



Project ELKOLL

Results for the comparison between e-scooter trips and their public transport and walking equivalent in the city of Gothenburg

Executive summary

This project examined shared e-scooter trips provided by the operator Voi and used a trip planner to determine the potential alternatives if users had chosen to walk or utilise public transportation (PT) instead.

The analysis reveals that Voi trips are typically brief, with 71% lasting less than 10 minutes, usually covering 1-2 kilometres, and mostly occurring within central Gothenburg. The trip planner indicated that walking would be the best alternative for roughly half of the trips, while public transportation would be the main alternative for the other half.

For the trips for which the trip planner suggested walking as the best alternative, 81% of them are less than 1 km long, meaning they could be alternatively covered by walking 15 minutes or less. Nonetheless, 89% of trips are faster with Voi, and 72% of them begin or end within 100 metres of a public transport stop, which strongly implies intermodal behaviour among e-scooter users and the use of e-scooters as a first/last mile solution; however, further research is necessary to support this statement.

Regarding the trips for which the trip planner suggested PT with no transfers, half of the users would have had to walk 500 m or more to access and egress PT and 80% of them started or ended within 100 m of a public transport stop, which can suggest users choosing Voi to replace a leg of their trips; or even the complete trip, considering that roughly half of these trips would have been theoretically cheaper with Voi instead of PT. Nonetheless, once again, more research is needed to support these hypotheses.

Generally, shared e-scooters hold the potential to complement public transportation services in densely populated urban areas, a notion supported by this study and prior academic and grey research. Even in the absence of parking regulations, users tend to initiate or conclude their trips near public transport stops, which can serve as a valuable guideline for developing parking policy.

In conclusion, shared e-scooters represent an important aspect of urban transportation that should not be overlooked. It is crucial to engage both existing and potential e-scooter operators in transportation planning to foster collaboration with municipalities, PT agencies and local communities. This collaborative effort should aim to promote multimodality, integrated ticketing solutions, and user-centric approaches that encourage a shift away from less sustainable transportation modes.



1. Introduction

Shared e-scooter services have been around in Europe since 2018, and have received a lot of criticism, being viewed as a safety hazard, obstructing sidewalks and being a general nuisance. At the same time, they do seem to be an attractive option for a lot of travellers as they are frequently used.

Due to their novelty, there's still a limited understanding of how e-scooters are used and research aimed at understanding e-scooter travel behaviour is still in its infancy. Most previous research revolves around surveys of users. The previous research have mixed results and it seems that e-scooter use is dependent on context, where some researchers have found that e-scooter are replacing car use, while others are finding that walking, cycling or public transport are being replaced [13]. However, surveys rely on people giving proper answers to questions and that the sample is representative, which may not be the case.

Therefore, in this study, we analyse the use of e-scooters in Gothenburg by looking into anonymised operator trip data, and showcasing what the alternative trip would have been had the person not used e-scooters. Using a trip planner, we analyse the corresponding trip to the e-scooter ride, exploring both public transport and walking alternatives. In short, we aim to answer if e-scooters are replacing or complementing public transport or walking trips.

In the coming sections, a methodology explaining the process and assuring traceability and repeatability is showcased. Then, a results and analysis section includes the explanation of the applied methodology. Finally, in the discussion and conclusion section, we give our perspectives on further research and recommendations for policy in this topic moving forward.

This project was funded by and carried out in partnership with Västtrafik and Voi.

2. Methodology

In order to find alternatives to the completed e-scooter trips, OpenTripPlanner (OTP) was used. OTP works similarly like trip planners such as Google Maps or Apple Maps and presents possible trips for a requested start point, end point and time for all modes of transport. In this instance, OTP was requested to find the best possible alternative for each e-scooter trip, with walking and public transport as the alternatives. The swiftest alternative for every e-scooter trip was chosen, and the findings are detailed in the subsequent section.

This section documents the steps involved in collecting and preparing the public transport and raw e-scooter data for its eventual analysis. The subsections include: (1.) the setup of Open Trip Planner, (2) the preparation of e-scooter data for querying (3) response analysis and results formulation.

The diagram below describes, at a high-level, the methodology of this project by illustrating the data dependencies, flow, and processing segments. As the legend indicates, the blue diagrammatic elements denote input/output files, and process blocks involved in the setup

and configuration of the querying process. Green elements denote the instances at which data is analysed and included in the interpretation of results.

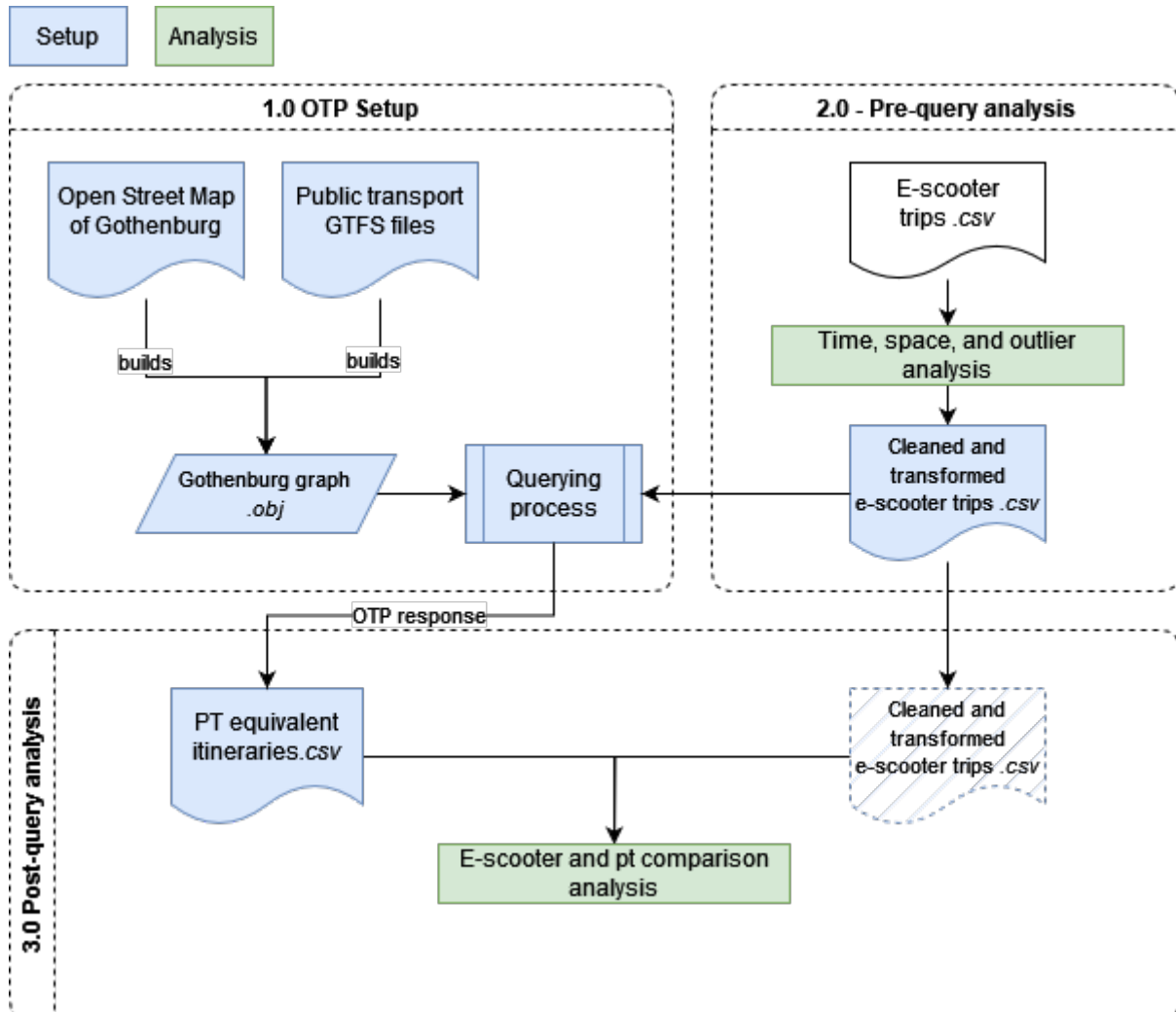


Figure 1 diagram of data dependencies, flow, and overarching methodology

- (1) **The setup of Open Trip Planner** subsection details the acquisition of GTFSs (General Transit Feed Specification) and Gothenburg's road network and their necessary conversions to initiate a locally-hosted OTP instance.
- (2) **The preparation of e-scooter data** subsection details the processes involved in handling the raw data: including, inter alia, removing outliers and data points deemed irrelevant, and reshaping necessary fields to ensure compatibility with OTP.
- (3) **The response analysis and results formulation** subsection details the steps involved in breaking-down the public-transport response data (from OTP) and drawing meaningful analysis and comparisons to the e-scooter trips.



