Are E-scooters used as a last-mile solution or a full-mile solution?

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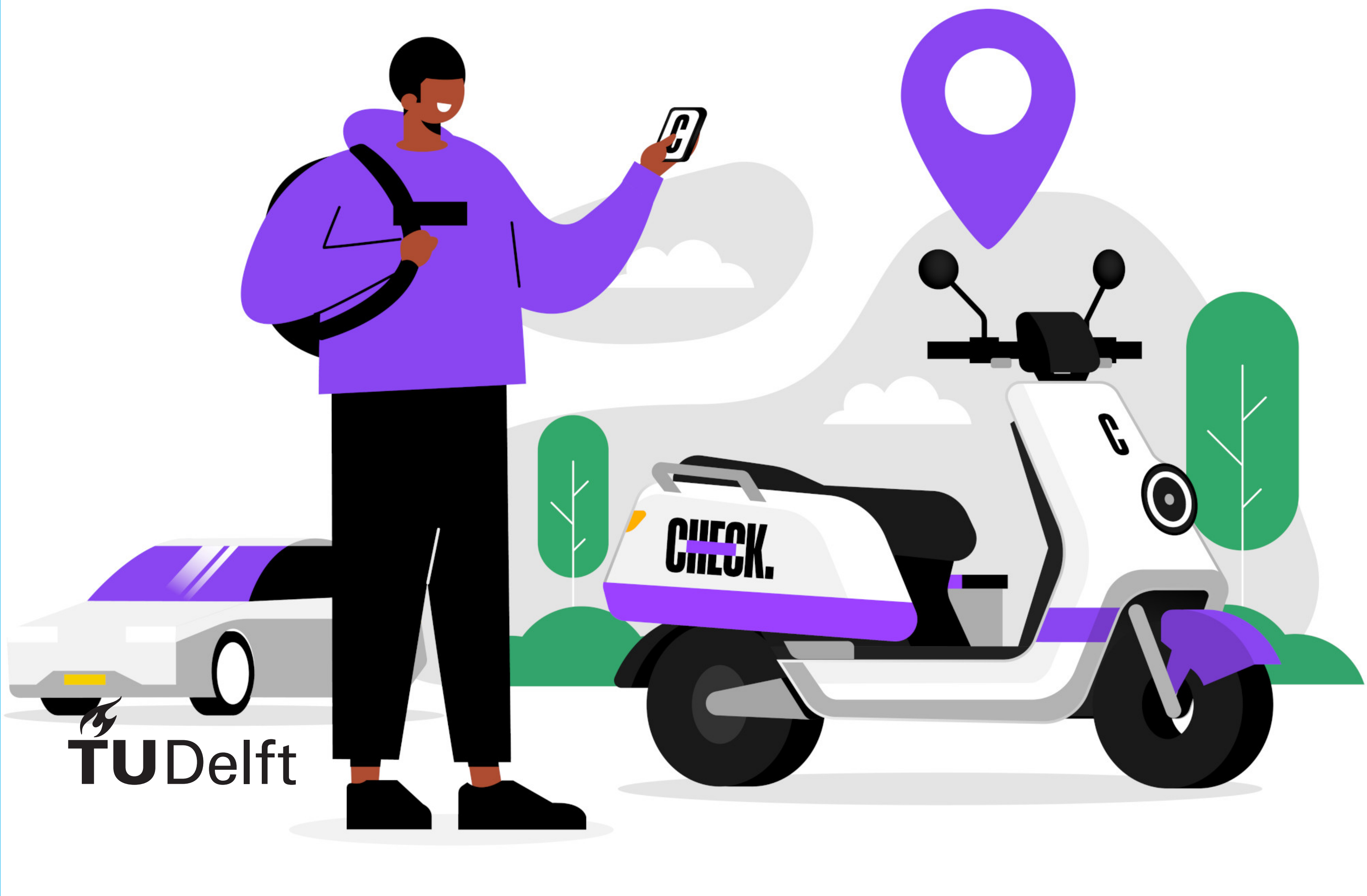
T. Pennock



TU Delft

Are E-scooters used as a last-mile solution or a full-mile solution?

To what extent are shared e-moped fleets in cities used as a first or last-mile addition in public transport

by

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Preface

Before you lies the bachelor thesis 'Are E-scooters used as a last-mile solution or a full-mile solution?', written at the TU Delft. This research was fulfilled from April to June 2023 to finalize my Civil Engineering bachelor's degree. It was made in the last period of my study and felt like a great way to finalize this chapter of my education.

I first started with the project out of my own interest, but I learned during the research that it would be more valuable to create a product for a target group. So after some research, I decided the end product would be an indicator for municipalities to inform them of the shared e-moped service in their cities. This helped me immensely by striving to create this useful product for people.

I like to thank my supervisors for guiding me during my investigations. My special thanks to Yufei Yuan and Sina Noordhoff for the weekly advice that you've given me. I also want to thank Niels van Oort for brainstorming with me about my research goal when I needed help. Furthermore, I want to thank Anouk van der Laan for obtaining and formatting the necessary data from Check. Finally, I want to thank my fellow students in my project group for the weekly reviews and tips.

T. Pennock
Delft, June 2023

Summary

Shared mobility is an innovation that has grown immensely in the past few years. This innovation brings positive and negative effects with it. The report looks at a possible positive effect of shared e-mopeds, the first-mile addition to public transport. This can encourage cities to decide whether to implement the service of e-mopeds or monitor the changes in the current service.

This research approximates an indicator for first-mile usage in the city of Amsterdam via spatial data analysis with trip data from Check imported in QGIS. This was conducted in multiple ways. The first indicator used an equation that simply counts the end trips at a railway station. The second takes into account the type of parking regulation and the third includes the type of land use around the station. This third 'zoning' indicator was considered the most accurate estimation and resulted in 6.59% first-mile usage in Amsterdam (Netherlands).

This result can be used as a first-mile indicator for Check mopeds. However, more research is advised. The results showed mixed proof of the assumptions made in the indicator equation and follow-up research can be done to improve the indicator. The results did show some new insights for a better approximation. The main insight was that city density is likely a necessary variable in the indicator equation.

