# Spatial behaviour of cyclists:

## An analysis of separate cycle paths


**Susan Vermeulen**

**381177**


**13 September 2018**


ERASMUS UNIVERSITY ROTTERDAM

Erasmus School of Economics

Urban, Port and Transport Economics

Supervisor: Giuliano Mingardo

Second assessor: Jan–Jelle de Witte

# Abstract

This research contributes to make more informed decisions on the design of infrastructure for cyclists. Currently the municipality of Amsterdam spends on average €22.6 million a year on improving, maintaining and constructing infrastructure for cyclists. These decisions are based on guidelines and expert judgement. This thesis focuses on the interaction of the cyclist on separate cycle paths. Two datasets are used. The dataset Amstelveenseweg consists of video motion detection tracks. The relationship between lateral position and speed is explored based on this dataset with a simple OLS regression. This is a one–way cycle path. The model is extended with the group size and the intensity. Results show that the lateral composition and speed are positively related and the number of cyclists has a positive effect on the lateral position as well. In order to interpret these results in a good manner, the dataset Zuidas is used for an analysis on type of users on two two–way cycle paths. This analysis on the type of users show that time and direct surroundings have effect on the composition of the type of users on the cycle path. We would recommend to the municipality that it might not be representative enough to only base the design guidelines on total number of cyclists per hour, but to extend it even further. We propose to base the design guidelines on five minutes instead of an hour, take speed ranges and even type of users into account when making infrastructure decisions.

# Table of contents

**List of tables**



**List of figures**



**List of graphs**

# 1. Introduction

Congestion is an occurring problem in agglomerations. Some cities foster a high level of automotive access in order to manage traffic congestion as a by–product of economic growth (Sweet, 2014). Whilst other cities have focused on alternatives transport modes. They have been successful in reducing or even stagnating the growth of car use. This result is due to an integral approach towards the goal of car reduction (Buehler, Pucher, Gerike, & Götschi, 2017).

These cities have implemented policy regarding walking, cycling and the use of public transport. In the Netherlands using alternative modes of transport has been stimulated over a long period of time. People currently choose the bike as a transport mean for around quarter of their trips (Kennisinsituut voor Mobiliteitsbeleid, 2017). In the capital city, Amsterdam, this percentage is even higher, namely 36%. Moreover the bike is currently the fastest growing modality in this city and the number of bicycle trips has grown enormously in the past 25 years. This growth is expected to continue due to 50.000 additional residential locations (Gemeente Amsterdam, 2017a). This increase and expected autonomous growth creates a new problem, not only congestion on the roads, but the cycle paths might have reached their limits.

## 1.1 Problem Statement

An often stated approach to solve this problem is to increase the space for cyclists. In an already existing city, you must take in to account the existing buildings, which leads to a scarcity of public space when expanding is not possible anymore. The public space can be divided into road for the cars, cycle paths, trams rails, dedicated bus lanes, a side walk, grass or even trees. When (re)designing a street, each part of the street will get a designated destination. Since the space is limited, trade–offs must be made between various modes of transport. These trade–offs are made in zoning plans. All plans and measures are reviewed by the Centrale Verkeers Commissie, which tests all the trade–offs that have been made (Gemeente Amsterdam, 2016). The Centrale Verkeers Commissie determines the width of a cycle path based on a table[1], which is copied of CROW (Gemeente Amsterdam, 2016).

[1] See Table 1 (page 15) for the design standards in various countries

On average €22.6 million each year has been reserved to spend on infrastructure for cyclists according to the long–term investment program of 2018 until 2022 (Gemeente Amsterdam, 2017b). The costs of a new asphalt cycle path costs around €100,– per $m^2$. This can be higher due to roots, pipes, cables or other existing infrastructure (Fietsberaad CROW, 2008). In general, infrastructure investments have a durability for approximately 35 years, therefore future thinking is necessary (Essen & Schroten, 2010). There are many positive external benefits of cycling, such as health benefits, fuels savings and environmental effects (Gotschi, 2011). However, it is difficult to express these monetary. A lot of these investment decisions are based on expert judgement, design standards and political preferences.

In order to decide in a more informed way, research must be done. The design standards, which vary greatly per country, have been tested by various scientific researchers. They found a wide range of operational capacities, however they have not concluded yet if there exists a linear relationship between the width and the capacity. Greibe and Buch (2016) have observed a pattern with leaps in Copenhagen, but this does not directly have to apply to Amsterdam as well. Since the average speed differs enormously between Copenhagen and Amsterdam. In Copenhagen the average speed is 21.6 km/h, whilst the average cycling speed is around 14.4 km/h in Amsterdam (Fietsersbond, 2016). This might affect the maximum capacity of a cycle path. Chinese researchers found that the operational capacity is around 2,500 cyclists per hour per meter (Zhou, Xu, Wang, & Jin, 2015; Jin, et al., 2015). This is lower than in Copenhagen. Hoogendoorn and Damen (2016) found an operational capacity of around 1,500 cyclists in the Netherlands[2]. None of the published studies have taken different types of users into account.

The crowdedness of the cycle path in Amsterdam can be attributed to various types of vehicles which use the cycle path according to the former Minister of Infrastructure and Environment of the Netherlands, Melanie Schultz van Haegen. She attributes the speed differences between cyclists and road racing cyclists as main cause in in the province Zeeland. Most problems occur regarding speed differences and high variety in cycle paths users (Schultz van Haegen, 2015).

[2] See Table 2 (page 17) for an overview of scientific studies on one-way cycle path capacity

The behaviour of cyclists is not easy to measure. TNO[3] developed a measurement method based on video footage. A video–motion detection algorithm was developed to follow cyclists and to subtract information. This algorithm has been developed by video footage of a place in Amsterdam. Four cameras were put above a cycling lane before an intersection and two after the intersection Amstelveenseweg – Zeilstraat. Even though the research was mainly focused on developing algorithms and a detection method, there were some interesting observations on the behaviour of cyclists in relation to the crowdedness, such as differences in space use of cyclists and light moped drivers (TNO, 2017).

## 1.2 Research question

In order to further investigate the relationship between the behaviour of cyclists, other users on the cycle path and the mix of users, the following research question has been composed:

*How do cyclists interact with each other on a cycle path?*

In order to narrow down this research question, three sub–questions are formulated. There will be mainly focused on the lateral position and the speed of a cyclist in this thesis, because they can be extracted by video–motion analysis. The lateral position is the distance of the cyclist to the curb. Patterns in different type of users will also be investigated. The sub–questions are:

- *What are the differences in lateral position due other users on cycle path?*
- *What kind of relationship is there between speed and lateral position?*
- *What systematic patterns can be observed for different type of users on a cycle path?*

The mix of users and the volume can differ at various locations and at various times. There are factors which might influence the lay–out of a cycle path, such as bushes, parked cars or even other cyclists. There is not much known about the relationship of speed and lateral position. The outcomes of this thesis can be used as insights for temporary measures for road work and a new lay–out for the public space.

[3] A Dutch organisation for applied scientific research. They are an organisation regulated by public law as an independent research institute.

## 1.3 Data

This analysis will be based on two datasets in Amsterdam Zuid, dataset Amstelveenseweg and dataset Zuidas. Each dataset is based on camera footage. One camera is placed above each bicycle path. The camera will be attached to light post close to the cycle path. There has been made a choice to look into bicycle paths instead of lanes, because cycle paths exclude more external factors, such as density of cars, speed of cars, the presence of trams and the delivery of goods.

The dataset Amstelveenseweg consists of video detection tracks of Amstelveenseweg. Video detection tracks are cyclists which have been detected by an algorithm. The original video footage of this cycle path has been erased due to privacy regulation, since the footage was recorded in 2017. The one–way cycle path on the Amstelveenseweg is close to a busy car road and has a small shopping area. The observation point was 48 meters before the intersection with the Zeilstraat. This intersection is known for its long wait at the traffic light. This cycle path has been chosen due to the crowdedness of the cycle path, since we hoped to capture a full range of different observations in this way.

The dataset Zuidas consists of video footage of two locations nearby the Zuidas. The footage was recorded in 2018, therefore we were able to watch it under strict conditions. We have filmed two two–way cycle paths, which have as main differences the width and the location. The Zuidas is a mixed business district, which has a lot of offices, schools and residential locations. Due to the diverse nature of Zuidas, the mix of users of a cycle path will be high, which might give interesting insights. This dataset will be used to gain more insights in the type of users, therefore we have chosen two locations which are less than 300 meters apart, but might have substantial differences in type of users.