2.1. Open Trip Planner setup

To find a rider's best (i.e., lowest generalised cost) public transport alternative, the origin and destination coordinates and the timestamp of their e-scooter trip were used as input to query a trip planner that returns a list of possible itineraries that could be completed solely by foot and/or public transport. Open Trip Planner (OTP) is open-source software project that provides passenger information and transportation network analysis services [1].

OTP's underlying network (referred to as a '*graph*') was constructed by combining an Open Street Map (OSM) network of Gothenburg with Västtrafik's public transport offering. Västtrafik's routes, schedules, and transport modes were extracted from GTFS files (General Transit Feed Specification) publicly downloadable from TrafikLab [2]. Since Västtrafik's regular schedule differs from the summer one, separate GTFS files representing each schedule were used. The KoDa API [3] in specific was deployed given the need for specific GTFS time frames. The schedule differentiation is important for a valid comparison to be drawn between an e-scooter trip and a potential public-transport equivalent. I.e., it is aimed to evaluate the public transport options at the time an e-scooter was taken at a reasonably sufficient level of fidelity. Details on the necessary data transformation are given in section below.

Given the large geographical coverage, network data was downloaded as a *.osm* file for the entirety of Sweden from *Geofabrik.de* [4] and then clipped using *Osmium* [5] to a rectangle with bounding coordinates covering only central Gothenburg. The reduced *.osm* file was then converted to *.pbf* (the required format for OTP) using *Osmconvert* [6].

For the setup and configuration of OTP V2, reference was continually made to the manual published by Open Trip Planner [7] and an instructional case-study in the city of Manchester [8], as well as to the public GitHub repository [9] of Cats et. al 2022 case-study (comparing ride-hailing and public transport [10]) for Python scripts to batch-query a locally hosted OTP server.

2.2. Pre-querying stage: data cleaning and transformation

With the central Gothenburg area defined, Voi trips with a point of origin or destination outside of the zone were removed. As mentioned in the section above, separate GTFS files were used to build separate 'regular' and 'summer' (schedule) *graphs*. Västtrafik's 2022 summer schedule ran from the 19th of June until the 20th of August, therefore all Voi trips outside this time bracket were implicitly 'regular' trips and queried separately. While there are individual differences for public transit schedules on a week-to-week basis, Västtrafik informed us that these changes were generally minor and would not impact overall results.

To ensure certainty that the start-date of an e-scooter trip is within the respective GTFS file, the start-date of each trip was changed to a date known to be in the schedule. The original weekday was retained, i.e., a trip on Monday in August would have been changed to the 'Monday equivalent' for the GTFS file's known date. The start-time of the e-scooter trips remained unaltered. The original e-scooter start-dates could still be accessed for analysis since their unique ID was retained. Full documentation on the data handling procedure, setup, and querying configuration can be found in the public GitHub repository of this project [11].



2.3. Post querying: results segmentation

Two main classifications were considered for clustering the data in this analysis: time of the week and time of the day. The first classification resulted in two clusters: "Weekdays," which included trips from Monday to Friday, and "Weekends," which included trips from Saturday to Sunday. The second classification resulted in three clusters: "Morning rush hour," which included trips from 6 a.m. to 9 a.m., "Daytime and evening," which included trips from 9 a.m. to 9 p.m., and "Late night and early morning," which included trips from 9 p.m. to 6 a.m.

Initially, the "daytime and evening" cluster was divided into three sub-clusters: "Morning off-peak" with trips between 9 a.m. and 3 p.m., "Evening rush hour" with trips between 3 p.m. and 6 p.m., and "Evening off-peak" with trips from 6 p.m. to 9 p.m. However, these trips did not show significant differences in the descriptive statistical analysis, so they were merged to increase simplicity.

The data analytics process was divided into four stages: Voi's descriptive analytics, Västtrafik-equivalent descriptive analytics, Voi-Västtrafik comparison, and descriptive geospatial analytics.

In the first stage, Voi's descriptive analytics, trips were analysed considering four main variables:

- **E-Scooter Total Travel Time (TTT_{ES})**: This is the time difference between the start and end times of the e-scooter trip, as recorded in the original dataset.
- **Theoretical Flying Distance**: This is the distance between the origin and destination coordinates of the e-scooter trip, measured in a straight line.
- **Theoretical Flying Speed**: This is the theoretical speed at which the e-scooter would travel if it could move in a straight line between the origin and destination points. It was calculated by dividing the Theoretical Flying Distance by the e-Scooter Total Travel Time.
- **Walking Equivalent**: This is the distance of the equivalent walking trip between the origin and destination coordinates from querying in OTP for walking. It represents the distance that a pedestrian would need to cover to travel between the same two points.

Four additional clusters were identified from the types of trips that resulted from the querying:

- **Unsuccessful trips**: These are trips for which OTP did not return any suitable trip option.
- **Walking trips**: These are trips for which OTP suggested walking as the most suitable alternative instead of a PT option, this was found to be common for short trips starting or ending in PT intensive areas or areas with high trip demands like universities.
- **PT trips without transfers**: These are trips for which the most suitable option is to use public transport without any transfers, this was found to be common for medium-length trips starting and ending in the centre and PT intensive areas.



- PT trips with transfers: These are trips for which the most suitable option is to use public transport with one or two transfers, this was found to be common for long trips starting or ending in a more disaggregated way throughout the city.

Trips with theoretical flying speeds above 20 km/h and/or theoretical flying distances less than 100 m were queried in Open Trip Planner (OTP) to return public transport (PT) or walking equivalents for the analysis of descriptive PT variables. Nonetheless, these trips were removed for the following stages.

In the second stage, Västtrafik-equivalent descriptive analytics, up to five different variables were analysed for each type of trip, depending on the trip type:

- PT Total Travel Time (TTT_{PT}): The time difference between the start and ending times of the Public Transport trip or walking equivalent provided by the querying in OTP.
- PT Initial Waiting Time (IWT): The time difference between the start time of the trip and the time when the suitable PT option arrives.
- Walking Distance to PT: The length that the user would have to walk from origin and destination to the suitable PT points.
- Transfer Time (TT): The time users would have to wait at the transfer point(s) for their connection provided by the querying in OTP.
- Walking Equivalent: This is the distance of the equivalent walking trip between the origin and destination coordinates from querying in OTP for walking. It represents the distance that a pedestrian would need to cover to travel between the same two points.

In the third stage, Voi-Västtrafik comparison, three new variables were created to compare the public transport or walking equivalents to the original trips, and trips were analysed depending on the trip type:

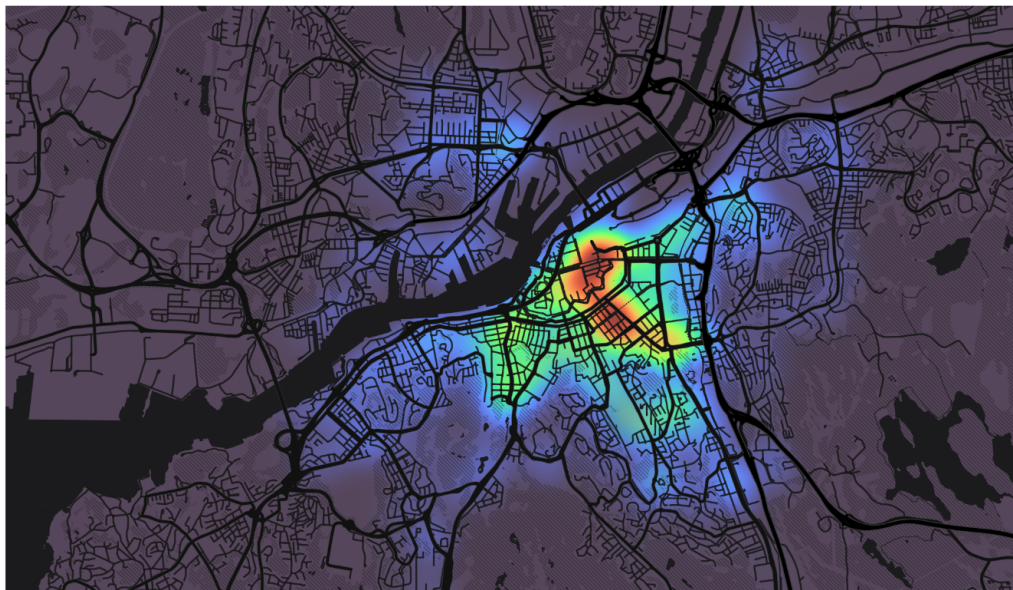
- Travel time difference: This variable measures the time difference between TTT_{ES} and TTT_{PT} , showing how much time users saved by choosing Voi instead of Public Transport or walking. A negative value represents time saved with Voi, while a positive value means that using Public Transport or walking would have been faster.
- Trip cost difference: This variable calculates the theoretical cost difference between Voi and Public Transport, assuming that users pay nothing for walking, 35 SEK for Public Transport, and 10 SEK + 3 SEK/min (rounded up to the next minute) for Voi. This variable aims to explain how much money users saved by choosing Voi instead of Public Transport. A negative value represents a cost saving with Voi, while a positive value means that using Public Transport or walking would have been cheaper.
- Distance to public transport: This variable measures the distance from the closest Public Transport point to a trip's origin or destination. It shows how close the start or end points of a trip are to the Public Transport stops in the corresponding GTFS file. The relevance of this variable was assessed by analysing buffer areas of 100 m around every Public Transport point.