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1
Introduction

Shared mobility has seen a massive boom in the 21st century. With the constant need for faster travel time and more efficient public transport (PT), a small sector in the transport market exploded after introducing cheaply manufactured micro-mobility vehicles (Figure 1.1). These are lightweight, usually single-person vehicles that provide transportation over short distances. The cheap costs allowed companies to buy a fleet of small vehicles and spread them throughout a city for the whole population to use via mobile phone.

Figure 1.1: The NIU's Changzhou factory. Main manufacturer for Check and Felyx (MyNIU.org, 2017).

The focus of this report will be on shared e-scooters. This is a concept with a relatively few amount of research around it compared to common PT such as trains or busses. To show the fast rise of this technology, we can look at the current definition of the word e-scooter, scooter, and motor scooter. As *Cambridge Dictionary* (n.d.) explains, an e-scooter is "a vehicle similar to a child's scooter but with an electric motor attached, used by adults and children". The type of scooter that will be looked at in this is closer to the definition of a motor scooter but with electric propulsion and will, from now on, be referred to as an e-moped.

1.1. Problem definition

Now that these vehicles are introduced in cities, people are asking themselves if these alternatives for the car are greener (Lelieveld, 2022). For example, the Dutch city of Utrecht canceled its contract with shared scooter companies in 2022 because the local government thought scooters replaced trips that initially would be taken with a bicycle or by walking (Hoving, 2022). A study on the life cycle of e-moped stated that "e-moped sharing has a similar environmental impact on global warming potential, in terms of passenger kilometers, as public transport, especially if long product lifetimes as well as efficient operation logistics are realized" (Schelte et al., 2021).

When considering public transport in cities, the city municipality has clear data on how many people they are servicing and a good estimate of their goal. the Dutch Railways or NS (2021) share the number of check-ins and outs every year. The problem with e-mopeds in a city is a huge web of trips, going to every inch possible. This causes an unclear view of how many trips are used for the PT and how many are not.

1.2. Objective and research questions

The report aims to determine how many trips with e-mopeds are used as a first or last-mile solution versus all trips. This can give cities an insight into the advantages or disadvantages that e-sharing companies can produce. To do this, we have to find an answer to the research question:

> To what extent are shared e-moped fleets in cities used as a first or last-mile addition in public transport?

This question can be answered via the following sub-questions

1. What is a good indicator of integration between an e-moped network and public transport?
2. How can a distinction be made between a first mile and a regular trip?
3. Who are the people with an interest or concern in the research?
4. What is the indicator value in the city of Amsterdam?

The research plan in Figure 1.2 shows the relation between these research questions. Sub-questions 1 and 2 create an understanding of the optimal way of analyzing the data. A stakeholder analysis is done to ensure the research's purpose is clear. The stakeholder overview and the data analysis product can then be combined to answer the main research question.

The report will focus on the municipalities of Amsterdam. A city with a large fleet of e-mopeds and high availability of reports on demographics and mobility.

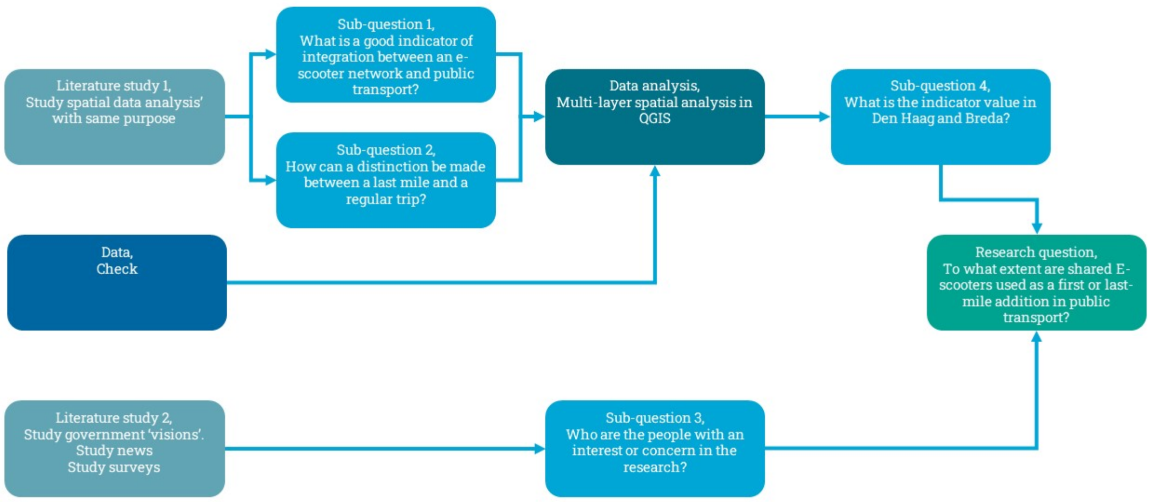


Figure 1.2: Main research plan.

1.3. Societal and scientific relevance

Kasper Baggerman (2022) States in an article about the development of e-mopeds that ”The cowboy years of the shared moped is over”. He mentions that with regulations starting to keep up with the service, the companies’ business model worsens. Society is now at a crossroads with the choice of supporting or limiting shared services. To make this choice, accurate data is needed.

The currently available scientific data consist mostly of surveys about the modal split or data analysis about e-bikes (Oeschger, Carroll, & Caulfield, 2020). The data analysis that is done about shared services looks at the rise of demand on PT locations (Wu, Lu, Lin, & Yang, 2019; Yang, Heppenstall, Turner, & Comber, 2019). The reason behind these analyses is to calculate possible growth in disturbance or demand. The scientific relevance of the paper is that it is a spatial analysis of the efficiency of the service. This will give a unique insight into the effects of the service in a city.

The research also introduces a new method to approximate the number of trips taken by the PT which can be used as a beginning for future research.

1.4. Report structure

The report will follow a general scientific structure. In Chapter 2, the methodology will be discussed. This contains how the research was conducted and how the results were reached. Chapter 3 contains the results and the data. Chapter 4 Discusses the results and possible future research. Chapter 5 concludes the report.

2
Methodology

In this chapter, the exact method of the research is explained. It's divided into two studies. The Literature study and the data analysis

2.1. Literature study

To understand the current knowledge in the field about the topic, a literature study has to be conducted. This was done in the following way.

