19/09/2022

Investment in cycling routes, based on cyclists' delay from GPS data

Within the Municipality of Enschede

Brian Oppers

Final Report

Committee:

Benjamin Groenewolt	–	Supervisor Municipality of Enschede
Baran Ulak	–	Supervisor UT
Joao Oliveira dos Santos	–	Second Supervisor UT

ENSCHEDE

UNIVERSITY OF TWENTE.

Preface

In front of you is the final product of my bachelor thesis research executed at the Municipality of Enschede. The research is about investments in cycling routes, based on cyclists' delay from GPS data, which ties in with what I have been doing for the past years at my bachelor Civil Engineering at the University of Twente. With this research I conclude my Bachelor of Civil Engineering at the University of Twente.

The last weeks I have worked on this research and I have enjoyed it as well. It was a for me the first time working in a new environment such as a municipality. However, during this time I learned a lot about using GPS data, and how the organization of the Municipality of Enschede works. Also, I got a lot more experience using MATLAB as coding language.

For this research I would like to thank multiple people. First Benjamin Groenewolt. He was my supervisor from the Municipality of Enschede. For multiple questions I could contact him, so that I could continue with the research. Next, Baran Ulak from the University of Twente. He guided me through this whole research, which was very useful. I also want to thank Tom Thomas, who guided me in the beginning of my thesis. I want to thank Johan Koolwaaij, from Mobidot B.V., for providing me with the data, and answering all the question I had about the data. Lastly, I want to thank the colleagues at the Municipality of Enschede for giving me a nice atmosphere to work in.

I hope you will enjoy reading my thesis, for questions you can always contact me.

Brian Oppers

Enschede, 19 September 2022

Abstract

In the inner-city centre is the bicycle the most common mode of transport in the Netherlands. To make it cyclists as comfortable as possible in the city centre, the Municipality of Enschede came up with a vision named: "*Fietsvisie Enschede 2030 – Leefbaar, Aantrekkelijk en Bereikbaar per fiets" (Liveable, Attractive and Accessible by Bike).* To reach this vision, the municipality came up with multiple goals: (1) stimulating more cycling in Enschede, (2) that there are less accidents, (3) that cyclists are satisfied. To achieve these goals, the municipality invest, among other things, a lot in cycling infrastructure and cycling routes. This also includes the local cycling network in Enschede. Since 2007, GPS data became more and more important when analysing bicycle traffic. The Municipality of Enschede uses an app, Enschede Fietst, to stimulate people to take the bike instead of the car. The municipality wants to know how and if the gathered data from this app can be used to determine a priority of routes, they should invest. Afterwards, they want to know how they can invest in this route. The aim of this research is to determine in which local cycling route the Municipality of Enschede should invest in to achieve their vision goals, based on the data from the app. Eventually, this research should determine how they can invest in this route.

The data that is used in this research is data from approximately 2000 persons over a timespan of 52 week in 2021, and consist out of the segment, time, duration, and distance of the user. With this data the total time delay per meter is calculated by subtracting the expected travel time from the real travel time. The total time delay per meter is used to calculate the total costs per meter for each segment. This is done by multiplying this delay with the value of time, which is €14.91 per hour. This resulted in route 4 having the highest priority with a total cost of €150.- per meter. Route 4 is the route from the city centre to Marssteden, a business area in the west of Enschede. Afterwards, the total costs per meter for each segment in route 4 is calculated. Looking at the results the segments Tweede Emmastraat, crossing of Volksparksingel, the Borstelweg, and the Parkweg have the highest priority. The second highest priority is the segment that crosses the Auke Vleerstraat.

After the segments with the highest priority were determined, the requirements and characteristics of a local cycling route were determined. This resulted in a list, which exists of requirements and characteristics a local cycling route should meet. For example, a closed pavement (asphalt), no speed bumps, no elevation, and a low number of intersections with cars.

Finally, the segments with the highest priority are compared with the requirements and characteristics a local cycling route should meet. The result was that the segment crosses the Auke Vleerstraat, already met most of the requirements and characteristics. Therefore, no appropriate improvements are suggested for this segment. When comparing the other segments with the requirements and characteristics this resulted in more suitable improvements. For the Tweede Emmastraat and Borstelweg, these improvements include changing the surface from stones to asphalt, remove the speed bumps, and increase the attractiveness by adding water, green and trees. For the crossing with the Volksparksingel, and Parkweg the improvement is to increase the space for cyclist to wait for the traffic lights.

Table of Contents

Table of Figures

Table of Tables

1. Introduction

The introduction consists of four different sections. The first section describes the problem context for this research. In the second section are the research aim and research questions described. Next, in section 3, the boundaries of this research are mentioned, related to study area, and data. Lastly, in the fourth section, a reading guide is provided.

1.1. Problem context

When it comes down to the inner-city centre, the bicycle is the most common mode of transport in The Netherlands. In every city there are more bikes than inhabitants (Van der Meer 2019). Since there are so many cyclists in The Netherlands, the roads need to be comfortable for cyclists to cycle on.

It sounds easy to make sure that cyclists cycle comfortable in a city. However, it is not. Since there are a lot of different routes within a city and between cities. For example, there are routes from one city to another city, from neighbourhood to neighbourhood, from university to the city centre, or from houses to the supermarkets or from the city centre to people's homes. It can be said there are many more routes within a city.

One of the main cities in The Netherlands regarding bicycle traffic is Enschede. The Municipality of Enschede wants to make cycling in Enschede as pleasant as possible (Enschede 2021). They want to make sure that cyclists feel safe and comfortable in the inner city of Enschede. Therefore the Municipality came with a vision named: "*Fietsvisie Enschede 2030 – Leefbaar, Aantrekkelijk en Bereikbaar per fiets" (Liveable, Attractive and Accessible by Bike)* (Groenewolt, et al. 2021).

In "*Fietsvisie Enschede 2030"*, the Municipality has set up three important goals to achieve before 2030. These goals are:

1. More cycling in Enschede.
2. Less accidents involving cyclists in Enschede.
3. Satisfaction of cyclists in Enschede.

To achieve these different goals the municipality invests, among other things, a lot in cycling infrastructure and different cycling routes. The bicycle network in Enschede consists out of four different categories. First, the regional cycling routes. Second, the local cycling routes (Dutch: "Doorfietsroutes"), third the basic cycling routes, and last the recreative cycling routes.

Next to the fact that there are more bicycles in the Netherlands, the use of GPS data became more important to analyse bicycle traffic in recent years. The first time GPS data was used to analyse bicycle traffic was in 2007 (Harvey and Krizek 2007). In 2010, the mobile phone was for the first time used to obtain GPS data in Los Angeles (Reddy, et al. 2010). GPS data can be used to estimate traffic volume, deciding the cyclist route choice, safety analysis and the estimation of bicycle traffic parameters. These parameters consist of accelerations, delays, and speed (Pogodzinska, Kiec and D'Agostino 2019). In Enschede there is an app called *"Enschede Fietst-app",* from Mobidot B.V., which stimulates people to take the bike instead of the car (Gemeente Enschede n.d.), with the use of some rewards. This app collects of GPS data from the users.

In the end, the municipality of Enschede wants to invest in local cycling routes within Enschede to achieve their goals they have for 2030. They want to know how and if GPS data, which is collected from the app, can be used to determine the priority of local cycling routes. With this data they can determine in which route they should invest. Lastly, they want to know how the local cycling routes can be improved.

1.2. Research aim and questions

This research will focus on the local cycling routes within the municipality of Enschede. How can these routes be improved by the municipality and how can they determine the priority of these routes. This is done by using the available data from the Enschede Fietst-app. This results in the aim of this research:

To determine which local cycling route should the municipality of Enschede invest in first to achieve their vision goals, with the use of GPS data from the app and eventually how they can invest in this route.

There are two main subjects that come forward in this research aim. These are the use of data from the Enschede Fietst-app to determine in which local cycling route the municipality should invest in, and the second subject is about how the municipality can invest in this route. Based on this there are two main questions that can be formulated to reach the research goal:

1. ***"Which local cycling route or segment should the municipality of Enschede invest in, based on their priority?"***
2. ***"How can the municipality improve the local cycling route or segment that needs to invest in based on the prioritizing?"***

To answer the first question, first two other questions should be answered. These questions are based on which local cycling routes need to be analysed and how the data should be used to determine the route or segment priority.

1.1 "Which local cycling routes need to be analysed, based on the demands of the municipality of Enschede?"

1.2 "How can the available data be used to determine the priority of routes which the municipality should invest in?"

The second question has also one sub question that is based on the requirements of local cycling routes.

2.1 "What are the characteristics and requirements of a good local cycling route"

1.3. Boundaries of research

In this section the study area and used data is described. Next to this, the boundaries and limitations of both are described as well.

1.3.1. Study Area

The study area of this research is the city of Enschede. Enschede has a large infrastructure network existing of car roads and bicycle roads. The bicycle roads are connected in a bicycle network as mentioned in the problem context. This bicycle network can be seen in Figure 1 (Groenewolt, et al. 2021). In here the blue lines are the regional bicycle routes. These are recognizable routes for medium distances with maximal comfort and minimal delay. These routes are going from the inner-city centre of Enschede to Hengelo, Oldenzaal, Losser, Gronau and Haaksbergen. The yellow lines are the basic bicycle network. These have a safe access to neighbourhoods, schools, shopping centres and business areas with a normal comfort and delay. Lastly, there are the green lines. These are the local cycling routes. These routes connect residential and commercial areas within Enschede, from the neighbourhoods to the city centre and Enschede west. Preferably, these routes are disconnected from distributor roads and have a high comfort and limited delay. Since the network of local cycling routes consists of multiple routes, segments and taking the limitation of research time into consideration.

Only a couple of routes are analysed in this research. How these routes are determined and what the routes are, will be discussed in, respectively section 3.2.1 and 4.1. The municipality is specifically interested in the routes that need new connections.

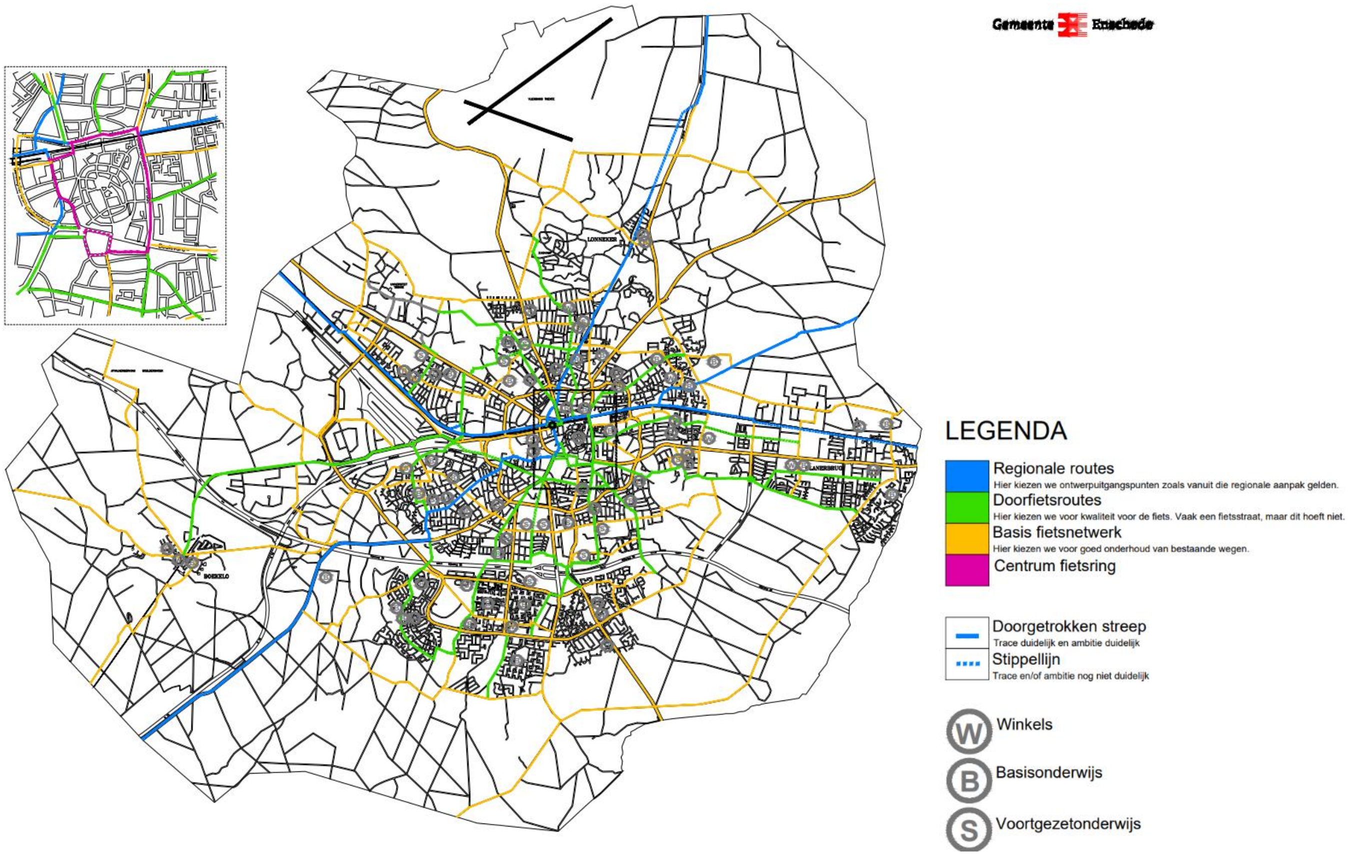

Figure 1: Bicycle network of Enschede (Enschede 2021)

1.3.2. Data

The data that is used in this research consist of two different types. The first data that is used, is gathered from the Enschede Fietst-app, as mentioned in the problem context (1.1). The app registers different data regarding the users on specific roads segments. The data that is used consists of four different variables. These variables are given in Table 1 with each his description. The wayid variable is used to determine on which segment the cyclists was cycling. The variable time is used to determine if the trip was inside or outside the peak hours. Determining the time delay for each cyclist can be done with the duration and distance of each cyclist.

Table 1: Variables of the data and their description

Nr	Variable	Description
1	wayid	OpenStreetMap (OSM) segment ID number
2	Time	Time on the day of cycling
3	Duration	Segment duration in seconds
4	Distance	Segment distance in meters

The dataset consists of aggregated data of approximately 2000 persons over a timespan from 52 weeks in 2021. In the dataset only the segments (wayid in Table 1) that are used by at least 10 different people are shown. Map matching the data has already been done by Mobidot B.V. Furthermore, it is important to know that the data is anonymized. This means, that from the data no individual person can be found and it is important regarding the behaviour of users. This will be elaborated in section 2.2. However, the used data has also its limitations. The first limitation is that the point speed is zero. This means that the intersections within the network do not exist in the data. Which in that only the segments itself can be analysed. The second limitation consists of the data only being available for each different segment sperate. This means that no trips can be included in the analysis.