Finally, in the descriptive geospatial analytics stage, buffer maps were used to analyse the coverage of Västtrafik's points, and heat maps were used to analyse the origins and destinations of different combinations of trip types with the clusters established based on time of day and week.

3. Results and analysis

3.1. General description of raw e-scooter data

The original dataset from Voi consisted of 1.040.631 trips that occurred between January 1st and November 11th, 2022. It included coordinates and start and end times for each trip. Before querying the data, trips outside of the central Gothenburg area were removed.



E-scooter points of origin and destination in Gothenburg, Sweden
1st January 2022 - 11th November 2022

ITRL - KTH

Figure 2 heatmap illustrating all e-scooter points of origin and/or destination in the central Gothenburg area.

There was little to no difference in the geographic distributions between the points of origin and destinations, nor between the trips in the summer and regular seasons. It is evident that trips occur either into the city-centre or out of it: from the intersection of Örgrytevägen, Korsgatan, and Skånegatan, along Södra Vägen and Gamla Allén, and spread across Gothenburg core, Inom Vallgraven.

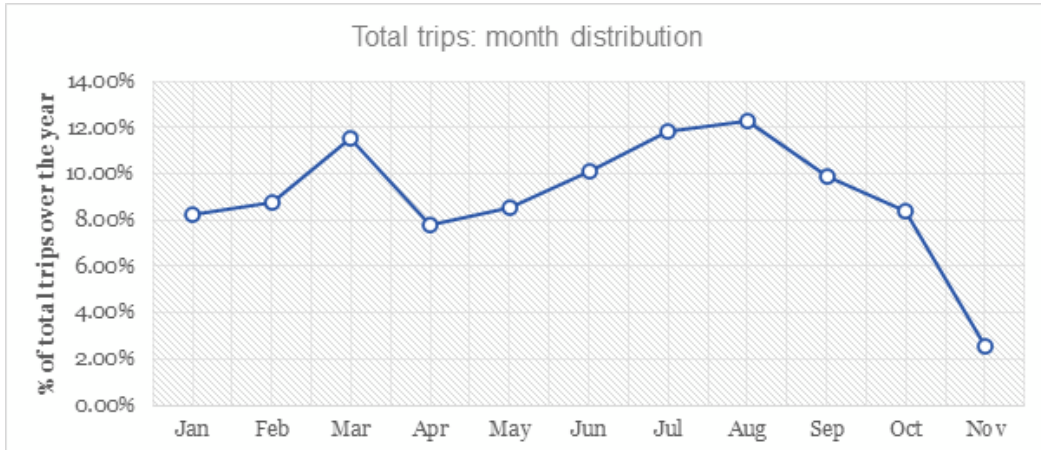


Figure 3 monthly count (% of total) e-scooter trips provided by Voi. The first trip was on 1st January 2022, and the last on 11th November 2022

In April 2022, the COVID-19 restrictions on public transport were lifted and operations were resumed. It is also worth mentioning that from April, a fleet cap was introduced in the city, meaning that Voi’s fleet was reduced and therefore the availability of the service, which could explain the drop that month and the subsequent ones. Aside from this, it is evident that more trips were carried out as the months crept towards the summer season bearing progressively warmer weather. Ridership declined as the regular season advanced and settled in: ~2% between August and September and a further ~2% between September and October.

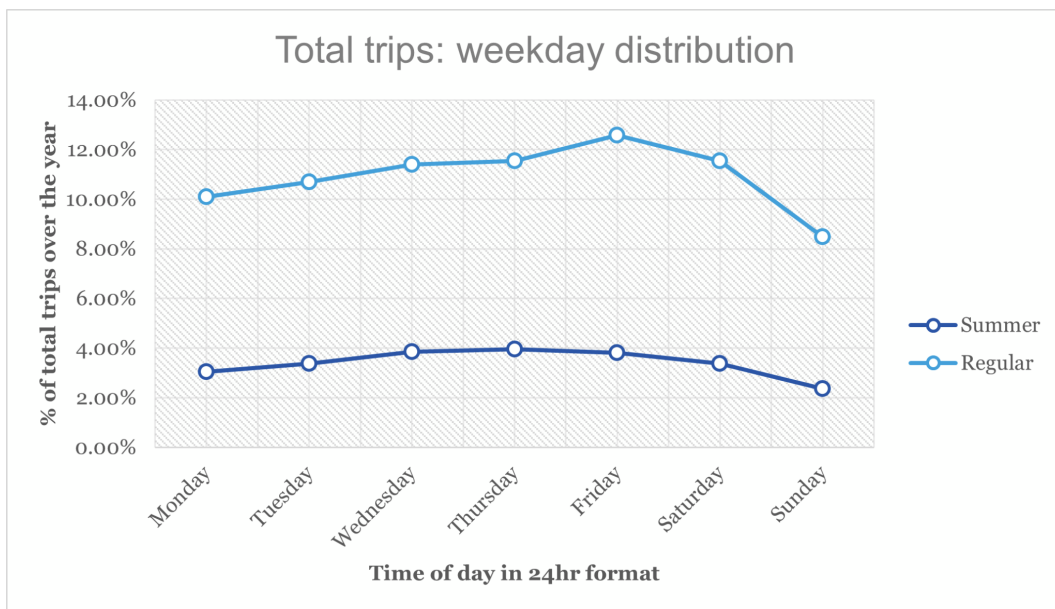


Figure 4 weekday distribution (as % of total) of e-scooter trips. Summer represents trips from the 19th of June-20th of August

It is evident that trips do increase by a slight incremental margin as the weekdays progress and decrease marginally in the weekend. Fridays in regular trips were marginally (~1% less

than seasonal mean) more common, and Sundays in summer trips marginally (~1% less than seasonal mean) less common.

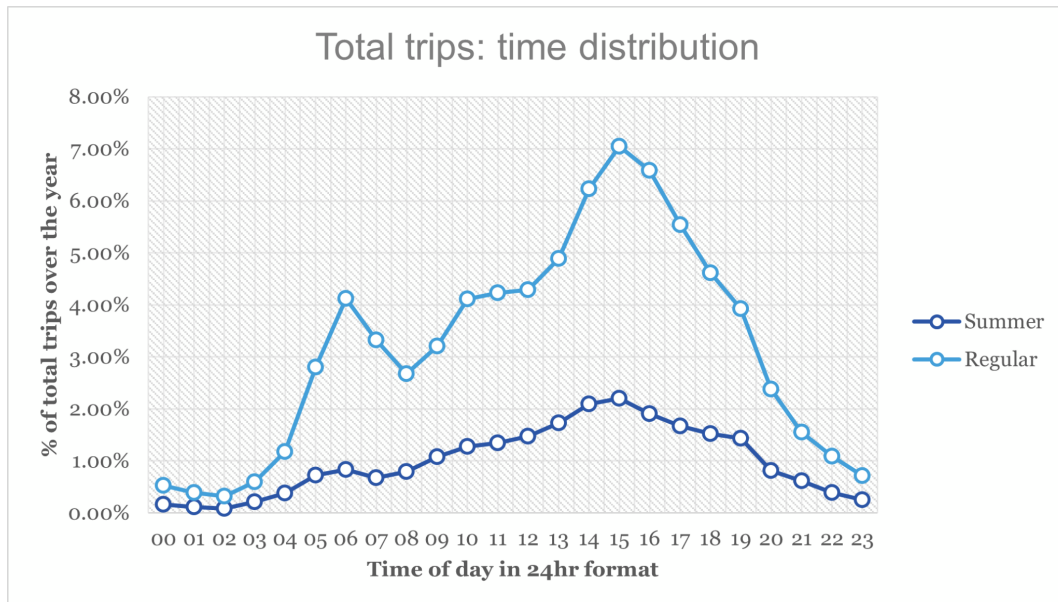


Figure 5 count of e-scooter trips (as % of total) distributed across the time of day. Duly note that a directive enacted in early 2022 made the usage of e-scooters illegal on Friday and Saturday evenings. Summer represents trips from the 19th of June-20th of August.