2.1.1. Understanding the e-sharing sector

The first step is to define the research goal and strategy. This was done by starting with the general topic 'The use of e-mopeds as a last-mile option' and then looking at current news articles about what the population wants to know. After finding that cities have different opinions on the usefulness of E-sharing companies in their cities, the research went into the next step, which is starting to search for scientific papers. This was done by searching with the keywords in Table 2.1.

Table 2.1: Search terms used to find relative articles.

Keywords	Variations
Public Transport	Train, Train stations, Transport,
Micro-mobility	Micromobility, E-scooters, E-sharing, Shared-mobility
Last-mile	First-mile, Accessibility, Covarage, Acces trips, Integration
Indicator	Data analysis, Big data, Spatial data analysis

2.1.2. Determining an indicator of integration

Research was carried out to search for known integration indicators to support the report's methodology. This was carried out by first searching a general overview of the topic. A literature review about the state of knowledge is a useful start for quick literature research.

2.1.3. Stakeholder analysis

The Stakeholder analysis was done via a literature study. This comprised examining news articles and research papers collected for the previous studies in sections 2.1.1 and 2.1.2. To find the opinions of people, news articles or surveys were used. The opinion of governmental bodies (cities or a country) was located in published plans of approach.

Multiple cities were looked at for the stakeholder analysis. This was done because the goal of the research is for it to be implemented nationwide.

The analysis includes a Power-Interest matrix. This matrix places every stakeholder on a location in the graph depending on their amount of power and interest in the research. This graph can be split up into quadrants. The stakeholder analysis technique originally published by Ackermann and Eden (2011) also adds a name and function to each quadrant. Quadrant A, 'Context setters', has to be consulted during the research. Quadrant B, 'Players', need to be collaborated with. Quadrant C, 'Crowd', have to be informed. Quadrant D, 'Subjects', have to be involved.

2.2. Data analysis

The type of data analysis used is a spatial data analysis (SDA). This is an analysis that puts data in a spatial environment. Fischer and Wang describe it as "At its most primitive, an atom of spatial data (strictly, a datum) links a geographic location (place), often a time, and some descriptive property or attribute of the entity with each other" (2011, p.2). The SDA in this research uses two types of data, point pattern data, and area data. Point pattern data is a collection of data points. Area data is a collection of zones.

To define the use of an e-moped trip, we have to look at available data for the research. In collaboration with the vehicle-sharing company Check (Check Netherlands B.V.), the data of their e-moped trips can be accessed. The data first had to be limited to contain the study in a clear scope. A database was used for the public transport data with the city stations and their coordinates. The Data was then connected via QGIS. This application can plot data on a map for spatial data analysis. A time period of one month was set to limit the size of the data further. To ensure that the data is up to date and not affected by quarantines, December 2022 was chosen.

2.2.1. Data processing

The trip data was received as a CSV with 2 columns for the coordinates of the endpoints and 1 column for the date. The service area of Check was received as a TXT file with the coordinates of the polygons. These were imported to QGIs without alternations.

2.2.2. Using QGIS to visualize the data

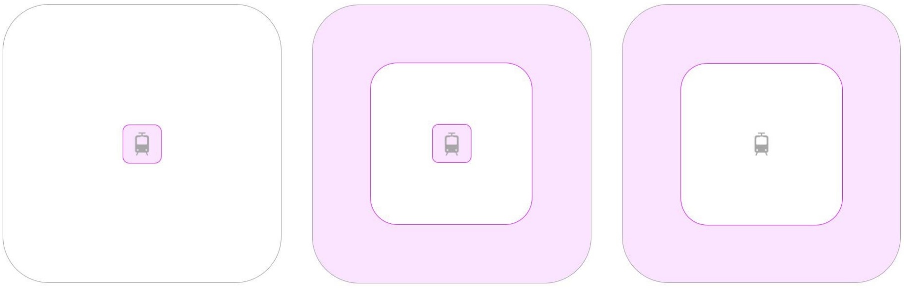
The data was visualized using QGIS. QGIS can create multiple layers and can calculate overlapping data. This feature was used in the following manner. Three layers were created. The first layer is a general map of the city to indicate the locations of the train stations. The second layer is a collection of points indicating a start or end of an e-moped trip. With this data, a boundary can be created around train stations. These boundaries are then turned into polygons. This collection of polygons is the third layer. The analysis between these layers uses a function called 'Points-in-Polygon'. This functions returns the number of points found in the designated polygons.

Figure 2.1: Method of last and first-mile calculation. Layers from left to right; The background map, start and end points, station zone, and calculation with n=3 trips inside the polygon.

2.2.3. Calculating the last and first mile trips

To create an unbiased indicator of the share of PT use, variables have to be created to take into account the different characteristics of the stations. To show the effect of the added variables, the analysis will first be done with the least amount of variables. After this, the analysis will be repeated but with an added variable. This will be done until the variables found in the research are depleted.

When looking at the stations in the Check application, there is a distinction between the parking zones. In Figure 2.2, the general possibilities are displayed. Figure 2.2a shows a station in a neighborhood or city with only parking directly on the station's ground. This will be called a parking 'island' situation. Figure 2.2c shows an exclusion zone around the station. This will be called a perimeter situation. In the middle, Figure 2.2b is a combination of the previous two options and will be called the 'hybrid' situation.



(a) 'Island' (b) 'Hybrid' (c) 'Perimeter'

Figure 2.2: The 3 possible ways of parking zoning.

These situations have different percentages of PT users (Chapter 3.2.1).To compensate for this, a variable was added for each situation. To address the stations that don't fit in one situation but are mixed between them, α was also added to calculate the amount of variety.

Figure 2.3: Different zoning levels of Amsterdam (Gemeente Amsterdam, 2022).

Another type of distinction that can be made is the types of zoning. The municipality of Amsterdam has seven 7 types of zoning in their city. Figure 2.3 shows how these types are related.

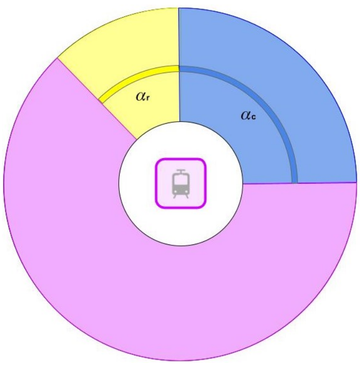


Figure 2.4: Demonstration of determining the α variable.

