513, part of the GoClose lines, was used to reach Sahlgrenska Sjukhuset but required transit

to other lines later. As seen in Figure 3.9, the distance to Frejaplan and Åsvägen is much shorter than to Stora Ringvägen, but Google Maps did not recommend these stops for transit as the total travel time was longer, as mentioned in Section 3.5.2.

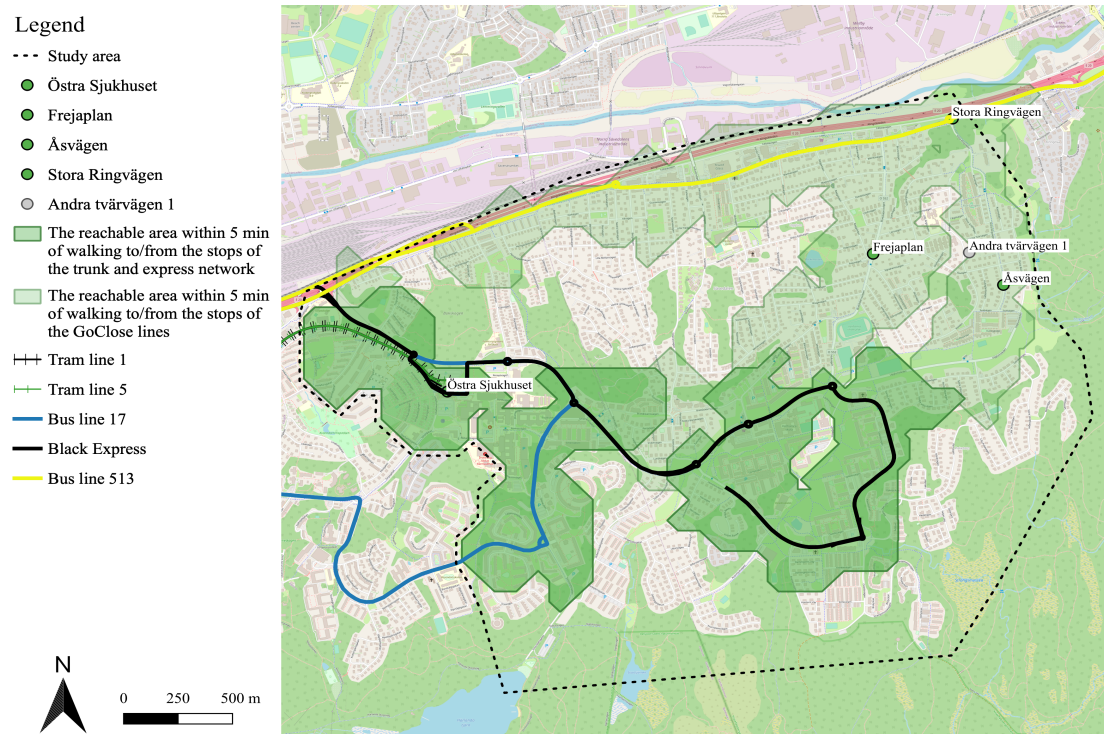


Figure 3.9 The location of Andra tvärvägen 1, Östra Sjukhuset, Stora Ringvägen, Frejaplan and Åsvägen, and the recommended lines were used to reach Brunnsparken from Andra tvärvägen 1. In addition, the catchment area of all public transit stops considering a five-minute walking distance to and from the stops.

3.6 Operational cost

The operational cost was determined by estimating the cost of buying e-scooters, the cost of charging the batteries, including the battery capacity and electricity price, and the cost of collecting the depleted e-scooters, including salary costs and fuel costs. First, the cost of buying e-scooters was determined. There were many different models of e-scooters with different prices and features. One e-scooter model Ninebot-Segway Max G30 was very similar to the Voyager 3 from Voi Technology (Wiles, n.d.). Therefore, the price of the Ninebot-Segway Max G30 was used to determine the cost of buying e-scooters. The cost varied, but the cheapest cost was used, which was equal to around 8 500 SEK per e-scooter, including 25% VAT (Prisjakt, 2022). Second, the cost of charging the batteries was determined using the battery capacity of Voi e-scooters and the electricity price for non-households in Sweden. For non-households, the average electricity price for all consumption levels was 1,19 SEK/kWh, including VAT in 2021 (Statistikmyndigheten SCB, 2022). As the battery capacity varied for different e-scooters models, an average value was calculated from Voi scooters, see Table 3.5 (Voi

Team, personal communication, June 2-9, 2022). The cost of charging all batteries was calculated according to Equation 3.4.

Table 3.5 The battery capacity of each e-scooter model that Voi Technology use and the average battery capacity of all the models.

E-scooter model	Battery capacity [Wh]
V3x	551
V4	1004
V5	1004
Average of all models	853

$$TCC = BC * EP * TA \quad (3.4)$$

where:

TCC is the Total Cost of Charging all batteries in SEK

BC is the Battery Capacity in kWh

EP is the Electricity Price in SEK/kWh

TA is the Total Amount of depleted scooters

Information about the scooter's battery level was needed to estimate the total number of depleted e-scooters in the study area that needed to be charged, which helped calculate the cost of charging the batteries of the depleted e-scooters. The State-of-Charge (SOC) level was equal to 20% of the battery level, according to Voi (Voi Team, personal communication, June 2-9, 2022). Some coding in Python was applied to find the battery level for each e-scooter, using the data from the Urban Mobility System Group at the Chalmers University of Technology, see Appendix E, Figure E.1. The number of e-scooters that needed to be charged was sorted out in Python, using a limit of 25%, hence providing a safety marginal for the calculations. As the numbers of deployed e-scooters varied during different times of the day, Excel was used to calculate the average share of depleted e-scooters for all times during the analysed day, see Appendix E, Table E.1. The average percentage of depleted e-scooters was applied to the deployed e-scooters in the study area to achieve the total number of depleted e-scooters in the study area, see Appendix E, Table E.3. The number of depleted e-scooters in the study area was necessary to calculate the total cost of charging all batteries, as in Equation 3.4

The total number of deployed e-scooters in the study area was based on Section 3.4.2. There were e-scooter parking spots in the residential area, at the public transit stops, and at the retail and service properties. The result in Section 4.2 showed that 110 e-scooter parking spots were needed in the residential area, while all trunk and express stops required parking spots for the e-scooters, see Table 3.6. For the retail and service properties, there was no need to have an e-scooter parking spot for every property, as

many properties were located at the exact location, see Figure 4.7 in Section 4.2. Therefore, only six e-scooter parking spots for the retail and service properties were needed, see Table 3.6. An estimation was necessary considering the number of e-scooters per parking spot, see Table 3.6. As mentioned in Section 3.4.2 more e-scooters were needed at the key destination of Östra Sjukhuset than at the other stops. The study area was estimated to have 490 deployed e-scooters, see Table 3.6.

Table 3.6 The number of parking spots, e-scooters per parking spot and the total amount of e-scooters for different areas.

Type of area	Number of parking spots	Number of e-scooters per parking spot	The total amount of e-scooters
Residential	110	3	330
Trunk and express stops	11	10	110
Key destination Östra Sjukhuset	20	1	20
Retail and service properties	6	5	30
All			490

Information about the e-scooter locations was needed to estimate the distance the operators were required to drive to pick up the depleted e-scooters. This helped calculate the cost of collecting the depleted e-scooters. First, a salary cost was estimated using an average salary of 120 SEK per hour for the employees collecting the depleted e-scooters. Second, the average distance between the depleted e-scooters was calculated to know the time and distance the operators needed to drive to collect the e-scooters. The distance between the depleted e-scooters was calculated according to Equation 3.5 in Excel. This equation was applied for all depleted e-scooters after importing the coordinates of the depleted e-scooters from the Python coding, see Appendix E, Table E.1. The distance between all the depleted e-scooters were calculated to find the closest distance between two e-scooters, see Appendix E, Table E.4. To make the results more accurate, an average distance for all times during the analysed day was calculated.

$$D = \arccos(\sin\phi_{LAT1} * \sin\phi_{LAT2} + \cos\phi_{LAT1} * \cos\phi_{LAT2} * \cos(\phi_{LON1} - \phi_{LON2})) * R \quad (3.5)$$

where:

D is the Distance between two locations in kilometres

ϕ_{LAT1} is the Latitude of the first coordinate in radian

ϕ_{LAT2} is the Latitude of the second coordinate in radian

ϕ_{LON1} is the Longitude of the first coordinate in radian

ϕ_{LON2} is the Longitude of the second coordinate in radian

R is the Radius of Earth (approximately 6371 kilometres)

The total cost of collecting the depleted e-scooters in Sävedalen was calculated using Equation 3.6, where the total salary cost was calculated using Equation 3.7. To determine the average time required to collect the depleted scooters, the average distance between the depleted scooters was divided by the average speed of 15 km/h. Later it was multiplied by the total amount of depleted e-scooters in Sävedalen. In addition, one minute was added for picking up each e-scooter by the operators to achieve the total time required to collect the depleted e-scooters.

$$TC = (AD * TA * TFP) + TSC \quad (3.6)$$

where:

TC is the Total Cost of collecting the depleted scooters in SEK

AD is the Average Distance between the depleted scooters in kilometres

TA is the Total Amount of depleted scooters

TFP is the Total Fuel Price in SEK per kilometre

TSC is the Total Salary Cost in SEK

$$TSC = ASC * AT \quad (3.7)$$

where:

TSC is the Total Salary Cost in SEK

ASC is the Average Salary Cost in SEK

ATC is the Average Time required to Collect the depleted scooters in hours

3.7 Operating income

The operating income was determined using a utilisation rate of e-scooters per day. As mentioned in Section 2.1.1 the utilisation rate was measured in many cities for several months, where a utilisation rate of 2,5 % per day was found to be accurate for Sävedalen. The daily utilisation rate was converted into minutes per day, equal to around 36 minutes. An average trip time was calculated by knowing the average trip distance of 1,7 kilometres, see Appendix C, Table C.1, and the average trip speed of 15 km/h for e-scooters. The average trip time and the utilisation rate in minutes were later used to calculate the average trips per day, as in Equation 3.8. The average trip cost was calculated by knowing the average trip distance and kilometre price according to Equation 3.9. Afterwards, the income per day for the e-scooters was calculated by knowing the total amount of e-scooters, the average trip cost, and the average trips per day, see Equation 3.10.

$$AT = \frac{ATT}{UR} \quad (3.8)$$

where:

AT is the Average number of Trips per day

ATT is the Average Trip Time in hours

UR is the Utilisation Rate in hours

$$ATC = ATD * KP \quad (3.9)$$

where:

ATC is the Average Trip Cost in SEK

ATD is the Average Trip Distance in kilometres

KP is the Kilometre Price for e-scooters in SEK per kilometre

$$IPD = TA * ATC * AT \quad (3.10)$$

where:

IPD is the Income Per Day in SEK

TA is the Total Amount of scooters

ATC is the Average Trip Cost in SEK

AT is the Average number of Trips per day

4 Results

The following chapter presents the public transit network in Sävedalen and its reachable area within 30 minutes on public transit. The accessibility to the trunk and express stops and e-scooter parking spots are presented as a catchment area. Travel times and costs for different modal splits are shown as well.

4.1 The transit network in Sävedalen

The analysis shows that the public transit network in Sävedalen has seven lines; four lines are part of the trunk and express network, see Table 4.1. Three are not part of the trunk and express network, referred to as GoClose lines; see Table 4.1. All lines, except bus line 513, connect to the stop of Östra Sjukhuset, see Figure 4.1. Östra Sjukhuset has an excellent connection to other parts of Gothenburg's metropolitan area within the 30-minute target, see Figure 4.2. In contrast, stops of the GoClose lines reach a much smaller area within the 30-minute target, see Figure 4.3 and Appendix A, Figure A.1 and Figure A.2. The trip frequency is very low for some of the GoClose lines, with two to three departures per hour on all days, see Appendix D, Figure D.3 to Figure D.6. For bus line 513 the trip frequency is higher, with up to six departures per hour during rush hours, see Appendix D, Figure D.1 and Figure D.2.

Table 4.1 The characteristics of the public transportation network in Sävedalen.