The segments in de available data from the app, are related to OpenStreetMap (OSM). In Figure 2, an example of such a road segment in OSM is shown. Every road segment in OSM has its own unique ID number, and surface (in this case 30976742, and asphalt). OSM is a project, with as goal to make a map which can be edited and accessed free (OpenStreetMap n.d.). The advantage of using OSM is that every road and segment has its own ID number, as mentioned before. This makes it easier to match certain data to specific roads. However, there is also a disadvantage of OSM. Since everyone can edit OSM, it is a less reliable source.

Figure 2: Example of segment in OSM (OpenStreetMap n.d.)

1.4. Reading Guide

In this chapter, the research has been introduced with the problem context, research aim and questions and the boundaries. In the remaining part, the research will be elaborated further. First in chapter 2, with the theoretical background. This is separated into three parts, the local cycling routes, GPS data, and influences on the speed of cyclists. In the following chapter, chapter 3, the methodology of the research is explained. Here will be described how the different questions will be answered. In chapter 4 the results of this research are discussed. Afterwards, in chapter 5, there will be a discussion regarding the research, a conclusion will be provided in chapter 6. Finally, in chapter 7, a recommendation for further research is given.

2. Theoretical background

In this chapter, the background of this study is explained. This is done in three different subjects. First the local cycling routes. There is investigated what are quality levels and principles of local cycling routes in the Netherlands. Next, there is investigated how GPS data has changed research and what you can and cannot do with it. Lastly, literature research is done about the influences of cyclists' speed. The reason for doing this, is because the speed of cyclists is used for this research.

2.1. Local cycling routes

In a study from 2022 about the local cycling routes in Gooi & Vechtstreek (Ruiter and Van Bekkum 2022), quality level and principles of local cycling routes are discussed. A high-quality local cycling route should increase the number of cyclists on these routes, according to Ruiter and Van Bekkum. Ruiter & Van Bekkum supply information on what makes a local cycling route a quality level route on several different aspects. The first aspect is the pavement and comfort of the route. A comfortable local cycling route is a route without obstacles, elevation difference, root pressure or speed bumps. Also, the underground should exist of a closed pavement (like asphalt) and no elements pavement (like clinkers or tiles). The second aspect that Ruiter & Van Bekkum are mentioning is that the local cycling routes should be well lighted. This will increase the safety of the road itself. The last aspect is the signage. The signage should ensure that it is directly clear when you cycle on a local cycling route.

A second study about the local cycling route 'De Groene As' (Rozema and Praamstra 2020) gives requirements about certain quality for local cycling routes. The first requirement is the directness of the routes. The local cycling routes should be in a straight line as possible, such that the routes will be attractive. The second requirement relates to the safety of the road. Specific here is the number of intersections with other traffic, like the car. The third requirement is related to the cohesion within the bicycle network. It should be clear for a cyclist that a certain road is part of a bigger network for cyclists. The fourth requirement is about comfort of the cyclists. Rozema & Praamstra are describing that annoyance of other road users and weather have an influence on the comfort for cyclists. Next to that it is mentioned that a local cycling route needs a closed pavement, like asphalt or concrete. This is consistent with what Ruiter & Van Bekkum state. The fifth, and last, requirement is the attractiveness. A local cycling route should increase the pleasure in cycling.

Next to these two studies, the municipality of Enschede has its own vision regarding local cycling routes (Enschede 2021). In here, they mentioned that the attractiveness of a cycling route decreases the experienced travel time of a cyclist. The factors that play a role are the variety and quality of the environment. This includes green, trees, water, architectural interesting buildings, but also facilities such as signage and benches. Besides attractiveness the main point of bicycle roads is usage. These kinds of roads should lead to better behaviour of car users and less car use in that particular street. Also, the traffic flow for crossing streets with traffic lights are mentioned in their vision. One of the solutions to increase the traffic flow is to create more space for cyclists before traffic lights. Resulting in more cyclists starting cycling at the same time. A second solution is the use of an app. With a specific app, cyclists can get a green light faster than cyclists without this app.

A study from Arjen Klinkenberg in 2018 (Klinkenberg 2018) is focused on the influence of person characteristics, natural environment and spatial structure on route choice behaviour of cyclists. The cycling routes in the province Utrecht are the basis of the study. Among other things, Klinkenberg looked at the influence of infrastructure such as the separation of modes, number of obstacles, the land use, the urban design, like the type of paving and road width, and the attractiveness of the non-naturally shaped landscape. The results of this study were that the separation of modes, type of paving, and the road width have the most influence on the route choice of a cyclists. Against that, the number of obstacles and how crowded the road is, have the least influence on the route choice.

2.2. GPS data

A study about GPS data in bicycle planning from 2020 gives a recommendation about how a representative GPS dataset for bicycle traffic should look like (Lißner, et al. 2020). In the study the researchers used an online survey to create a group of 200 participants within the city of Dresden. These participants placed themselves, via an online survey, in 4 different types of users: Passionate, Pragmatic, Functional and Ambitious. With this, the researchers wanted to have a look if the type of user has an influence on the behaviour of cyclists. These 200 participants were, after the survey, tracked with GPS during a two-week field study. From this field study, the researchers concluded that the type of users had only a low influence on the cycling behaviour of people. However, they concluded that the variables gender, age, and trip purpose are significantly correlated on people's cycling behaviour. According to Lißner and the other researchers, is it important for planners and researchers when they use GPS cycling data, to filter the data or check the sample for gender, age and trip purpose (Lißner, et al. 2020).

A second study about speed, travel time, and delay for intersections and road segments in Montreal from 2017 (Strauss and Miranda-Moreno 2017). This study proposes an approach for how to use GPS data to estimate cyclists travel times, delays, and speed on a road network. An important part of this research is that the data used is anonymous. This results in the cyclist's behaviour not being affected by their trips (Strauss and Miranda-Moreno 2017). In this study they use a methodology with eight different steps to have a final segment speed model. With the use of this methodology the researchers obtained average speeds from cyclists along different type of roads (arterials and non-arterials), but also on different times of a day or riding up- or downhill. Besides, the fact that people can estimate peoples speed, travel times, and delay from the GPS data, the use of GPS data also have some limitations according to Straus and Miranda-Moreno. One limitation is the representativeness of the sample. Since several groups such as males and younger people, are more represented in the data. The second limitation is the self-selection of trips. This means that the researchers cannot say with certainty that the user stops the application when change modes (Strauss and Miranda-Moreno 2017).

A third study that make use of GPS data is about predicting bicycle travel speeds along different facilities (El-Geneidy, Krizek and Iacono 2007). In this study, the researchers focus on predicting the travel times and speeds from cyclists on different types of facilities and conditions along a network. In here, the researchers have only a small number of people, eight to be specific, who were participating within the study. To these people a GPS unit to register their trips was attached. An important fact in this study is that the people did not know this data was used to create a speed model. The result of this study shows that it is possible to gather bicycle travel speeds regarding different facilities. However, out of this study also comes forward that it is difficult to determine, with only GPS data, if a slower speed is the result of a congestion or that maybe other factors have played a role. This could be for example the fatigue of the cyclists or bad pavements conditions.

2.3. Influences on speed of cyclists

There are several studies regarding the speed of cyclists. The speed of cyclists is important for this study because the expected travel time needs to be determined. A paper from Keypoint Consultancy (Keypoint 2018) gives answers on some myths about cycling. It is shown that e-bikes cycle on average faster than non-e-bikes, since people can cycle faster with a small motor. A second myth that is discussed is about that people cycles faster when it is bad weather. According to Keypoint, this is true. The average speed of cyclists is about 0.5 km/h faster when the weather is bad (Keypoint 2018). The last myth that Keypoint discussed is that people cycles faster when the road is better. According to them, people cycle faster when the road surface is better and when there are fewer side streets on their route.

A second study shows the results of cyclists' speeds when there is a combined pedestrian and cycle path (Eriksson, et al. 2019). Data sources from the measurements of cyclists' speed in three different Swedish municipalities, Eskilstuna, Linköping, and Stockholm are used. The result of this study is that the average cyclists' speed varied between the 12.5 km/h and 26.5 km/h. However, the lower average speeds were found near intersections and uphill directions, while the higher average speeds were found on commuter routes and downhill. A second result of this study is that there is almost no difference in cyclists' average speed throughout the day, week, and year.

A third study focuses on the influence of surfaces on the cyclists' speed (Toljic, Brezina and Emberger 2021). For this study the speed of 3750 cyclists is measured with a radar gun. This is tested on seven different surfaces:

- Smooth and rough asphalt.
- Painted cycle lanes.
- Concrete.
- Gravel.
- Large and small cobblestones.

The result of this study shows that there is a weak correlation between the mean cyclists' speeds on these surfaces. This mean speed lies between the 23.0 km/h and 29.8 km/h, with gravel the lowest mean speed and concrete the highest mean speed. Secondly, this study gives results about the braking distance on each surface related to the surfaces. This is an important factor for the safety of cyclists. The braking distance varied from 8.7 meters, from rough asphalt to 11.7 meters for concrete. From this study it can be concluded that there is only a weak correlation between the surface of the road regarding the cyclists' speeds.

In another study about volunteered mass cycling self-tracking data (Schnötzlinger, Brezina and Emberger 2021), they examined, among other things, how cyclists' speed is influenced by the type of cycling infrastructure in Vienna. In here the cycling infrastructure is categorised by the organisational form which all covers one or more infrastructure type:

- On-street mixed: Dedicated cycle route; Mixed traffic
- On-street marked: Multi-purpose lane; Bicycle lane
- Off-street: Mixed foot and bicycle path; Separated foot and bicycle path
- Traffic-calmed: Residential street; Shared space; Pedestrian area

The results of the average speeds are for on-street mixed 22.86 km/h, on-street marked 22.63 km/h, off-street 21.25 km/h, and for traffic-calmed 18.03 km/h. From these results can be concluded that there is only a miner difference between the average speeds for the first three categories, while the last category, traffic-calmed, has significantly less high average speed. The study about cyclists' speeds at combined pedestrian and cycle path (Eriksson, et al. 2019) confirms these results.

In a fifth study is about bicycle travel speed and disturbances, the difference in cycling speed due to disturbance is analysed (Bernardi and Rupi 2015). This research has been executed in Bologna, Italy. Researchers looked into the influence of different types of disturbances was on the cyclists' speed. The disturbances were: Bikes in same direction, bikes in opposite directions, 1 to 3 pedestrians, 4 or more pedestrians, two-wheeled vehicles, 1 car or more, 1 bus or more, and heavy vehicles. The results of this study were that the influence of the disturbances can divided into three groups. The bikes in the same direction, bikes in opposite directions, and two-wheeled vehicles has a speed reduction between 0% and 10%. The second group consists of the disturbances of 1-3 pedestrians and 4 or more pedestrians. These disturbances have a speed reduction between 15% and 30%. The last group consists of the 1 car or more, 1 bus or more, and heavy vehicles. This group has a speed reduction of 30% or higher. The conclusion is that when there are bigger disturbances for cyclists, the speed will be reduced.

3. Methodology

In this chapter, the methodology of this research is explained. First, a schematic overview of the methodology is given. Then in section two, the methodology for the routes is explained, while in the last section the methodology for the investment is discussed.

3.1. Conceptual model

In Figure 3, the conceptual model of this research is provided. This model gives an overview on all the steps that are taken in this research to give answers on the different research questions. In the following two sections, 3.2 and 3.3, the methodology of the route choice, use of data and how to invest in the route are explained.

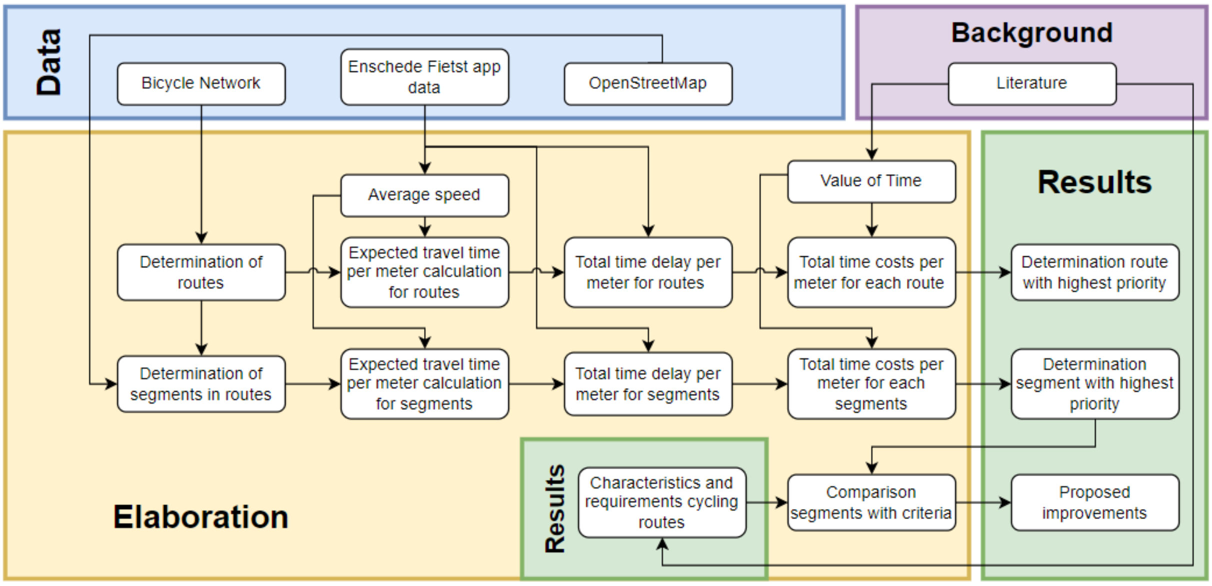

Figure 3: Schematic overview of the methodology

3.2. Routes

The first research question is about which local cycling route or segment should have priority for the municipality of Enschede to invest in. This is done by comparing the total costs per meter caused by delay of each segment in the peak hours (7:00 h – 9:00 h and 16:00 h – 19:00 h) (Boers 2022). There is no distinguishing between different times of years because there is almost no difference in speed throughout the year (Eriksson, et al. 2019). Based on the total costs per meter, is concluded which route or segment should have the highest priority, the one with the highest total costs per meter. In the following two sections it is first discussed how the different routes that will be analysed are selected. Then how to determine the total costs per meter of each route and segment is discussed.

3.2.1. Selection of routes

Which local cycling routes should be analysed is based on the demands of the municipality of Enschede. The municipality created a bicycle network with several local cycling routes which is shown in Figure 1 in section 1.3.1. Within this network several routes are created. These routes will be elaborated with the available data. How this is done is described in the following section.