Both lines – although the regular one more evident – almost resemble a typical public-transport distribution of increased activity at peak-commuting hours, albeit substantially smaller for the morning peak. It is evident that trips increase as the day progresses, peaking at around 15:00 (3 pm) in both summer and regular.

3.2. E-scooter descriptive analytics

After querying, unrealistically short and fast trips were cleaned. After this, the remaining dataset comprised 1.009.407 trips. The results from the first stage of Voi's descriptive analytics are based on this cleansed dataset.

After the querying process, it was found that 97.968 (9,4%) of the responses were unsuccessful (i.e. failed to return a travel itinerary (PT or otherwise) due to a technical error which could not be found). Out of the successful trips, 436.239 (41,9%) returned walking itineraries in the OTP, 458.805 (44,1%) returned PT trips without transfers, and 16.395 (1,6%) trips required transfers. Among these trips with transfers, only 106 (0,01%) of the trips required two transfers, while the rest only needed one transfer. None of the trips required more than two transfers.

For the Västtrafik-equivalent descriptive analytics, Voi-Västtrafik comparison, and descriptive geospatial analytics, only the 911.439 trips corresponding to walking, PT without transfers, and PT with transfers equivalents were considered. The unsuccessful trips were excluded from these analyses.

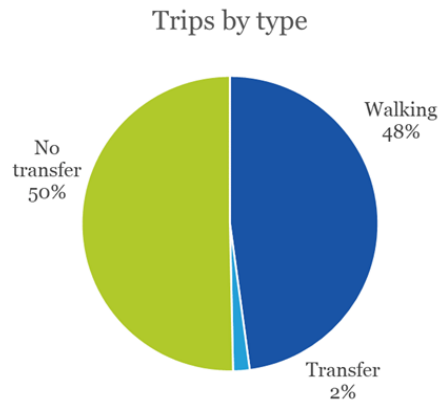


Figure 6 Trips by type

For the purpose of these analyses, only two statistical measurements will be considered: the mean and the median. The mean represents the average value of a variable for a particular set of data, while the median is the value at which the data is divided into two equal parts. It's important to note that these two measures are not interchangeable and have different meanings.

For example, if we say that the mean Total Travel Time for e-scooters (TTT_{ES}) for all trips is 8,98 minutes, it means that the average value of this variable is 8,98 minutes. On the other hand, if we say that the median of TTT_{ES} is 6,48 minutes, it means that half of all trips are shorter than 6,48 minutes, while the other half are longer.

When the median value of a variable is lower than the mean value, it suggests that most of the trips have values that are lower than the average. Conversely, if the median value is higher than the mean value, it suggests that most of the trips have values that are higher than the average. Using our previous example, we can conclude that the majority of the trips are shorter than the average duration of 8,98 minutes. For this analysis, the time-wise clusters include trips as follows:

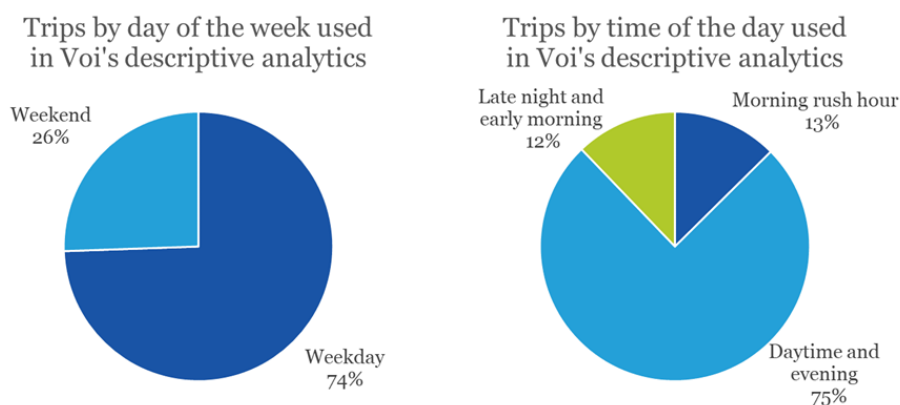


Figure 7 Trips by day of the week and time of the day

The conclusions from these pie charts are the same as the ones previously mentioned in the “General description of raw e-scooter data” section. When looking into Voi’s data, the most prominent variable is the e-scooter travel time:

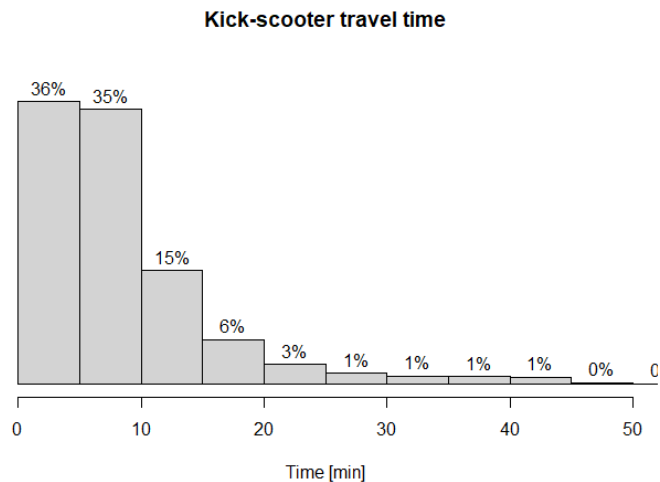


Figure 8 E-scooter travel time

The majority of Voi trips in Gothenburg, 71% for all trips are 10 minutes or less, ranging from 67-77% depending on the time cluster being analysed. For comparison, the maximum speed of a shared e-scooter is 20 km/h meaning that a ten-minute trip can roughly be translated to 2 km in distance. Morning rush hour has the highest percentage of short trips, with 77% of trips being 10 minutes or less, followed by late-night and early-morning trips at 75%. Weekend trips, on average, are slightly longer, with a difference of 1.5 minutes compared to weekday trips.

3.3. Västtrafik-equivalent descriptive analytics

For these analyses, the time-wise clusters include trips as follows:

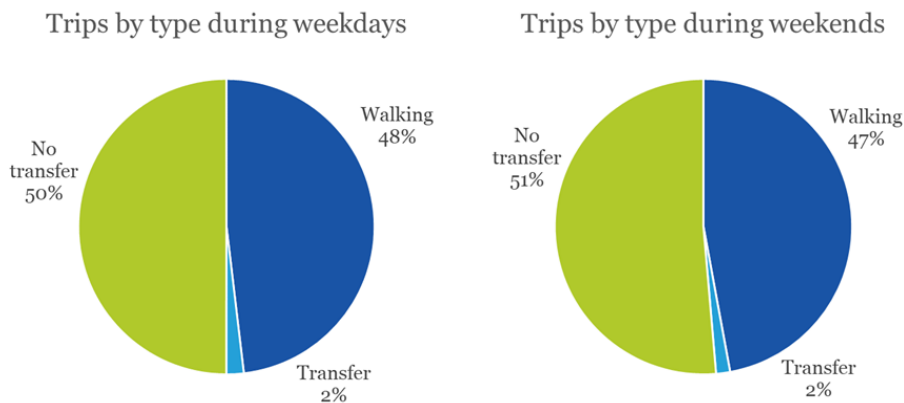


Figure 9 Most suitable alternatives from OTP by day of the week

Based on these findings, it can be concluded that the proportion of trip types replaced by Voi does not significantly differ between weekdays and weekends. Most of these trips replace PT

trips without transfers that could also be made using public transportation, while only a small number of trips replaced involve transfers between different modes of public transport.