Line	GoTerm	Network
Tram line 1	GoFrequent	Trunk
Tram line 5	GoFrequent	Trunk
Bus line 17	GoFrequent	Trunk
Black Express	GoFast	Express
Bus line 513	GoClose	-
Bus line 514	GoClose	-
Bus line 515	GoClose	-

Legend

- Study area
- Stops of the trunk and express network
- Stops of the GoClose lines
- ⚡ Tram line 1
- ⚡ Tram line 5
- Bus line 17
- Black Express
- Bus line 513
- Bus line 514
- Bus line 515

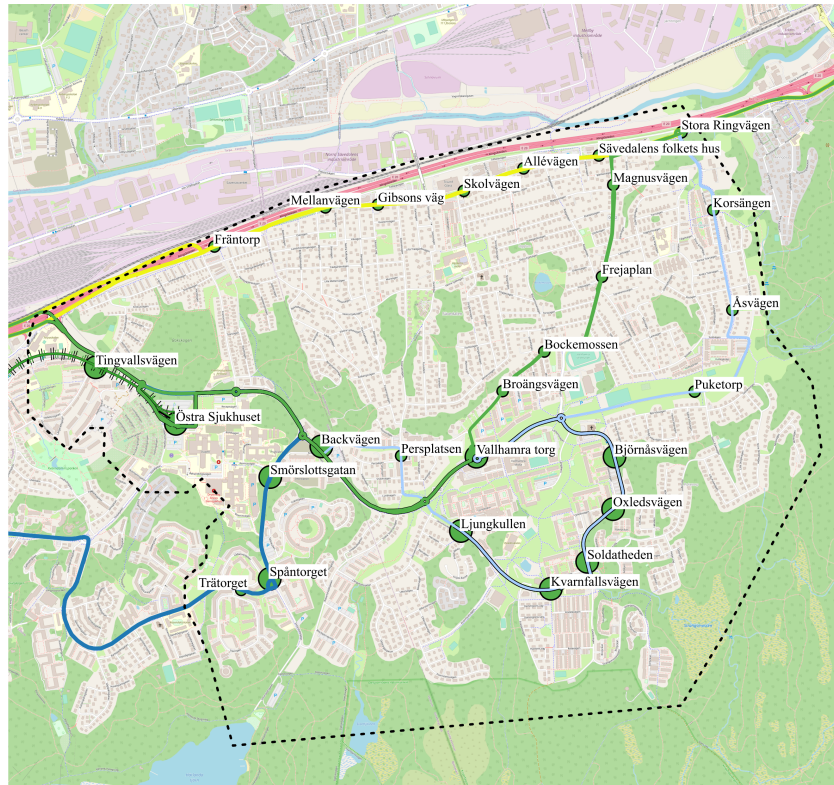
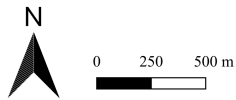


Figure 4.1 The public transit network in Sävedalen with all lines and stops.

Legend

- Study area
- Östra Sjukhuset
- The reachable area within 30 min on public transit from Östra Sjukhuset, where a walking time of 5 min is included

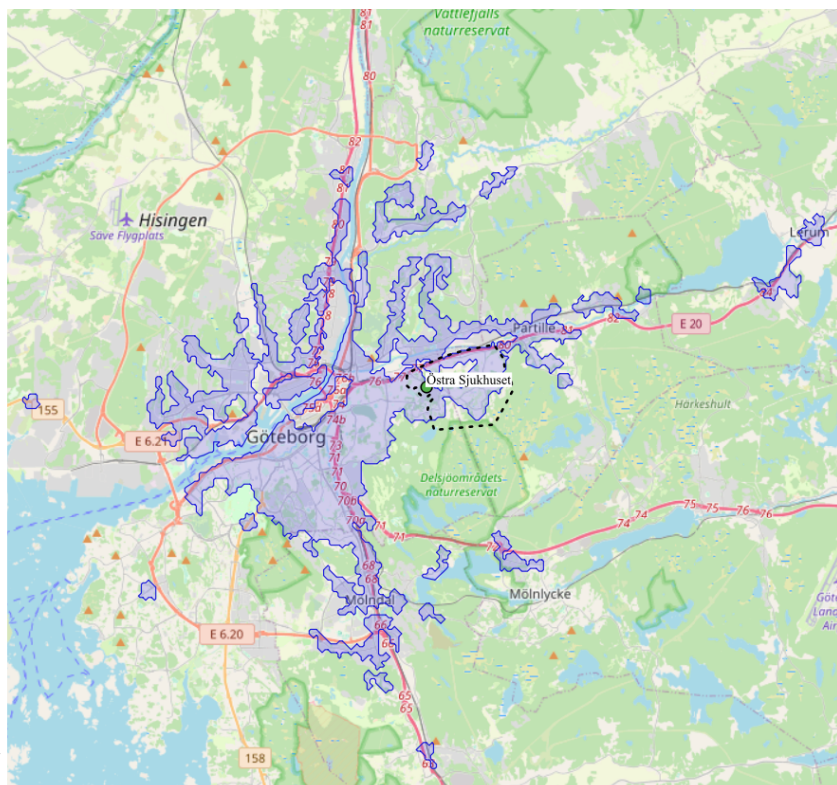


Figure 4.2 The reachable area within 30 minutes on public transit from Östra Sjukhuset, where a walking time of five minutes is included.

Legend

- Study area
- Skolvägen
- The reachable area within 30 min on public transit from Skolvägen, where a walking time of 5 min is included

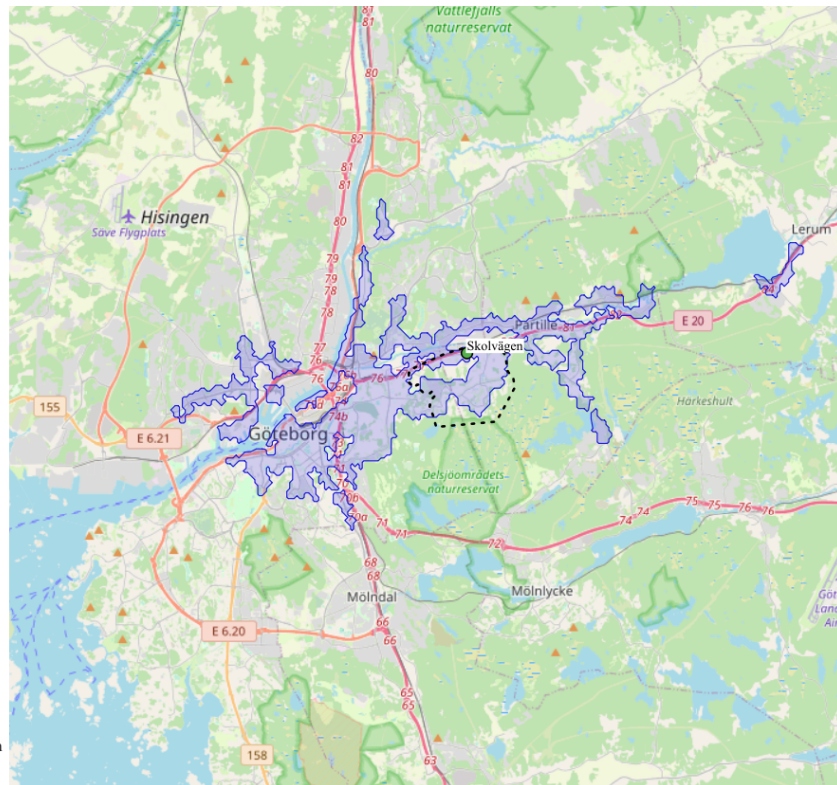
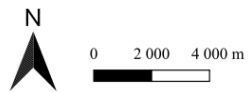


Figure 4.3 The reachable area within 30 minutes on public transit from Skolvägen, where line 513 departures, where a walking time of five minutes is included.

4.2 Accessibility to the e-scooters and the trunk and express network

The walking distance to and from the trunk and express stops exceeds five minutes for a large part of the study area, see Figure 4.4. The catchment area of the trunk and express network is small compared to the catchment area of e-scooters considering a travel distance of five minutes to and from the stops, see Figure 4.5. Still, the entire study area is not reached by an e-scooter during a travel distance of five minutes. In eight minutes, it is possible to reach most of the study area with an e-scooter, see Figure 4.6. The walking distance is less than two minutes to the e-scooter parking spots for most of the study area, see Figure 4.7. It is needed to have around 110 e-scooter parking spots in the residential area to achieve convenient accessibility to the e-scooters. Regarding the accessibility to the trunk and express, the south of the study area has more bike paths than in the north; see the blue lines in Figure 4.8.

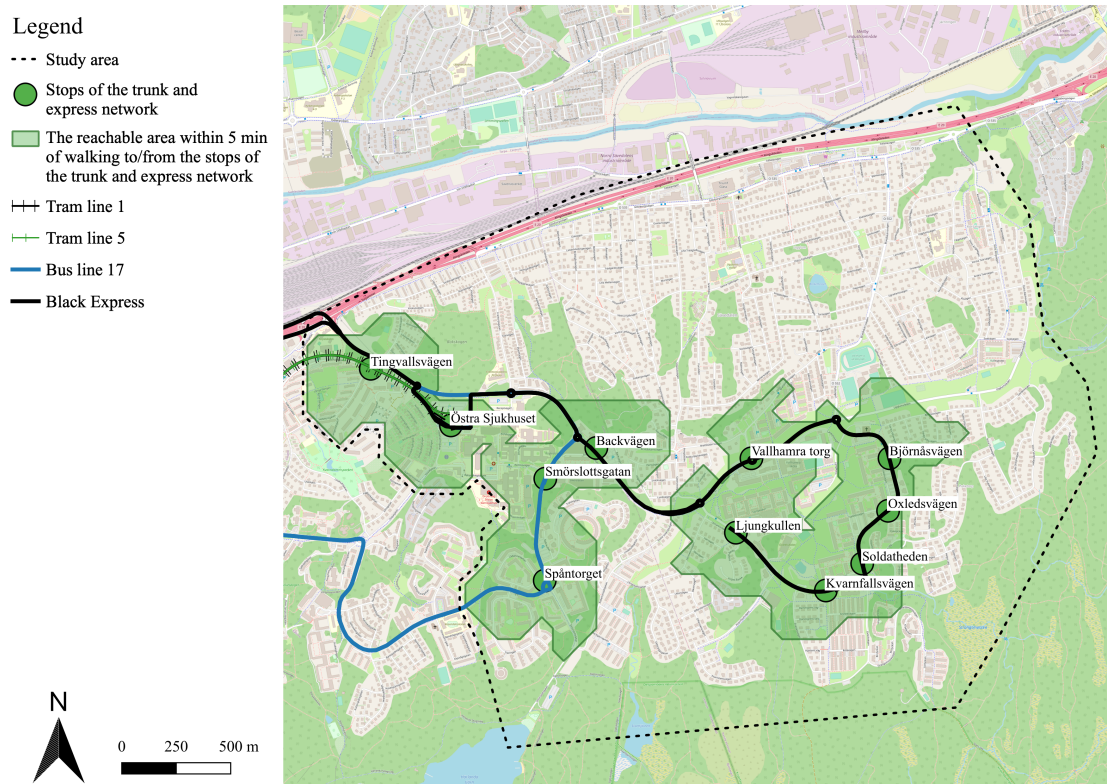


Figure 4.4 The walking accessibility to the trunk and express network stops in Sävadalen, considering five minutes of walking.