The first result will use the basic calculation of integration (Formula 2.1). This divides the sum of PT trips (n) per station (i) by the total number of trips (T).

$$PTII_1 = \frac{\sum_i n_i}{T} \tag{2.1}$$

After this, the situation variable (z_i) is added to create Equation 2.2. This requires the area around the station to be dived in segments (j) with angle α_j. This equation also adds the A parameter, which is derived from the average of a region with no PT. The scenarios each have a different value for the radius r_j. Because of the circular area, the radius is squared.

$$PTII_2 = \frac{\sum_i (n_i - \sum_j (\alpha_j * A * r_j^2))}{T} \tag{2.2}$$

This penalty is added to subtract the trips in the polygon that weren't used for the PT. This is done by taking an average of a circular area without public transport. Because the scenarios will be defined by the angle of its existence in reference to the parking, the number of e-mopeds (n) in the area is divided by 360°. To distinct the penalties per scenario, the radius (r) of the circular area is used. In an interview with Check, they mentioned that the maximum amount most people who will walk to an e-moped is around 225. This will be used as an assumption for the radius in the island scenario to subtract all the mopeds that wanted to go in a radius of 225 meters around the station but had to park at the station because it was the only possibility.

In the hybrid scenario, the radius was set to 0 to make the total scenario penalty 0. This is done because of the assumption that in the hybrid scenario, all trips in the parking zone inside the station were used by the PT. This is because people always want the shortest walk to their final destination, and the hybrid scenario allows users to park at their destination.

In the perimeter scenario, a few trips wanted to reach the destination inside the perimeter, which isn't the PT. The radius of the perimeter is used to penalize this. *If the radius is larger than 225 meters, it is assumed that no public transport trips are used because the walk would be too long.* not sure yet. Table 2.2 summarizes the chosen radius assumptions.

Table 2.2: Different radius (r_j) values for varying parking scenarios.

j	Scenario	$r_j[m]$
I	Island	225
H	Hybrid	0
P	Perimeter	r_p

The last equation adds more attributes to the segments via the zoning status (k) of the segment (Equation 2.3). This includes the difference in parking averages due to their zoning, by creating an average (A_k) made in the specified zone. The number of trips in this zone per degree (α) can be calculated by taking a zone without PT and calculating how many trips are made to that zone.

$$PTII_3 = \frac{\sum_i (n_i - \sum_j \sum_k (\alpha_{j,k} * A_k * r_{j,k}^2))}{T} \tag{2.3}$$

The Final result is a table with an overview of all city indicators.

3 Results

3.1. Stakeholder analysis

The Stakeholder analysis is done to find all the groups with an interest or concern in the research. In this research, the following groups were found:

1. Government of the Netherlands.
2. Municipality using shared e-mopeds.
3. Citizens of cities using shared e-mopeds.
4. E-moped organizations.

3.1.1. Government of the Netherlands

The Dutch government was included in this analysis because the city doesn't always have the final say in its policies. The Netherlands Institute for Transport Policy Analysis or KiM (Kennisinstituut voor Mobiliteitsbeleid) did a study about light electric vehicles (LEV) to advise the 'Ministry of Infrastructure and Water Management' on possible policy points of action. In this study, they found that the focus groups of the population think that e-mopeds are better for the environment and don't think about the shorter life span or the harmful production of the batteries. The report doesn't have advice for an immediate policy change, the conclusion being that the e-sharing companies can become more environmentally friendly by pursuing higher millage, expanding life expectancy or usage of recycled materials.

3.1.2. Municipality using shared e-mopeds

The cities that were studied are Amsterdam, Den Haag, and Breda. These are all cities with a positive opinion on shared e-mopeds.

Amsterdam, Den Haag, and Breda all have visions they publish about how they want to develop their transport network. Gemeente Amsterdam (2023b) has the 'Nota Deelvervoer' (ND), Gemeente Den Haag (2020) has the 'Haagse Nota Mobiliteit' (HNM) and Gemeente Breda (2022) has the 'Mobiliteitsvisie Breda' (MB). The ND says it wants to take the shared e-moped program to a fixed policy and possibly double the number of shared e-mopeds in the city. The HNM says it will focus more on e-sharing possibilities, and the MB says Breda will commit more to inner-city travel with, for example, shared e-mopeds. With only concentrating on parking and overcrowding as negative side effects. Both cities see e-sharing as a way of improving the PT by adding more users, gradually, to the system.

3.1.3. Citizens of cities using shared e-mopeds

The policies implemented by the parties elected by citizens can be viewed as a reflection of their collective opinions and values towards their city. These can be seen in the city's legislation. With the KiM stating that people see e-mopeds as a green addition to mobility (Section 3.1.1), and the municipality's reports saying they want to expand e-sharing (Section 3.1.2).

3.1.4. E-moped organizations

The stake of the e-moped companies is their very existence. When the general population is informed of the negative side-effects of e-mopeds, then legislation might be enacted to reduce e-moped companies or even forbid them. To prove the possible benefit of their company, the results of this research can be used to show the public how their service is used in each city. The other way, the results can be used as a reference for newer implementations like better parking at PT stations. This can show how integrating their company with the PT can improve the integration indicator of the city.

3.1.5. Power-Interest matrix

In Figure 3.1 the relation between the stakeholders is shown through a power interest matrix. On top of the power spectrum is the Dutch government. This stakeholder has the final say in the situation. They can create legislation to govern the other stakeholders. But they also have a lot to govern about, limiting their interest in the situation. This puts them in section A, which makes them a party to consult about the research. Section B contains the municipality and the organizations. These are the parties with high power and interest that must be collaborated with. The municipality has a higher power level than the organizations because it can put up legislation limiting the power of the organizations. The organizations have the highest interest because, as mentioned before, their existence depends on it. Finally, there are the users in section D with limited power and high interest. These can be consulted in the research.