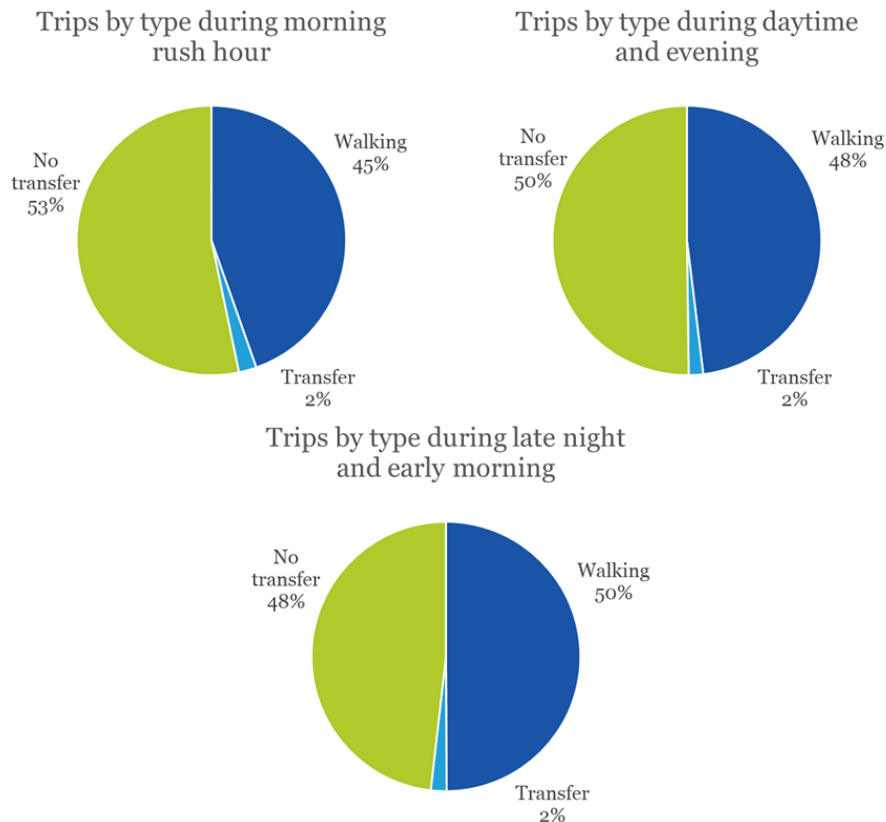


Figure 10 Most suitable alternatives from OTP by time of the day

Several conclusions can be drawn from these results. Firstly, during morning rush hour, Voi trips tend to replace a slightly higher proportion of public transport trips without transfers, while during late night and early morning, the share of Voi trips replacing walking trips increases. Furthermore, as previously mentioned, there is only a small percentage of Voi trips that replace public transport alternatives involving transfers, and this proportion remains consistent throughout different times of the day and days of the week.

For this analysis, all Voi trips in Gothenburg were initially examined together and then categorised into three clusters based on trip type: walking, PT without transfers, and PT with transfers.

3.3.1. Trips with walking as the suggested alternative

When it comes to walking trips, the most interesting variable is the distance. The following graph showcases the walking distance equivalent of the trips for which OTP suggests walking as the fastest option. This distance is the length that users would have had to walk if e-scooters were not an option:

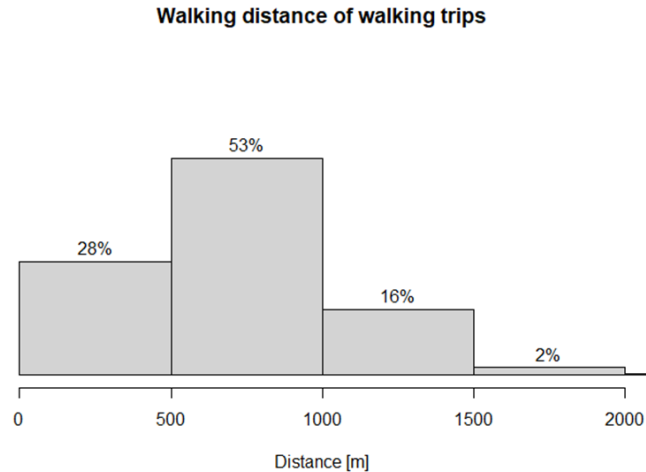


Figure 11 Walking distance equivalent of trips with walking as the suggested alternative

Upon analysing the table and histograms, several conclusions and insights can be drawn regarding these trips. Notably, the PT Total Travel Time and Walking Equivalent variables are directly linked through an established walking speed set in OTP, which makes individual analyses of such variables redundant.

It can be observed that between 73-84% of the trips for which OTP suggest walking as the most suitable alternative are replacing trips that could have been completed by walking 1 km or less, depending on the time cluster analysed. Assuming a walking speed of 4 km/h, these trips could be completed in under 15 minutes. This equates to a two-fold share when compared to the complete dataset, indicating that trips replacing walking are twice as likely to be shorter than 1 km than the other trips.

The weekends cluster has the highest percentage of short trips, with 41% of all trips falling within this category. Trips during weekends and daytime/evening periods also have a high proportion of short trips, with 84%, and 83%, respectively. For both these clusters, trips shorter than 500 m walking constitute 31%, and 29%, respectively, which is the highest of all clusters.

Conversely, trips during the late night and early morning periods that are less than 1 km long account for 73% of all trips, making this cluster the one with the longest trips. On average, trips during this period are 127 m longer than the other trips, which may be attributed to poorer spatial coverage of Västtrafik services during night time.

3.3.2. Trips with PT without transfers as the suggested alternative

When analysing PT trips without transfers, an interesting variable is the Initial Waiting Time:

Initial Waiting Time for Public Transport with no transfers

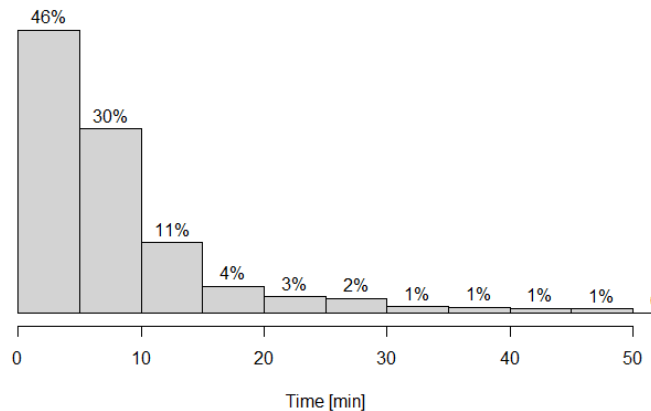


Figure 12 Initial Waiting Time of trips with Public Transport without transfers as the suggested alternative

Most PT trips without transfer, 76% have an Initial Waiting Time (IWT) of 10 minutes or less, ranging from 50-80% depending on the time cluster being analysed. The cluster with the highest initial waiting time is the late night and early morning period, where only 50% of trips have an initial waiting time of 10 minutes or less. This can be explained by poorer time coverage of Västtrafik services during this period. Additionally, the initial waiting time during weekends is slightly longer than weekdays, which can also be attributed to the time coverage difference between the two types of days.

Nonetheless, this is a good sign of Västtrafik’s network design when it comes to time coverage in the city centre of Gothenburg. Nonetheless, this design has to be contrasted with the real life punctuality of the service, which is out of the scope of this report.

Walking Distance for Public Transport with no transfers

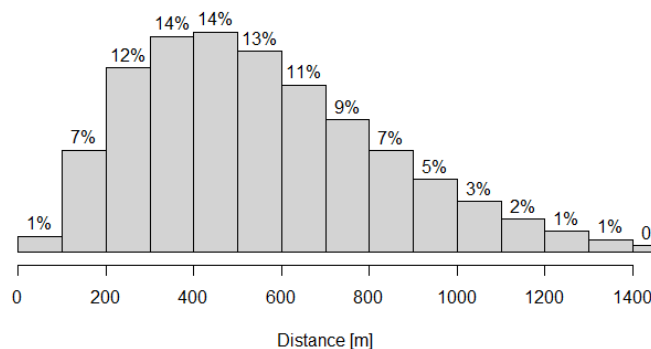


Figure 13 Access and egress distance to PT of trips with PT without transfers as the suggested alternative



Another interesting variable is the walking distance to Public Transport. This variable shows no significant variability regardless of the cluster analysed. Typically, users would have to walk around 500-600 meters as part of their PT journey. This distance is the distance that users would have had to walk from their origin to the PT trip starting point plus to the distance from the PT ending point to their destination.

When it comes to the distance that users would have had to walk if they would have chosen PT instead of Voi, half of the users would have had to walk more than 500 m to access and egress the service. This is a sign that for these specific journeys, the PT alternative was quite poor and e-scooters provided an alternative that likely complemented PT.