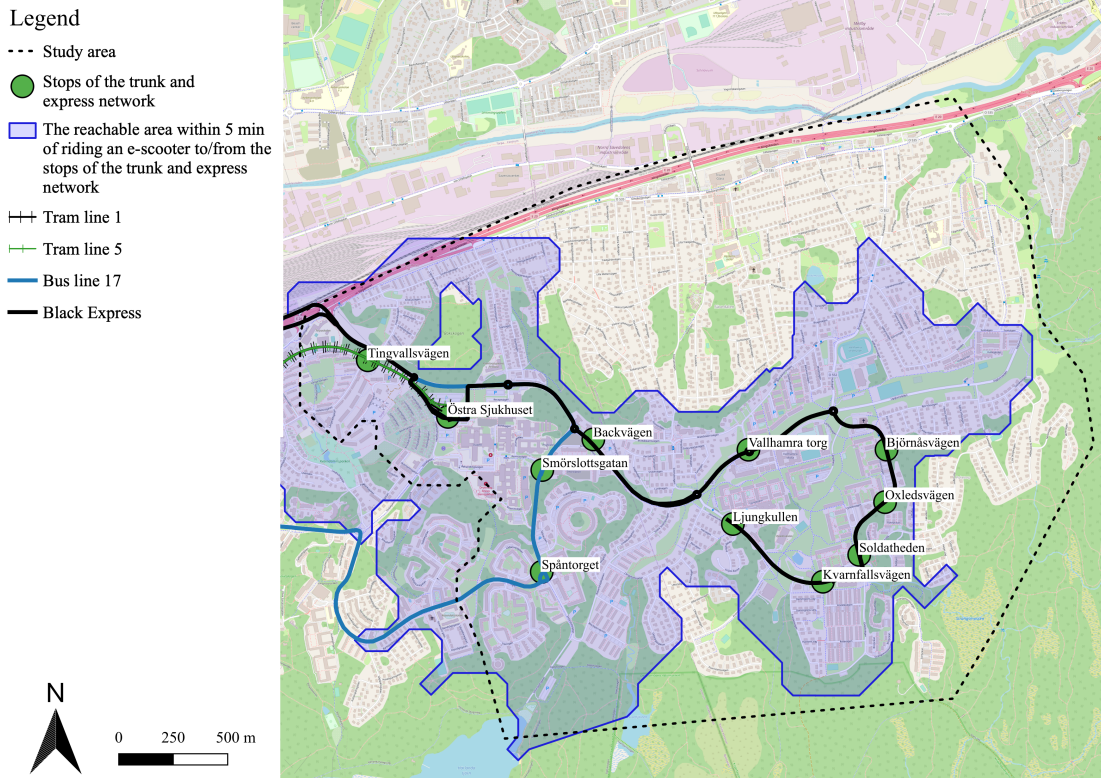


Figure 4.5 The e-scooters' accessibility to the trunk and express network stops in Sävadalen, considering five minutes of riding an e-scooter.

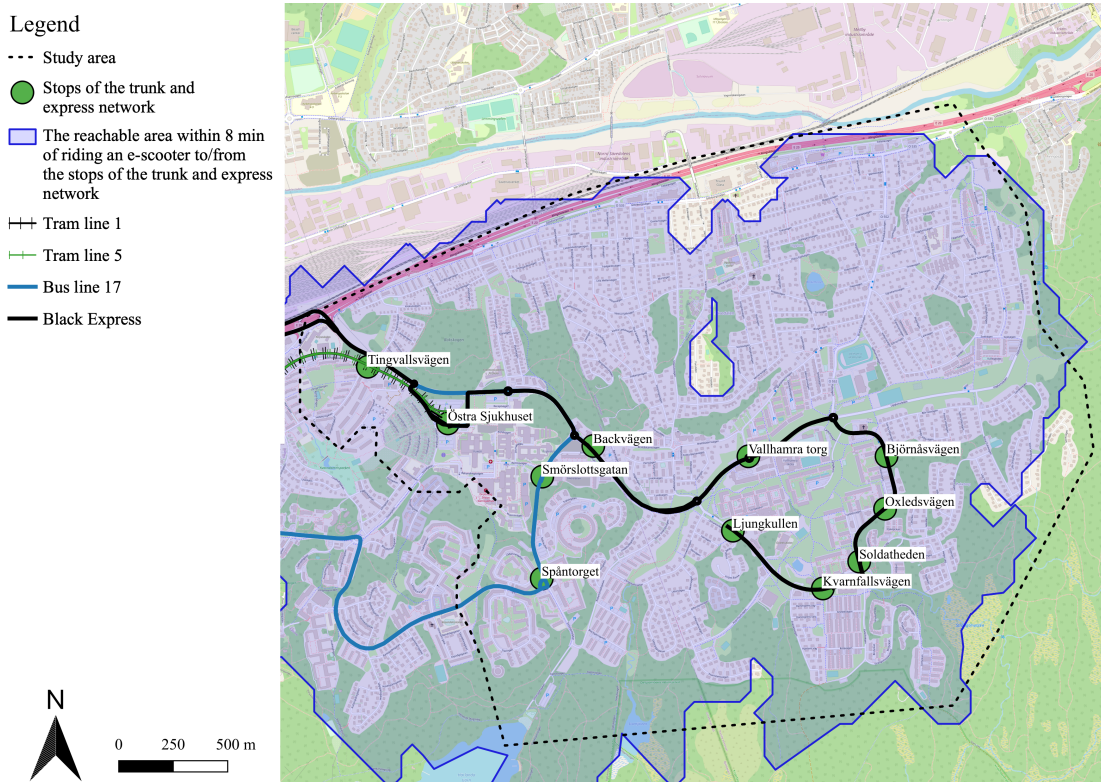


Figure 4.6 The e-scooters' accessibility to the trunk and express network stops in Sävadalen, considering eight minutes of riding an e-scooter.

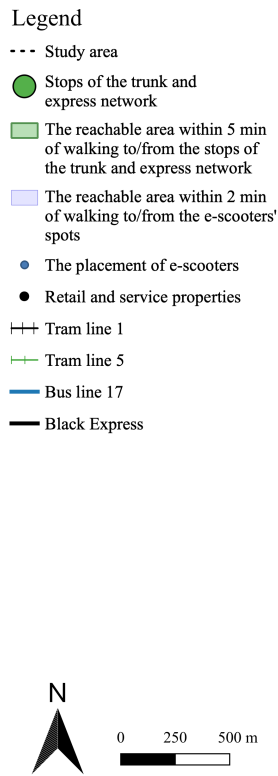


Figure 4.7 The locations of e-scooters parking spots and the walking accessibility to these locations, considering two minutes of walking in relation to the catchment area of trunk and express stops and the service properties.



Figure 4.8 The bicycling network in Sävadalen represents the blue lines and the trunk and express network stops are marked in green dots.

4.3 Travel times and costs

The result shows that car riding is the fastest travel mode, followed by bicycling, see Table 4.2. Car trips vary in travel time, and with less traffic, these trips can be more than twice as fast as bicycling. The travel cost for car trips is nearly the same as all modal splits, except for bicycling, which is free, see Table 4.2. E-scooters are a bit more expensive than walking, and transit at the recommended stop is cheaper than Östra Sjukhuset, see Table 4.2. In contrast, there is a small time-saving transiting at Östra Sjukhuset instead of transiting at the recommended public transit stop, see Table 4.2. The results show that using e-scooters as a first and last-mile connection to public transit can speed up the total travel time by around six to seven minutes but at a 2-6 SEK higher cost than walking to the stops, see Table 4.2.

Table 4.2 The average travel time and the costs of all four travel routes, for different modal splits.

Modal split	Travel time (min)	Travel costs (SEK)
E-scooter + Public transportation (Transit at Östra Sjukhuset)	35	41
E-scooter + Public transportation (Transit at the recommended stop)	36	37
Walking + Public transportation	42	35
Bicycling	34	0
Car	15-29	34

E-scooter trips to public transit stop correspond only to a small part of the cost for the modal split between e-scooters and public transit, ranging from 1-6 SEK, see Appendix B, Table B.1 to Table B.4. The cost is small because the travel distance of e-scooters is relatively short for all routes. The shortest trip is around 500 meters, while the most extended trip is around 3,2 kilometres, whereas the median distance is 1,7 km, see Appendix C, Table C.1. The climb gradient can affect the e-scooters speed from Ugglumsskolan to Östra Sjukhuset. The inclination is almost 10%, see Appendix B, Figure B.2. For all other routes, the inclination rate is lower, see Appendix B, Figure B.2, Figure B.3, Figure B.5, Figure B.7, Figure B.9, Figure B.10, Figure B.12, Figure B.13, Figure B.15 and Figure B.17. The median value of all inclinations is 5,6%, see Appendix C, Table C.2.

4.4 Operational profitability

The amount of depleted e-scooters in Sävedalen is equal to 24 e-scooters, using the same share of depleted scooters as in the rest of Gothenburg, which was around 4,9% on average, see Appendix E, Table E.1. The cost of collecting all depleted e-scooters, including fuel costs and salary costs is equal to 131 SEK, see Appendix E, Table E.3. It is operational profitability to have e-scooters in Sävedalen according to the proposal of e-scooter parking spots and the number of e-scooters per spot, as mentioned in Section 3.6. The operating income per day and vehicle for a utilisation rate of 2,5 % is higher than the operational cost per day and vehicle, see Table 4.3. The e-scooters are also operational profitably for a lower utilisation rate of 1 % per day, see Table 4.4. This lower utilisation rate is around 14 minutes per day per e-scooter, which corresponds to about two average trips per day considering the time aspect, see Appendix E, Table E.2.

Table 4.3 The total operating income and cost per day for e-scooters in Sävedalen with a utilisation rate of 2,5% per day per e-scooter.

Total operating income per day	6 615,00 kr
Total operating income per day and e-scooter	13,50 kr
Total operating cost per day	155,34 kr
Total operating cost per day and e-scooter	0,32 kr
Total profits per day and e-scooter	13,18 kr

Table 4.4 The total operating income and cost per day for e-scooters in Sävedalen with a utilisation rate of 1% per day per e-scooter.

Total operating income per day	2 646,00 kr
Total operating income per day and e-scooter	5,40 kr
Total operating cost per day	155,34 kr
Total operating cost per day and e-scooter	0,32 kr
Total profits per day and e-scooter	5,08 kr

5 Discussion

The discussion consists of the operational profitability and social benefits of e-scooters. Discussing the importance of parking regulations, fleet size, and network infrastructure of e-scooters provides a better understanding for a future scenario with e-scooters as a first and last-mile connection to public transit.

5.1 Social benefits and operational profitability

Using an e-scooter as a first and last-mile connection to public transit can bring social benefits considering faster trips than walking, see Table 4.2. The choice of transit stop between e-scooters and public transit does not matter considering faster travels for the travel routes, as only a minute differs, see Table 4.2. The trunk and express lines or bus line 513 depart from the different recommended stops, see Section 3.5.4 to 3.5.7. However, bus line 513 has a higher trip frequency during rush hours than bus line 514 and 515, see Section 4.1, making it an alternative for achieving fast trips. As neither bus line 514 nor 515 is considered an alternative for the recommended stops due to a low trip frequency, the total travel time depends on the trip frequency. On the other hand, fewer locations in Gothenburg's metropolitan area are reached with bus line 513 from Skolvägen compared to Östra Sjukhuset within the 30-minute target, see Figure 4.2 and Figure 4.3. The main reason is that bus line 513 is not part of the trunk and express network. Hence the connections may not be as fast for reaching a significant area. Another reason is that only one line departs from Skolvägen compared to six lines from Östra Sjukhuset, see Figure 4.1. Six lines provide more options in many directions, increasing the reached area within 30 minutes. Therefore, connecting to public transit, which has fast and frequent connections to many parts of Gothenburg, is vital for achieving the social benefits of e-scooters.

The social benefits and profitability would not be the highest for this study area, as an eight-minute e-scooter trip is needed to provide the entire area with an excellent connection to and from the trunk and express network. This is above the goal of five minutes to achieve the maximum benefits and profitability of e-scooters, as mentioned in Section 3.4. On the other hand, eight minutes is still below ten minutes. Ten minutes is an adequate travel time if the destination has fast and frequent public transit, see Section 2.2. As the destinations for the first mile trips are the trunk and express stops, people may be willing to travel three minutes longer with e-scooters. The social benefits and profitability are therefore believed to be good enough.