3.2.2. Calculation of total costs per meter

To calculate the total costs for each segment the value of time (VoT) in the Netherlands for cyclists is used. The VoT of cyclists for commuting travel was €13,43 per hour in 2014 (van Ginkel 2014). The inflation in the period from 2014 till 2021 is 11.06% (CBS 2022). This results in a VoT of €14.91 per hour, which is €0,004 per seconds. The total costs for each segment and route are calculated with

Equation 1. The available data from Mobidot B.V., which is explained in section 1.3.2, is used to calculate the total time delay per meter for each segment and route. The total time delay per meter is calculated with Equation 2. This is the sum of all the separate time delays per meter at that segment. With Equation 3, the time delay per meter per cyclist is calculated by subtracting the expected time duration per meter from the real time duration per meter. The real time duration per meter is calculated with the data from Mobidot B.V. This can be done by dividing the real duration with the distance of the segment, as shown in Equation 4. Equation 5 is used to calculate the expected time duration per meter for each cyclist. For the calculation of the expected duration, the recorded cycling speeds are used.

Elizabeth Knap used in her study the recorded speeds of cyclists to determine an average speed (Knap 2022). The same method is used here, which resulted in an average speed of 21.5 km/h, which is 5.97 m/s. In Appendix A: Average speed, the determination of the average speed of the cyclists is shown. For each cyclist the same expected speed is used, since from studies discussed in section 2.3, came forward there is almost no difference between cyclists' average speed throughout the day, week and year (Eriksson, et al. 2019) and there is only a weak correlation between the surface of the road and cyclists' speeds (Toljic, Brezina and Emberger 2021). Since the expected time duration per meter needs to be known and the same speed is used, the expected time duration per meter is for everyone the same, which is 0.17 seconds.

$$Costs = D_{total,meter} \times VoT$$ *Equation 1*

Where:

$Costs$ = the total costs per meter of a segment or route [€].

$D_{total,meter}$ = the total time delay per meter of a segment or route [seconds].

VoT = Value of Time [€ / seconds].

$$D_{total,meter} = \sum D_{j,meter}$$ *Equation 2*

Where:

$D_{j,meter}$ = the time delay per meter for a segment or route for cyclist j [seconds].

$$D_{j,meter} = D_{real,j,meter} - D_{expected,j,meter}$$ *Equation 3*

Where:

$D_{real,j,meter}$ = the real time duration per meter for a segment or route for cyclist j [seconds].

$D_{expected,j,meter}$ = the expected time duration per meter of the segment for cyclist j [seconds].

$$D_{real,j,meter} = \frac{D_{real,j}}{Distance}$$ *Equation 4*

Where:

$D_{real,j}$ = the real time duration of the segment for cyclist j [seconds].

$Distance$ = the distance of the segment [meter].

$$D_{expected,j,meter} = \frac{Distance}{Speed_{average}} = \frac{1}{5.97} = 0.17\ s$$ *Equation 5*

3.3. Investment

To determine how the municipality of Enschede can invest in specific routes or segments, first the characteristics and the requirements of a local cycling route are determined. This is done by using the literature research about local cycling routes. It is difficult to determine the reason why a road segment or route has a slow speed based on GPS data (El-Geneidy, Krizek and Iacono 2007). For this reason, the characteristics and requirements for local cycling routes are extracted from the studies of Ruiter and Van Bekkum and Rozema and Praamstra. Next to the characteristics and requirements based on the literature, there is also investigated in the Fietsvisie (Enschede 2021) and the assessment frameworks for public space in Enschede (Dutch: "Toetsingskader openbare ruimte") (Gemeente Enschede 2022). The results of all these characteristics and requirements are shown in section 4.3. Afterwards, in section 4.4, the segments with the highest priority are compared with all the characteristics and requirements of these local cycling routes. Based on this comparison, there is investigated how the segments can be improved to decrease the costs of the segments.

4. Results

In this chapter, the results are given. The results are split in four different parts. First, the results of which routes are analysed is given. Then, the results of the prioritising of the routes and segments are discussed. In the third section, the results of the characteristics and requirements for local cycling routes are listed. Lastly, the proposed improvements for the segments, with the highest priority, are discussed, based on the characteristics and requirements of the third sections.

4.1. Selection of routes

In this section the different routes that are analysed is shown. As mentioned in section 1.3.1 the municipality has preference for the routes that are not finished. Therefore, there are seven different routes determined. They are respectively, in the direction of Eschmarke, Vaneker, Helmerhoek, Marssteden, University of Twente, Glanerbrug, and Hogeland. These routes are shown in Figure 4. Four of these routes include a dashed line which means the routes have preference for the Municipality. These are route 1, 2, 3 and 4. In Appendix B: Routes, all the different segments of all these seven routes are listed with their road name and segment ID number. As can be seen in Figure 4, routes 3 & 4 and routes 6 & 7 have some overlap in segments. These segments are considered in both routes.

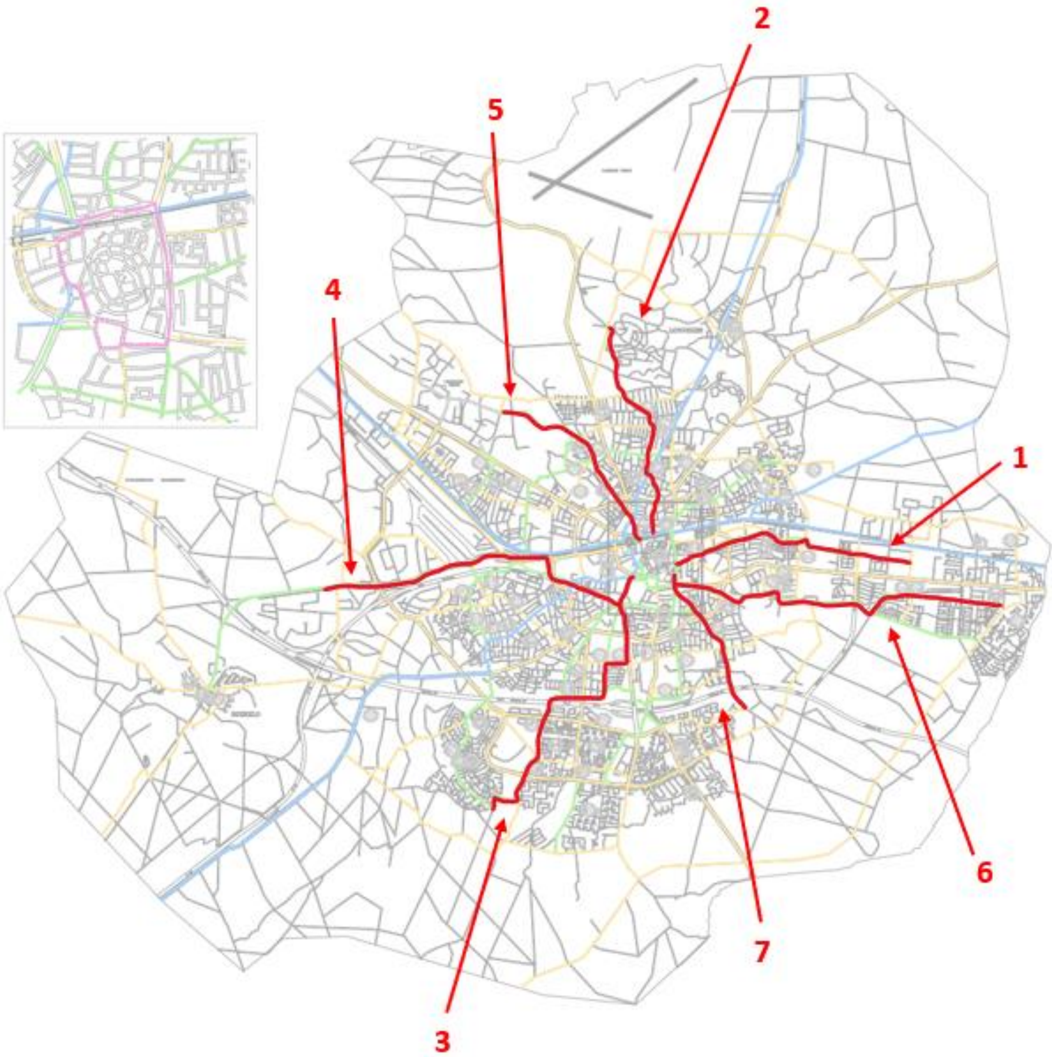

Figure 4: Local cycling routes that are analysed

4.2. Order of priority

In Figure 5 the results of the total costs per meter for each route is shown. Here can be seen that there is only a small difference between the routes 2 till 7. It can also can be seen that route 4 has the highest priority of all the seven different routes, with a value of €150.-. Route 4 is the route that goes from the city centre to business park Marssteden in the west of Enschede. Therefore, the total costs per meter of the segments in route 4 are compared. These results are shown in Figure 6. The segments are from the city centre to Marssteden. There are several segments after each other that have a high total cost. This results in these segments having the highest priority. Next to these segments, there is another segment with relatively high costs at the end of the route. In Figure 7 the location of the two highest priorities is shown. On the left, the blue star, is the segment with the second highest priority which crosses the Auke Vleerstraat, and on the right, the purple star, the six consecutive segments with the highest priority. These are the Tweede Emmastraat, crossing of the Volksparksingel, the Borstelweg, and Parkweg. The high amount of costs of these segments can come due to the fact that not all the surface exists out of a closed pavement, and that there is not wide parking area in front of the traffic lights. For the second highest priority segment, the high costs can be due to bridge which is located there. In section 4.4, these possible causes of high results due to their characteristics are discussed and a possible improvement is provided.

In Figure 8 the total number of users of each route is given. Interesting here is that route 4 has almost the lowest number of users, while route 2 and route 6 has a high number of users. This can be the result that route 4 going in the direction of a business park. Only people that work there need to go in that direction. Routes 2 and 6 on the other hand go to residential areas. In Figure 9, the total number of users per segment in route 4 is shown. Here, it is visible that almost the entire route the number of users is the same. Except for the beginning and one segment in the middle of the route. For the beginning of the route this can be due to the fact that people cycling a little bit different to the city centre then the local cycling route. For the segment in the middle of the route this can be due to the fact that this segment is located next to a big intersection between the Parkweg and Hendrik ter Kuilestraat. In Appendix C: Results of routes, the total delay of the segments in route 4 is shown. Next to that, the results of the segments of the other routes are also shown, with a small map of the locations with the highest priority on that specific route.

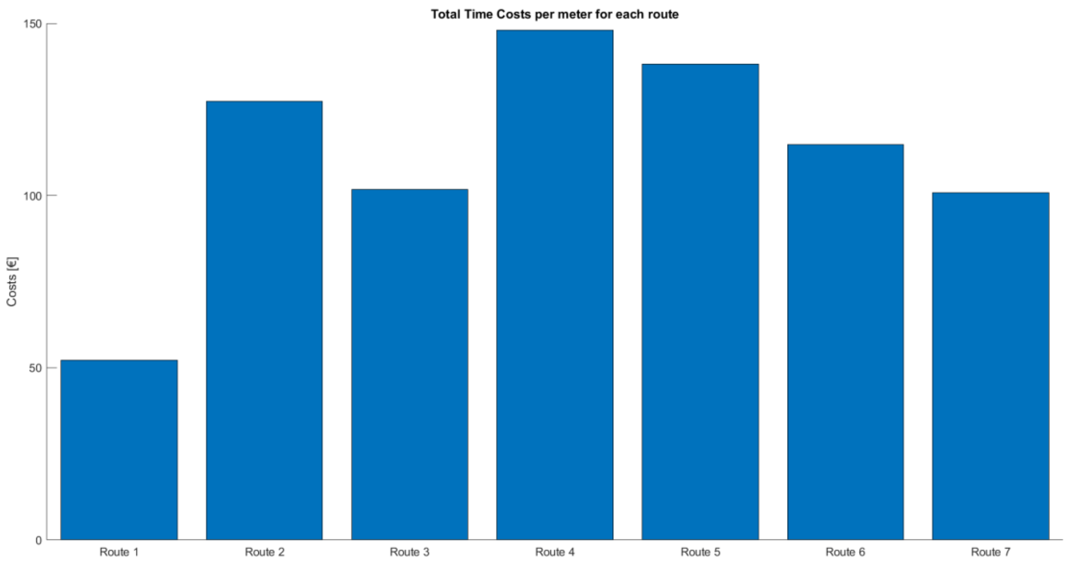

Figure 5: Total time costs per meter for each route

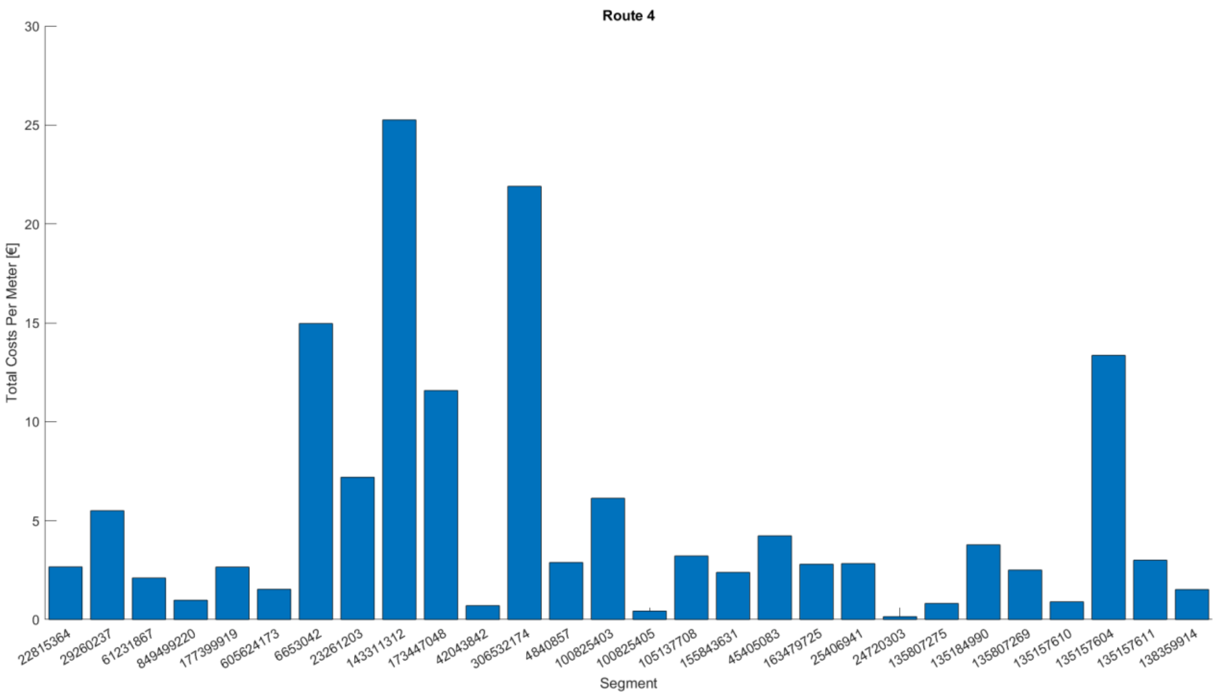

Figure 6: Total costs per meter for the segments of route 4

Figure 7: Segments on route 4 with the highest priority, on the right (purple star), and the second highest priority, on the left (blue star)