3.3.3. Trips with PT with transfers as the suggested alternative

Even though PT trips with transfers only account for 2% of the total dataset, it is interesting to look into the Transfer Time variable:

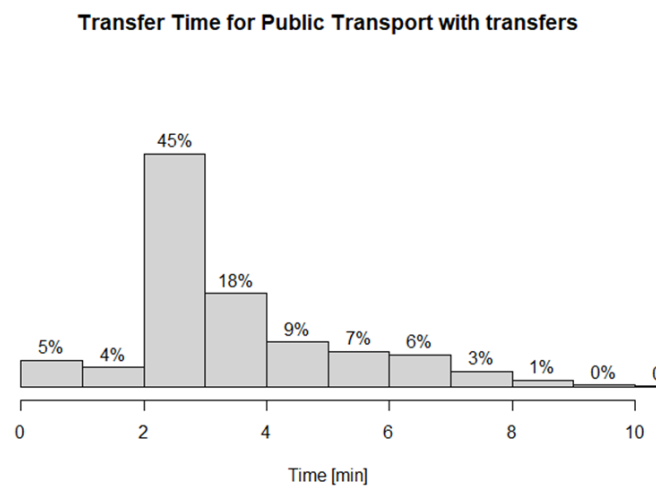


Figure 13 Transfer Time of trips with PT with transfers as the suggested alternative

Most PT trips with transfers, 81%, have transfer times of 5 minutes or less, ranging from 63-83% depending on the time cluster being analysed. Late night and early morning trips have the highest transfer time, with only 63% of trips having transfer times of less than 5 minutes, likely due to poorer time coverage of Västtrafik services during these hours. The second highest transfer time is during morning rush hours, with 80%. Transfer times during weekends are slightly longer than on weekdays, which can also be explained by time coverage differences.

Nonetheless, this is a good sign of Västtrafik's network design when it comes to time and space coverage in the city centre of Gothenburg. Nonetheless, this design has to be contrasted with the real-life punctuality of the service, which is out of the scope of this report.

3.4. Voi-Västtrafik comparison

In general, over 90% of the trips save time by choosing Voi instead of the Public Transport alternative. The extent of these savings is greater for longer trips, especially for PT trips with transfers.

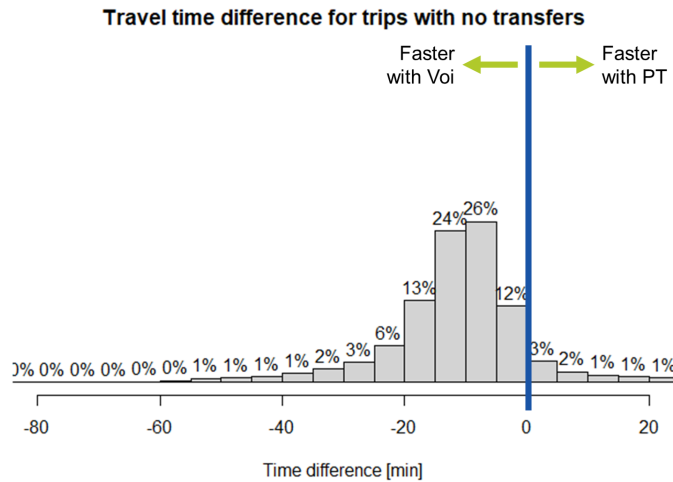


Figure 13 Travel time comparison of Voi vs. PT for trips with PT without transfers as the suggested alternative

Nonetheless, those times in saving come at a monetary cost for the users. When it comes to PT trips without transfers, there is an equal split between users who save money by choosing Voi over PT, and those who would have saved money if they chose PT.

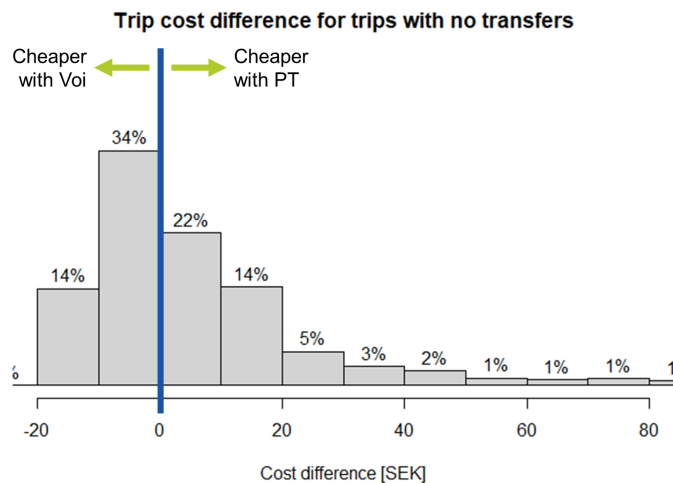


Figure 14 Trip cost comparison of Voi vs. PT for trips with PT without transfers as the suggested alternative

Further analysis shows that for walking trips, the majority (between 74-81%) save less than 10 minutes by choosing Voi over walking. This is in line with the analysis of the walking equivalent variable for walking trips performed previously. For walking trips, the cost differences are higher since walking is free. However, the convenience and time savings with

Voi may explain the modal choice. Nonetheless, further recommendations will be provided in this report to support these findings.

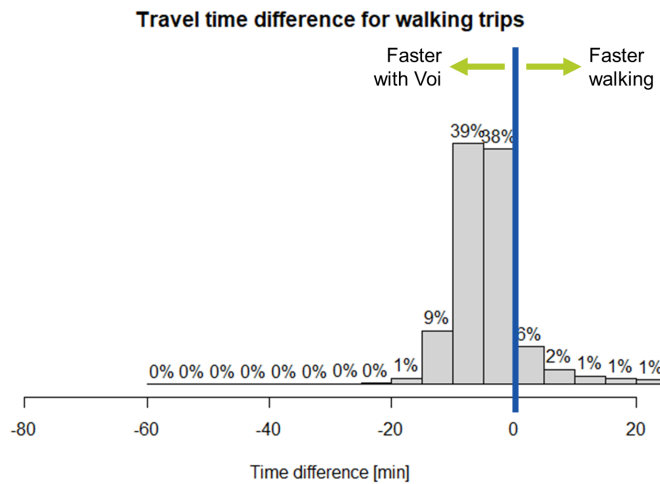


Figure 15 Travel time comparison of Voi vs. walking for trips with walking as the suggested alternative

The most interesting variable here, is the distance to a public transport stop from the closest origin or destination:

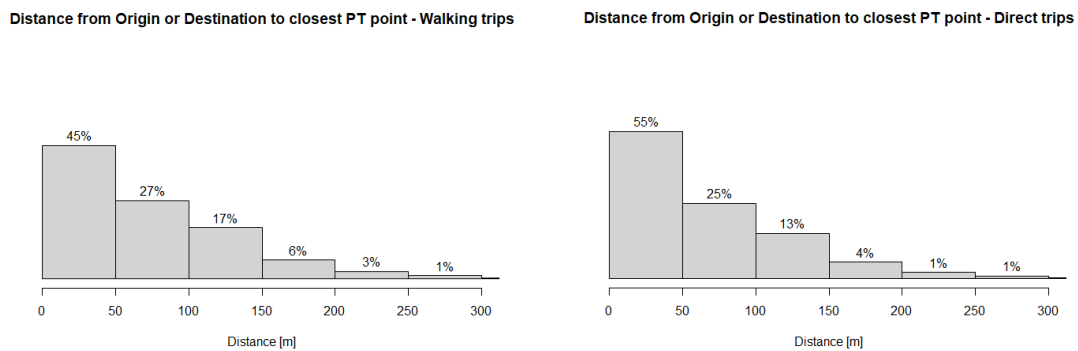


Figure 16 Distance from origin or destination to closest PT point for trips with walking and PT without transfers as the suggested alternatives

For walking trips, it can be observed that a majority of the trips, 72% either start or end within 100 meters of a Public Transport stop, ranging between 71-82%, depending on the cluster analysed. This highlights the potential use of Voi as a first or last mile solution to access public transport in the city centre.

For PT trips without transfer, this number is even higher, reaching 80% for trips that either start or end within 100 meters of a Public Transport stop. Even a big chunk of 55% of trips either start or end within 50 metres of a Public Transport stop. This strongly suggests that Voi users use the service to complement their trips.

It is important to note that during the analysed period, e-scooters operated in a completely free-floating scheme in Gothenburg, allowing users to park the scooters wherever they want within the operational area of Voi, with few exceptions of no-parking zones. This variable may not hold as much relevance in cities where scooters must be parked in established parking stations, especially if such stations are located in proximity to public transport stops, unlike in Gothenburg.

3.5. Descriptive geospatial analytics

This analysis consisted of two parts: a buffer analysis of Västtrafik stops and an analysis of heat maps for origins and destinations of Voi's trips. For the buffer analysis, a 100-meter radius was added to all Västtrafik stops within the Voi operational area. This buffer corresponds to an average walking time of one minute. It should be noted that Västtrafik stops and Voi's operational areas change slightly from summer to regular, but the differences are generally small. This analysis validates the relevance of the distance to the Public Transport variable.