These two dataset are complementary to each other. Even though, there are measured in two different time periods, they create explanatory power. The insights due to one dataset can be used to create better understanding of possible problems in the other dataset. Especially since the dataset of the Amstelveenseweg does not have any video footage anymore due to privacy, thus it only exists out of raw motion detection tracks, whilst the dataset of the Zuidas captures an extensive analysis of the users.

## 1.4 Structure of the thesis

The thesis will be structured as followed. First a literature review will be presented. Various design standards and scientific studies about capacity of a cycle path will be discussed, but there will also be made a distinction in type of user. Based on the literature a conceptual framework will be composed, which will lead to several hypotheses. Thereafter the methodology will be explained in detail. A part of the methodology will be the description of the location, where data is gathered and the variables of the statistical analysis. A description of the raw data of the algorithms and the video footages will follow. Thenceforth an analysis on the data will be executed. First an analysis on the dataset of the Zuidas will be executed and then the regression analysis on the dataset of the Amstelveenseweg will follow. Lastly the conclusions will be drawn and recommendations will be given.

# 2. Cycling, capacity and behaviour

A concise examination of existing literature will be given in this chapter. First, economic theory will be discussed in order to show how people behave in traffic situations. This is followed by a description of capacity, density and flow. Then an overview of the existing literature around capacity of cycle paths will provided. This is followed by a short item about the perception of crowdedness. Thereafter a breakdown of different types of users will be shown. Consecutively external factors on bicycle behaviour will be discussed. At last, a summary of this chapter is presented.

## 2.1 Economic theory in relationship to transportation

Disaggregate travel models pursue to explain why an individual would travel. These models are based on discrete choice analysis and are characterized by two essential elements. First, Ben–Avika and Lerman (1985) explicitly acknowledge that travel decisions arise from optimizing an individual's utility. Each decision has alternatives, where each aspect such as cost, time and comfort is taken into account. Each individual experiences different choice situations and has different preferences restricted by the disposable income of an individual. The second element is based on the fact that most disaggregate travel models are based on the "attributal theory of demand" of Lancaster (1966). This concept expects that individuals seek to maximize utility on the basis of attributes instead of the quantity of goods actually consumed. Wright (1992) converted this theory into four hypothesis concerning transportation:

1. Transport users receive utility from the attributes of mode instead of the mode itself
2. An attribute can be obtained from more than one mode, whilst a mode usually has multiple attributes.
3. A combination of modes may possess other attributes then when each mode is used separately.
4. The attributes can be objectively measurable, however individuals might value the same attributes differently.

Recently disaggregate travel models have been criticised heavily, mainly due to assumption of utility maximization.  Travellers do not necessary maximize their utility (Avineri & Prashker, 2005). When choosing a specific route, travellers might adopt some rules. Thorndike's law of effect (1927) states a choice that resulted in good outcomes in a specific setting will have a higher probability of being chosen again when being in a similar setting. This often leads to cognitive biases, which are systematic errors in thinking. Due to this bias, individuals are not capable to maximize utility for transport decisions in every situation. Therefore, behavioural economists criticise the utility maximization theory as a base for transportation.

Khaneman and Tversky (1979) propose an alternative: the prospect theory. This is a theory about decision–making under uncertainty and risk. The prospect theory states that people identify the outcomes as gains and losses rather than welfare and wealth. The gains and losses are determined towards a neutral reference point. The reference point can be influenced by the way of framing the choice, thus the way attributes are presented can affect the outcome. The prospect theory has the following assumptions:

- Loss aversion: the pain of losing is valued more than equivalent gains
- Diminishing sensitivity: the marginal value of gains and losses decreases when their magnitude increases
- Non–linear weighted probabilities: an individual outweighs outcomes that have a low probability, whilst it attaches a relative low probability to events that happen more frequently.

Mahmassani states that prospect theory can be the base to model and understand driving behaviour. Risk–perception, risk–taking and uncertainty are key in decision making in traffic situations. These values account in all kind of traffic conditions, such as the free flow, congestion, accidents–prone conditions and extreme weather conditions (Van Wee, 2010). Your behaviour in traffic depends on your reference point. This is the case for all road users, also for cyclists. The prospect theory states that behaviour differs per person.  The behaviour of cyclists might have an influence on their use of space of the cycle path. Therefore the prospect theory can be used to explain the differences in behaviour of various cyclists even when they are in the same category.

## 2.2 Capacity, density and flow

The overall space of a cycle path is limited to its width. In the Netherlands, it is the case that not all cycle paths have the same width. Therefore, the capacity of the cycle path can differ, but how do you estimate cycle path capacity?

There are two main methods to estimate highway capacity. The first method is to detect the headway between vehicles in saturated flow. The second method is to calibrate the density–flow relationship (Jin, et al., 2015). Gould and Karner (2009) were the first to show that the density–flow relationship (Figure 1) also exists for cyclists. They used three locations in Davis to gather data and modelled the critical density point. The critical value of density is the point where the traffic flow converts from a free–flow to a congested flow in a density–flow relationship.

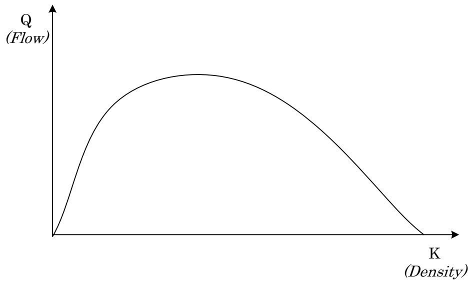


*Figure 1: Theoretical flow-density relationship*

Gould and Karner (2009) estimated a critical density of 0.008 bikes/ft$^2$ – 0.025 bikes/ft$^2$. The variety in the critical point of density is due to several factors. One factor is that the highway traffic flow is reported per lane, however bicycle paths do not have set lanes. Therefore the bicycle traffic flow is often reported per unit of path width. It is not clear yet if there is a linear relationship between the width of the cycle path and the capacity. Greibe and Buch (2016) stated that a little bit of extra width does not necessarily increase the capacity, however if there is an extra lane for cyclists the capacity increases. Serani et al. (2015) state the contrary, namely that the saturation flow almost grows linearly with the width. The saturation flow on a cycle path is the maximum observed number of cyclists. The saturation flow can be extrapolated from a few seconds to an hour to get a statistic expressed in *number of cyclists per hour per meter.* Other factors that influence the critical density point are the difference in cycling speed, the probability of overtaking, weather conditions, infrastructure design and bicycle type (Gould & Karner, 2009; Wierbos, Goñi-Ros, Knoop, & Hoogendoorn, 2017).

When there is an interrupted flow of cyclists, for example a signalled intersection, the effective green time and the type of signalled traffic cycle should be taken into account when calculating capacity. The capacity of an intersection is often lower than the saturation flow of an intersection (Seriani, Fernandez, & Hermosilla, 2015). For the capacity of a cycle path, we assume that saturation flow is equal to maximum measured capacity, because it is often an uninterrupted flow.

Capacity can be defined in various ways. The definition of Botma and Papendrecht (1991) is used in this thesis. It was one of the definitions, which included cycling at a desired speed. Cycling at a desired speed was determined when there was at least a headway of 2.5 seconds to the front. This is based on visual observation through a rear view. There was chosen for this definition, because it was one of the only definitions which looked at the speed of individual users.