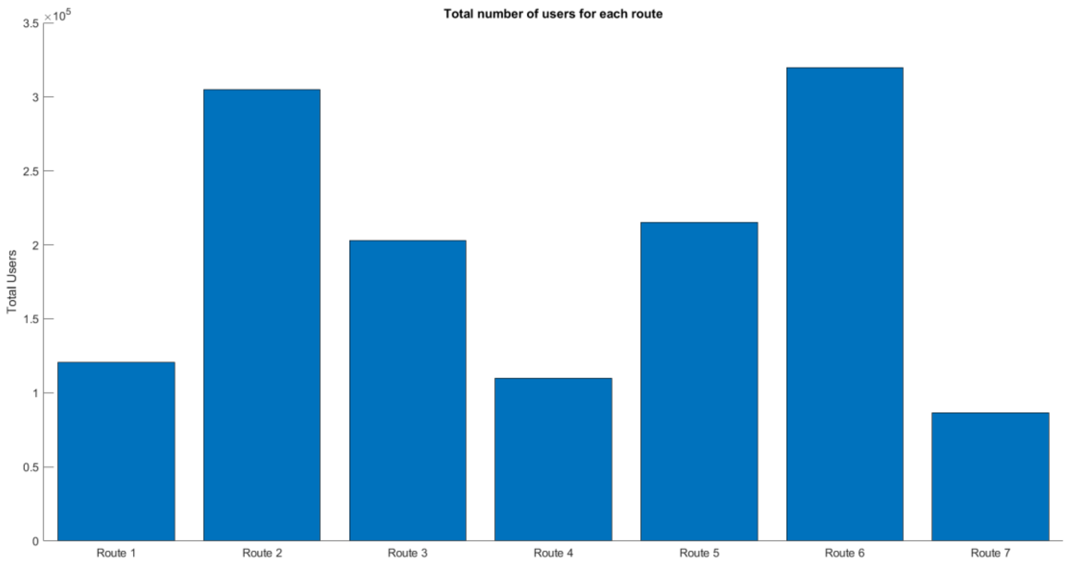

Figure 8: Total number of users of each route

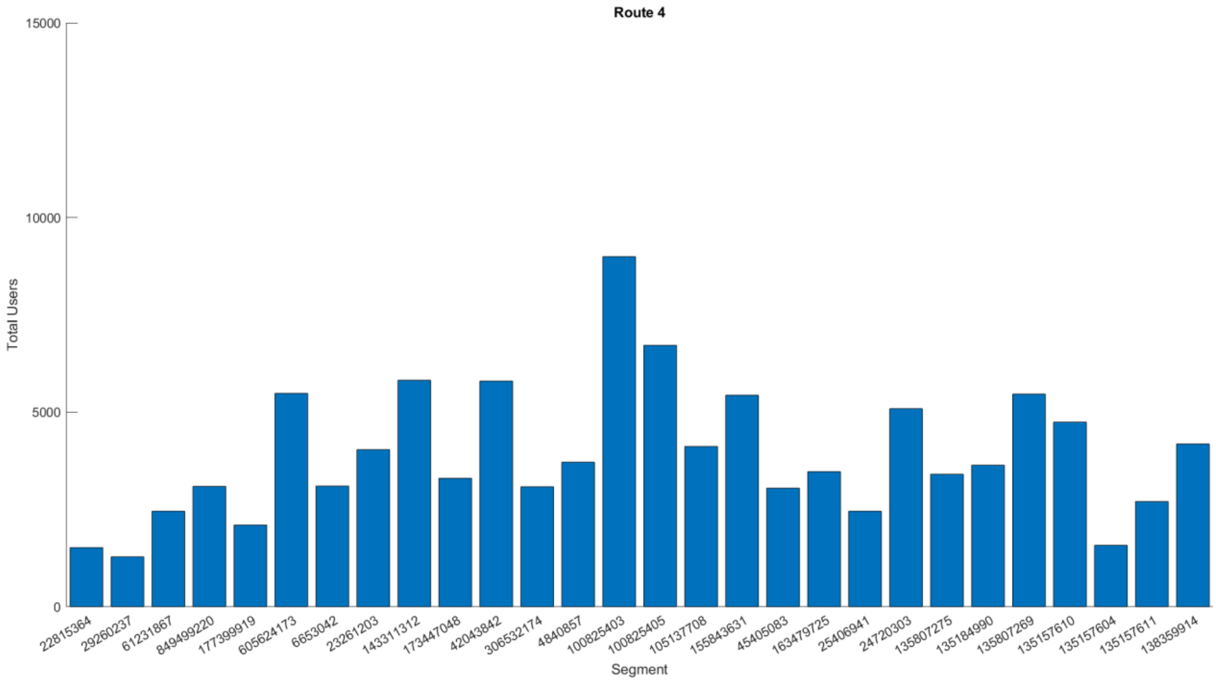

Figure 9: Total number of users of each segment in route 4

4.3. Characteristics and requirements

From the studies of Ruiter and Van Bekkum (R & vB), Rozema and Praamstra (R & P), Fietsvisie, and assessment frameworks for public space in Enschede (TOR) several characteristics and requirements of local cycling routes are extracted. Below, these characteristics and requirements are listed in two different categories. First the category of design choices. Secondly the category of maintenance. The list of design choices is the largest one, because in here the basis of the cycling route will be determined. There is no priority between all the characteristics and requirements. The reason for this is there is no clear prioritisation has been given in literature.

Design choices

- A local cycling route should have a closed pavement (like asphalt) – (R & vB), (R & P) and (TOR)
- A local cycling route should have a low number of intersections with cars – (R & P)
- A local cycling route should not have any obstacles – (R & vB)
- A local cycling route should not have a lot of elevation difference – (R & vB)
- A local cycling route should not have speed bumps – (R & vB)
- A local cycling route should have a good connection with the bicycle network – (R & P)
- Bicycle lanes within urban areas have the colour red – (TOR)
- If possible, there is a preference for free-flowing bicycle lanes – (TOR)
- Wide parking area for cyclists in front of intersections, improves traffic flow – (Fietsvisie)
- The routes should be attractive for cyclists, with green, trees and water – (Fietsvisie)

Maintenance

- A local cycling route should not have root pressures – (R & vB)
- A local cycling route should be well lighted – (R & vB)
- A local cycling route should have good signage – (R & vB)

4.4. Investment

In this section the possible investment in the segments with the highest priority and second highest priority are described.

4.4.1. Highest Priority

The segments with the highest priority on route 4, are located closer to the city centre. In Figure 10 these segments are shown. As mentioned in section 4.2, these segments are, as seen from the city centre, the Tweede Emmastraat, crossing of the Volksparksingel, the Borstelweg, and Parkweg. In the next part, all these segments are compared separately.

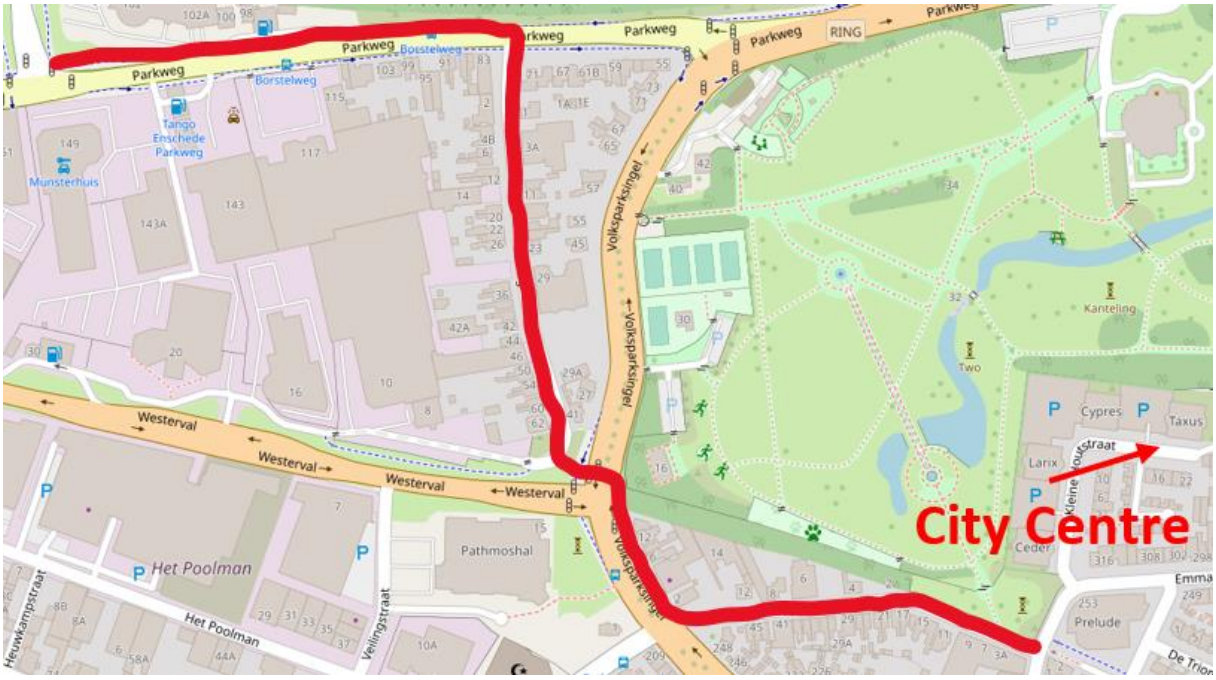

Figure 10: Segments with the highest priority (OpenStreetMap n.d.)

Tweede Emmastraat

In Figure 11, the situation of the Tweede Emmastraat as of September 2022 can be seen. In here can be seen that several characteristics of a local cycling route not met. The first one is that it does not exist of a closed pavement. Currently, there are stones and no asphalt. Next to that, there is a speed bump in the middle of the segment. Also, when looking at the street, it is not attracting cyclists with water, green and or trees. Therefore, this segment can be improved by changing the surface from stones to asphalt, removing the speed bump and increase the attractiveness by adding some more green and water.

Figure 11: Situation of the Tweede Emmastraat as of September 2022

Crossing of the Volksparksingel

In Figure 12, the current situation of the crossing is shown. In here can be seen that some requirements are met. For example, the road exists of asphalt, the colour is red, and it lies free from the car road. However, there is not much space for cyclists to wait for the traffic lights. This will decrease, according to Fietsvisie, the traffic flow. Therefore, this segment can be improved by making more space for cyclist to wait for the traffic lights.

Figure 12: Situation of the crossing of the Volksparksingel as of September 2022

Borstelweg

In Figure 13, the current situation of the Borstelweg is shown. The situation of this segment is like the one of the Tweede Emmastraat. The road exists of stones and no asphalt and due to the connection of the pavement and the road, there is not that much green for the attractiveness. Therefore, an improvement here is also similar to the Tweede Emmastraat: changing the surface to asphalt and increase the attractiveness with more green and some water.

Figure 13: Situation of the Borstelweg as of September 2022

Parkweg

In Figure 14, the current situation of the Parkweg is shown. Here can be seen that this segment consists of a sperate bicycle lane with a closed surface of asphalt. Also, this segment does not have much intersection with other traffic, no elevation and no obstacles. However, there is only one small piece on the segment that does not meet the characteristics. On the right picture can be seen that there is almost no place for cyclists to park in front of the traffic lights. The reason for this can be the high amount of costs for this segment. Therefore, the possible improvement of this segment is to increase the space for cyclists to park before the traffic lights.

Figure 14: Situation of the Parkweg as of Augustus 2022 (Google Maps 2022)

4.4.2. Second highest priority

The segment with the second highest priority is located at the crossing of the local cycling route and the Auke Vleerstraat. This is segment is shown in Figure 15 between the two red lines. Here can be seen that this segment already met most of the characteristics and requirements of a local cycling route. The colour is red, it has no obstacles, it has a closed pavement, it has no intersection with cars, it has no speed bumps, has a good connection with the other bicycle network, and it is attractive for cyclists. However, there is an elevation difference in this segment because it crosses the Auke Vleerstraat with a bridge, this can cause the higher costs for this segment. Important to know is that this segment has already been changed in 2011. Before the current situation, the bicycle lane crossed the Auke Vleerstraat on the same level as can be seen in Figure 16, between the two red lines. This results, that there is no elevation, but there is an intersection with cars, and it has obstacles, like traffic lights. Therefore, it is difficult to say if this segment can be improved regarding the requirements and characteristics of a local cycling route.

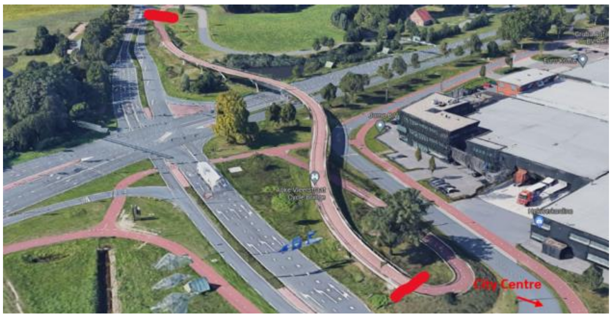

Figure 15: Segment with the highest priority (Google Maps 2022)

Figure 16: Segment with highest priority before 2011 (Bicycle Dutch 2013)

5. Discussion

The research aim is to come up with a priority of the local cycling routes for the municipality of Enschede and give an indication in how they can improve the segments with the highest priority. This is done by using the methodology from chapter 3. However, in this chapter will be discussed what is not considered and what are some shortcomings within the methodology, that could have an influence on the results.

First there is the use of MATLAB. Since the available data was too big for MATLAB, it was necessary to split up the data into ten different parts. This is not a nice way to analyse data, because more steps are taken to analyse the data. This can result in some data may be lost or duplicated within the research.

Secondly, the choice to select only seven routes from the local cycling network. Due to the limited time for this research, there is chosen to only analyse the seven most important routes for the municipality. The priority of these seven routes is still in the correct order. However, when there is more time to analyse all the routes within the local bicycle network, this priority could change. There could possible be another route which has a higher priority using the method in this research.

Third, there is a limitation on the available data. The data is anonymized and consist only of data of specific segments. Therefore, age, gender, trip motivation, type of bike, and trip direction cannot be considered. When this is available, the priority can be based on more different aspects, which can lead to different results.

Fourth, there are some constraints with the use of the data and some variables. First, the elevation difference of all the segments is not considered. This is done, because it increased the calculation time for MATLAB, which was one limitation of this research. In the literature stated that elevation has an influence on cyclists' speeds. However, the elevation difference within one segment in Enschede is not that big. Therefore, the segments with elevation difference will have a slightly higher value then others. Secondly, the number of trips is calculated by searching for gaps in time in the data. This is done because there was no data available of trips for all the segments. It can be that there is a small error in the number of trips per segment. However, this will not lead to a big difference in results. The third constraint is about the average speed of the cyclists. This average speed is determined by a normal distribution. This number is on the high side for the Netherlands. This can be caused by a high number of e-bikes. Nevertheless, it is not known on which bikes the people where driving during the trips. The last constraint about the data is that the intersection speed is zero. This means that there can only be looked into the segments itself. However, it could be that some intersections have the most delay of a route.