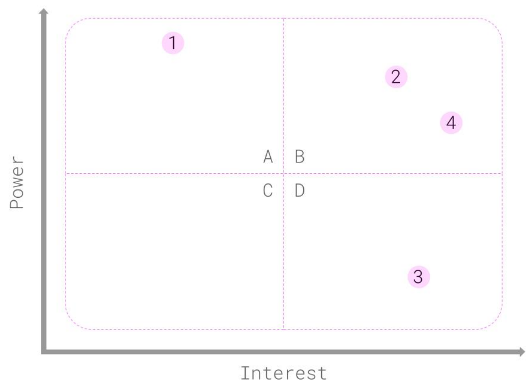
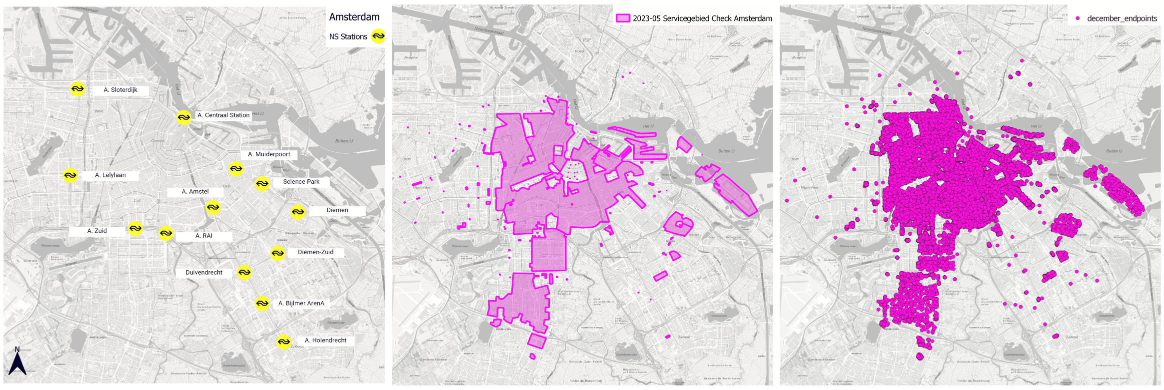


Figure 3.1: Power interest matrix of the stakeholders.

3.2. Trip data of Amsterdam

To create an overview of the PT in Amsterdam, Figure 3.2a was created in QGIS after importing the station data from Esri Nederland (2023), which shows the NS stations in Amsterdam. There are 13 NS stations in Amsterdam. 12 of them have a connection to the Check network. Figure 3.2b and 3.2c were created using the data provided by Check. These figures show the current parking zones and the endpoints of the trips made in December 2022.



(a) (b) (c)

Figure 3.2: General layers of Amsterdam.

Noticeable in Figure 3.2b are the different types of parking regulations. The center of Amsterdam has close to no parking restrictions, while the sides have a strict parking policy. These parking regulations restrict the endpoints of the trips as seen in Figure 3.2c.

3.2.1. Determining the basic indicator

The basic indicator was calculated by Equation 2.1 described in Chapter 2.2.3. The polygons used to calculate the number of trips can be seen in Figure 3.3. The borders of these polygons were created following the zoning and trip maps of Figure 3.2, and following the guidelines of the 'scenarios' mentioned in Chapter 2.2.3. Some polygons are larger than others. This has to do with the size difference between the station and the resulting larger size of the parking area.

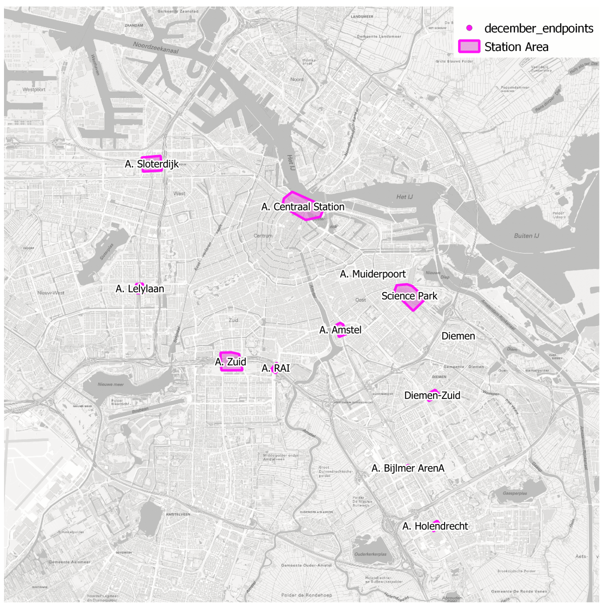


Figure 3.3: Polygons created around the stations.

3.2.2. Determining the scenario indicator

This section shows the results of the scenario research. Figure 3.4 shows the 9 random circular polygons with a radius of 225 meters that were randomly distributed around Amsterdam. This resulted in an average of 597 e-mopeds (Appendix, Table A.3).

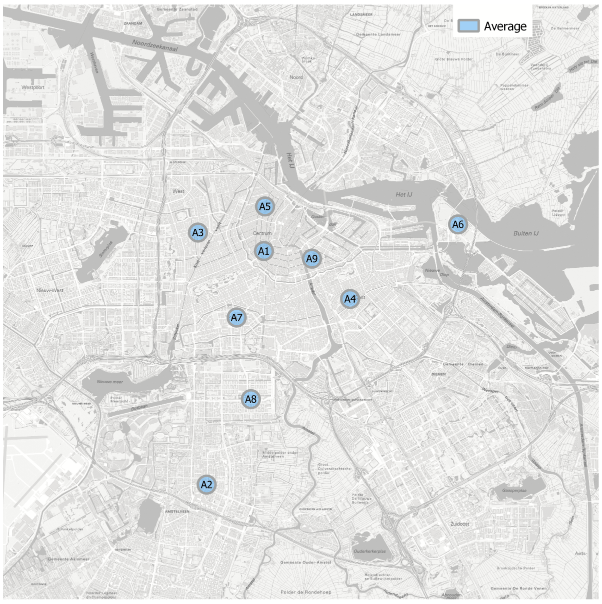
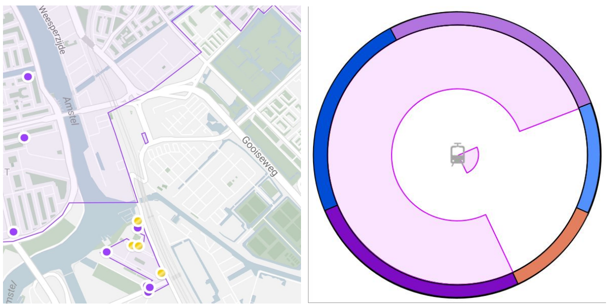


Figure 3.4: Polygons created around Amsterdam to calculate an average without PT.