> *Capacity has been reached when everybody cannot cycle at their desired speed and is constrained to follow a bike in front of them.*

The capacity will be reached at the critical density point, however a cycle path is not always used at its maximum. The bicycle flow can differ at various points in time. Gerlough and Huber (1976) express the bicycle flow ($Q_t$) as followed:

$$Q_t = \frac{N}{t} \tag{1}$$

Where:

$Q_t$ is number of users per time period

N is the total number of users

t is the time period measured

Just like the flow, the density levels can differ from time to time. If there are no users at all during a certain time period, the density level would be zero cyclists per hour per meter. Gerlough and Huber (1976) state that the relationship between the density per time period ($K_t$), mean speed and number of users is as followed:

$$K_t = \frac{Q_t}{v_t} \tag{2}$$

Where:

$K_t$ is the density per time period

$v_t$ is the mean speed per time period

In order to compare situations, the density of a cycle path must be expressed related to the width. Even though scientific literature is not convinced on a linear relationship, density relative to width enables comparison. Therefore it is useful to employ density expressed per meter ($K_{tm}$).

$$K_{tm} = \frac{K_t}{w} \tag{3}$$

Where:

$K_{tm}$ is the density per time period per meter

w is the width of the cycle path expressed in meters

The observed bicycle flow is often not high enough in order to observe the full range of traffic conditions (Jiang, Hu, Wu, & Song, 2017). In order to find the critical density point, experiments are used. There is currently limited experimental data, thus it is still hard to determine the critical density point. Additionally these analyses have not taken into account the various types of cyclists and the various compositions of bicycle traffic flow. Therefore, it is difficult to determine when the capacity of a cycle path is reached.

## 2.3 Cycle path capacity

There has been various scientific literature published about one–way cycle path capacity and saturation flow, but not enough about two–way cycle paths. Design standard are published for both (standards of a two–way cycle path can be found in Appendix I). Hence this overview focuses on one–way cycle paths. First an overview of a few design standards of one–way cycle path is given. These standards can be found in design manuals of various countries.

| **Institute** | **Year** | **Country** | **Width** | **Recommendations** *(Cyclist/hour)* |
|---|---|---|---|---|
| Transportation Research Board | (2000) | The United States of America | 2.4 m | 4,000 |
| CROW | (2006)[4] | The Netherlands | 2 m | 0 – 150 |
| | | | 2.5 – 3 m | 150–750 |
| | | | 4 m | > 750 |
| Vejregler | (2012) | Denmark | 2 m | 2,000 |
| | | | + 1 m | 1,500 |
| Transport for London | (2014) | London, United Kingdom | 1.5 m | < 200 |
| | | | 2.2 m | 200 – 800 |
| | | | ≥ 2.5 m | > 800 |

*Table 1: Overview of design standards of a one–way cycle path*

[4] The recommendations in the updated version have remained the same (Fietsberaad CROW, 2016).

Table 1 shows that there is a range of design standards. The Netherlands has relative low standards compared to the United States of America, Denmark and London. It must be noted that the American values are converted from cyclist/hour/lane into cyclist per hour. The Dutch design standards are based on an article of Theo Zeegers. Zeegers (2004) states that is not about the actual number of cyclists, but about the number of total overtakes. The total number of overtakes is not only dependent of number of cyclists, but also on the variation of speed. The Dutch design guidelines are often used as standard in most municipalities in the Netherlands. In Amsterdam the desired width of a one–way cycle path is minimal 2.5 meters. The guidelines "Leiddraad Centrale Verkeerscomissie" state that the desired width is dependent on type of usage, intensities, and composition of users, however there is a need for specific recommendations (Gemeente Amsterdam, 2016).

In the beginning of 2017 only 34% of the one–way cycle paths, which are determined as "Plusnet Fiets[5]", have the minimum desired width (Gemeente Amsterdam, 2017a). The remainder has a smaller cycle path than the guidelines state. This is often due to lack of space. Scientific research have tried to estimate cycle path capacity. Researchers have used observation methods by using video footage or have set up an experimental setting. Table 2 has been composed to give an overview of scientific studies about capacity. First of all, it is important to know that Table 1 and Table 2 cannot be compared directly. The saturation flow in Table 2 is expressed in cyclist/hour/meter whilst in Table 1 in cyclist/hour. This is due to the non–linearity in some design standards.

A striking observation of Table 2 is that between 1994 and 2015 barely any scientific studies about capacity of cycling path have been published, whilst there have been design standards published. In order to understand the outcomes better, each study type has been published. Most observation studies extrapolate the highest number of cyclists observed to saturation flow, often intervals of 1 to 20 seconds are used. The chosen length of the interval has an influence on the estimated saturation flow. The theoretical studies make assumptions about speed, width of a cyclist and other factors in order to determine the saturation flow, whilst experiments are done in an abstract environment.

[5] A route for cyclists that is safe, spacious, comfortable and fast.

The experiment of Navin (1994) shows the highest saturation flow. This was in experimental setting, namely driving circles at a parking lot. The experiment of Serani et al. (2015) was done in existing infrastructure. The observational studies all show similar saturation flows. It must be noted that this was the highest observed number of cyclist at a certain time frame which has been extrapolated, thus it might be possible that the capacity is even above this number.

| **Author** | **Year** | **Place** | **Study type** | **Width** | **Saturation flow** *(cyclist/hour/meter)* |
|---|---|---|---|---|---|
| Smith | (1972) | Davis, The United States of America | Observation Extrapolate highest flow | 1 m | 2,000–2,250 |
| Botma, & Papendrecht | (1991) | The Netherlands | Observation Extrapolate highest flow | 2.5 m | 3,600 |
| Wright | (1992) | N.A. | Theoretical calculation | 1.22 m | 1,476 |
| Liu, Shen & Ren | (1993) | Beijing, China | Observation | 3.2 – 6.5 m | 2,000 |
| Navin | (1994) | Vancouver – Canada | Experiment Extrapolate highest flow | 4 m | 4,000 |
| Khisty | (1994) | N.A. | Theoretical calculation | 1.2 m | 1,500 |
| Li, Huang, Yang, Zhou & Ye | (2015) | Nanjing, China | Observation Extrapolate flow | 1.2 – 3.5 m | 3,300 |
| Serani, Fernadez & Hermosilla | (2015) | London, United Kingdom | Experiment Extrapolate highest flow | 1.0 m | 2,070 |
| Jin, Qu, Zhou, Xu, Ma & Wang | (2015) | Hangzhou, China | Observation Extrapolate highest flow | 2.27 – 4.60 m | 2,348[6] |
| Zhou, Xu, Wang & Jin | (2015) | Hangzhou, China | Observation Extrapolate highest flow | 2.27 – 4.60 m | 2,500 |
| Greibe & Buch | (2016) | Copenhagen, Denmark | Observation Extrapolate highest flow | 2 m | 1,500 |
| Hoogendoorn & Damen | (2016) | Delft, The Netherlands | Observation Extrapolate highest flow | 3 m | 1,531 |

*Table 2: Overview of scientific studies on capacity of one–way cycle path*

[6] 70% of the sample is e-bike and the remainder without electronic support

## 2.4 Perception of crowdedness

Despite the fact that there might be an optimal number of users on the cycle path, cyclists can have a different perception of crowdedness. This might be a reason why the design standards in the Netherlands are lower than observed in reality. The CROW[7] has published a report about the perception of crowdedness on cyclist facilities. They surveyed 2,063 people. 60% of the surveyed cyclist experienced crowdedness. They stated that behaviour of other cyclists contribute to the crowdedness on the cycle path. The crowdedness is mostly experienced in highly urbanized areas and is more often encountered on two–way cycle paths. Cyclists express that the width of the cycle path, the number of other cyclists and speed differences contribute to the crowdedness. Some cyclists declare that difference in speed is mainly thanks a certain group of cyclists, such as adolescents or fast rider (van den Munckhof, Zengerink, & ter Avest, 2017). This indicates that the type of users might influence the speed of the cyclist.

DTV consultants researched the perception of crowdedness of cyclists in combination with the width of the cycle path and the intensity on the cycle path. Their research was only focused on two–way cycle paths. The mark of their cycle journey was negatively dependent on the percentage of mopeds and the intensity related to the width in centimetres with an $R^2$ of 0.44 (DTV Consultants, 2018).

## 2.5 Type of users

Several types of users can be identified on the cycle path. Recently new types appeared on the cycle path, such as stints and commercialized cargo cyclists. The composition of users can differ per place and can change over time. Kircher et al. (2018) did a semi–controlled study with several types of cyclists and observed that types show different behaviour at the same location. Their distinction in types cannot be used in this thesis, because it was based on soft factors. One important criterion for the distinction in user types is that the user should be easy recognizable on video recordings. The SWOV[8] has distinguished five groups which are recognizable: a bike, a bike with a crate, a moped, a cargo bike and a vehicle for disabled (SWOV, 2015). This base is used, but adapted to create a better fit for our research area. There have been done two on–street observations of 15 minutes to control if all expected categories fitted our research area.