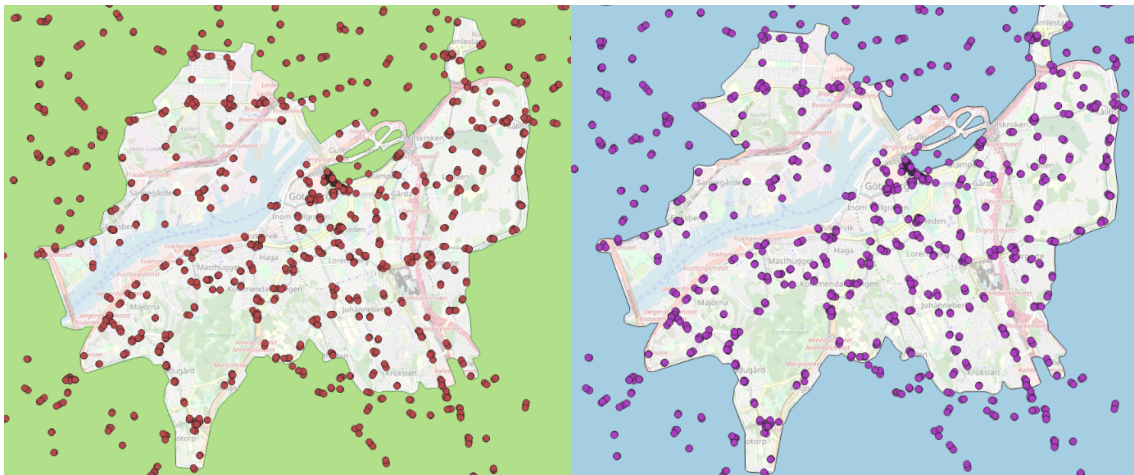


Figure 17 Public Transport points with a 100-metres buffer zone compared to Voi's operational area for summer and regular schedules

On the other hand, to analyse heat maps for the origins and destinations of Voi's trips, the locations of each cluster were represented with colour gradients indicating the intensity of trip origins or destinations within each area. In the map, each point represents a 10-meter radius. Areas with higher densities are shown with warmer colours, such as red or orange, while areas with lower densities are represented by cooler colours, such as blue or green.

As previously mentioned, the "daytime and evening" cluster was initially divided into three subgroups: "Morning off-peak", "Evening rush hour", and "Evening off-peak". However, geospatial analysis revealed differences in the trips, and therefore these subgroups were considered separately in this section.



Overall, the heat points for walking and PT trips without transfers were primarily located at Göteborg C and Valand for all origins and destinations, regardless of the time of day or week.

However, some specific heat points were found, such as Chalmers University being a strong destination for walking trips during morning rush hours and Göteborg University being a strong origin for walking trips during the same time period. Järntorget became a stronger heat point during late night and early morning for all trip types, while Kornsvägen became relevant during weekends.

For PT trips with transfers, the data was more disaggregated due to the lower number of trips, but some interesting heat points were still found, such as Linneplatsen being a popular location on weekdays, Östra kyrkogården being a popular origin on weekends, and Chalmers University being a popular destination during weekends. Additionally, Gårdatorget was found to be a popular destination during morning rush hours and late night and early morning.



4. Limitations

Scope of time: Voi's data only covers a limited period and may not show the full picture of e-scooter usage patterns. Different seasons may affect e-scooter usage, and external factors like regulation changes or availability may impact long-term trends.

Unsuccessful trips: 8-9% of the queried trips through OTP did not produce an itinerary at all, despite multiple attempts and investigation. Unfortunately, no explanation or resolution was found for this issue. However, upon examining heatmaps and time-distribution charts of the failed trips, no significant visual deviation was observed from the 91-92% of the successfully queried trips. Therefore, it can be concluded that the results may only lack the observations from the failed trips, and are not necessarily skewed as a result of them.

Unknown relevance of closest public-transport stops: It is unclear whether the public transport stop closest to the e-scooter's origin or destination provides a route that could complement the rider's trip, by providing an itinerary from their starting point.

Lack of explanatory information about e-scooter trips: The purpose behind e-scooter trips is unknown, which makes it difficult to understand whether they are choosing e-scooters over public transport for reasons related to convenience, speed, or other factors.

Assumptions of flat rates: The assumption of a flat rate for Voi and public transport may not provide a fair comparison between the two modes of transportation. Promotional discounts and monthly passes are common for e-scooter companies, and infrequent users of public transport may not be familiar with the service offering or benefitting from a pass that significantly reduces the cost per trip. This lack of information about the true cost of each mode of transportation may bias the results of the analysis and limit the ability to draw accurate conclusions about the relative attractiveness of e-scooters versus public transport.

Knowledge limited to origins and destinations: The research is limited in its understanding of e-scooter usage patterns through the city, as it does not provide information about the actual route taken by the riders. Consequently, the true final destination, as well as any intermediate destinations, remain unknown.

Unknown topographical relevance: This research did not consider the differences in height between origins and destinations, nor the possible height difference in the equivalent walking routes. Looking into this might give a glimpse of the motivations for usage of Voi over public transport or walking.

Data limited to one operator: This analysis includes data only of Voi, in 2022, Lime, Bolt, Bird, and TIER also operated in the city. Different commercial strategies from each company might influence the behaviour and access of users. However, discussion with both Västtrafik, Göteborg municipality and Voi concluded that the results are likely similar for other operators as the offerings do not differ substantially. This is also affected by fleet caps and evolving regulations in the city.



5. Discussion

When comparing an e-scooter trip with its potential public-transport equivalent, the focus was solely on the ability of each mode of transportation to facilitate travel between specific e-scooter points at a given time. In other words, the only meaningful comparison between public transport and e-scooters can be made based on topology (i.e., the public-transport route between a point of origin/destination) and, if available, travel time.

Travel time is composed of several factors, including the walking distance from the point of e-scooter origin to the nearest relevant public-transport stop (without knowing the rider's true point of origin, only the moment they tapped 'start ride'), waiting time, and in-vehicle time. Due to several limitations outlined before, other factors such as price, design, comfort, and other features were either considered but not conclusive (such as an estimation of travel cost), or not considered at all.

As observed from the heat maps, it is evident that trips start and end in the same areas of the city all year-round. The only real difference between summer and regular, as seen in Figure 2, is that more trips occur as the months progress towards summer: suggesting, unsurprisingly, that e-scooters are used more frequently under warmer months. The areas of high usage are in the city-centre, where the city is well adjusted to walking, e.g., with wide pavements, exclusive pedestrian zones and short distances.

Interestingly, transfer trips, even though few, can give a glimpse of potential future needs for PT services or pilots that promote multimodality of PT with shared e-scooters, creating a seamless integration for usage of both, like ticketing, booking, and such. A question arises from this analysis: what if transfer trips are such a small share because people who face similar conditions opt for ride-hailing or private vehicles? Integration pilots and collaboration in transport planning could help prevent this, but that is still on the way.

This therefore validates that the short distances of e-scooters explain why trip planners suggest walking rather than public transport in half of the cases. Additionally, given that the proximity of public transport stop (station) was tested for relevance to an e-scooter's point of origin and destination (i.e., it is unknown as to whether the 'closest stop' services the PT route a rider could have taken), it is inconclusive that e-scooters are directly replacing or competing with public transport, but rather might be complementing it as a mode of mobility faster than walking in areas of the city that public transport does not service and for benefits that public transport does not necessarily offer.

Nonetheless, this is an important insight for parking policy suggestions. It is clear that people start or end trips close to PT transport stops, which suggests placing e-scooter parking spots close to PT to encourage multimodality. Nonetheless, this should not be limited to that. It's essential to understand that limiting parking stops only to public transportation (PT) stops would promote rivalry rather than cooperation. Therefore, it's crucial to have e-scooter parking areas in densely populated regions such as residential areas, work districts, universities, and city centres to promote multimodality and complementarity.



It is risky to see the trips for which OTP suggests walking as the most suitable alternative as undesirable and/or detrimental to public health since more research is needed to understand users' motivations. For instance, what if some users choose Voi to travel to the gym, and they may feel less motivated if they had to walk? What if others have physical disabilities that make walking exhausting for them? And what if some users are students who want to sleep a bit longer but still arrive on time for their morning classes?

A study of 419 interviews with shared micro mobility users run by Gothenburg's municipality during Spring and Autumn 2022 found that 40% of e-scooters combine their trips with PT. User research performed by Voi with users in Sweden (1307 respondents) shows that time savings, convenience, and accessibility rank as the main motivations for usage. From the research that this report is covering, it can be validated that the perception of time saving is a reality for the big majority of Voi users in Gothenburg.

Voi has expressed that their customer base in Sweden is 57% between 18 and 34 years old, which could explain the concentration on trips in educational areas and around student housing. Västtrafik manifested that young people tend to avoid buying public transport periodical tickets since they are perceived as expensive. Living in a student accommodation close to the university and having trips that are rather short, can make opting for a cheaper Voi Pass rather than a Västtrafik periodic pass look like a reasonable choice. Nonetheless, more research is needed in this matter.