The scenario distribution around the stations is calculated by the angle of the zone with respect to the station. The values were based on the simplified figures in the Appendix (Figure A.1). An example of the simplification can be seen in Figure 3.5. The inside of the circle shows the distribution of the scenarios by angle. The final values of the angles of all stations can be found in Table A.1 in the Appendix.



(a) (b)

Figure 3.5: Example of simplification of Amsterdam Amstel viewed from Check (2023) application, and simplified. All figures can be found in the Appendix, Figure A.1.

The final variable is the radius. These were predefined in the Island and Hybrid scenario, but the perimeter radius had to be visually calculated. The 2 stations that contain a perimeter scenario are A. Centraal Station and A. Amstel. The radii resulted in 200 and 50 meters respectively.

3.2.3. Determining the zoning indicator

The zoning research resulted in the map of Figure 3.6. With this information, the zoning data was added to the outer rim of the simplified view of the station (Figure 3.5b). There was no information about the stations Diemen and Diemen-Zuid in the Amsterdam database so the 'Bestemmingsplannen' map was used (Gemeente Amsterdam, 2023a).

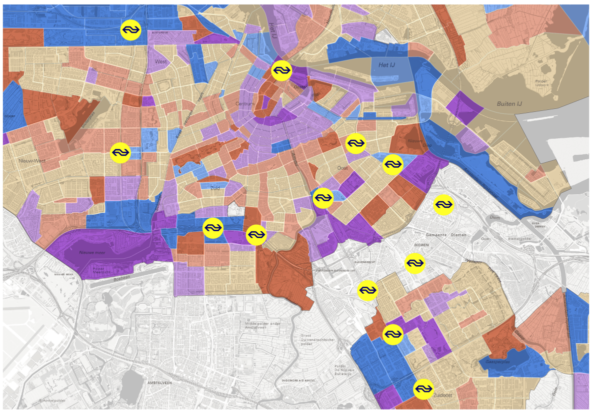


Figure 3.6: Zoning Amsterdam (Gemeente Amsterdam, 2022).

The averages needed for Equation 2.3 had to be calculated in their own zoning type. The chosen polygons can be seen in Figure 3.7. The locations of these polygons were chosen based on Figure 3.6 and the assumption that the more diverse the polygons are distributed in Amsterdam, the better the average becomes.

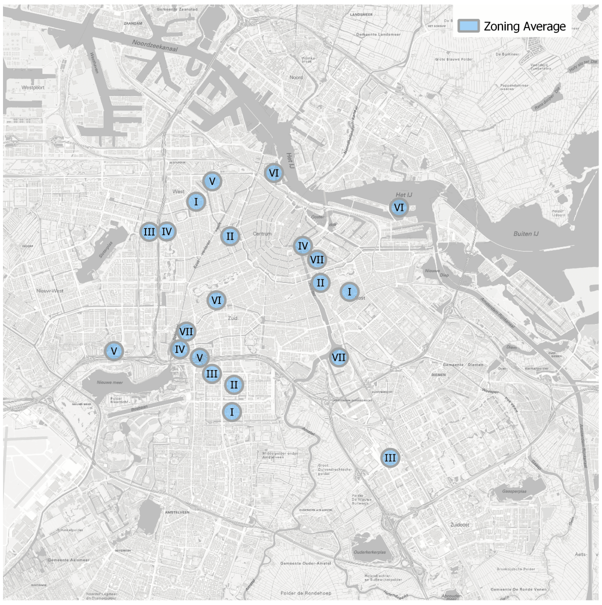


Figure 3.7: Polygons created around Amsterdam to calculate an average without PT, with local zoning included.

The average amount of trips in every zoning type can be found in Table 3.1 together with the resulting A_k variable.

Table 3.1: Different z_i values for varying zoning.

k	Zone	$n[\#]$	$A_k[n/m^2/°]$
I.	Residential	299	1.6E-05
II.	Residential - Commercial	778	4.3E-05
III.	Commercial	510	2.8E-05
IV.	Commercial - Work	452	2.5E-05
V.	Work	433	2.4E-05
VI.	Work - Residential	383	2.1E-05
VII.	Work - Commercial - Residential	435	2.4E-05
	Average	470	2.6E-05

3.2.4. Overview of the final results

The results of the 'Points in Polygons' analysis are shown in the second column of Table 3.2. The station of Duivendrecht has 0 calculated trips because it doesn't contain any parking spaces in the vicinity. Notable are the 2 biggest values of Amsterdam Centraal Station and Amsterdam Zuid.

Table 3.2: $PTII_1$ values of the stations of Amsterdam.

Station	$PTTI_1$	$PTTI_2$		$PTTI_3$	
	$n[\#]$	$n[\#]$	Δn	$n[\#]$	Δn
A. Centraal Station	3,784	3,399	385	3,425	359
A. Sloterdijk	1,278	681	597	845	433
A. Lelylaan	832	235	597	371	461
A. Zuid	2,208	2,208	0	2,208	0
A. RAI	139	139	0	139	0
A. Muidenpoort	173	0	173	0	173
A. Amstel	804	633	171	643	161
A. ArenA	349	-248	597	-69	418
A. Holendrecht	312	-285	597	-103	415
Duivendrecht	0	0	0	0	0
Diemen	68	-231	299	-82	150
Diemen-Zuid	234	-65	299	51	184
Science Park	379	-218	597	-32	411
Total	10,560	6,422		7,571	

The total amount of trips (T) made in December in Amsterdam is 114,967. This results in the final values in Table 3.3. The first method shows a 9.19% of last-mile usage of the total fleet in Amsterdam. The scenario method 5.59%, and the zoning method 6.59%. After obtaining all the results, the scenario equation was recalculated with the total average of 470 trips (Table 3.1). This resulted in 6.35%.