Lastly, this research is only based on data and literature. From the results of the segment priority come some interesting segments with the highest priority. However, there is not investigated what the difference in priority is when improving the segments. So it could be that after improving the segments, the priority will stay the same. Nevertheless, when comparing these segments with the requirements and characteristics, can be seen that they do not meet all the requirements and characteristics. So, it seems the method works to determine a priority.

6. Conclusion

The aim of this research was to determine a priority for the municipality of Enschede for the local cycling routes, in which they should invest in first. This is based on the available data from the Enschede Fietst app. Next, also how they can invest in the route with the highest priority. Therefore, multiple research questions and sub questions have been formulated. Here, the conclusions of these question will be discussed. First the sub questions will be discussed. Then the conclusions of the two main questions will be discussed.

1.1 "Which local cycling routes need to be analysed, based on the demands of the municipality of Enschede?"

For this question, the local bicycle network from Enschede, as given in Fietsvisie 2030 is used. It shows that there are several local cycling routes to neighbourhoods and business areas. The preference for the municipality lies on the routes and segments that are not finished yet. Concluded, this resulted in a total amount of seven different routes, which of four exists of not finished segments. These routes are respectively, in the direction of Eschmarke, Vaneker, Helmerhoek, Marssteden, University of Twente, Glanerbrug, and Hogeland.

1.2 "How can the available data be used to determine the priority of routes which the municipality should invest in?"

The conclusion of this question is to calculate the total costs per meter for each segment. To calculate the total costs per meter, the value of time, and total time delay per meter are necessary. The value of time is €14.91 per hour / €0.004 per second. While the total time delay per meter is calculated based on the expected travel time and the real travel time. The expected travel time is calculated with the average cyclists' speed. This speed is determined with a distribution of all the cyclists' speeds, which resulted in an average speed of 21.5 km/h. The real travel time is extracted from the available data from the Enschede Fietst app.

2.1 "What are the characteristics and requirements of a good local cycling route"

To answer this question, literature is used. Based on the literature about the principles and quality measurements of local cycling routes from Ruiter and Van Bekkum, Rozema and Praamstra, and the municipality of Enschede, a list of characteristics and requirements is made. This list consists, among other things, that local cycling routes should have asphalt, no speed bumps, and a good attractiveness by adding green, water and trees.

1. "Which local cycling route or segment should the Municipality of Enschede invest in, based on their priority?"

The conclusion of the first main question is route 4. After calculation, the total costs per meter for each route, route 4 has the highest costs of €150 per meter. This results that route 4 have the highest priority of all the different routes. Route 4 is the route that goes from the city centre to the business park Marssteden on the west of Enschede. Within route 4 there are two different places which have priority. The highest priority is the combination of segments of the Tweede Emmastraat, crossing of the Volksparksingel, the Borstelweg and the Parkweg. The second highest priority is the segment crossing the Auke Vleerstraat. These are the segments which have the highest priority for the Municipality to invest in.

2. ***"How should the municipality improve the local cycling route or segment that needs to invest in based on the prioritizing?"***

On this question there are two different conclusions. For the segment with the second highest priority, there is probably no improvement possible. Since in 2011 most of the requirements and characteristics for a local cycling route are already met when changing the intersection. The only requirement and characteristic that is not met, is the elevation. However, when changing the intersection back to how it was used to be, it can cause a high amount of costs due to the other requirements and characteristics. For segments with the highest priority, there is some improvement possible. For the Tweede Emmastraat and Borstelweg, these improvements are changing the surface from stones to asphalt, remove the speed bumps, and increase the attractiveness with more water and green. While for the crossing of the Volksparksingel and the Parkweg, the space for cyclists waiting for the traffic lights should be increased, to increase the traffic flow and speed.

7. Recommendations

In this chapter several recommendations are made, for the implementation of this research and for further research.

As already mentioned in the discussion, it is not investigated if the results are working. Therefore, it is recommended to implement one or multiple improvements on the segments. Afterwards, data from a new time period can be used, to check if the specific segment has a lower priority than before.

For further research, investigations can be made about adding requirements for the priority. Currently, the priority is only based on the total time costs per meter of each segment. However, it could be interesting to also research the safety of each segment or the implementation of costs of redesigning the segment. To make it easier to add them, the results of the total time delay per meter are already transformed to costs.

Another interesting addition of this research could be to implement the delay at intersections as well. Currently, this is not done due to the available data. However, it could be interesting to have a look in which intersections have a high amount of costs as well.

Bibliography

Bernardi, Silvia, and Federico Rupi. 2015. "An analysis of bicycle travel speed and disturbances on off-street and on-street facilities." Bolgona. doi:10.1016/j.trpro.2015.01.004.

Bicycle Dutch. 2013. *Cycle Bridge Enschede.* 28 February. Accessed September 08, 2022. https://bicycledutch.wordpress.com/2013/02/28/cycle-bridge-enschede/.

Boers, Joost. 2022. *ZO VERMIJD JE FILES EN DRUK VERKEER TIJDENS DE SPITS.* 18 Februari. https://www.autoweek.nl/verkeer/zo-vermijd-je-files-en-druk-verkeer-tijdens-de-spits/?referrer=https%3A%2F%2Fwww.google.com%2F#:~:text=In%20het%20algemeen%20kun%20je,tussen%2016.00%20en%2019.00%20uur.

CBS. 2022. *Consumentenprijzen.* 6 September. Accessed September 08, 2022. https://opendata.cbs.nl/statline/?dl=3F0E#/CBS/nl/dataset/83131NED/table.

El-Geneidy, Ahmed, Kevin J. Krizek, and Michael Iacono. 2007. *PREDICTING BICYCLE TRAVEL SPEEDS ALONG DIFFERENT FACILITIES.* Paper, School of Urban Planning, Transportation Research Board. doi:10.1.1.526.2095.

Enschede, Gemeente. 2021. *Fietsvisie 2030: Enschede gaat voor (nog) meer, beter en veiliger fietsen!* 26 Januari. https://enschedefietsstad.nl/fietsvisie2030/.

Eriksson, Jenny, Åsa Forsman, Anna Niska, Susanne Gustafsson, and Cunilla Sörensen. 2019. *An analysis of cyclists' speed at combined pedestrian an cycle paths.* Taylor & Francis. doi: 10.1080/15389588.2019.1658083.

Gemeente Enschede. n.d. *Enschede Fietst-app.* https://enschedefietsstad.nl/enschede-fietst-app/.

Gemeente Enschede. 2022. "Toetsingskader Openbare Ruimte."

Google Maps. 2022. *Google Maps.* Accessed September 08, 2022. https://www.google.nl/maps/@52.216874,6.8394706,79a,35y,294.75h,69.25t/data=!3m1!1e3.

Google. n.d. *maps.google.* Accessed 08 16, 2022. https://www.google.com/maps/search/google+maps+verwijzen/@52.2341817,6.9043856,14z/data=!3m1!4b1.

Groenewolt, Benjamin, Kees Lems, Richard ter Avest, Martijn Ruijgers, and Iris Lansink. 2021. "Fietsvisie Enschede 2030 Leefbaar, Aantrekkelijk en Bereikbaar per fiets."

Harvey, Francis J., and Kevin Krizek. 2007. *Commuter Bicyclist Behavior and Facility Disruption.* St. Paul: Minnesota Department of Transportation. https://trid.trb.org/view.aspx?id=811576.

Keypoint. 2018. *Mythbusting: Over fietsen, feiten en fabels.* Paper, Keypoint Consultancy. https://www.keypoint.eu/upfiles/Mythbusting_-_over_fietsen_feiten_en_fabels.pdf.

Klinkenberg, Arjen. 2018. *Schoonheid of comfort? De fietser.* Utrecht: Universiteit Utrecht.

Knap, Elizabeth. 2022. *Developing a composite indicator for the 15-minute city concept based on.* Master Thesis, Enschede: University of Twente.

Lißner, S., S. Huber, P. Lindemann, J. Anke, and A. Francke. 2020. *GPS-data in bicycle planning: "Which cyclist leaves what kind of traces?".* Dresden: Elsevier Ltd. doi:https://doi.org/10.1016/j.trip.2020.100192.

MathWorks. n.d. *What is MATLAB.* Accessed 08 16, 2022. https://nl.mathworks.com/discovery/what-is-matlab.html.

OpenStreetMap. n.d. *OpenStreetMap.* Accessed 08 16, 2022. https://www.openstreetmap.org/way/30976742#map=19/52.21980/6.90157&layers=D.

Pogodzinska, Sylwia, Mariusz Kiec, and Carmelo D'Agostino. 2019. *Bicycle Traffic Volume Estimation Based on GPS Data.* Cracow University of Technology, Lund University, Rome: Elsevier B.V. doi:10.1016/j.trpro.2020.02.081.

Reddy, Sasank, Katie Shilton, Gleb Denisov, Christian Cenizal, Deborah Estrin, and Mani Srivastava. 2010. *Biketastic: Sensing and Mapping for Better Biking.* Atlanta: Center for Embedded Networked Sensing. University of California at Los Angeles (UCLA), Los Angeles, CA 90095. doi:10.1145/1753326.1753598.

Rozema, Mervin, and Hans Praamstra. 2020. *Doorfietsroute De Groene As deeltraject Sluis De Punt - Witte Molen.* Groningen: Sweco. https://node1.123dok.com/dt12pdf/5doknet/000/681/681497.pdf.pdf?X-Amz-Content-Sha256=UNSIGNED-PAYLOAD&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Credential=7PKKQ3DUV8RG19BL%2F20220622%2F%2Fs3%2Faws4_request&X-Amz-Date=20220622T121322Z&X-Amz-SignedHeaders=host.

Ruiter, Ross, and Peter Van Bekkum. 2022. *Uitwerking doorfietsroutes Gooi en Vechtstreek.* Sweco & MuConsult. https://www.regiogv.nl/wp-content/uploads/2022/04/Rapportage-uitwerking-prioritaire-doorfietsroutes-Gooi-en-Vechtstreek.pdf.

Schnötzlinger, Patrick, Tadej Brezina, and Günter Emberger. 2021. *Volunteered mass cycling self-tracking data – grade of.* Vienna: Taylor & Francis. doi:https://doi.org/10.1080/23249935.2021.1948929.

Strauss, Jullian, and Luis F. Miranda-Moreno. 2017. *Speed, travel time and delay for intersections and road segments in the Montreal network using cyclist Smartphone GPS data.* Department of Civil Engineering and Applied Mechanics, McGill Universit, Montreal: Elsevier Ltd. https://doi.org/10.1016/j.trd.2017.09.001.

Toljic, Marko, Tadej Brezina, and Guenter Emberger. 2021. *Influence of surface roughness on cyclists' velocity choices.* ICE Publishing, 2 - 13. doi:10.1680/jmuen.18.00058.

Van der Meer, Sophie. 2019. *Nederland heeft meer fietsen dan mensen en het worden er alleen maar meer.* 07 December. Accessed June 15, 2022. https://nos.nl/nieuwsuur/artikel/2313742-nederland-heeft-meer-fietsen-dan-mensen-en-het-worden-er-alleen-maar-meer.

van Ginkel, Jeroen. 2014. *The value of time and comfort in bicycle appraisal.* Enschede: University of Twente - Faculty of Engineering Technology.

Appendices

Appendix A: Average speed

In Figure A 1 the recorded cycling speeds from the data is shown in a distribution. This distribution is a normal distribution with mode at 21.5 km/h. That the number is on the higher side could be due to a high number of e-bikes. The numbers close to zero can be caused by a short distance of the trip.

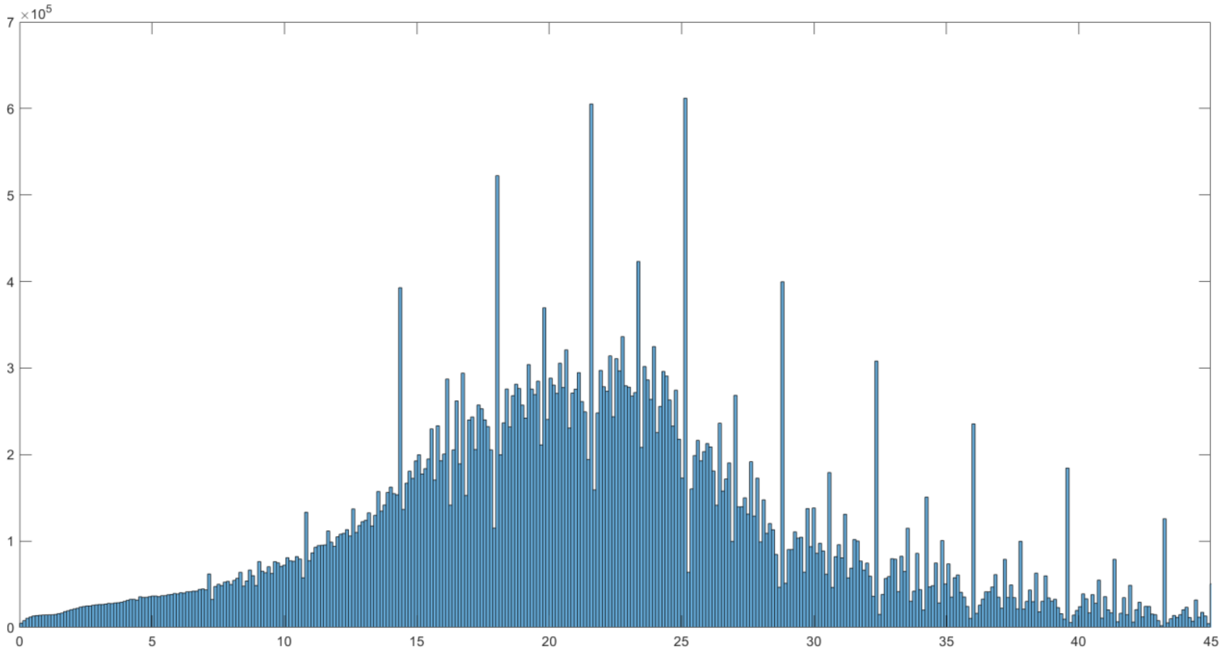

Figure A 1: Cycling speeds

Appendix B: Routes

Table B 1: Route 1

Name of road	Segment ID number
De Klomp	30976742
De Klomp	6651775
Lipperkerkstraat	6651813
Lipperkerkstraat	6651740
Lipperkerkstraat	6651709
Lipperkerkstraat	6651913
Lipperkerkstraat	6651915
Lipperkerkstraat	6651682
Lipperkerkstraat	6651857
Lipperkerkstraat	6650156
Lipperkerkstraat	227231258
Lipperkerkstraat	6650209
Lipperkerkstraat	6650211
Lipperkerkstraat	6650201
Lipperkerkstraat	6650332
Lipperkerkstraat	6650269
Lipperkerkstraat	6650318
Lipperkerkstraat	6650320
Noord Esmarkerrondweg	164602330
Noord Esmarkerrondweg	164681025
Sleutelweg	314578977
Sleutelweg	6650275
Sleutelweg	249293481
Sleutelweg	162851270
Sleutelweg	321556866
Sleutelweg	1040568655
Sleutelweg	14578982
Sleutelweg	6649855
Louis Bothastraat	6649885
Louis Bothastraat	6649919