[7] CROW = Knowledge institute regarding infrastructure, traffic, transport, safety in the Netherlands.
[8] SWOV = An independent Dutch research centre for traffic safety

Regular cyclist

The regular cyclist is a person on a bike. It is the most common type on a cycle path in Denmark (Greibe & Buch, 2016). They have various types of commutes, such as cycling to work, to go to shops or just for leisure, but they can also be tourists. Parents with children on their bike are included, since differences were not observed in on–street observations. In existing literature this group can be segmented into further detail (Heinen, Maat, & Van Wee, 2011; Xing, Handy, & Mokhtarian, 2010). These characteristics cannot be observed on video recordings.

*Figure 2: Various regular cyclists*

Parent–child cyclist

The parent–child cyclists are very easy recognizable. It is a combination of parents cycling with their child. The parent often cycles on the left side of the child, so that the child is between the curb and the parent. In the Netherlands, most children can cycle without support around the age of five. When children are nine, they can cycle independently to school (Koperberg & Broer, 2015). This combination is often seen nearby schools.

*Figure 3: Various parent-child cyclists*

Side–by–side cyclist

The side–by–side cyclists is quite easy recognizable. It is a combination of two cyclists next to each other. This can be adolescents, adults or students. CROW report about crowdedness and perception specifically named adolescents as a group that often irritates other cyclists (van den Munckhof, Zengerink, & ter Avest, 2017). However, it is hard to segment only adolescents' cyclists on video recordings. Therefore all cyclists who cycle together are being put into one category.

*Figure 4: Various adolescent cyclists*

Fast cyclists

Some cyclists have a higher speed than others. In order to reduce the differences within the category "regular cyclist", speed is taken as benchmark. "Fast cyclists" must have a speed that is higher than 20 km/hour. This category can be split up into further detail:

- E–cyclists
- Professional cyclists
- Very active cyclists

*Figure 5: Various fast cyclists*

An e–cyclist uses a bike with electronic support. The maximum speed is 25 km/hour with electronic support. It is not always easy to distinguish e–cyclists from regular cyclists. The battery on the bike can be a giveaway, however the battery can be put in different places and can be hid away.

Professional cyclists have a bike with smaller tires, which gives them less resistance. They often wear special gear and use their bikes for recreational purposes, but can also be used it for longer distances as a commute.

The very active cyclist is a group who does not ride a special designed bike nor has electronic support, but cycles relatively fast.

Non–commercial cargo cyclist

The non–commercial cyclists are mainly used to transport kids and are not used in a commercial way. The width can differ per type of cargo bike. The cargo bikes with three tires are often wider than those with two (Fietsberaad CROW, 2016). They might have electronic support, but a distinction will not be made in order to keep the number of categories manageable, because it is difficult to distinguish electronic support.

*Figure 6: Various non-commercial cargo cyclist*

Commercial cargo cyclist

A commercial cargo cyclist has a cargo bike with two or three tires. These commercial cargo cyclists might have electronic support. A distinction in categories will not be made, due to hard nature of discovering electronic support. They can deliver a various range of goods, such as packages, food, groceries and medication. There are physical limitations of the dimensions of the goods. They can be recognized by its closed storage and work uniform.


*Figure 7: Various commercial cargo cyclists*

Stint

A stint is a relatively new way to transport goods and children. They are allowed on the cycle path if the width is smaller than 1.1 meters due regulation (Beleidsregel aanwijzing bijzondere bromfietsen, 2014). They always have electronic support. There are various forms of stints. It is used to transport children from school to after–school care, but also for packages, groceries and business to business deliveries. They can be recognized by people standing behind the vehicle.


*Figure 8: Various stint users*

Moped rider

In the Netherlands there are two types of mopeds defined by law:

- Light moped (blue licence plate)
- High–speed moped (yellow licence plate)

There is a difference towards the legal position of a moped on the cycle path. A light moped is currently allowed to use a cycle path, whilst a high–speed moped is banned (RVV 1990). There has been chosen to put them in the same category. This is mainly because it is very hard to distinguish them on camera footage.


*Figure 9: Various moped riders*

Moreover video analysis of the Prins Hendrikkade show that the average speed of moped riders was 29.4 km/h, 80% of the mopeds drove above the maximum speed of 25 km/h (van der Horst, de Goede, de Hair–Buijssen, & Methorst, 2013). This might be caused by high–speed moped riders who also use the cycle path or light–speed mopeds that drive above the speed limit. The comparable behaviour of both mopeds is another reason to put them in the same category.

Mini–sized vehicles

Dutch regulation states that vehicles especially designed for disabled can choose where they want to ride, such as a road, a cycle path, a sidewalk, a cycle lane. They are obligated to use bicycle facilities if there are facilities (Wet Regeling Voertuigen, 2018). In Amsterdam, these vehicles are not only used by disabled, but are also commercialized. Therefore the category name "mini–sized vehicles" is used. The vehicles cannot exceed a width of 1.1 meters. This category has been put into one category, since these vehicles can be used by non–disabled persons.

*Figure 10: Various mini-sized vehicles*

These are the initial categories. There are also other users, which are not mentioned in the categories stated above, such as skateboards, scooters and other extraordinary vehicles can be found in the observations. In order to keep the number of categories manageable, all types which do not clearly fit in a category will be excluded from this research. If other users show specific behaviour which is observed, this can be mentioned. However, this will not be specifically examined.

## 2.6 External factors on cycle behaviour

There might be external factors which affect the behaviour of cyclists. In order to show a good relationship, the external factors should be taken into account. Previous research shows the following external factors:

- Weather
- Obstacles next to the cycle path
- Marking
- Other

Weather

Winters et al. (2010) showed that more days of rainfall and more days of temperatures below zero degrees were both associated with a lower degree of utilitarian cycling in a city in Canada. Rietveld and Daniel (2004) show that this relationship is not seen in the Netherlands. This was based on average temperature per city and average cycling percentage. The average temperature difference between cities is probably more divergent in Canada than in the Netherlands. In Auckland, New Zealand, effect of weather on the variability in volume of cyclists has been researched on daily basis. They observed significant correlations between the weather variables[9] and the number of cyclists. On a daily basis the regression had $R^2$ of 0.49–0.57 (Tin Tin, Woodward, Robinson, & Ameratunga, 2012). Saneinejad et al. (2012) exhibit that the use of bicycles is lower when there is rain or less than 15 degree Celsius or wind speed or showers. This indicates that weather can have a huge impact on the amount of cyclists.

Obstacles next to the cycle path

Angel–Domenech et al. (2014) conducted a conflict analysis of bicycles in Valencia. 19.1% of the observed conflicts were with a static object. The static objects included bushes, trees, parallel parking spots, angled parking places and curbs. The impact of the static objects varied over locations, but the location with parking lanes and trees had a relative high number of conflicts compared to the location with only trees and bushes. Cyclists do not want to have a conflict with a static object. Li et al. (2012) found that the perception of the cyclists on comfort is mainly influenced by surrounding conditions and road geometry when there is separate cycle path. Surrounding conditions can be a bus stop, separate pedestrian facilities, trees, bushes and parking places. Greibe and Buch (2016) show that if there is a parked vehicle on one side of the cycle path that the effective width will be reduced by 10–15 centimetres. This shows that obstacles on the side of the road do have an effect on the lateral position of the cyclist. This shows that objects next to the cycle path can have an influence on the lateral position of the cyclists.

Recently, researchers started to investigate the relationship between the objective environment and the perception of the environment. Ma et al. (2014) studied this relationship specifically for cyclists. They found that the objective environment only

[9] Rain, maximum temperature, total amount of sunshine hours, maximum wind speed

indirectly affects cycling behaviour by influencing perceptions. This indicates that obstacles might have an effect on the effective width, however it might be mediated via perception into the position of the cyclists.

<u>Marking</u>

Marking in the middle of the cycle path affects the lateral position on the cyclist. In rural areas in the Netherlands, research on two–way cycle paths shows that the marking is desirable when a path is above 3 meters. It shows that marking might not be desirable when it is crowded or when the cycle path is smaller than 3 meters. The definition of crowded cycle path was 500 cyclists per day. Cyclists cycle more towards the curb of the cycle path when there is marking. This indicates a relationship between marking and lateral position. The result might not directly apply in Amsterdam, since the study was done in rural areas (Boer, 2016).