It is easy to believe that e-scooters are better as a first and last-mile connection to the recommended stops than Östra Sjukhuset due to lower total travel costs, see Table 4.2. Key destinations, nodes or cores seem to be less beneficial transit locations between e-scooters and public transit, considering the total travel costs. Overall, the best way to encourage scooters first and last-mile trips is to lower the total travel cost to the same level as the current public transit cost. Today, it is up to 6 SEK more expensive to take

an e-scooter to the public transit stops than to walk, as mentioned in Section 4.3. As most commuting trips are two-way, this cost increases to 12 SEK per workday. In the long term, for daily commuters, this will result in a fee of 240 SEK per month if they work 20 days a month. There is a problem reducing the cost to the same level as the public transit cost, as the e-scooter companies must earn money to be operationally profitable in the area. The solution is to discount the public transit cost if e-scooters are used as a first and last-mile connection. Implementing a discount on the public transit cost needs a mobile application where people can plan and pay for their multi-modal transportation trips, as described in Section 2.4. Using the already established application called Whim is suggested, where subscription plans or one-time payment is possible. However, discounting the public transit cost is probably not operationally profitable for the public transit company, Västtrafik. Therefore, a market analysis must be carried out that guarantees Västtrafik some security for continued profits and profitability.

On the other hand, lowering the public transit cost by favouring lower total travel costs for the modal-split e-scooters and public transit can increase the public transit trips. People may find it attractive and profitable to switch from other transportation modes, such as cars, to a combined mobility solution between e-scooters and public transit. It may be possible to discount the public transit cost even more so that the total travel cost of e-scooters and public transit becomes lower than only using public transit. Therefore, a lower total travel cost of using e-scooters as first and last-mile connections to public transit could work as a policy instrument for reducing car trips and increasing the social benefits and profitability of e-scooters and public transit.

The operational profitability is an essential factor to consider as the operators need to make money to have e-scooters in the study area. There are many concerns about the exact operational profitability, as it is impossible to determine the utilisation rate and the number of e-scooters in advance. There are also some concerns about the estimations considering the cost of collecting the e-scooters, for example, salary and fuel costs. However, the average distance between two e-scooters, around 240 meters, seems accurate for the study area, as the e-scooters are placed within a short walking distance of each other. To achieve a more precise operational analysis, it could be necessary to study the usage pattern for e-scooters in relation to population and workplace density, socioeconomic factors, and traffic patterns. From the result, a utilisation rate of 1% is enough to make profits of about 5 SEK per e-scooter and day. A utilisation rate of 1% means that every e-scooter in the area must be used twice per day for around seven minutes of travel each time, see Section 4.4. To base, the result on a utilisation rate of 1% seems more accurate than a utilisation rate of 2,5%. The higher utilisation rate is equal to over five-seven minutes trips per day and e-scooter. It seems unrealistic that every e-scooter in the area should be used over five times per day for an average trip time of around seven minutes. This is probably more accurate for city centres than for suburban areas. In city centres, e-scooters are probably used more for the fun aspect, as mentioned in Section 2.1.1. However, both a utilisation rate of 1%

and 2,5% generate profits, and it is up to the e-scooters companies to determine if the profits are enough.

5.2 Regulating the parking of e-scooters

One critical point of e-scooters is that people can park them inappropriately on pavements or in front of properties. Mainly, the regulations are few, decreasing the control of the public space. The new law proposal mentioned in Section 1, considering parking limitations for pavement and bike paths, is welcomed to increase the power of public spaces. The pressure on the e-scooter companies is believed to make them adapt to the situation and improve their parking regulations to prevent fees. On the other hand, the parking regulation of e-scooters can threaten the free-floating system. If there are not enough parking spots, it causes problems considering the free-floating aspect. E-scooters would therefore be very similar to docked modes. But docked infrastructure on dockless modes could strengthen the attractiveness of e-scooter as a first and last-mile solution, see Section 2.2.2. The proposal of e-scooter parking spots in Section 4.2, simulates a docked infrastructure and the e-scooters simulate a dockless mode. To guarantee the free-floating aspect, the companies must implement many parking spots for all land use, especially at public transit stops, retail and services properties, and in residential areas. Every place important for first and last-mile connections to public transit must have parking spots, and the proposal of e-scooters parking spots in Section 4.2 is a perfect example of how to implement these parking spots. Preferably within a maximum walking distance of two minutes for all land use, with shorter distances for public transit stops and retail and service properties, as mentioned in Section 3.4.2. This is believed to increase the social benefits and profitability for e-scooters. First, the social benefits are considered to improve in terms of an acceptable walking distance for the users for all land use. Second, the operational profitability is expected to increase, as the maintenance work by the e-scooter companies considering the distribution of e-scooters is expected to reduce, as people are required to park e-scooters in these parking spots. For example, the e-scooter companies would not have to collect inappropriately parked e-scooters and transport them to their original parking spots, thanks to the parking zones. The parking spots help the companies to achieve a time-effective and cost-effective collection of the depleted e-scooters.

The law proposal to forbid parking on pavement and bike paths can threaten the free-floating system considering all e-scooter trips. This is solved by having many regulations instead of one to maintain the freedom for e-scooter users. It is challenging to invent new rules that control parking and protect the free-floating system. However, one regulation could be to park e-scooters in racks beside the new parking spots. There are already racks for cyclists that can be used for e-scooters to increase the free-floating experience. Placing e-scooters in racks would not need parking zones, and users can choose between new parking spots or racks. This could be applied to all e-scooter trips. With two parking options, it is possible to regulate inappropriate parking according to the law proposal and remain free-floating. The system for controlling the parking in the

racks and parking spots would need intelligent solutions such as QR technology. For example, every e-scooter rider must scan a QR code where they park their e-scooter after each trip. The application would, through QR technology, recognise if it is parked in a rack or parking spot.

5.3 Fleet size and e-scooter parking spots

The proposal of e-scooter parking spots in Sävedalen will make first and last-mile services easy and accessible for all users. The tricky question to answer is the fleet size. For example, how many e-scooter should be in service in Sävedalen and how many e-scooter should be placed at each location. As the free-floating system should remain, as described above, people can travel with an e-scooter into the city centre if the zone of Sävedalen is connected to the city. The probability of these zones being connected is high, as the city centre zone's boundaries are not far from Sävedalen today. Maintaining the fleet size in Sävedalen is harder when these zones are connected, as a larger area is covered, probably the entire city. If the fleet size does not meet the current demand, the social benefits decrease and if the fleet size is overdemand, the operational profitability decrease. The main challenge is always to ensure that the supply meets the demand.

There might be a problem with the site of e-scooters parking spots as people must know where they are located. Having them visual insight would attract travellers not planning to use e-scooters, as mentioned in Section 2.1.1. Especially important to have them visible at public transit stops and retail and service properties. This would encourage more people to use the e-scooters for first and last-mile connections, increasing the operational profitability and social benefits of e-scooters users. Another solution could be to implement signs with directions on where it is adequate to park the e-scooters. According to the proposal, there are 110 parking spots where an e-scooter is recommended to be parked to achieve an excellent distribution of the e-scooters in the residential area and to avoid fees. For the parking at the public transit stops and the retail and service properties, the number of e-scooters is higher than in the residential area, as people from all over the area will travel to and from these locations. The highest number of e-scooters must be planned for Östra Sjukhuset, as this is a key destination, where the public transit connections are fast and frequent to a large part of Gothenburg's metropolitan area. Promoting e-scooters to this transit location at a lower total travel cost, as mentioned in Section 5.1, is believed to increase social benefits and profitability for the e-scooter users.

5.4 The e-scooter network

E-scooter users would need to use the roads more significantly in the north than in the south to connect to the trunk and express network stops, as the bicycling network is not as well-developed in the north part, see Figure 4.8. This may reduce the opportunities for using e-scooters as a first and last-mile service in the north. E-scooters on bike paths

enable fast, convenient, and safe connections. Building new bike paths in the north requires space and is expensive. The most cost-effective solution for increasing the safety of e-scooter users is to implement speed bumpers for motor vehicles to decrease the speed of motor vehicles. Promoting an environment with high safety is expected to increase the social benefits and profitability of using an e-scooter. In addition, there are already many narrow streets in the north of Sävedalen. The narrow streets provide less vehicle space, encouraging drivers to slow down and increasing the safety of using an e-scooter on the roads. Implementing bike lanes is also a cost-effective solution for expanding the passability of e-scooters. Bike lanes can provide fast and convenient connections to public transit but also increase the safety for e-scooters users as the space for motor-vehicles decreases encouraging drivers to slow down. On the other hand, bike lanes are only a solution for streets with enough width. Hence, bike lanes and speed bumpers are essential for the social benefits and profitability of e-scooter users, especially in the north of the study area.

6 Conclusions

E-scooters as a first and last-mile connection to public transit can make the total travel time six to seven minutes faster than walking, considering a one-way trip in Gothenburg's metropolitan area. Some of the recommended public transit stops for this analysis have access to high trip frequency during rush hours, and high trip frequency positively affects the total travel times. Therefore, the total travel time from a recommended stop with high trip frequency is nearly the same as from a key destination. On the other hand, the reachable area within the 30-minute target becomes less extensive for the recommended stops with high trip frequency than for the key destination. Therefore, the recommended stops are not always the best transit location between e-scooters and public transit; as in some cases, it is required to transit at a key destination, nodes or core to achieve a fast trip, while for other destinations, the frequency aspect is enough. Connecting e-scooters to public transit with fast and frequent connections to other parts of the city is vital for achieving social benefits and profitability of e-scooters.

Parking regulations, such as e-scooter parking spots and racks solve the parking problems and facilitate the operators. It protects the free-floating system and increases the accessibility to the trunk and express network. One vital factor is that the e-scooters' parking spots should be reachable for anyone within an acceptable walking distance. For public transit stops and retail and services properties, it is necessary to have parking spots or racks at the location, both for fast transit and to attract travellers not planning to use e-scooters for first and last-mile connections. An application is needed to provide an excellent multi-modal transportation solution where users can arrange and pay for all their trips, both one-way and by subscriptions. This would make the user experiences excellent, increasing the social benefits of using an e-scooter to connect to public transit. Another vital factor increasing the social benefits and profitability of e-scooters is the increased catchment area of the trunk and express network. Almost the entire study area is covered within eight minutes of using an e-scooter. Hence the study area has adequate access to the trunk and express network within the time limit of ten minutes to these stops. Excellent profitability and social benefits are achieved within five minutes of travelling to the trunk and express network, where the catchment area increased compared to walking. In addition, e-scooters are operational profitability even with a low utilisation rate of 1%, indicating that e-scooters can be implemented for first and last-mile trips to public transit.

It is possible to increase the social benefits and profitability of e-scooters by discounting the total travel cost of the modal split between e-scooters and public transit to the same level as the public transit cost or below. For this research, the total travel cost must be 1-6 SEK lower, and it is necessary to discount the public transit cost to provide the e-scooters companies with profits. A lower cost of the modal split between e-scooters and public transit can result in more public transit trips, as people may find it attractive and profitable to switch from other transportation modes to a combined mobility solution.

Therefore, discounting the public transit cost in favour of lower total travel cost between e-scooters and public transit could work as a policy instrument for reducing car trips.

6.1 Further research

Some proposal for further research on this thesis is as follows:

- Calculating the total cost, including ownership and insurances of each mode as cars are often expensive to own.
- Determine the fleet size for e-scooter parking spots concerning population density, employment density, and usage patterns to make the analysis more accurate and detailed.
- Calculating the environmental footprint of e-scooters in comparison with other substituting modes such as cars, public transit, and bikes, considering the entire life cycle perspective.