Table B 2: Route 2

Name of road	Segment ID number
Willem Brakmanstraat	6652128
H.B. Blijdensteinlaan	6660886
H.B. Blijdensteinlaan	6660390
H.B. Blijdensteinlaan	6660789
H.B. Blijdensteinlaan	6660833
H.B. Blijdensteinlaan	6660350
Museumlaan	6660403
Museumlaan	6660653
Museumlaan	6660628
Museumlaan	6660584
Lonnekerspoorlaan	30976737
Lonnekerspoorlaan	344111892

Name of road	Segment ID number
Lonnekerspoorlaan	30198687
Roomweg	6660721
Stroinksbleekweg	6660852
Stroinksbleekweg	6660880
Stroinksbleekweg	6660618
Stroinksbleekweg	6660649
Stroinksbleekweg	6660427
Stroinksbleekweg	960664030
Stroinksbleekweg	6660440
Stroinksbleekweg	6660661
Stroinksbleekweg	6660494
Lijsterstraat	6660966
Dollardstraat	6660493
Dollardstraat	6660298
Winkelcentrum Deppenbroek	221663204
Winkelcentrum Deppenbroek	30099707
Winkelcentrum Deppenbroek	30099708
Waalstraat	6660280
Waalstraat	6660299
Waalstraat	6660519
Waalstraat	6660502
Waalstraat	960664017
Vanekerstraat	6660985
Vanekerstraat	315532434
Vanekerbeekweg	6660929
Vanekerbeekweg	6660932
Vanekerbeekweg	6660976
Vanekerbeekweg	177900025
Zuidkampweg	813912630
Zuidkampweg	274807720

Table B 3: Route 3

Name of road	Segment ID number
Zuiderval	868878022
Zuiderval	863910976
Zuiderval	177400794
Zuiderval	28378622
Zuiderval	23219789
Zuiderval	6652478
Zuiderval	6652558
Zuiderval	452148264
Weghouder Beverstraat	23224835
Weghouder Beverstraat	6652976
Utrechtlaan	6652869
Utrechtlaan	181656179
Utrechtlaan	6652838
Utrechtlaan	6652747
Zuidhollandlaan	6652854

Name of road	Segment ID number
Zuidhollandlaan	6652940
Zuidhollandlaan	6652857
Bicycle path under A35	27156902
Bicycle path under A36	23285384
Bicycle path under A37	75613079
Bicycle path under A38	75613078
Bicycle path under A39	23267088
Bicycle path under A40	23267089
Bicycle path under A41	23266986
Bicycle path under A42	170849298
Bicycle path under A43	314263828
Bicycle path under A44	170849301
Bicycle path under A45	314263827
Geessinkweg	32937491
Geessinkweg	403503660
Geessinkweg	605624179
Geessinkweg	314263829
Geessinkweg	883761543
Geessinkweg	711078121
Geessinkweg	711078122
Geessinkweg	266222325
Geessinkweg	711078123
Geessinkweg	32886654
Geessinkweg	711080310
Geessinkweg	883761541
Geessinkbraakweg	6654618
Geessinkbraakweg	711080311
Usselermarkweg	26194279
Bicycle path in Helmerhoek	26194231

Table B 4: Route 4

Name of road	Segment ID number
Bicycle Path & Blekerpad & Korte Boog	22815364
Bicycle Path & Blekerpad & Korte Boog	29260237
Bicycle Path & Blekerpad & Korte Boog	61231867
Bicycle Path & Blekerpad & Korte Boog	849499220
Bicycle Path & Blekerpad & Korte Boog	177399919
Enschede-Ahaus	623584537
Tweede Emmastraat	605624173
Tweede Emmastraat	6653042
Volksparksingel	23261203
Volksparksingel	143311312
Borstelweg	173447048
Borstelweg (crossing)	42043842
Parkweg	306532174
Parkweg	4840857
Parkweg	100825403
Hendrik ter Kuilestraat	100825405

Name of road	Segment ID number
Hendrik ter Kuilestraat	105137708
Hendrik ter Kuilestraat	155843631
Hendrik ter Kuilestraat	45405083
Hendrik ter Kuilestraat	163479725
Hendrik ter Kuilestraat	25406941
Hendrik ter Kuilestraat	24720303
Hendrik ter Kuilestraat	135807275
Strootsweg	135184990
Strootsweg	135807269
Bicycle path till Marssteden	135157610
Bicycle path till Marssteden	135157604
Bicycle path till Marssteden	135157611
Bicycle path till Marssteden	138359914

Table B 5: Route 5

Name of road	Segment ID number
Deurningerstraat	6652447
Deurningerstraat	1006309857
Deurningerstraat	461216775
Deurningerstraat	6661028
Deurningerstraat	753778395
Deurningerstraat	753778398
Deurningerstraat	6660793
Deurningerstraat	718104852
Deurningerstraat	753567881
Deurningerstraat	718104032
Kottendijk	732031344
Kottendijk	6660359
Kottendijk	6660373
Kottendijk	6660751
Kottendijk	6660593
Kottendijk	6661602
Kottendijk	6661616
Kottendijk	6661527
Mozartlaan	6661449
Mozartlaan	6661344
Mozartlaan	174858487
Doctor Zamenhoflaan	6661661
Doctor Zamenhoflaan	6661715
Doctor Zamenhoflaan	6661694
Doctor Zamenhoflaan	6661745
Doctor Zamenhoflaan	291443306
Viermarkenweg	6661747
Viermarkenweg	6661728
Viermarkenweg	291443307
Viermarkenweg	34205971

Table B 6: Route 6

Name of road	Segment ID number
Boulevard 1945	164686069
Boulevard 1946	164687540
Heutinkstraat	6651760
Heutinkstraat	6651807
Heutinkstraat	6651810
Heutinkstraat	6651957
Heutinkstraat	6651987
Heutinkstraat	823098877
Tegelerweg	6650345
Tegelerweg	6650495
Tegelerweg	6650348
Tegelerweg	6650351
Wooldrikshoekweg	914093335
Wooldrikshoekweg	823101061
Wooldrikshoekweg	463339615
Wooldrikshoekweg	6650421
Stenversweg	55424096
Zuid Esmarkerrondweg	437109596
Zuid Esmarkerrondweg	463339616
Keppelerdijk	242878198
Keppelerdijk	6650066
Keppelerdijk	103019761
Keppelerdijk	44807256
Moerasspirealaan	44807258
Moerasspirealaan	112632472
Moerasspirealaan	6650030
Waterkerslaan	6650028
Waterkerslaan	6649842
Waterdriebladlaan	6650083
Waterdriebladlaan	6650082
Waterdriebladlaan	6650080
Waterdriebladlaan	6650111
Vederkruidlaan	6650109
Keppelerdijk	6650067
Keppelerdijk	6650106
Keppelerdijk	6650064
Keppelerdijk	6650065
Keppelerdijk	6650108
Keppelerdijk	164184234
Keppelerdijk	878579017
Keppelerdijk	878579016
Keppelerdijk	6650112
Keppelerdijk	6649624

Table B 7: Route 7

Name of road	Segment ID number
Mooienhof	8018425
Ledeboerstraat	563738157
Brinkstraat	6651705
Brinkstraat	6651790
Brinkstraat	6651789
Brinkstraat	6651815
Brinkstraat	6651896
Brinkstraat	6651963
Brinkstraat	6652058
Hogelandsingel	6652056
Brinkstraat	6651606
Brinkstraat	579229723
Brinkstraat	6651649
Brinkstraat	6651627
Brinkstraat	1040630863
Brinkstraat	163029947
Brinkstraat	163028955
Brinkstraat	6651648
Brinkstraat	6651636
Brinkstraat	6650530