<u>Other</u>

The literature was relatively limited on external factors on cyclist behaviour. We expect other external factors like the condition of the road, the number of holes, curb bulges, rain puddles, the use of mobile phones or any other distraction to have an effect as well. Since it was not mentioned in the literature that these factors affect on the lateral position, we do not take it into account in our analysis.

## 2.7 Summary

The main focus of this thesis is the behaviour of the cyclists when cycling. A lot of decisions when cycling are made under uncertainty and risk, because behaviour of others is not known beforehand. The prospect theory can be used to comprehend the behaviour of cyclists. The number of cyclists on a cycle path is restricted to the width. According to various researchers the density–flow relationship accounts for cars as for cyclists. This relationship states that the flow converts into a congested flow at a critical point of density. The critical point of density for cyclists has not been observed yet, because there are external factors which influence the critical density point, such as types of cyclists. The following types are categorized in this thesis: a regular cyclist, a parent–child cyclist, a side–by–side cyclist, a fast cyclist, a non–commercial cyclist, a commercial cyclist, a moped, a stint and a mini–sized vehicle. There are also three external factors that might affect the lateral position of cyclists: weather, obstacles and marking. These will be taken into account when studying the behaviour of cyclists.

# 3. Conceptual framework

The following framework has been set–up to give an overview of all the elements together in order to gain insights of the behaviour of cyclists. All the elements discussed in chapter two are taken into account.

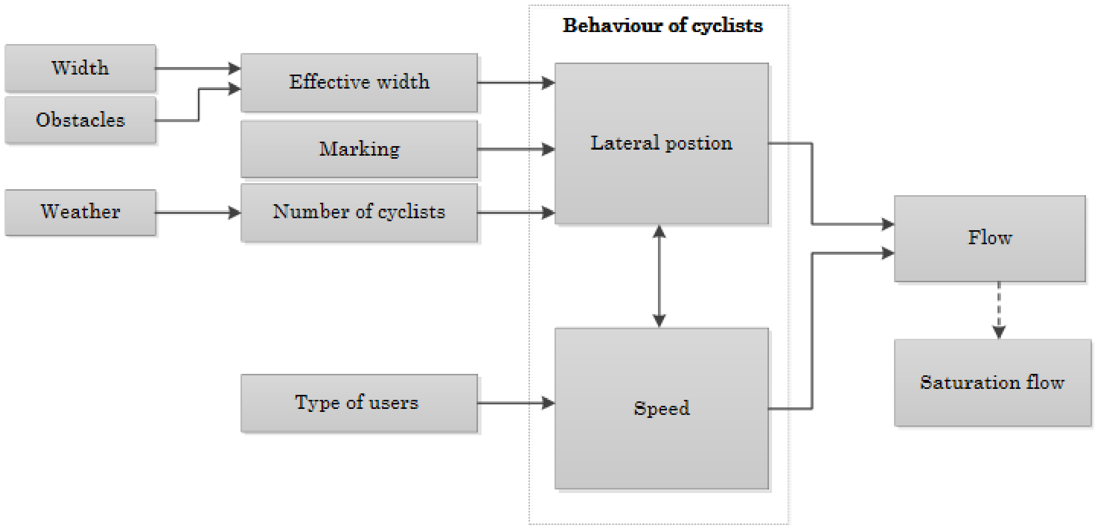



*Figure 11: Conceptual framework of the behaviour of cyclists on the cycle path*

The framework is split up into two important behavioural factors: the lateral position and the speed of cyclists. These variables have been chosen, since they are both measurable with the motion detection algorithm. There is a certain interaction between these factors. The factors together represent the behaviour of the cyclist and will lead to the flow on the cycle path. As stated in section 2.2, we assume the maximum observed flow on a cycle path is equal to the saturation flow. This relationship is expressed in a dotted line. First the elements, which influence the lateral position will be discussed and afterwards there will be looked at the factor that influences the speed of cyclists according to the framework.

Conform literature, there are a few factors which influence the lateral positon of the cyclist. The first factor is the effective width. Section 2.6 states that obstacles reduce the effective width, thus the lateral position. This might be mediated via perception. Scientific literature does not state anything about a relationship between the effective width and the lateral positon. It is expected deriving out of logical reasoning that cyclists overtake with less distance between each other if the effective width is relatively small.

Another influence on the lateral position is the marking. A middle line can lead to a different lateral position, which is more towards the curb as stated in 2.6. The last factor is the number of cyclists. There might be more overtaking due to more cyclists, which might influence the lateral position. This relationship is not tested in scientific literature, but seems a logical relationship. As stated in section 2.6, the number of cyclists is influenced by weather. Bad weather such as rain, low temperatures and high wind speed, can significantly influence the number of cyclists.

The speed of cyclists might be influenced by the type of users. This relationship is not tested yet. The types of users are defined in section 2.2. The various users on the cycle path affects behaviour of cyclists according to the CROW report (van den Munckhof, Zengerink, & ter Avest, 2017). There are nine different categories of types. Some cyclist might not fit into one of the nine categories, but we think enough categories have been created to capture the vast majority of the cyclists.

As far as known, this is the first framework that is used to examine cyclists on a cycle path. It could be the case that other variables mentioned in "other "section 2.6 also affect the lateral position or the speed. These are excluded from this research.

## 3.1 Hypotheses

In order to test partially this framework, three hypotheses have been composed. The relationship between weather and number of cyclist will only be used as a control factor, since this relationship has already been frequently proved.

The first hypothesis focusses on the variable the type of users in the framework. This hypothesis tests if there are other external factors, which can influence the composition of the type of users, therefore it focuses on systematic patterns in the composition of the type of users. The users might differ per location due to the surroundings of a cycle path, such as a school, a university or a shopping area. This hypothesis will help identify whether our framework is extensive enough.

*H1: The location of a cycle path contributes to the mix of users*

This analysis will be based on dataset Zuidas. Two two–directional cycle paths have been filmed, which have less than 300 meters distance. The footage of these cycle paths is watched in parts of five minutes and will be analysed into great detail. The type of users for each five minutes will be written down.

Second, the relationship between the speed and lateral position will be tested on a one–directional cycle path. There has not been many research on this yet. If they are highly correlated, it will be impossible to test any of the other hypothesis. Since people overtake on the left side, the following is expected:

> *H2: If the speed of a user is higher, the average lateral position will be more towards the middle of cycle path.*

The second hypothesis will be tested based on the dataset of the Amstelveenseweg. A simple regression will be executed, where lateral position plays a role as the dependent variable and the speed of a cyclist as the independent variable.

Additionally the relationship between the number of users and the lateral position will be tested in the second hypothesis. There will be a great variety of situations, since a crowded cycle path was chosen. This enables us to test this across a range of situations.

> *H3: The average lateral position will be more towards the middle of the cycle path when there is a large flow of cyclists compared to a low flow of cyclists.*

This relationship will be tested on the dataset Amstelveenseweg. The large flow of cyclists can be expressed in two type of variables, namely the group size between two points of the cycle path and the number of cyclists going over the same measuring point within 10 seconds will be used to test this hypothesis in a systematic way. There will be controlled for the speed of a cyclist in the regression analysis. It is too difficult to exclude the side–by–side cyclists out of the dataset.

There are a two relationships within the framework, which will not be tested. This is the relation between the lateral position and marking and the lateral position and the effective width. The set–up of our two datasets does not enable us to test these relations.

# 4. Methodology & Data

In order to test the hypotheses three cameras will be placed in Amsterdam Zuid, our research area. Before the footage will be analysed, the characteristics of the research area will be explained in detail. Thereafter a portrayal of the camera placement will be presented. This is followed by a detailed description of the cycle paths to identify the differences. Furthermore, there will be elaborated on the measurement period. Additionally, the analysis of the footage and variables of the motion detection algorithm will be examined. Then the weather data source will be examined. At last, the findings of the on–street observations will be presented to show possible external factors.

## 4.1 Research area

The research takes place in Amsterdam. There are two datasets of Amsterdam Zuid. One dataset is in the Zuidas and one dataset is on Amstelveenseweg. The cycle path around the Amstelveenseweg has a relatively busy car road next to it, has a small shopping area and is known for its long wait at the intersection with the Zeilstraat. It functions mostly as an ongoing route towards Zuidas, where a lot of offices are located. The dataset on the Zuidas is in a mixed business district. There are large offices located close to our location, but also two primary schools, three high schools and a large university hospital are located close by the cycle paths. The cameras are also close to train station Amsterdam Zuid, an intermodal transport hub.