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A. Appendix – Travel Time maps

- Legend**
- Study area
 - Åsvägen
 - The reachable area within 30 min on public transit from Åsvägen, where a walking time of 5 min is included

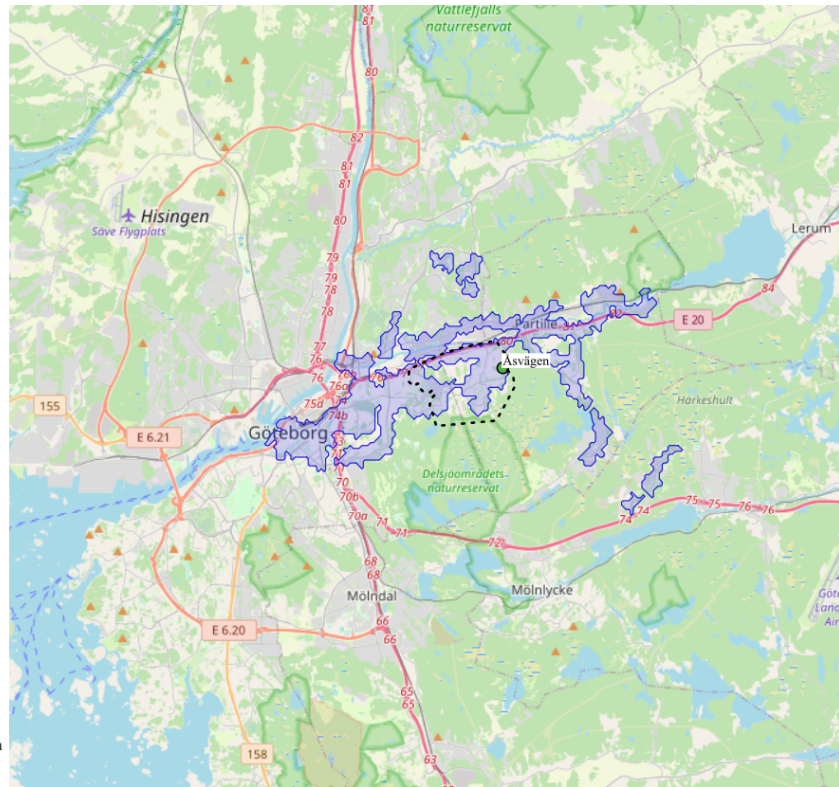
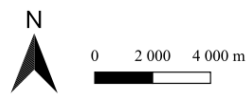


Figure A.1 The reachable area within 30 minutes on public transit from Åsvägen, where line 514 departures. A walking time of five minutes is included.

- Legend**
- Study area
 - Frejaplan
 - The reachable area within 30 min on public transit from Frejaplan, where a walking time of 5 min is included

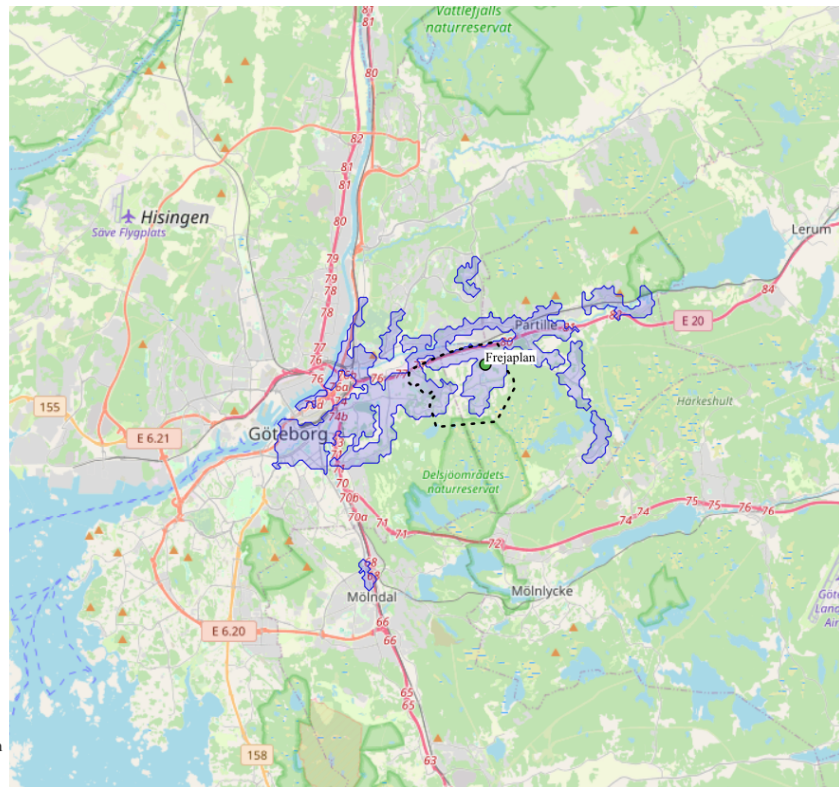
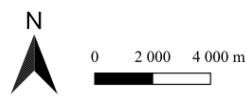


Figure A.2 The reachable area within 30 minutes on public transit from Frejaplan, where line 515 departures. A walking time of five minutes is included.

B. Appendix – Travel Routes

Table B.1 The travel times and costs for different modal splits for the travel route Ugglums school to Brunnsparken, with a departure time at around 07:30 on a random weekday.

Modal split	Travel time (min)	Travel costs (SEK)
E-scooter + Public transportation (Transit at Östra Sjukhuset)	$11 + 20 = 31$	$6 + 35 = 41$
E-scooter + Public transportation + E-scooter (Transit at Skolvägen and Polhemsplatsen)	$2 + 21 + 2 = 25$	$1 + 35 + 2 = 38$
Walking + Public transportation + Walking (Transit at Skolvägen and Polhemsplatsen)	$7 + 21 + 8 = 36$	35
Bicycling	23	0
Car	12-30	31

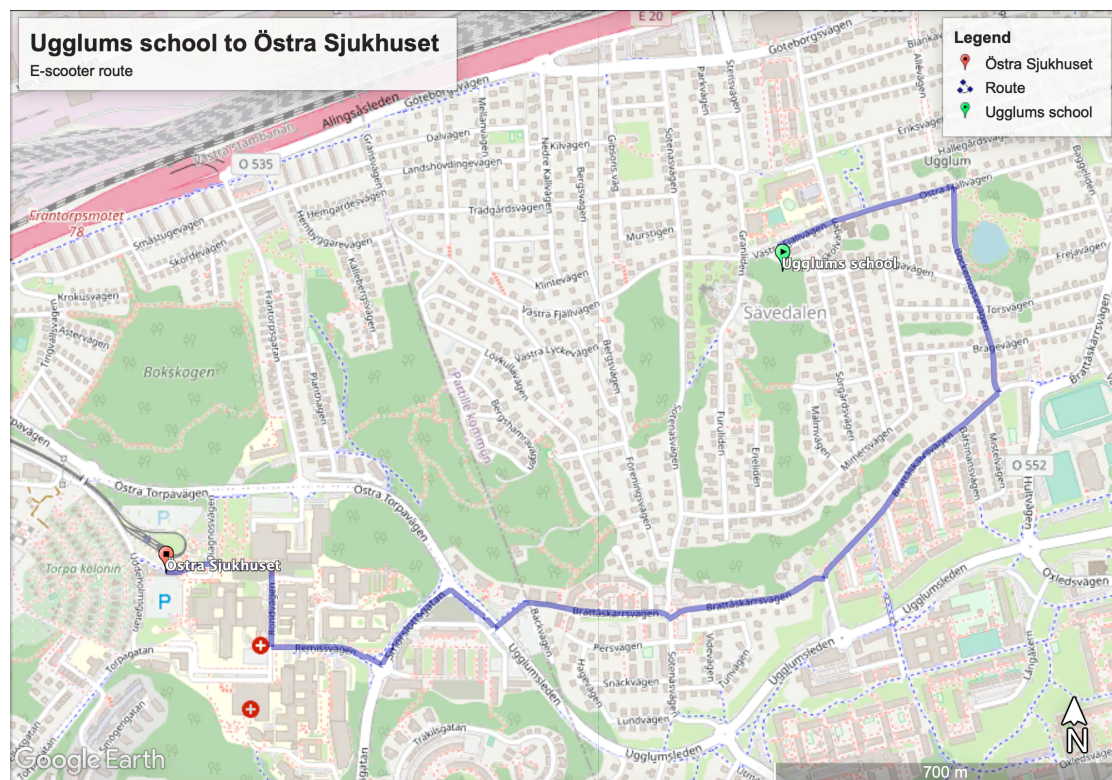


Figure B.1 The e-scooter route Ugglums school to Östra Sjukhuset.

Distance = 3,0 km

Price: = 3,0 km x 2 SEK/km = 6 SEK ≈ 6 SEK

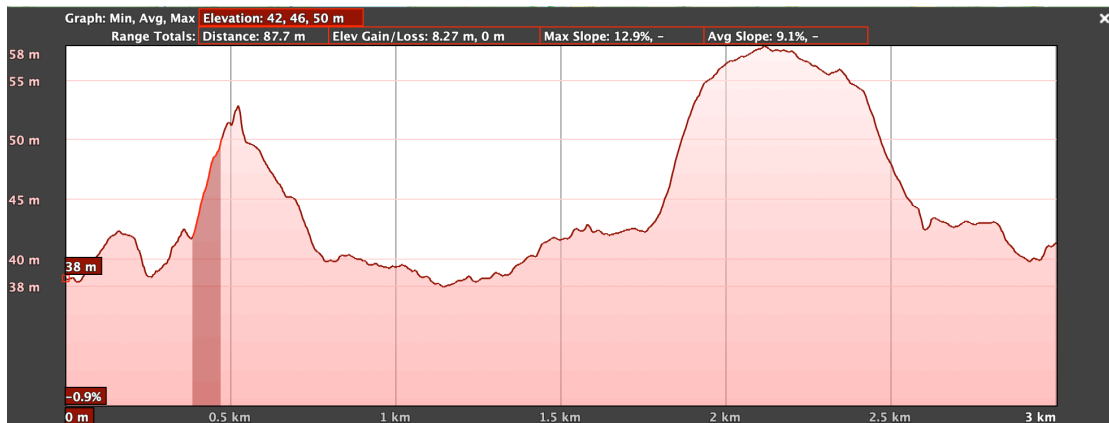


Figure B.2 The elevation profile for the e-scooter route Ugglums school to Östra Sjukhuset, where the first large inclination is marked.

Inclination rate = 9,1 %

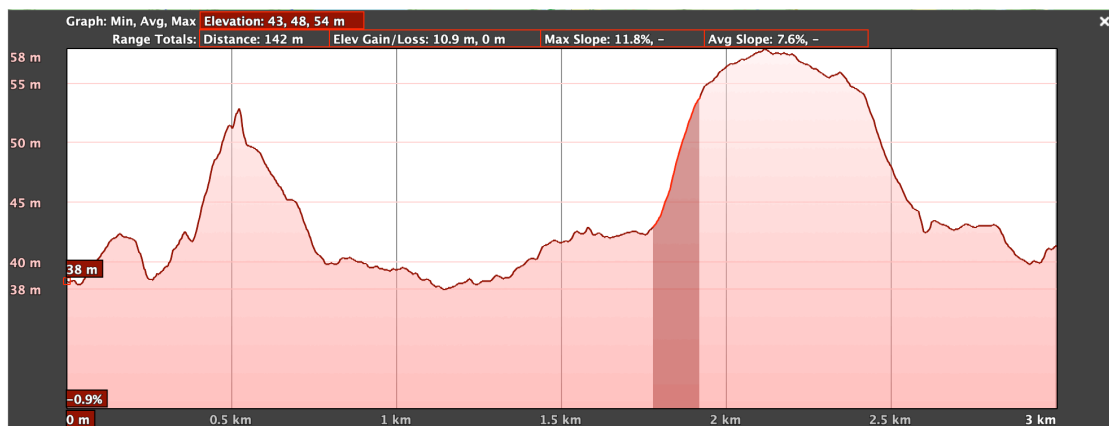


Figure B.3 The elevation profile for the e-scooter route Ugglums school to Östra Sjukhuset, where the second large inclination is marked.