Appendix C: Results of routes

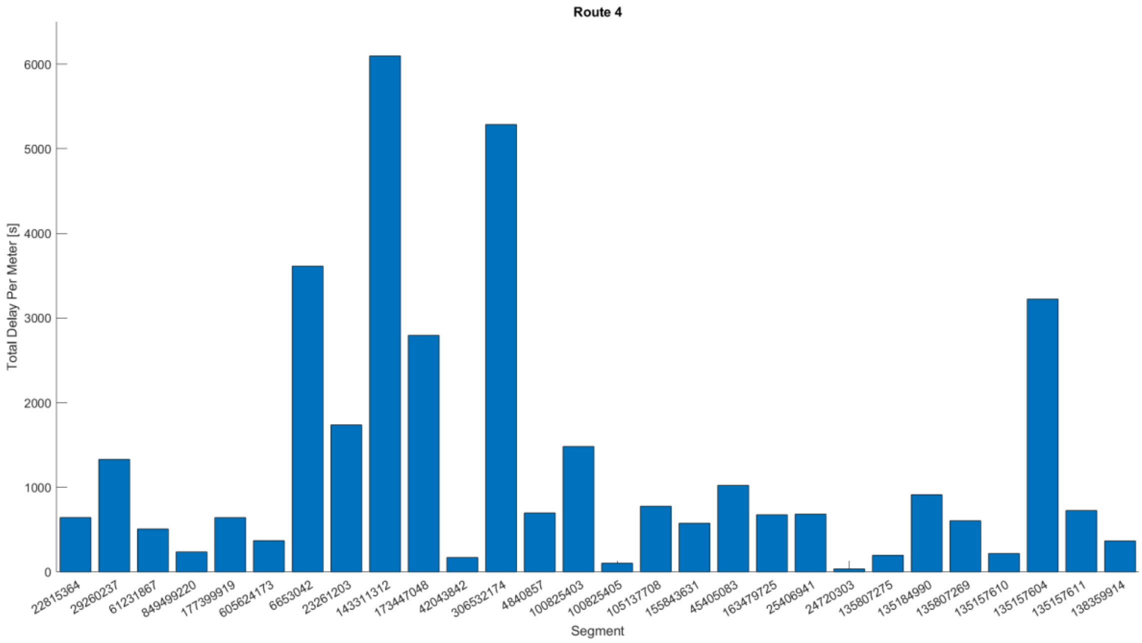

Figure C 1: Total delay per meter for the segments of Route 4

Route 1

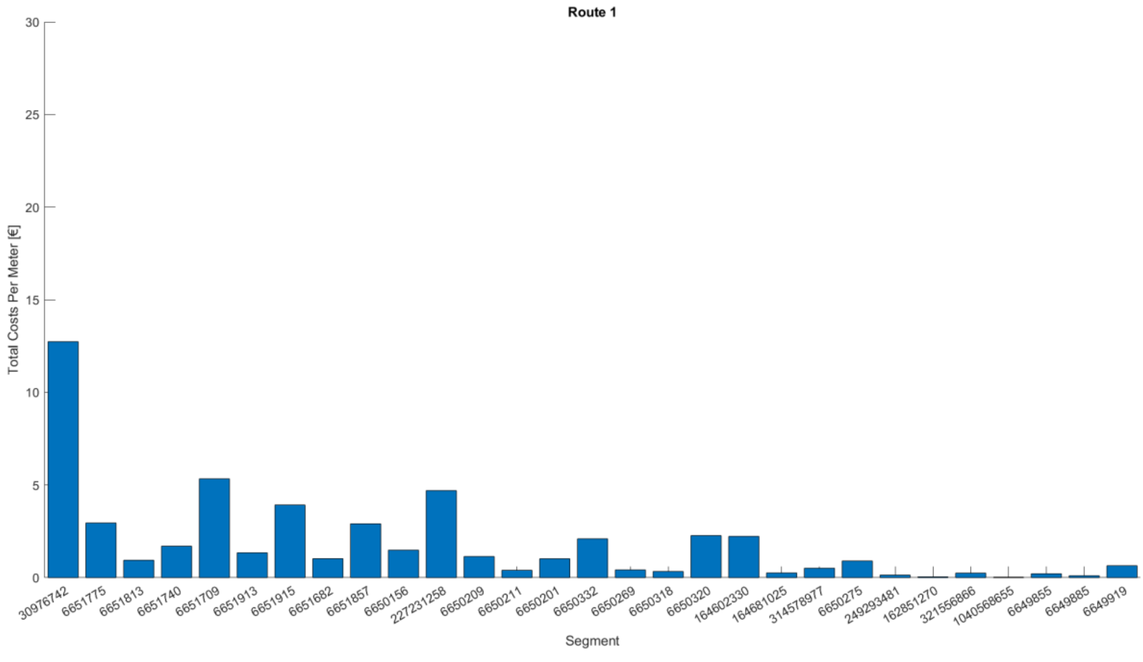

Figure C 2: Total costs per meter for the segments of Route 1

Figure C 3: Segment with the highest priority in Route 1

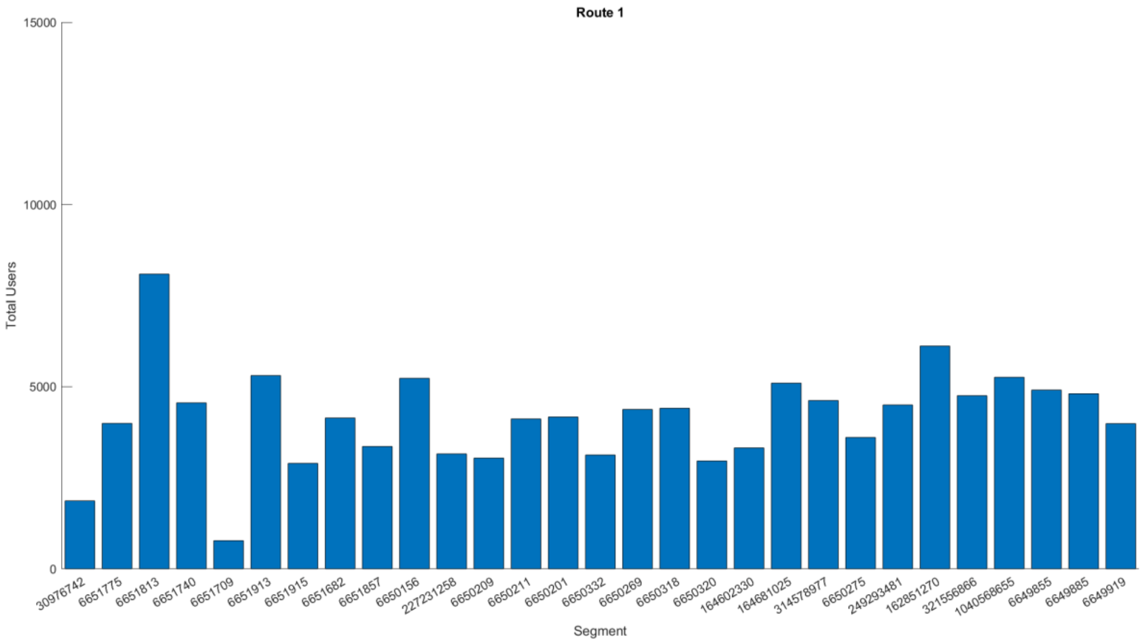

Figure C 4: Total number of users of each segment in Route 1

Route 2

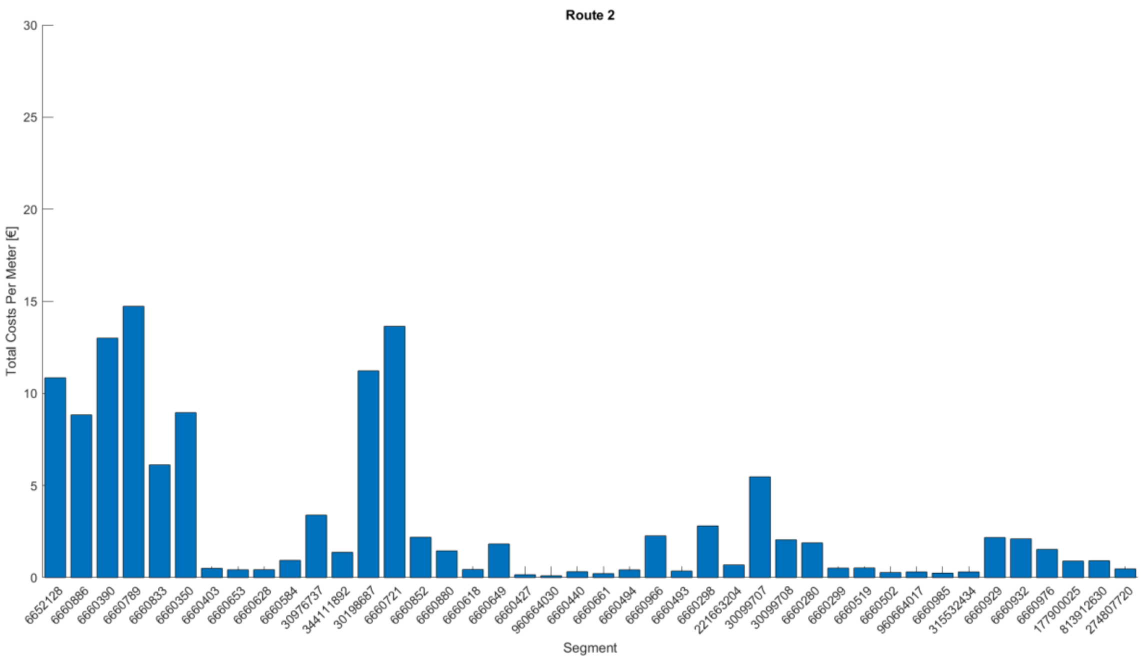

Figure C 5: Total costs per meter for the segments of Route 2

Figure C 6: Segments with the highest priorities in Route 2

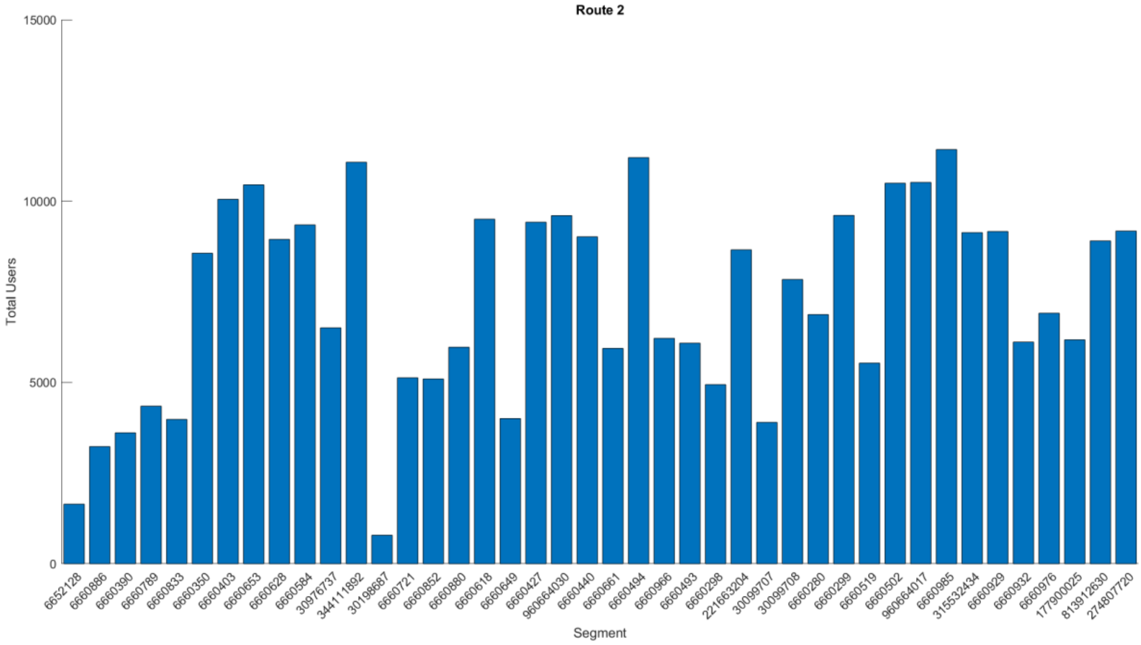

Figure C 7: Total number of users of each segment in Route 2

Route 3

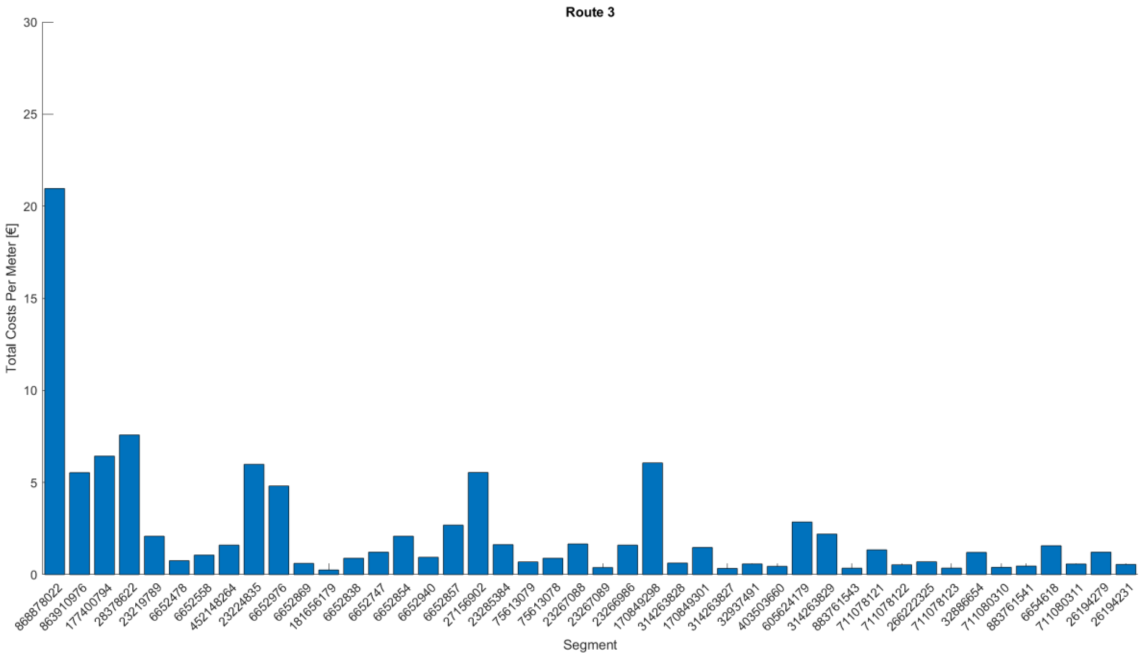

Figure C 8: Total costs per meter for the segments of Route 3

Figure C 9: Segments with the highest priorities in Route 3

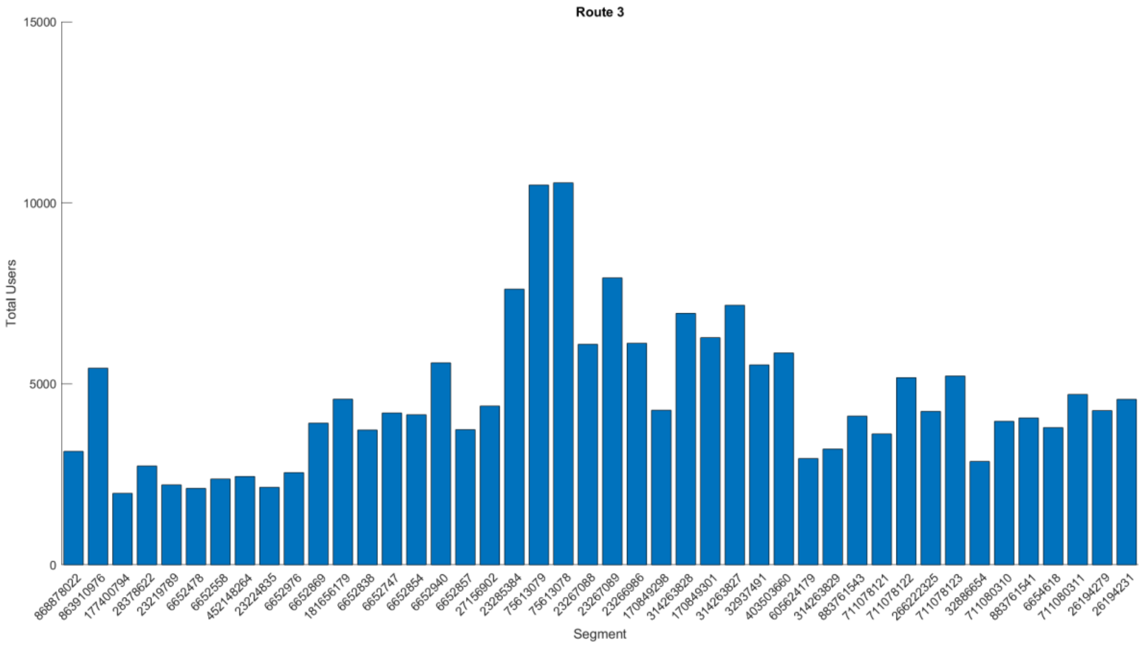

Figure C 10: Total number of users of each segment in Route 3