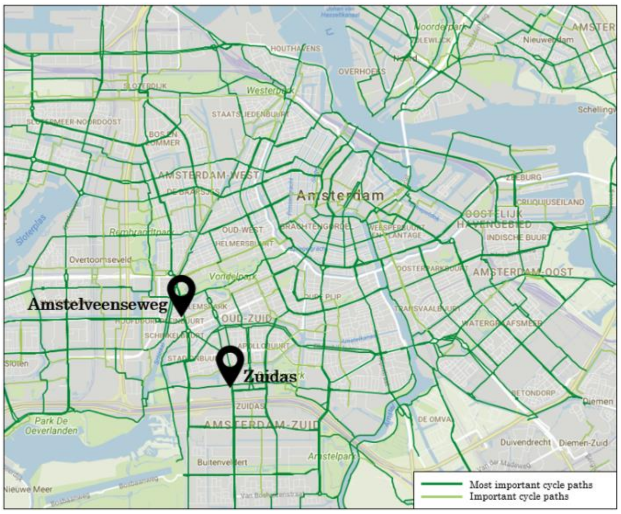


*Figure 14: Research area in Amsterdam*

*Figure 13: Camera on the Amstelveenseweg*

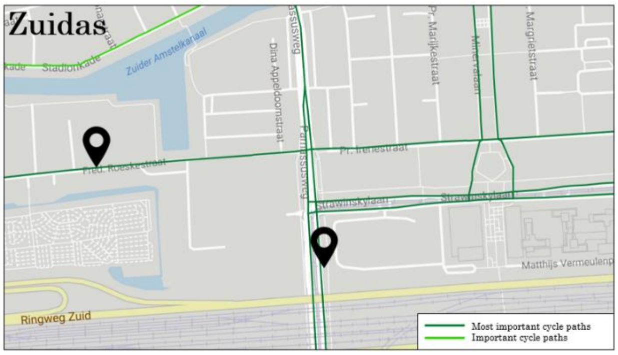


*Figure 12: Two cameras in the Zuidas*

The camera location nearby the Fred Roeskestraat is surrounded by three high schools and two primary schools. It is also a convenient route for people living in Amsterdam New–West to go to the train station or to go to work in the Zuidas. This cycle path does not have any middle–line marking. The camera point near the Parnassusweg is expected to have less parent–child combinations since it is more distanced to schools, but is more surrounded by offices and more seen as a connection route. There is also one school, but this is a lot less than on the Fred Roeskestraat.

### 4.2 The placement of the cameras

In both of our datasets, cameras were placed in the section below the placement of the cameras will be discussed. First the two cameras in the Zuidas will be discussed and afterwards the camera on the Amstelveenseweg will be described. Figure 16 shows the camera nearby the Fred Roeskestraat, located in the Zuidas. The camera has been mounted on a streetlight. At the bottom of the lamppost, there is a box to provide the electricity for the camera. The box is a little too big to fit on the green strip; therefore a small part of the box is on the cycle path. This can be seen as an obstacle. Since the camera is mounted quite low, cyclist on the cycle path can be observed for around 40 meters.

*Figure 16: Camera on the Fred Roeskestraat*


*Figure 15: Camera view of the cycle path of the Fred Roeskestraat*

Figure 19 represents the location near the Parnassusweg, located in the Zuidas. The camera is also mounted on a streetlight. The electricity box does not hinder the cycle path and there has been written that this camera is for research purposes on the box. The camera is mounted at a similar height as the camera near the Fred Roeskestraat. The view of this camera is toward the tunnel, which blocks the view. The camera can observe about 24 meters. Figure 18 represents the camera view.

*Figure 19: Camera on the Parnassusweg*

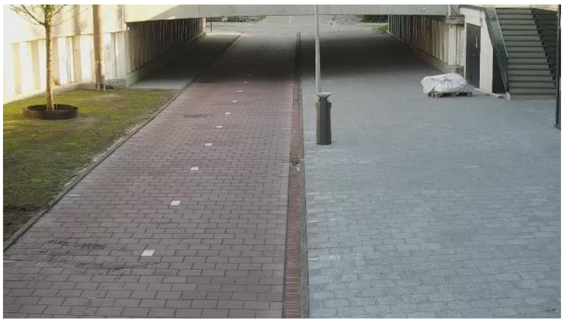


*Figure 18: Camera view of the Parnassusweg*

The light post of the Amstelveenseweg was higher than the ones on the Parnassusweg and the Fred Roeskestraat. This created a top view of the Amstelveenseweg. There is not a picture of the camera on the light post in 2017, thus the picture is taken in 2018. As can be seen in Figure 20, there were a few objects, which might hinder the cyclists. The camera can observe for around 12 meters long. The red boxes in Figure 20, are not observed in real life. They show how the cyclists will be detected in MATLAB. The table is detected as 0.76 chance of being a bike. This shows that this system is not flawless, therefore it is important that peculiar observations are dropped.

*Figure 17: Light post of camera on the Amstelveenseweg*

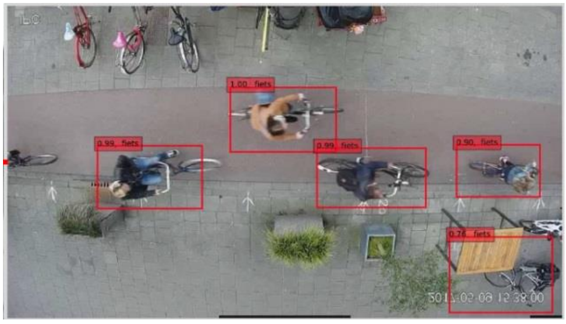


*Figure 20: Camera view of the Amstelveenseweg*

### 4.3 Description of the cycle paths

In order to understand the outcomes better, there will be a short part about lay–out of all the cycle paths. This might affect the results regarding the lateral position. All cycle paths allow low–speed moped riders and not allow high–speed moped riders. Nevertheless high–speed mopeds were seen during on–street observations, even though it is not allowed by law. There are some differences between the cycle paths. First the two cycle paths in the dataset of the Zuidas will be discussed and thereafter the cycle path in the dataset of the Amstelveenseweg will be examined.

Fred Roeskestraat

Figure 21: A close up of the cycle path of the Fred Roeskestraat

The cycle path of the Fred Roeskestraat is 4.0 meters wide and two–directional. It is located in the Zuidas. It has red tiles as a surface, but it must be noted that there are various manhole covers on the cycle path (Figure 21). Our video camera covers two of these manholes. These manholes covers might be seen as an obstacle, since they are often higher than the tiles. Additionally, it seems that not all the tiles are on an equal level, which can create less comfort for cyclists.  Figure 21 also shows that the Fred Roeskestraat does not have a middle line. There is a bush on one side of the cycle path and a curb on the other side.

Parnassusweg

Figure 22: A close up of the cycle path near the Parnassusweg

The cycle path near the Parnassusweg has a width of 4.2 meters and is two–directional. It is located in the Zuidas. There is a gutter near the curb. The gutter is excluded from the 4.2 meters. The other side has some grass. Figure 22 shows a close–up of the cycle path. The tiles seem to be on an equal level. On this cycle path, there is a clear middle marking dividing both directions.

Amstelveenseweg

Figure 23: A close-up of the cycle path on the Amstelveenseweg

The cycle path on the Amstelveenseweg is 1.8 meters wide and accommodates to cycle in one direction. The surface is red asphalt. This differs from the tiles used on the two–directional cycle paths. There is a sloped curb on one side which makes it easier to just go on the sidewalk. On the other side there is directly a sidewalk which can be use as extra space for cyclists. There are some obstacles on this space.

## 4.4 Measurement period

There are two datasets and each dataset has a different measurement period. The Amstelveenseweg was recorded in May 2017, whilst the cameras in the Zuidas on Parnassusweg and Fred Roeskestraat, we placed in May 2018. First, the measurement period of dataset of the Amstelveenseweg will be reviewed and thereafter measurement period of the Zuidas.

Cameras have been put on the Amstelveenseweg from the 9th of May 2017 until the 22nd of May 2017. There were not any holidays or surrounding roadworks during this period, which might influence the results. The holiday period was from the 22nd of April until the 7th of May. The cameras started recording on a Tuesday and ended on a Monday.