Inclination rate = 7,6 %

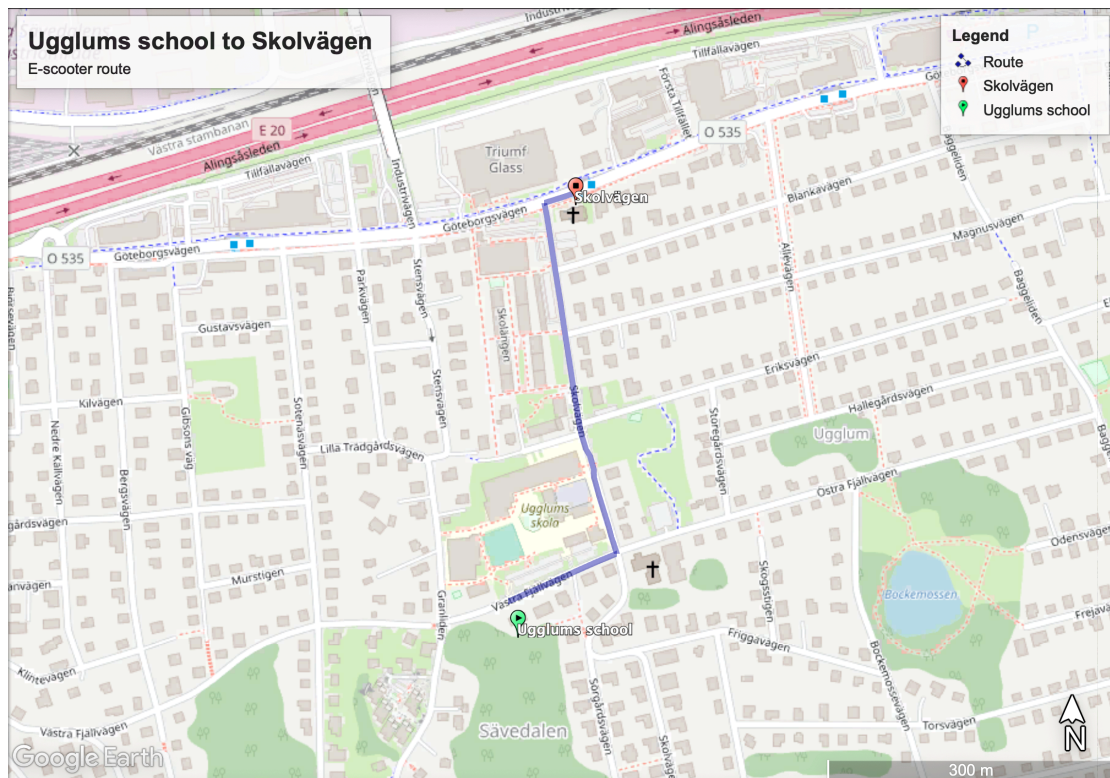


Figure B.4 The e-scooter route Ugglums school to Skolvägen
 Distance: 0,535 km
 Price: = 0,535 km x 2 SEK/km = 1,07 SEK \approx 1 SEK

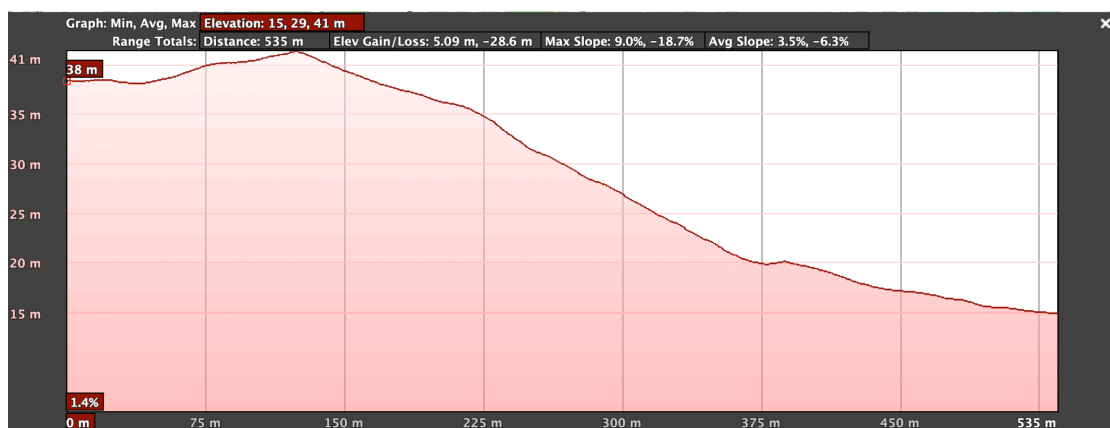


Figure B.5 The elevation profile for the e-scooter route Ugglums school to Skolvägen, No large inclinations.

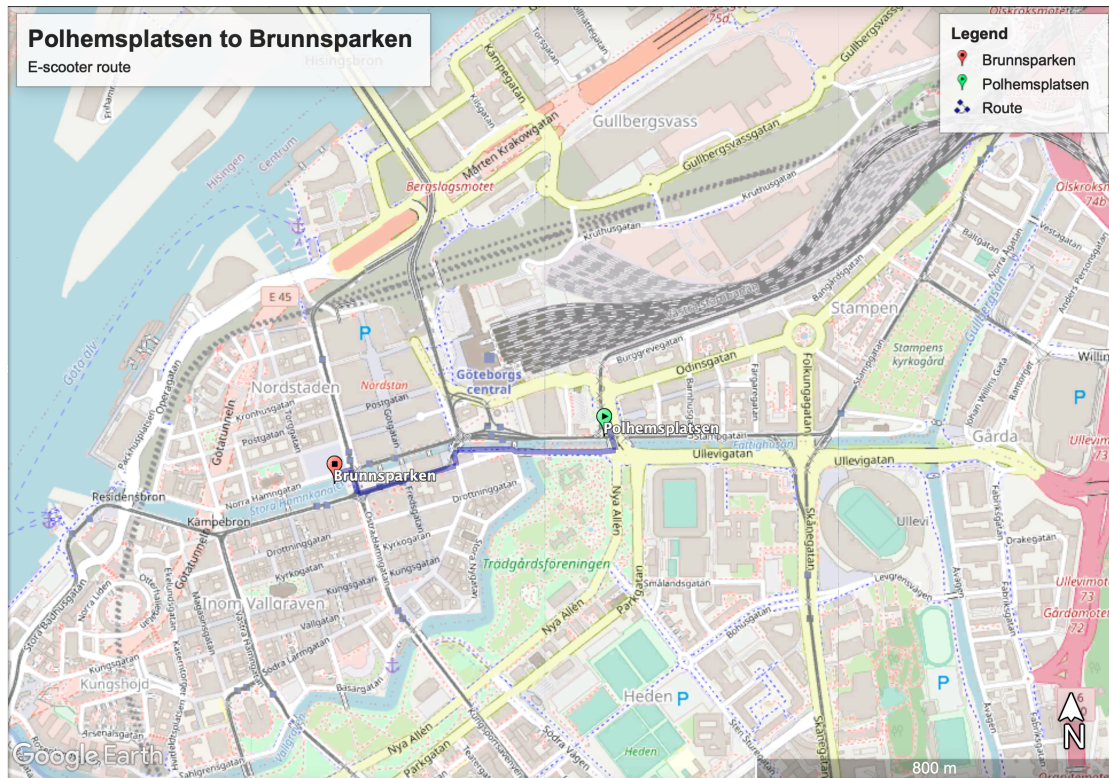


Figure B.6 The e-scooter route Polhemsplatsen to Brunnsparken

Distance: 0,776 km

Price: = 0,776 km x 2 SEK/km = 1,552 SEK \approx 2 SEK



Figure B.7 The elevation profile for the e-scooter route Polhemsplatsen to Brunnsparken.

No large inclinations.

Table B.2 The travel times and costs for different modal splits for the travel route Kvarnhjulsvägen 8 to Brunnsparken, with a departure time at around 07:30 on a random weekday.

Modal split	Travel time (min)	Travel costs (SEK)
E-scooter + Public transportation (Transit at Östra Sjukhuset)	9 + 20 = 29	5 + 35 = 40
E-scooter + Public transportation + Walking (Transit at Kvarnfallsvägen and Central Station)	3 + 24 + 5 = 33	2 + 35 = 37
Walking + Public transportation + Walking (Transit at Kvarnfallsvägen and Central Station)	10 + 24 + 5 = 39	35
Bicycling	27	0
Car	14-22	32

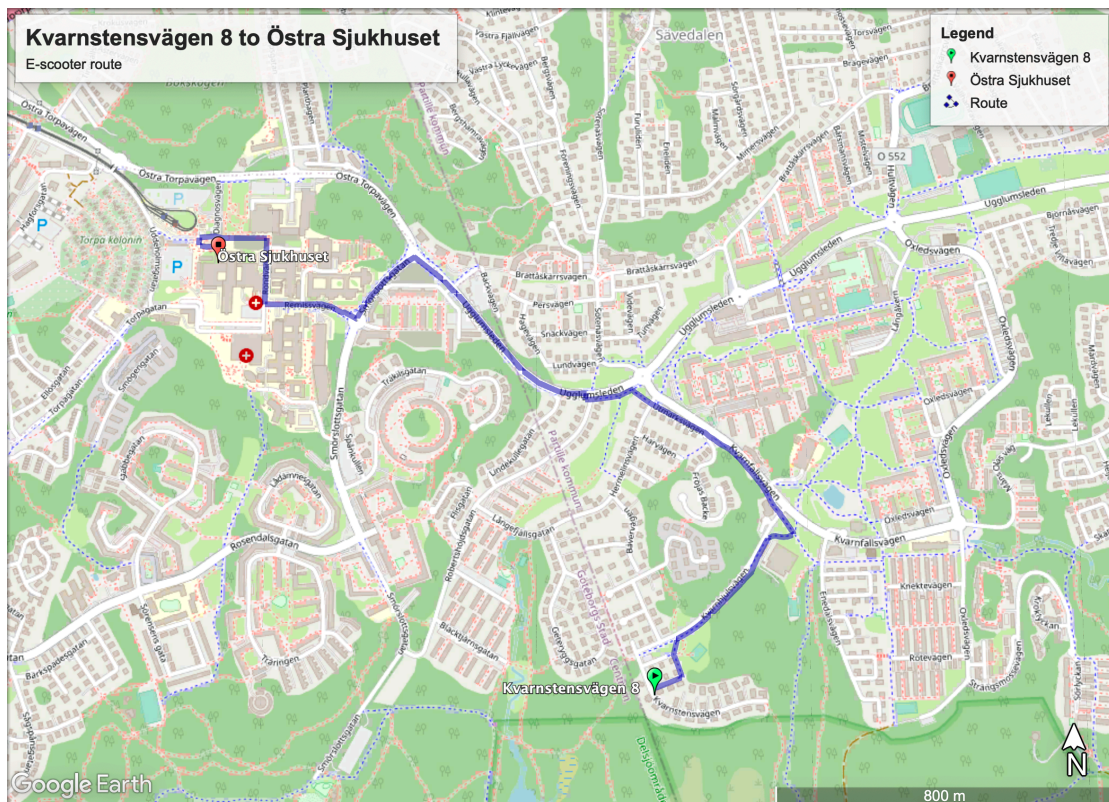


Figure B.8 The e-scooter route Kvarnhjulsvägen 8 to Östra Sjukhuset.

Distance: 2,62 km

Price = 2,62 km x 2 SEK/km = 5,24 SEK ≈ 5 SEK



Figure B.9 The elevation profile for the e-scooter route Kvarnstensvägen 8 to Östra Sjukhuset, where the first large inclination is marked.

Inclination rate = 4,0 %



Figure B.10 The elevation profile for the e-scooter route Kvarnstensvägen 8 to Östra Sjukhuset, where the second large inclination is marked.

Inclination rate = 4,4 %



Figure B.11 The e-scooter route Kvarnstensvägen 8 to Kvarnfallsvägen.

Distance: 0,87 km

Price = 0,9 km x 2 SEK/km = 1,74 SEK \approx 2 SEK



Figure B.12 The elevation profile for the e-scooter route Kvarnstensvägen 8 to Kvarnfallsvägen, where the first inclination is marked.

Inclination rate = 5,6 %



Figure B.13 The elevation profile for the e-scooter route Kvarnstensvägen 8 to Kvarnfallsvägen, where the second inclination is marked.

Inclination rate = 4,1 %

Table B.3 The travel times and costs for different modal splits for the travel route Ugglums school to Sahlgrenska Sjukhuset, with a departure time at around 07:30 on a random weekday.

Modal split	Travel time (min)	Travel costs (SEK)
E-scooter + Public transportation (Transit at Östra Sjukhuset)	11 + 28 = 39	6 + 35 = 41
E-scooter + Public transportation (Transit at Skolvägen)	2 + 38 = 40	1 + 35 = 36
Walking + Public transportation (Transit at Skolvägen)	7 + 38 = 45	35
Bicycling	42	0
Car	16-30	35

Table B.4 The travel times and costs for different modal splits for the travel route Andra Tvärvägen 1 to Sahlgrenska Sjukhuset, with a departure time at around 07:30 on a random weekday.