Route 5

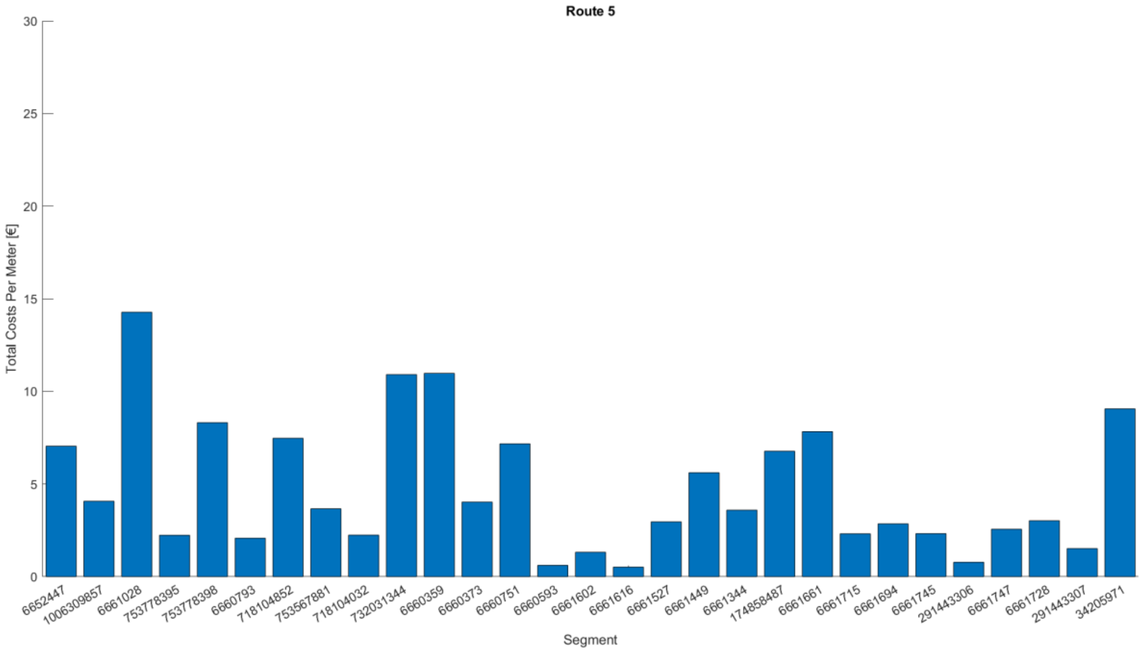

Figure C 11: Total costs per meter for the segments of Route 5

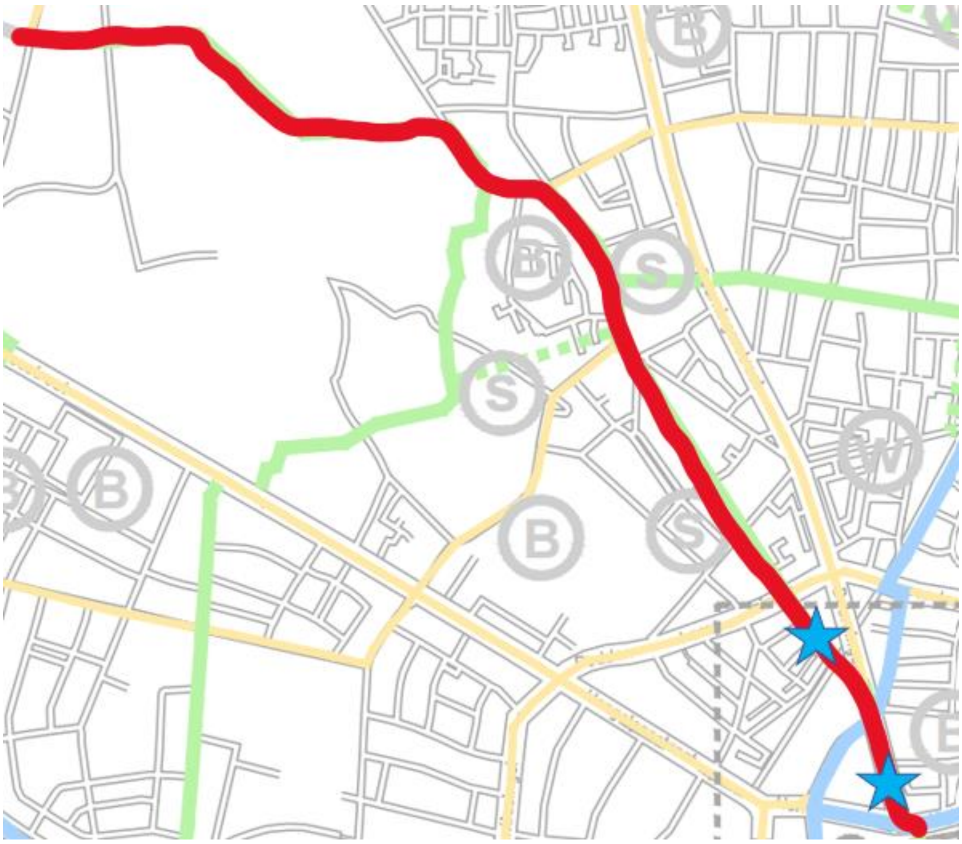

Figure C 12: Segments with the highest priorities in Route 5

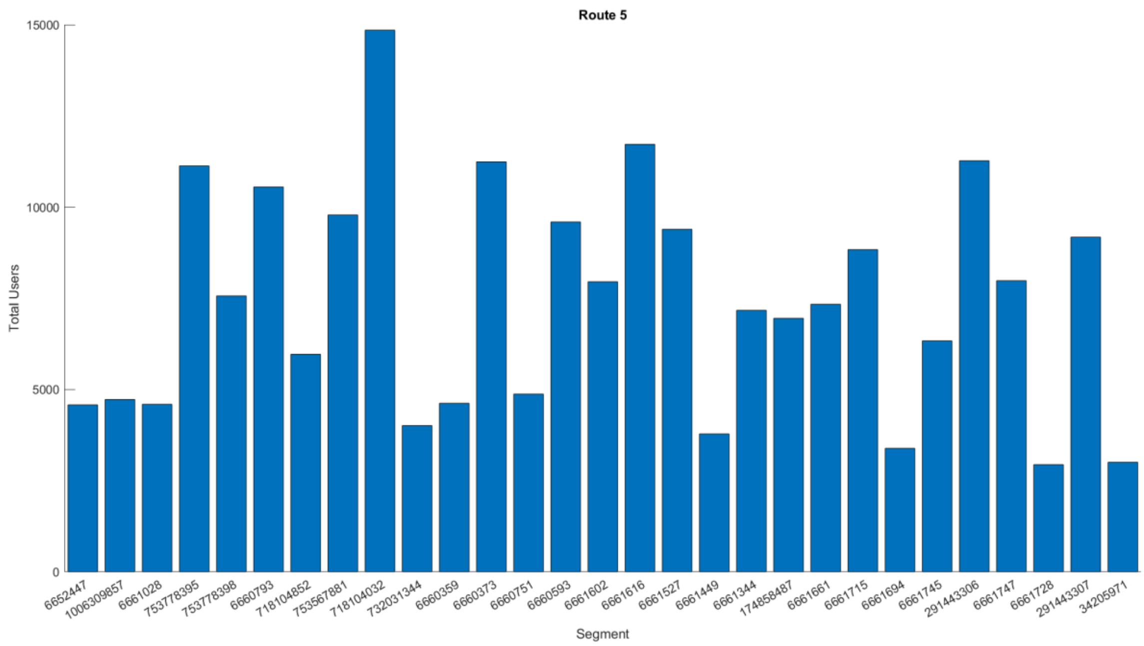

Figure C 13: Total number of users of each segment in Route 5

Route 6

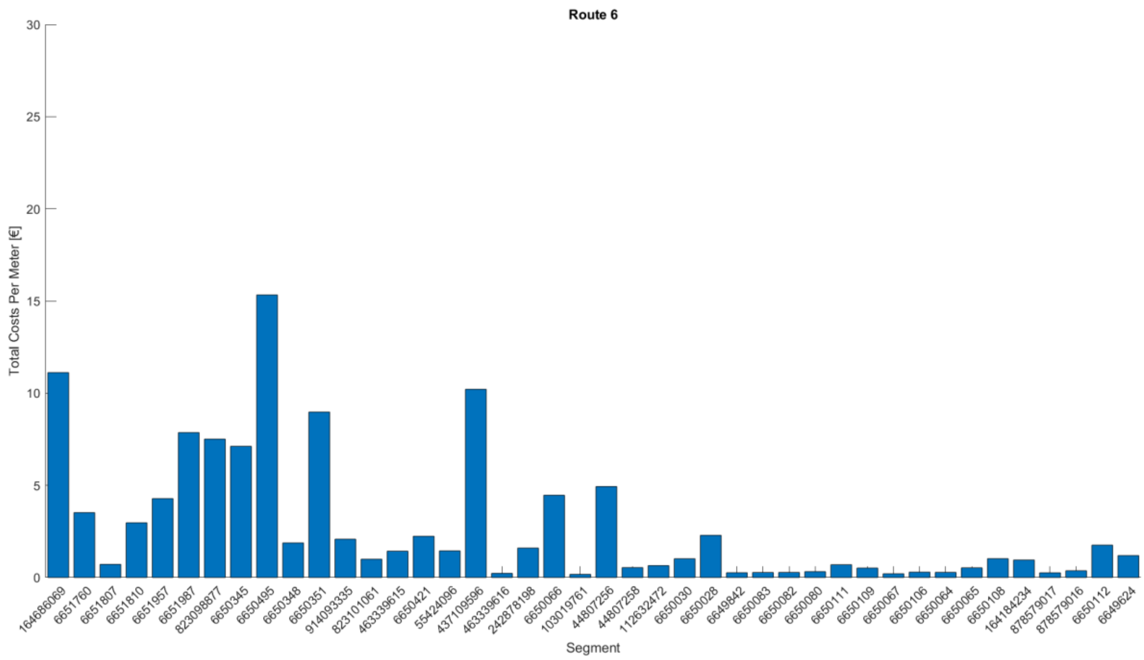

Figure C 14: Total costs per meter for the segments of Route 6

Figure C 15: Segments with the highest priorities in Route 6

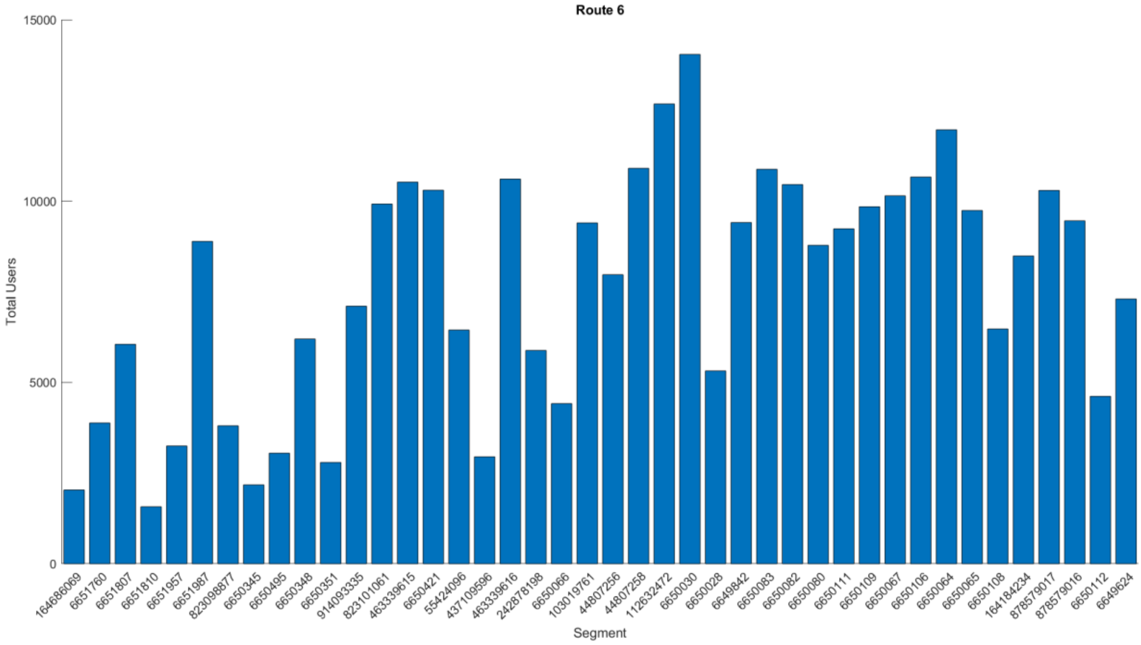

Figure C 16: Total number of users of each segment in Route 6

Route 7

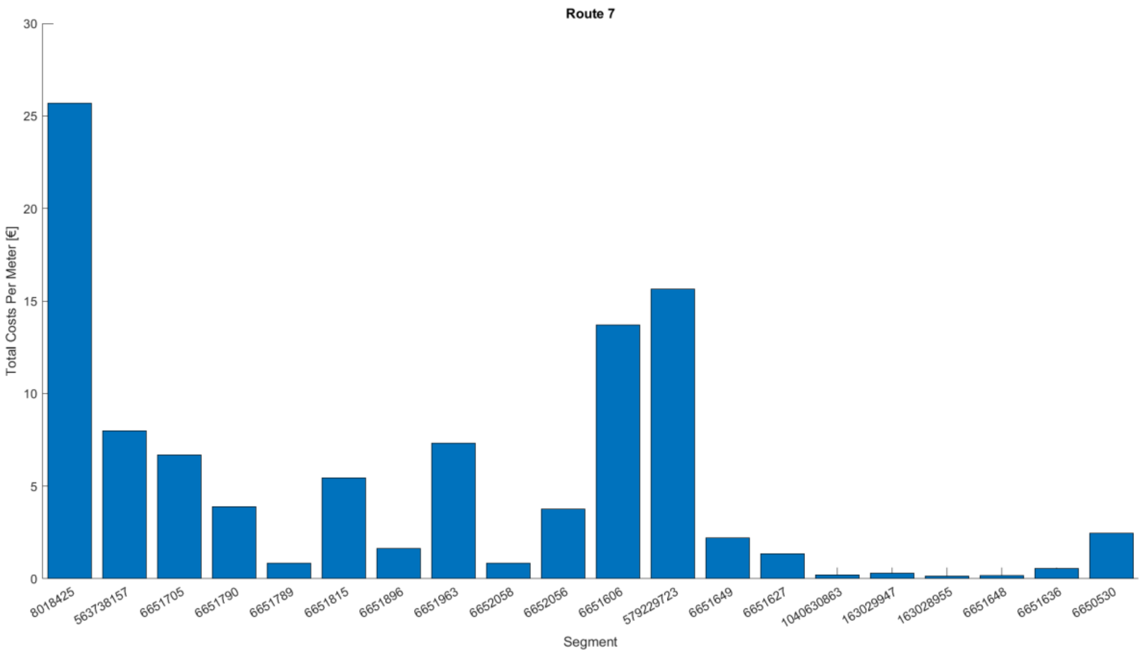

Figure C 17: Total costs per meter for the segments of Route 7

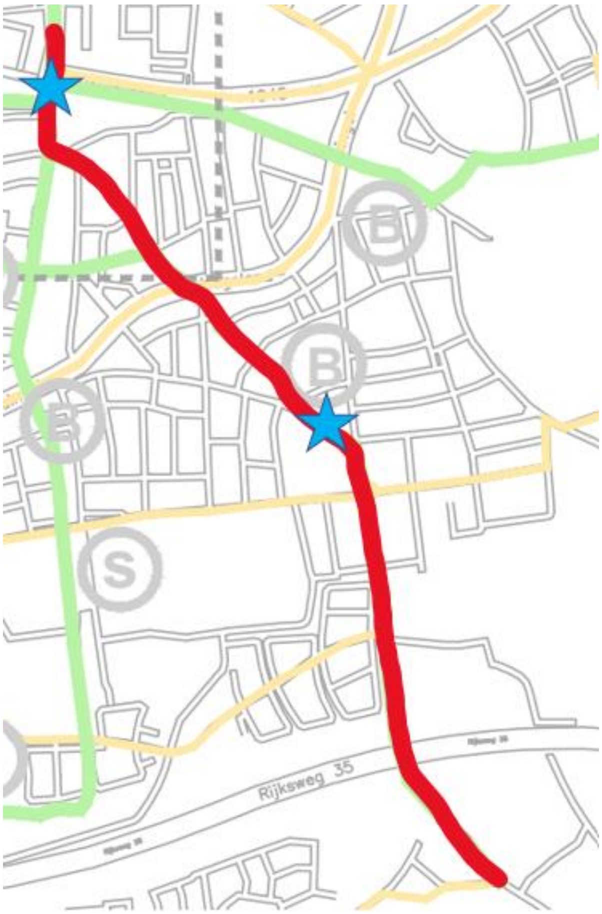

Figure C 18: Segments with the highest priorities in Route 7

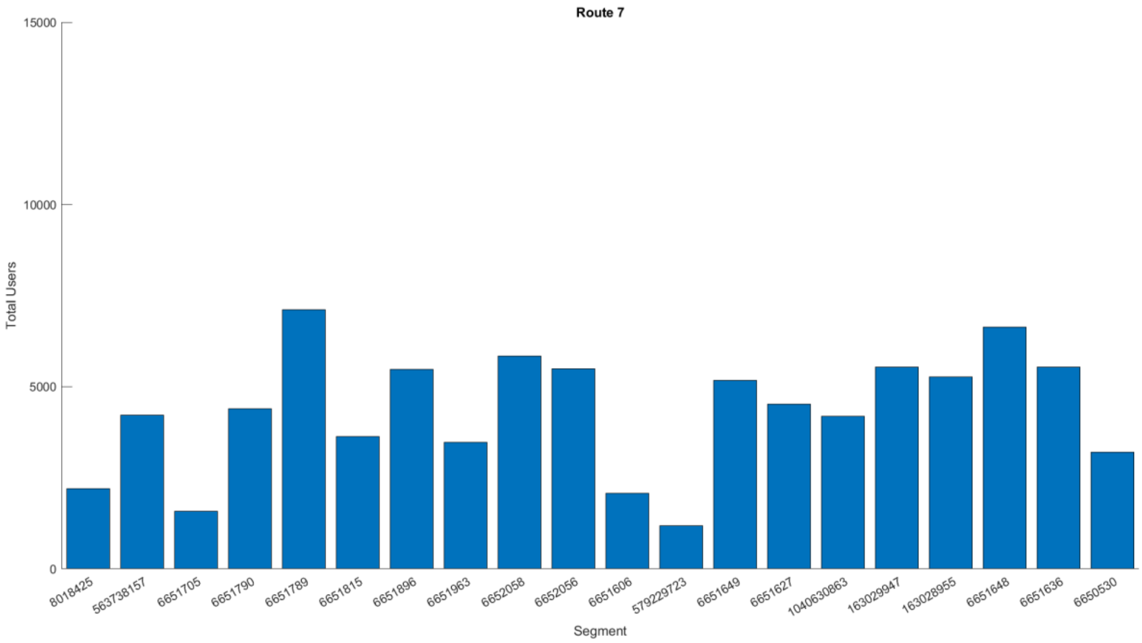

Figure C 19: Total number of users of each segment in Route 7