The measurement period of the cameras in the Zuidas area was the 14th of May 2018 until the 27th of May 2018. This period is chosen, because the cycle path next to the Strawinskylaan was closed until the 25th of April and most of the schools have a holiday from the 27th of April until 13th of May. It is expected that this influences the total number of cyclists significantly at one of our locations. Therefore the consecutive period seems the most representative. The period after the 27th of May might give less representative results due to final exam periods of various schools and additional days of holiday. There is one day in the period from the 14th of May – 27th of May, which might not give representative results. This is 21st of May. It was With Monday. During this day, schools and offices are closed; this will not probably give a similar behavioural pattern as on a normal working Monday.

## 4.5 Weather data

The weather can be used as a control factor for the total number of cyclists. This data will only be used to compare situations and will not be used in a regression analysis. It gives context to an external variable that has influence on the number of cyclists. The data will be collected of the Royal Netherlands Meteorological Institute (KNMI). This is an institute of the Dutch government, which measures and predicts various weather related variables, like rainfall, temperature and wind speed. The variables are expressed in days (see Appendix II). The weather data will be added as a control factor. There are around 35 official weather stations of KNMI. Schiphol is the nearest within a radius of 6 kilometers. There is an unofficial weather station in a radius of 1 kilometer of our research area, however the quality of this data is not guaranteed.

Therefore we assume that the weather at our research area is the same as at Schiphol. Tin Tin et al. (2012) have shown the effect of weather on number of cyclists, similar variables will be used in this thesis.

- Rain
- Maximum temperature
- Total amount of sunshine hours
- Maximum wind speed

## 4.6 Analysis on type of users of dataset Zuidas

The algorithm was not able to distinguish type of users yet. For the type of users, we needed at least two locations in order to see if there were any differences. Therefore the locations on the Zuidas are used for the analysis on type of users.

Video footage will be divided in parts of 5 minutes. The corresponding types of users will be written down in Excel. In these five minutes, the focus will be on the several types of users, in addition it will give an impression of peculiar things that happen. In total 40 out of 642 hours video footage has been watched. These forty hours consist of footage of two days, Tuesday 15th of May and Thursday the 24th of May. Both days are weekdays and have a temperature which is close to the median. On each day, a morning period and an early evening period was watched. Each period consists of five hours. The morning period was from 06:15 until 11:15 and the early evening period from 14:30 until 19:30.

When watching the footage, each individual bike or vehicle was counted as one. Thus a side–by–side cyclist and a parent–child were at least two vehicles when observed. Additional rules were created, since the existing rules were not clear enough in certain situations. First, when three people were cycling together, three side–by–side cyclists were noted down. Additionally the determination of a fast cyclist has been done on visual appearance, thus not all fast cyclists might have been captured how they have been described as stated in section 2.5. Since tracks of this dataset was not reliable enough. The third rule was adapted for children cycling in front of their parents, they are not counted as parent–child cyclists but both as regular cyclists. The last rule was set–up for non–commercial cyclists cycling with someone else. This has been counted as a side–by–side cyclist.

## 4.7 Motion detection on dataset Amstelveenseweg

The video footage must be transformed into variables. TNO has developed algorithms which can track the speed, lateral position, direction and number of cyclists of video footage. This is done with MATLAB, because MATLAB is able to store various sizes and types of data into a structure and is able to do a video–based motion analysis. In order to collect various variables of the video footage, a local coordinate system has been set–up to determine the exact position of the cyclist. A raster has been put on the entire research area. Each path has been measured by TNO and they have determined the local coordinate for each cycle path. In this way it is possible to determine the speed, lateral position, group size at a specific point. This has been executed on the dataset of the Amstelveenseweg.

In order to measure the lateral position, it is important that a specific line on the cycle path is drawn. Our raster starts at the 12 meter point and ends at the 24 meter point. The line that has been chosen is the 18 meter line, which is the exact middle of our captured cycle path. The x–coordinate that we are using is 18.

The following variables are captured per track

- ID
- Time when the cyclists passed the x–coordinate 18
- Speed of the cyclist when at 18 meters
- Lateral position of the cyclist at 18 meters expressed in a y–coordinate
- Group size between 17 meters and 19 meters (including the cyclists itself), 12 and 17 meters and 19 and 24 meters
- Intensity at 18 meters, which is the number of cyclist cycling on 18 meters in a time period of 10s, 60s, 120s and 300s. For 10 seconds, this is 5 seconds before a cyclists passed the 18 meter point and 5 seconds after.

In the given dataset, there were variables which were captured on other cameras as well. There were also variables which tracked every point on the cycle path, they were often in the format of matrices. These will be dropped for our analysis. Thereafter the structure can be converted into a table in MATLAB and a table can easily be converted into a csv–file, which can be imported in STATA. STATA is used to perform the statistical analysis on the data and to test the hypotheses.

## 4.8 Regression analysis on the dataset Amstelveenseweg

When the data is in STATA, a regression analysis will be executed. The dependent variable for our regression analysis is the lateral position of the cyclist in meters. This is expressed in as a local y–coordinate in the dataset. A conversion to meters can be created by dividing the coordinate by two. The lateral position is the distance of the cyclist to the curb expressed in meters. Our independent variables for the regression analysis are the following:

- Speed
- Group size
- Intensity

Time will be used as a control variable, thus measured in the busy period or in the quiet period. This will be done to check if the regression holds at each time point or that it only holds under certain conditions. Since the regression will be executed during the time of one day, there will not be controlled for weather. We assume that the weather is the same during the entire day.

Our regression will be a simple OLS regression. The first model will be a simple regression with only one independent variable. The $\varepsilon$ in the model represents the error term, whilst the $\beta_0$ is the intercept of this model. This model will be expanded with other independent variables. The base model is as followed:

$$lateral\ postion_i = \beta_0 + \beta_1 speed_i + \varepsilon \qquad for\ each\ i = 1,2,3, \dots \quad (4)$$

This model will be expanded with other cyclists on the lateral position. In our dataset there are two different variables which represent other users, namely intensity of 10 seconds and the group size. The variables represent different dynamics on the cycle path. The intensity of 10 seconds states the users that are 5 seconds in front of the cyclist and 5 seconds behind the cyclists, whilst the group size represents the cyclists 1 meter in front of the user and 1 meter behind the user at the point in time it is detected. Since we want to know the effect of both variables three models are composed, namely a model with intensity, a model with group size and a model with both variables.

$$lateral\ postion_i = \beta_0 + \beta_1 speed_i + \beta_2 intensity_i + \varepsilon \qquad for\ each\ i = 1,2,3, \dots \quad (5)$$

$$lateral\ postion_i = \beta_0 + \beta_1 speed_i + \beta_2 groupsize_i + \varepsilon \qquad for\ each\ i = 1,2,3, \dots \quad (6)$$

$$lateral\ postion_i = \beta_0 + \beta_1 speed_i + \beta_2 intensity_i + \beta_3 groupsize_i + \varepsilon \qquad for\ each\ i = 1,2,3, \dots \quad (7)$$

Our dataset contains observations in the morning ($mrng$) and in the afternoon. There might be some difference between the morning and the afternoon. We wanted to make a model which contains a dummy variable of the morning period. In this way it is possible to see if the observations in the morning and afternoon differ substantially.

$$lateral\ postion_i = \beta_0 + \beta_1 speed_i + \beta_2 intensity_i + \beta_3 groupsize_i + \beta_3 mrng_i + \varepsilon \quad for\ each\ i = 1,2,3, \dots \quad (8)$$

There are certain assumptions that must hold under an OLS–regression. The key assumption of OLS regression is zero conditional mean. Statistical tests will be executed to see if these assumptions hold. The variables in dataset Amstelveenseweg have the following descriptive statistics, which are shown in Table 3. The maximum speed is relatively high and there are some cyclists which are detected outside of the bounds of the cycle path.