Table 3.3: PTII values of the stations of Den Haag.

	$PTII_1[\%]$	$PTII_{2;597}[\%]$	$PTII_{2;470}[\%]$	$PTII_3[\%]$
Amsterdam	9.19	5.59	6.35	6.59

4

Discussion

Using shared e-mopeds data is a massive source for mobility research that will undeniably be a great source of new knowledge. This research tries to create a start to understanding trip behavior, knowing that the intentions of the trips are still not 100 percent certain. This chapter will discuss the results, uncertainties, and assumptions of the research outcomes.

4.1. Summary of findings

The findings of the literature study were variable. The literature research to find an indicator for integration did not result in any helpful method. It did give a better understanding of the possibilities of data research. The stakeholder analysis did result in a useful guide for creating the study goal.

The end results of the data analysis are as expected. The basic equation gives a rough estimate. The section equation over-penalizes the first results. The zoning equation creates the most realistic approximation by providing the scenario with more realistic variables based on their surroundings. The research did make assumptions to create the end results. These will be discussed in the following sections.

4.1.1. The goal of trips in different scenarios

The assumptions made in the scenario equation about the radii for certain scenarios could not be verified with the results. The Hybrid scenarios show no accumulation of trips on the perimeter zone around the station which could be interpreted as proof for the radius choice of 0 but isn't absolute proof. The chosen 225 meters radius for the island scenario could also not be proven by the results. A survey could be made to find if the assumption made for the scenarios is accurate.

4.1.2. The definition of public transport stations

One of the big assumptions was that the e-mopeds aren't being used as a first-mile solution for bus or metro stations. The reason behind this was that people using the e-moped did not need to exchange their e-moped for a bus or metro if it could get them to the same destination. Looking at the data, this assumption turned out to be partially accurate. Most small bus and train stations wouldn't have a visual increase in trips. Stations with large barriers to the train network (Noord/Zuidlijn) did have an accumulation of trips around them.

4.1.3. Obtaining the right average

Looking at the zoning averages of Table 3.1, the results showed two significant outliers. This means that there is a significant difference between the areas. The residential zone has the lowest average, which is to be expected, but the highest is the residential/commercial zone. This is not intuitive and can be explained by another variable.

The zoning indicator uses an average that doesn't consider the area's density. This causes zones with a high density like the residential/commercial zone to have a higher average than zones with low densities. This also results in penalties that cause negative trips at stations in low-density areas compared to stations in high-density areas that aren't penalized enough. These imperfections however are minimal because the average is based on a city-level as is the end indicator.

When looking at the city-level average, The number of trips found for the scenario indicator (597) was higher than the zoning trips (470). One could conclude that is the reason for the large difference between the two methods. However, when using the average of 470, PTII2 results in 6.35% which is still a significant difference between PTII3. Furthermore, this average was a result of the method for PTII3, which only confirms that land use is a factor in the equation.

4.2. Future Research

Two important attributes of the study can be improved in future research. First, there is a lack of data about last-mile trips. To obtain a whole PT use indicator, first- and last-mile trips must be examined.

The second attribute is the assumptions that were made for the equations. These can be proven by surveys or more in-depth spatial analyses.

In the end, the goal is to create an indicator for the city that can also be compared to other cities. This opens up future research in other cities. Though it's recommended that the research method should first be improved.

5 Conclusion

This study created a possibility to indicate the amount of first-mile usage of a shared-mobility system via spatial data. To distinguish the end trips at a station between public transport use and regular parking, a method was created using the layout of the parking areas and the type of land use around the station. The end results are an overview of three indicators.

The first indicator gives a 9.19% usage rate. This is the result of measuring all the trips that end at a train station divided by the total amount of trips. The second 'scenario' indicator resulted in a percentage of 5.59%. This indicator over-penalizes the stations in Amsterdam by taking the last trip average of Amsterdam, while not looking at the station environment. The last 'zoning' indicator returns a percentage of 6.59%. An increase from the last indicator because it includes the type of neighborhood around the station and penalizes trips with an average that is closer to the actual environment.

The study finds this zoning indicator the most useful for indicating the amount of first-mile usage but does mention that with the limited size of the research, the best approximation is not reached yet. The study also doesn't include last-mile usage because of the limited data used. To reach a better approximation of reality and to better answer if shared mobility adds to public transport, a study has to be conducted with a better understanding of the local trip average and including last-mile trips. By creating these approximations a better understanding of the usefulness of shared mobility can be given and the decision between implementing it in a city or not can be made accordingly.

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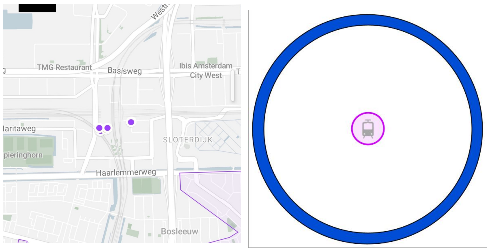
A
Analysis



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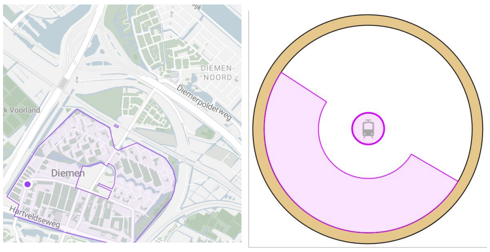

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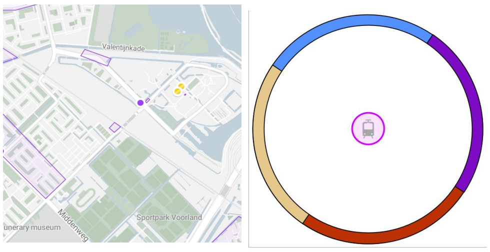
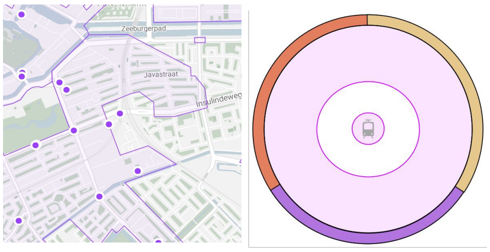