Modal split	Travel time (min)	Travel costs (SEK)
E-scooter + Public transportation (E-scooter to Östra Sjukhuset)	13 + 28 = 41	6 + 35 = 41
E-scooter + Public transportation (E-scooter to Stora Ringvägen)	3 + 41 = 44	2 + 35 = 37
Walking + Public transportation	9 + 39 = 48	35
Bicycling	43	0
Car	18-35	37

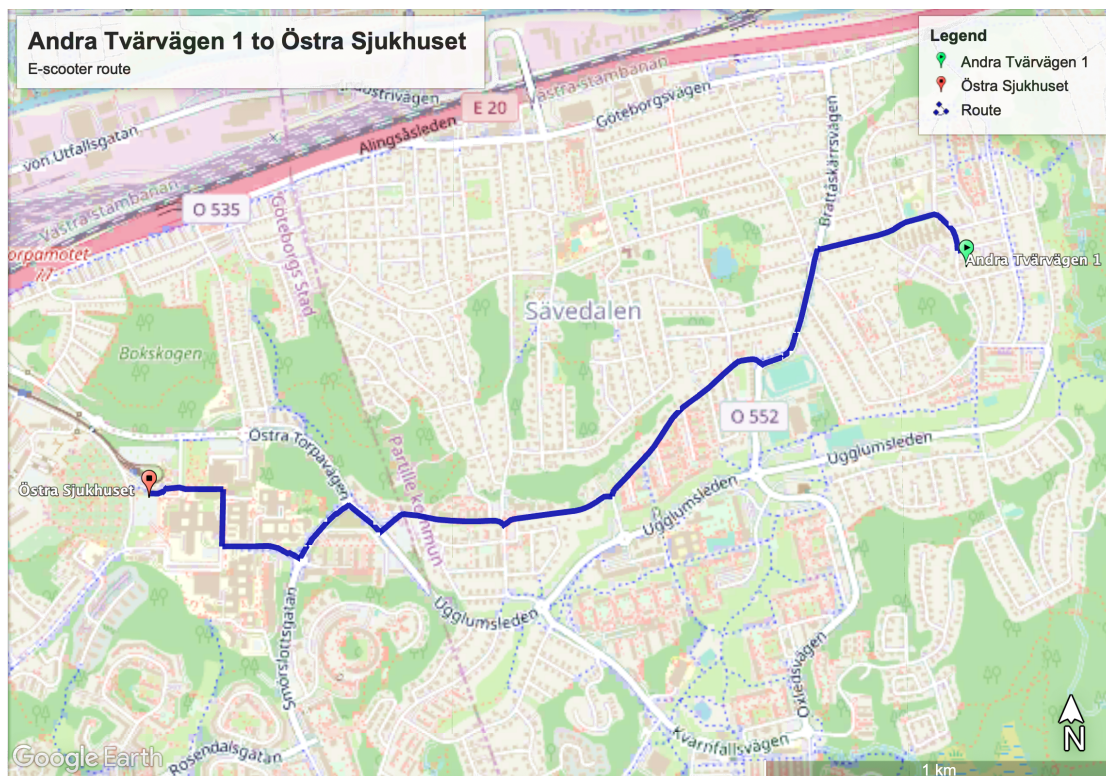


Figure B.14 The e-scooter route Andra Tvärvägen 1 to Östra Sjukhuset.

Distance: 3,2 km

Price: 3,2 km x 2 SEK/km = 6,4 SEK ≈ 6 SEK

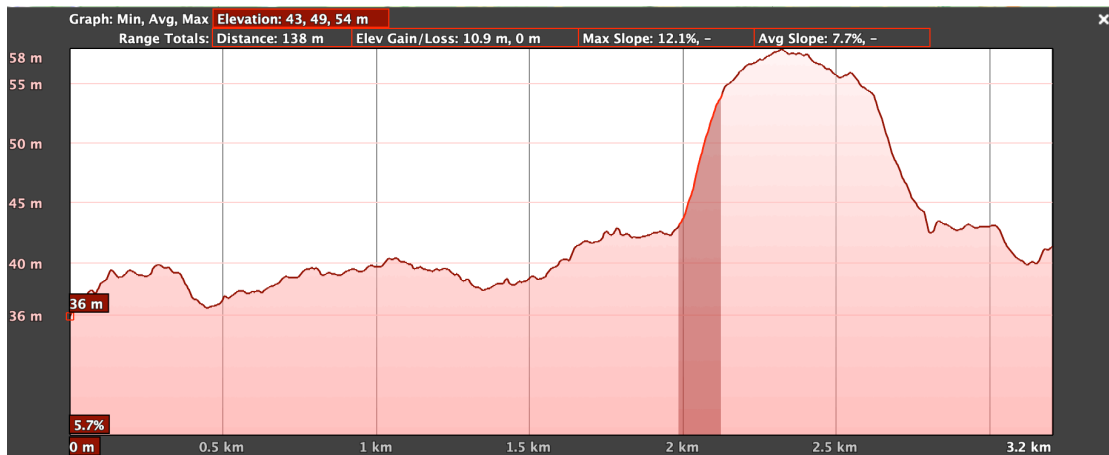


Figure B.15 The elevation profile for the e-scooter route Andra Tvärvägen 1 to Östra Sjukhuset, where the large inclination is marked.

Inclination rate = 7,7 %



Figure B.16 The e-scooter route Andra Tvärvägen 1 to Stora Ringvägen.

Distance: 0,825 km

Price: 0,825 km x 2 SEK/km = 1,65 SEK \approx 2 SEK



Figure B.17 The elevation profile for the e-scooter route Andra Tvärvägen 1 to Stora Ringvägen 8.

No large inclinations.

C. Appendix – Travel distances and climb gradients


Table C.1 *The travel distance for each e-scooter route and the median and average distance for all routes.*

Distance [km]	Travel route
3	Travel route 1 (Transit at Östra Sjukhuset)
0,776	Travel route 1 (Transit at Polhemsplatsen)
0,535	Travel route 1 (Transit at Skolvägen)
2,62	Travel route 2 (Transit at Östra Sjukhuset)
0,87	Travel route 2 (Transit at Kvarnfallsvägen)
3	Travel route 3 (Transit at Östra Sjukhuset)
0,535	Travel route 3 (Transit at Skolvägen)
3,2	Travel route 4 (Transit at Östra Sjukhuset)
0,825	Travel route 4 (Transit at Östra Stora ringvägen)
Median distance [km]	0,9
Average distance [km]	1,7

Table C.2 *The average climb gradient for all e-scooter routes with inclinations and the median and average climb gradient for all routes.*

Climb gradient [%]	Travel routes
9,1	Travel route 1 (Transit at Östra Sjukhuset)
7,6	Travel route 1 (Transit at Östra Sjukhuset)
5,6	Travel route 2 (Transit at Kvarnfallsvägen)
4,1	Travel route 2 (Transit at Kvarnfallsvägen)
4	Travel route 2 (Transit at Östra Sjukhuset)
4,4	Travel route 2 (Transit at Östra Sjukhuset)
7,7	Travel route 4 (Transit at Östra Sjukhuset)
Median	5,6
Average	6,1


D. Appendix – Timetables

513 Skolvägen till Partille centrum				
MÅNDAG – FREDAG	LÖRDAG	SÖNDAG	HÅLLPLATSER	
00 20 50	00 20 50	00 20 50	0 Skolvägen	
01 20	01 20 50c	01 20 50b	1 Allévägen	
	02 20c 50c	02 20b 50b	2 Sävedalens folkets hus	
	03 20c	03 20b	3 Stora Ringvägen	
			4 Finngösa	
			7 Partille centrum	
05 19 49	05 50	05 50		
06 08 28 48	06 20 50	06 20 50		
07 08 28 48	07 20 50	07 20 50		
08 08 28 48	08 20 50	08 20 50		
09 09 29 49	09 20 50	09 20 50		
10 09 29 49	10 19 49	10 19 49		
11 09 29 49	11 19 49	11 19 49		
12 09 29 49	12 19 49	12 19 49		
13 09 29 49	13 19 49	13 19 49		
14 08 28 48	14 19 49	14 19 49		
15 08 18 28 38 48 58	15 19 49	15 19 49		
16 08 18 28 38 48 58	16 19 49	16 19 49		
17 08 18 28 38 49 59	17 19 49	17 19 49		
18 09 29 49	18 19 50	18 19 50		
19 19 49	19 20 50	19 20 50		
20 20 50	20 20 50	20 20 50		
21 20 50	21 20 50	21 20 50		
22 20 50	22 20 50	22 20 50		
23 20 50	23 20 50	23 20 50		
ANMÄRKNING		BRA ATT VETA		
<p>b Går inte 25 dec, 6 jan, 18 april, 26 maj och 6 juni.</p> <p>c Går inte 24 dec - 31 dec.</p>		<p>Tiderna är ungefärliga. Kundservice 0771 - 41 43 00. Gäller 12 dec 2021 - 10 dec 2022 utom 13 juni - 14 aug</p>		

1313A




Figure D.1 The timetable for bus line 513 from Skolvägen to Partille centrum.

513 Skolvägen till Heden				
MÅNDAG – FREDAG	LÖRDAG	SÖNDAG	HÅLLPLATSER	
00 05 35	00 05 35	00 05 35	0 Skolvägen	
01 05 35f	01 05 35bf 35c	01 05 35df 35e	1 Gibsons väg	
	02 05c 35c	02 05e 35e	2 Mellanvägen	
	03 05c 35cf	03 05e 35ef	4 Fräntorp	
			6 Torpamotet	
			9 Munkebacksmotet	
			12 Gustavsplatsen	
			16 Svingeln	
			20 Polhemsplatsen	
			22 Heden	
05 07 37	06 05 35	06 05 35		
06 07 27 47 57	07 05 35	07 05 35		
07 07 17 27 37 47 57	08 05 35	08 05 35		
08 07 17 27 37 47	09 05 35	09 05 35		
09 07 27 47	10 06 37	10 06 37		
10 07 27 47	11 07 37	11 07 37		
11 07 27 47	12 07 37	12 07 37		
12 07 27 47	13 07 37	13 07 37		
13 07 27 47	14 07 37	14 07 37		
14 07 27 47	15 07 37	15 07 37		
15 07 27 47	16 07 37	16 07 37		
16 07 27 47	17 07 37	17 07 37		
17 07 27 46	18 07 36	18 07 36		
18 07 26 46	19 05 35	19 05 35		
19 06 36	20 05 35	20 05 35		
20 05 35	21 05 35	21 05 35		
21 05 35	22 05 35	22 05 35		
22 05 35	23 05 35	23 05 35		
23 05 35				
ANMÄRKNING		BRA ATT VETA		
<p>b Går endast 24 dec - 31 dec.</p> <p>c Går inte 24 dec - 31 dec.</p> <p>d Går endast 25 dec, 6 jan, 18 april, 26 maj och 6 juni.</p> <p>e Går inte 25 dec, 6 jan, 18 april, 26 maj och 6 juni.</p> <p>f Slutar vid Svingeln.</p>		<p>Tiderna är ungefärliga. Kundservice 0771 - 41 43 00. Gäller 12 dec 2021 - 10 dec 2022 utom 13 juni - 14 aug</p>		

1313B



Figure D.2 The timetable for bus line 513 from Skolvägen to Heden.

514 Åsvägen till Partille centrum				
MÅNDAG – FREDAG	LÖRDAG	SÖNDAG	HÅLLPLATSER	
00 21	00 21	00 21	0 Åsvägen 1 Korsängen 3 Stora Ringvägen 4 Fingösa 7 Partille centrum	
05 50	06 21 51	06 21 51		
06 20 50	07 21 51	07 21 51		
07 20 50	08 21 51	08 21 51		
08 20 50	09 21 51	09 21 51		
09 20 50	10 20 50	10 20 50		
10 20 50	11 20 50	11 20 50		
11 20 50	12 20 50	12 20 50		
12 20 50	13 20 50	13 20 50		
13 20 50	14 20 50	14 20 50		
14 20 50	15 20 50	15 20 50		
15 20 50	16 20 50	16 20 50		
16 20 50	17 20 50	17 20 50		
17 20 50	18 21 51	18 21 51		
18 20 50	19 21 51	19 21 51		
19 20 51	20 21 51	20 21 51		
20 21 51	21 21 51	21 21 51		
21 21 51	22 21 51	22 21 51		
22 21 51	23 21 51	23 21 51		
23 21 51				

BRA ATT VETA
 Tiderna är ungefärliga.
 Kundenservice 0771 - 41 43 00.
 Gäller 12 dec 2021 - 10 dec 2022



13127 A 

Figure D.3 The timetable for bus line 514 from Åsvägen to Partille centrum.