Overall, modal choice of e-scooters could be explained by the psychology of transportation. Even if saving times are not significant, a user can be more prone to choose a more expensive mode of transport in exchange of an increased feeling of control, reduced anxiety, and a generalised sense of certainty.

Among mobility professionals, it is very common to view alternative modes of transportation to public transport as undesirable, except when they involve active mobility such as walking or biking. This paternalistic perception is based in a belief that "more people should use public transport". This belief is rooted in the notion that public transport must be profitable or at least break even on its own. The most feasible way to achieve this is by increasing usage at a set capacity without considering level of service and other human factors in mobility.

Nonetheless, contrary to this belief, one representative from Västtrafik expressed that e-scooters could be a potential support to alleviate crowds in the city centre. Gothenburg is a very dense city when it comes to tramways in the city centre, meaning very low speeds that are worsened if users take the trams to do intra-city centre trips. If these trips can be supported by shared micro mobility, it is a positive thing for the operation of the whole public transport system.

Despite the lack of information regarding the motivations, demographics, intermodality, and usage patterns of e-scooter riders in Gothenburg, it cannot be ignored that residents have chosen to use Voi over a million times in less than a year. Shared e-scooters have become a prominent mode of transportation in urban areas, and municipalities and operators must



collaborate to establish regulations that ensure their use is sustainable, safe, organised, and convenient for citizens.

Moreover, e-scooters have the potential to assist public transport operators in alleviating congestion during peak hours and within dense urban areas, while encouraging individuals to avoid purchasing private vehicles, contributing to a greener and more sustainable future.

Aligned with this, to avoid people from using private vehicles, people must have sustainable options that are convenient, affordable, and safe for them. Shared e-scooter can have a big impact if they are integrated into the transportation planning of urban areas.

For this integration, innovative solutions in joint communications, integrated ticketing, and multimodality pilots are needed. A baseline for this is to approach it from a user-centric perspective. Transport planning is historically performed in a top-to-bottom perspective, with mobility experts suggesting what they think is the best solution for mobility. This has led to Public Transport being unable to meet all the mobility needs, resulting in people resorting to unsustainable alternatives, primarily due to the convenience factor. Nonetheless, this can be changed if the transport planning process is shifted towards a bottom-up perspective, with the users and their needs at the centre of the service design.

For this, collaboration between municipalities, PT operators, shared micro-mobility operators, and local communities is key. Also, a shift from a PT-centric perspective into a mobility-centric perspective is essential to approach congestion and pollution problems with a broader perspective and in order to achieve a sustainable mode-shift.

5.1. Further research

Three further research topics are suggested:

- **Value of time analysis:** With the existing data, an economic analysis of the hypothetical value of time perceived by the users can be assessed. This research could support a pricing strategy that makes either Voi or Public Transport more attractive to use in an integrated way. Nonetheless, for a more realistic analysis, more data on passes both from Voi and Västtrafik would be needed.
- **Altitude difference analysis:** Gothenburg has a particular topography with high points that might explain the choice of e-scooters over walking or even biking. This analysis can be easily done using GIS tools that calculate the altitude difference between the origin and destinations and then such data can be analysed. A more advanced method could be calculating with OTP the equivalent biking itinerary, assume such route as the one taken by the user, and calculate the increase in altitude through the route. This analysis was not performed in this project due to a time constraint.
- **Surveying on users:** This project should be complemented with in-person surveying. The results from the analysis presented here suggest the times and geospatial places where surveys should be performed to understand further the behaviour or users.



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Appendix: Generalities of the results

Pre-querying analytics: E-scooters descriptive variables

The original dataset included 1.040.631 trips, of which, After, unrealistically short and fast trips were cleaned. This summary covers the remaining 1.009.407 trips. Then, they were clustered based on the day of the week and the time of the day.

The first categorization resulted in two clusters: "Weekdays", which included 751,493 trips from Monday to Friday, and "Weekends", which included 257,914 trips from Saturday to Sunday. The second categorization resulted in three clusters: "Morning rush hour", which included 126,881 trips from 6 a.m. to 9 a.m., "Daytime and evening", which included 759,752 trips from 9 a.m. to 9 p.m., and "Late night and early morning", which included 122,772 trips from 9 p.m. to 6 a.m.

Post-querying analytics: PT descriptive variables

The query resulted in the following clusters: 97.968 trips (9,4%) returned an unsuccessful respond from OTP, 436.239 trips (41,9%) were identified as the most suitable option for walking, 458.805 trips (44,1%) were identified as the most suitable option for using public transport without transfers, and 16.395 trips (1,6%) were identified as trips with transfers.

Since the unsuccessful trips were excluded from further analysis, this summary focuses on the remaining 911.439 trips. In terms of the time of the week, 675.077 trips occurred on weekdays and 236.362 trips on weekends. For the time of the day, 110.968 trips occurred during the morning rush hour, 690.681 during the daytime and evening, and 109.790 during late night and early morning.

Post-querying analytics: PT descriptive variables: Walking trips

The 436.239 trips where walking was the most suitable option will be referred to as "walking trips". Variables related to the query results can be analysed. Two variables are created to describe walking trips: Total Travel Time and Walking Equivalent.

For walking trips, in terms of the time of the week, 324.857 trips occurred on weekdays and 111.382 trips on weekends. For the time of the day, 49.488 trips occurred during the morning rush hour, 331.953 during the daytime and evening, and 54.798 during late night and early morning.

Post-querying analytics: PT descriptive variables: PT trips without transfers

The 458.805 where the most suitable mode of transport is Public Transport without transfers are referred to as "PT trips without transfers". Variables related to the query results can be analysed. Three variables that describe PT trips without transfers are created based on the OTP querying process: Total Travel Time, Initial Waiting Time, and Walking Distance.

For PT trips without transfers, in terms of the time of the week, 337.413 trips occurred on weekdays and 121.392 trips on weekends. For the time of the day, 59.113 trips occurred during



the morning rush hour, 346.786 during the daytime and evening, and 52.906 during late night and early morning.

Post-querying analytics: PT descriptive variables: PT trips with transfers

The 16.395 trips where the most suitable trip would be done with Public Transport with transfers will be called “PT trips with transfers”. Among these, 16.289 would require only one transfer, while 106 (0,01% of the complete dataset) would require two transfers. No trips require more than two transfers. Variables related to the query results can be analysed. Four variables are created to describe PT trips with transfers: Total Travel Time, Initial Waiting Time, Walking Distance, and Transfer Time.

For PT trips with transfers, in terms of the time of the week, 12.807 trips occurred on weekdays and 3.588 trips on weekends. For the time of the day, 2.367 trips occurred during the morning rush hour, 11.942 during the daytime and evening, and 2.086 during late night and early morning.

E-scooter – Public Transport comparison: Travel time difference

New variables are created to compare the e-scooter trips with the Public Transport or walking equivalents. One of these variables is called the "travel time difference" and is calculated as the difference between the Total Travel Time for the e-scooter trip from the original dataset and the Total Travel Time for the Public Transport or walking equivalent obtained from querying OTP.

The purpose of this variable is to indicate how much time the users saved by choosing the e-scooter instead of the Public Transport or walking equivalent. A negative value indicates time saved when using the e-scooter, while a positive value means that it would have been faster to perform the trip using the Public Transport or walking equivalent.

E-scooter – Public Transport comparison: Travel cost difference

Another variable created to compare the Public Transport or walking equivalents to the original trips is called “travel cost difference”. It calculates the cost difference between the e-scooter trip (using the start and end times from the original dataset) and the Public Transport fare for those trips with a non-walking equivalent as a result of the OTP querying process.

This variable assumes that if users did not choose the e-scooter, they would either not pay any fee for walking trips or a full fare of 35 SEK for Public Transport. For the e-scooter trip cost, it assumes that all users pay a fare of 10 SEK + 3 SEK/min (rounded up to the next minute), without considering that users may have different kinds of monthly passes, discounted fares, or periodic Public Transport passes.

The purpose of this variable is to show how much money users saved by choosing the e-scooter instead of the Public Transport or walking equivalent. A negative value represents a saving in money when using the e-scooter, while a positive value means it would have been cheaper to perform the trip using the Public Transport or walking equivalent. However, these results depend on the assumptions mentioned above.



E-scooter – Public Transport comparison: Distance to public transport

Lastly, a geospatial analysis process in QGIS was used to create another variable that compares the Public Transport or walking equivalents to the original trips. This variable is called “distance to public transport” and it measures the distance from all trip origins and destinations to the nearest valid Public Transport point, as defined by the corresponding GTFS file.

To calculate this variable, the distance to the closest Public Transport point was calculated for each origin and destination, and the lowest value was selected. This variable is useful for understanding how close the trip start and end points are to Public Transport stops.