(c) Science Park



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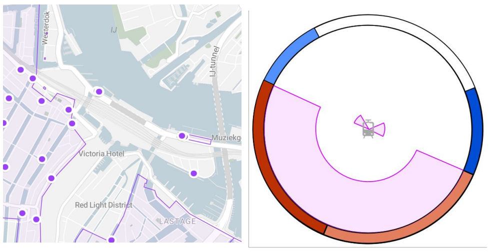

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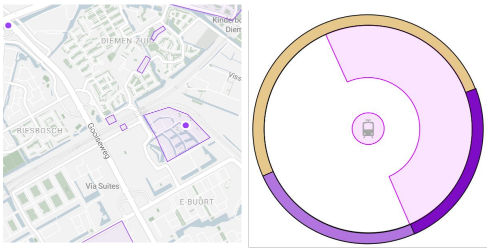

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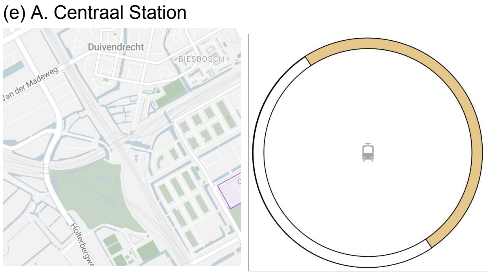
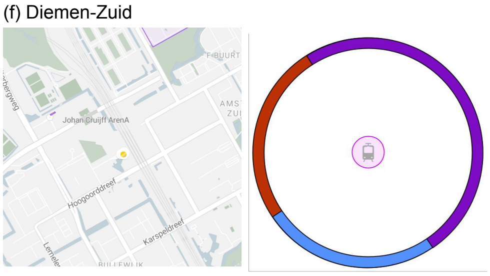


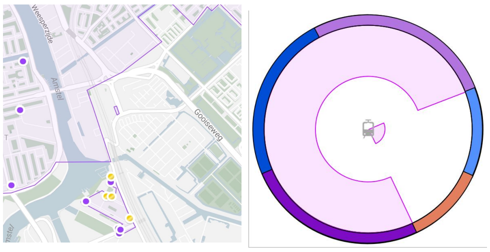
(g) Duivendrecht



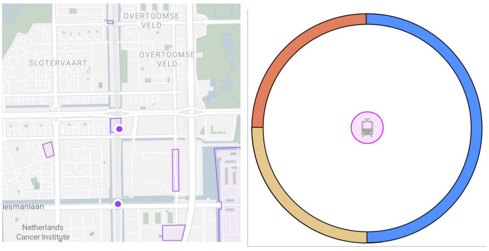
(h) A. Bijlmer ArenA

Figure A.1: Stations of Amsterdam simplified (Check, 2023).

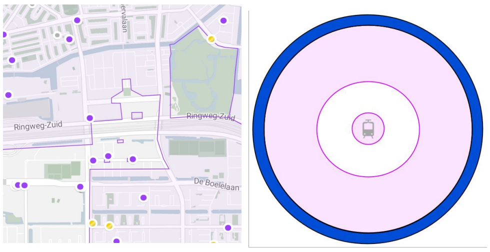
(i) A. Holendrecht



(j) A. Amstel



(k) A. Lelylaan



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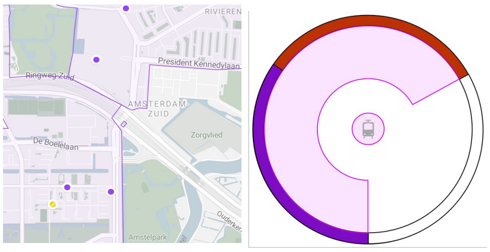

(m) A. RAI

Figure A.1: Stations of Amsterdam simplified (Check, 2023)

Table A.1: $PTII_2$ values of the stations of Amsterdam

Station	$\alpha_I[°]$	$\alpha_H[°]$	$\alpha_P[°]$
A. Centraal Station	90	0	180
A. Sloterdijk	360	0	0
A. Lelylaan	360	0	0
A. Zuid	0	360	0
A. RAI	0	270	0
A. Muidenpoort	0	360	0
A. Amstel	90	0	270
A. ArenA	360	0	0
A. Holendrecht	360	0	0
Duivendrecht	0	0	0
Diemen	180	180	0
Diemen-Zuid	180	180	0
Science Park	360	0	0

Table A.2: $PTII_3$ values of the stations of Amsterdam.

station (i)	$\alpha_{j,k}$[°]									
	Island				Hybrid			Perimeter		
	1	2	3	4	1	2	3	1	2	3
A. Centraal Station	30	60	0	0	0	0	0	90	90	0
A. Sloterdijk	360	0	0	0	0	0	0	0	0	0
A. Lelylaan	180	90	90	0	0	0	0	0	0	0
A. Zuid	0	0	0	0	360	0	0	0	0	0
A. RAI	0	0	0	0	135	135	0	0	0	0
A. Muidenpoort	0	0	0	0	120	120	120	0	0	0
A. Amstel	45	45	0	0	0	0	0	90	90	90
A. ArenA	180	90	90	0	0	0	0	0	0	0
A. Holendrecht	180	90	90	0	0	0	0	0	0	0
Duivendrecht	0	0	0	0	0	0	0	0	0	0
Diemen	180	0	0	0	180	0	0	0	0	0
Diemen-Zuid	90	90	0	0	90	90	0	0	0	0
Science Park	90	90	90	90	0	0	0	0	0	0

Table A.3: Average polygon values of Amsterdam.

Zoning		A_g	A	Scenario	
I	97			A9	600
I	469	299	1.6E-05	A8	164
I	331			A7	509
II	996			A6	210
II	1161	778	4.3E-05	A5	1101
II	176			A4	357
III	138			A3	1028
III	838	510	2.8E-05	A2	104
III	555			A1	1306
IV	814				
IV	295	452	2.5E-05		
IV	246				
V	251				
V	388	433	2.4E-05		
V	661				
VI	328				
VI	128	383	2.1E-05		
VI	693				
VII	532				
VII	302	435	2.4E-05		
VII	470				
A_g	470				597
A	2.6E-05				3.27E-05