514 Åsvägen till Östra Sjukhuset				
MÅNDAG – FREDAG	LÖRDAG	SÖNDAG	HÅLLPLATSER	
00 05	00 05	00 05	0 Åsvägen 2 Puketorp 4 Vallhamra torg 7 Björnåsvägen 8 Oxledsvägen 8 Soldatheden 9 Kvarnfallsvägen 11 Ljungkullen 13 Persplatsen 14 Backvägen 18 Östra Sjukhuset	
05 35	06 05 35	06 05 35		
06 05 35	07 05 35	07 05 35		
07 06 36	08 05 35	08 05 35		
08 06 36	09 05 35	09 05 35		
09 05 35	10 05 35	10 05 35		
10 05 35	11 05 35	11 05 35		
11 05 35	12 05 35	12 05 35		
12 05 35	13 05 35	13 05 35		
13 05 35	14 05 35	14 05 35		
14 06 36	15 05 35	15 05 35		
15 06 36	16 05 35	16 05 35		
16 06 36	17 05 35	17 05 35		
17 06 36	18 05 35	18 05 35		
18 05 35	19 05 35	19 05 35		
19 05 35	20 05 35	20 05 35		
20 05 35	21 05 35	21 05 35		
21 05 35	22 05 35	22 05 35		
22 05 35	23 05 35	23 05 35		
23 05 35				

BRA ATT VETA
 Tiderna är ungefärliga.
 Kundenservice 0771 - 41 43 00.
 Gäller 12 dec 2021 - 10 dec 2022


13127 B 

Figure D.4 The timetable for bus line 514 from Åsvägen to Östra Sjukhuset.



515 Frejaplan till Partille centrum				
MÅNDAG – FREDAG	LÖRDAG	SÖNDAG	HÅLLPLATSER	
00 04 49	00 04 49 01 49c 02 49c	00 04 49 01 49b 02 49b	0 Frejaplan 1 Magnusvägen 3 Stora Ringvägen 5 Fingösa 9 Partille centrum	
05 04 34 59 06 19 39 59 07 18 38 58 08 18 38 58 09 19 39 59 10 19 39 59 11 19 39 59 12 19 39 59 13 19 39 59 14 19 39 59 15 18 38 58 16 18 38 58 17 18 38 58 18 19 39 19 04 34 20 04 34 21 04 34 22 04 34 23 04 34	06 04 34 07 04 34 08 04 34 09 04 34 10 04 34 11 04 34 12 04 34 13 04 34 14 04 34 15 04 34 16 04 34 17 04 34 18 04 34 19 04 34 20 04 34 21 04 34 22 04 34 23 04 34	06 04 34 07 04 34 08 04 34 09 04 34 10 04 34 11 04 34 12 04 34 13 04 34 14 04 34 15 04 34 16 04 34 17 04 34 18 04 34 19 04 34 20 04 34 21 04 34 22 04 34 23 04 34		
ANMÄRKNING		BRA ATT VETA		
b Går inte 25 dec, 6 jan, 18 april, 26 maj och 6 juni. c Går inte 24 dec - 31 dec.		Tiderna är ungefärliga. Kundenservice 0771 - 41 43 00. Gäller 12 dec 2021 - 10 dec 2022 utom 13 juni - 14 aug		

Figure D.5 The timetable for bus line 515 from Frejaplan to Partille centrum.



515 Frejaplan till Gamlestads Torg Västra				
MÅNDAG – FREDAG	LÖRDAG	SÖNDAG	HÅLLPLATSER	
00 20b 01 05c	00 20b 01 05c 02 05cd 03 05cd	00 20b 01 05c 02 05ce 03 05ce	0 Frejaplan 1 Bockemossen 2 Broängsvägen 3 Vallhamra torg * Puketorp * Vallhamra torg 6 Backvägen 9 Östra Sjukhuset 13 Munkebäcksmotet 14 Gustavsplatsen 16 Kristinedal 18 Gamlestads Torg Västra	
04 50f 05 20f 50f 06 15f 36f 56f 07 16f 36f 56f 08 16f 36f 56f 09 16f 36f 56f 10 16f 36f 56f 11 16f 36f 56f 12 16f 36f 56f 13 16f 37f 57f 14 17f 37f 57f 15 17f 37f 57f 16 17f 37f 57f 17 17f 37f 57f 18 17f 36f 56f 19 21f 51f 20 21f 51f 21 20f 50f 22 20f 50f 23 20f 50f	05 50f 06 20f 50f 07 20f 50f 08 20f 50f 09 20f 50f 10 20f 50f 11 20f 50f 12 20f 50f 13 20f 50f 14 20f 50f 15 20f 50f 16 20f 50f 17 20f 50f 18 20f 50f 19 20f 50f 20 20f 50f 21 20f 50f 22 20f 50f 23 20f 50f	05 50f 06 20f 50f 07 20f 50f 08 20f 50f 09 20f 50f 10 20f 50f 11 20f 50f 12 20f 50f 13 20f 50f 14 20f 50f 15 20f 50f 16 20f 50f 17 20f 50f 18 20f 50f 19 20f 50f 20 20f 50f 21 20f 50f 22 20f 50f 23 20f 50f		
ANMÄRKNING		BRA ATT VETA		
b Slutar vid Östra Sjukhuset. Stannar inte vid hållplatserna Puketorp - Vallhamra torg. c Slutar vid Östra Sjukhuset. d Går inte 24 dec - 31 dec. e Går inte 25 dec, 6 jan, 18 april, 26 maj och 6 juni.		f Stannar inte vid hållplatserna Puketorp - Vallhamra torg. Tiderna är ungefärliga. Kundenservice 0771 - 41 43 00. * Restid kan inte anges. Gäller 12 dec 2021 - 10 dec 2022 utom 13 juni - 14 aug		

Figure D.6 The timetable for bus line 515 from Frejaplan to Gamlestads Torg.

E. Appendix – Operational profitability

```
file=open('/Users/alexandererlandsson/Desktop/0.csv','r')
x=file.readlines()

import json

def clean_row(data):
    json_object=""
    date=""
    index=1
    while(data[index]!="\n"):
        if (data[index]=="\r"):
            json_object=json_object+"\r"
        else:
            json_object=json_object+data[index]
        index=index+1
    index=index+2
    while(data[index]!="\n"):
        date=date+data[index]
        index=index+1
    return (json.loads(json_object), date)

(json_object, date)=clean_row(x[1])
level=0
for v in range(0,1604):
    battery_level = (json_object["vehicle_groups"][0]["vehicles"][v]["battery"])
    limit = 25
    if battery_level<limit:
        #print("equal or below 25 percent")
        print((json_object["vehicle_groups"][0]["vehicles"][v]["location"]))
    else:
        level=level+1
        #print("above")

print(level)
```

Figure E.1 *The Python code used to determine the numbers of depleted e-scooters (SOC < 25%) and their location. The code was applied for all CSV files, where the upper range had to be changed according to the total number of deployed e-scooters during the specific analysed time corresponding to the different files.*

Table E.1 The total amount of deployed e-scooters and the total amount of depleted e-scooters during the specific analysed time, as well as the average and median share of depleted e-scooters for all times.

CSV file	Total amount of deployed e-scooters	Total amount of depleted e-scooters (<25%)	Share of depleted e-scooters [%]
0	1604	94	5,86%
1	1565	85	5,43%
2	1528	90	5,89%
3	1538	84	5,46%
4	1548	77	4,97%
5	1520	70	4,61%
6	1590	76	4,78%
7	1571	74	4,71%
8	1568	70	4,46%
9	1544	74	4,79%
10	1527	69	4,52%
11	1520	64	4,21%
12	1512	67	4,43%
13	1507	70	4,64%
14	1499	72	4,80%
15	1525	79	5,18%
16	1534	80	5,22%
17	1602	80	4,99%
18	1633	73	4,47%
19	1682	76	4,52%
20	1703	76	4,46%
21	1656	76	4,59%
22	1611	76	4,72%
23	1578	73	4,63%
24	1529	77	5,04%
25	1521	81	5,33%
26	1533	83	5,41%
27	1537	79	5,14%

Average value	4,90%
Median value	4,79%

Table E.2 The calculation of the operating income in Sävedalen using a utilisation rate of 2,5%.

Utilisation rate [%]	2,50%
Hours per day	24
Utilisation hours	0,60
Utilisation minutes	36,00
Residential area	
Number of e-scooter parking spots	110
E-scooters per spot	3
Total amount of e-scooters	330
Income per day [SEK] excl. VAT	4 455,00 kr
Public transit stops	
Number of public transit stops	11
E-scooters per stop	10
E-scooters per stop (Östra Sjukhuset)	20
Total amount of e-scooters	130
Income per day [SEK] excl. VAT	1 755,00 kr
Retail and service properties	
Number of retail and service properties	6
E-scooters per property	5
Total amount of e-scooters	30
Income per day [SEK] excl. VAT	405,00 kr

Distance, speed, time and cost	
Average distance [km]	1,70
Kilometer price <15min [SEK/km] excl. VAT	1,50 kr
Average trip cost [SEK] excl. VAT	2,55 kr
Average trip time [min]	6,80
Average trip velocity [km/h]	15,00
Average trip distance [km]	1,70
Trips per day (using the utilisation rate of 2,5%)	5,29

Operating income	
Total operating income per day excl. VAT	6 615,00 kr
Total amount of e-scooters	490
Total operating income per day and e-scooter excl. VAT	13,50 kr

Table E.3 The calculation of the operating cost in Sävedalen using the same share of depleted e-scooters as in Gothenburg.

E-scooter model	Battery capacity [Wh]
E-scooter V5	1004,00
E-scooter V4	1004,00
E-scooter V3x	551,00
Average battery capacity of all e-scooter models [Wh]	853,00

Amount of e-scooters in Sävedalen	
Total amount of deployed e-scooters	490,00
The average share of depleted e-scooters (SOC<25%) in Gothenburg from 2020-11-07	4,90%
Total amount of depleted e-scooters (SOC<25%)	24,02

Distance, speed and time	
Average distance between two depleted e-scooters [m]	243,32
Total average distance driven to collect the depleted e-scooters [m]	5845,06
Average speed [km/h]	15,00
Average time between two depleted e-scooters [s]	118,40
Time required to collect all depleted e-scooters [hours]	0,79

Type of cost when charging the depleted e-scooters	Incl. VAT
Electricity price [SEK/kWh]	1,19 kr
Cost of charging per e-scooter [SEK]	1,01 kr
Total cost of charging all e-scooters per day [SEK]	24,32 kr
Type of cost when collecting the depleted e-scooters	Incl. VAT
Salary cost per hour [SEK]	120 (excl.VAT)
Total salary cost of collecting the depleted e-scooters [SEK]	124,59
Total cost of collecting the depleted e-scooters incl. fuel cost [SEK]	131,02
Fuel price [SEK/km]	1,10
Operating cost	Incl. VAT
Total operating cost	155,34 kr
Total operational cost per vehicle and day	0,32 kr

Table E.4 Example of the calculation of the distance between the depleted e-scooters in Sävedalen.

Lon		11,9845 7717895 50	11,9457 3783874 51	12,0032 1578979 49	11,9647 9797363 28	11,9837 1219635 00
	Lat	57,6990 0512695 31	57,7120 1705932 61	57,7118 0725097 65	57,7107 5057983 39	57,7126 0452270 50
11,9845 7717895 50	57,6990 0512695 31	0,00	2,72	1,80	1,76	1,51
11,9457 3783874 51	57,7120 1705932 61	2,72	0,00	3,41	1,14	2,26
12,0032 1578979 49	57,7118 0725097 65	1,80	3,41	0,00	2,28	1,16
11,9647 9797363 28	57,7107 5057983 39	1,76	1,14	2,28	0,00	1,14
11,9837 1219635 00	57,7126 0452270 50	1,51	2,26	1,16	1,14	0,00

DEPARTMENT OF ARCHITECTURE AND
CIVIL ENGINEERING
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2022
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