| **Variable** | | **Obs** | **Mean** | **Std. Dev.** | **Min** | **Max** |
|---|---|---|---|---|---|---|
| speed_18m | (km/h) | 2,258 | 19.90676 | 4.587068 | 2.255179 | 87.56206 |
| lateral_position_18m | (m) | 2,258 | 0.7376472 | 0.2970982 | -0.67504 | 1.998169 |
| groupsize_12m_17m | (# cyclists) | 2,258 | 0.8826395 | 0.8769938 | 0 | 6 |
| groupsize_17m_19m | (# cyclists) | 2,258 | 1.15279 | 0.3848524 | 0 | 3 |
| groupsize_19m_24m | (# cyclists) | 2,258 | 0.5310009 | 0.7419125 | 0 | 4 |
| intensity_10s | (# cyclists) | 2,258 | 5.309566 | 3.154184 | 1 | 19 |
| intensity_60s | (# cyclists) | 2,258 | 23.59655 | 11.53407 | 1 | 63 |
| intensity_120s | (# cyclists) | 2,258 | 45.20018 | 21.30964 | 5 | 93 |
| intensity_300s | (# cyclists) | 2,258 | 109.5833 | 48.87325 | 17 | 185 |

*Table 3: Descriptive statistics variables*

# 5. Results

In order to answer our research question, an analysis on the data must be executed. First, a small analysis on the weather will be done. This is important since not all weather conditions are observed. Thereafter the camera footage of the Zuidas will be analysed. First there will be a small part about any peculiarities and then the collected data will be analysed. This analysis will include a description of the type of users, time and location. Afterwards the data of the Amstelveenseweg will be analysed. First descriptive statistics will be discussed, then a regression analysis will be made on the data. At last, the insights on the type of users of the Zuidas will be applied on the Amstelveenseweg to create a better overall image.

## 5.1 Weather

We will first discuss the weather of the dataset of the Amstelveenseweg, thereafter we will review the weather of the Zuidas dataset. The average maximum temperature during the research period from the 9$^{th}$ of May until the 22$^{nd}$ of May 2017 was around 19.9°C, which is above the normal temperature of 17.4 – 18°C (Koninklijk Nederlands Meteorologisch Instituut, 2018). There were two days, which did not exceed the maximum temperature of 15°C. Rain was observed on nine of the fourteen days, of which most during the night. It rained during the days on the 14$^{th}$ and 15$^{th}$ of May. The dataset Amstelveenseweg only contains data which has been taken on the 10$^{th}$ of May, which has a temperature of 14.3°C. As stated in section 2.6, the amount of cyclists is smaller when there is a temperature below 15°C. This effect has not been proven in the Netherlands, but only in Australia. There might be a small downwards effect on the total number of users.

The dataset of the Zuidas had a research period from 14$^{th}$ of May until the 27$^{th}$ of May 2018, the average temperature was 21.7°C. There were only a few relatively cold days in our observation period. When it was raining, it rained mostly during the night. Rain was observed on seven of the fourteen days, of which four days had less than 0.05 mm rain. It rained during the day on the 22$^{nd}$ of May and the 23$^{rd}$ of May. It was very humid on these days. The dataset contains data on the 15$^{th}$ of May and the 24$^{th}$ of May. The temperature on the 15$^{th}$ of May was 23.8°C and on the 24$^{th}$ of May was 22.9°C, a higher temperature than on the Amstelveenseweg.

The statistics of the daily weather can be found in Appendix II. The weather of the periods used is not that similar, but on both days no rain was observed. The temperature is quite different, which can have an influence in total number of cyclists. It is not clear what the effect of weather is on type of users. It should be noted that the results of this thesis might not apply to days where heavy rain, snow or any weather conditions which were not present during the observation period are observed.

## 5.2 Observations of the video footage in the Zuidas

There were some noteworthy observations detected when watching the footage. It must be noted that high–speed mopeds were spotted multiple times, often at times just before the peak of cyclists was observed. These are not allowed on cycle paths. Additionally fifteen persons have not been identified as a user, since they were often using inline skates or skateboards. Third of all, the highest number of cyclists observed on the same x–coordinate was five. This has been observed two times at the Fred Roeskestraat.

There was also some remarking behaviour of cyclists. It did not happen often, so it will probably not influence a regression analysis. However, it is good to sketch the dynamics of the cycle path, since cyclists have to anticipate on others. There were no accidents observed when watching the footage. First of all, four cyclists stopped to throw something in the bin that was located close to the cycle path. Secondly a stint stopped in the middle of the cycle path to deliver a package. Additionally a woman parked her bike on the cycle path to let her small child urinate. At last, various cyclists were observed cycling on the pavement, especially on the location nearby the Parnassusweg. This is presumably to avoid the intersection, since their desired destination is probably on the “wrong side” of where they are supposed to cycle.

Some users were seen operating their phone. It was difficult to analyse their behaviour in a systematic way and the effect on their speed and lateral position. Some were swinging, whilst others cycled very slowly. There was not a specific type that used their phone more than other types taking into account the ratio of the type of users. It might affect the lateral position and the speed of the cyclists,

*Figure 24: Mobile phone use by various types of users*

however the vast majority was not using their phone. We estimate around 0.5–1% of our overall sample was using their phone whilst cycling. Since the algorithm is not able to detect if cyclists are using their phone, thus it is impossible to include in our analysis, even though there might be an effect on the lateral position and the speed of the user.

### 5.3 Type of users in the Zuidas

As stated in the methodology, two days which consists of a morning period and an afternoon/early evening period have been watched in order to analyse the type of users. The analysis of the type of users is divided into two parts. First, the morning period will be reviewed and thereafter the afternoon period will be discussed.

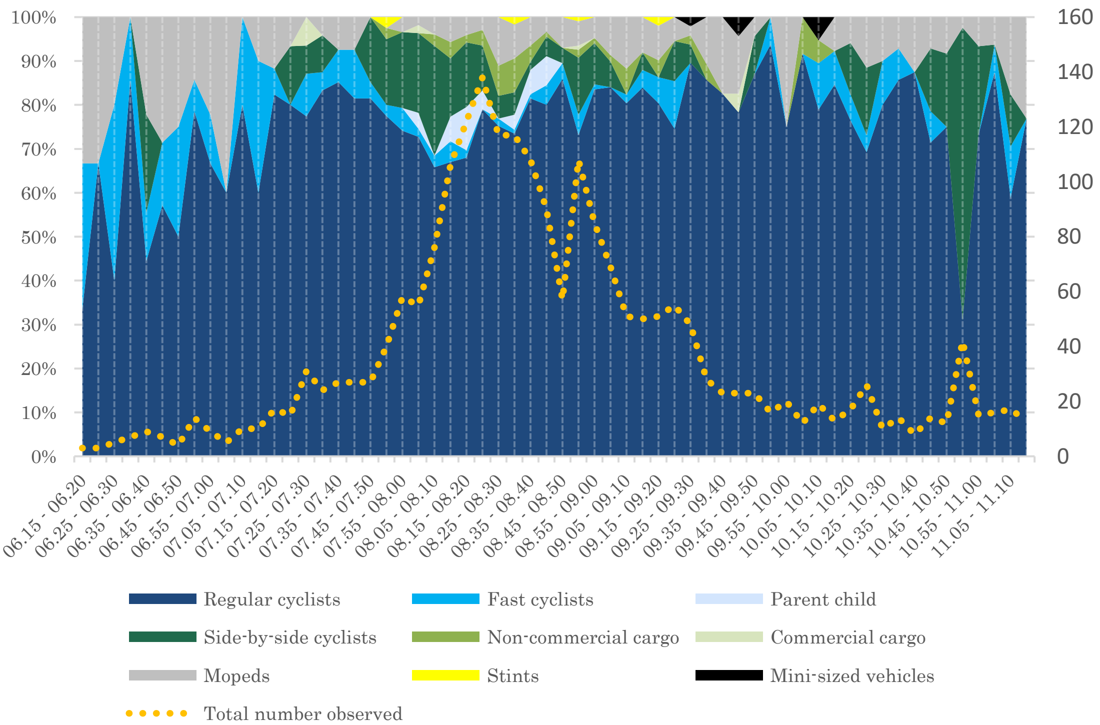
| | Fred Roeskestraat *15th of May* | | Fred Roeskestraat *24th of May* | | Parnassusweg *15th of May* | | Parnassusweg *24th of May* | |
|---|---|---|---|---|---|---|---|---|
| | *Total* | *Percentage* | *Total* | *Percentage* | *Total* | *Percentage* | *Total* | *Percentage* |
| Regular cyclist | 1701 | 76.07% | 1719 | 73.49% | 2251 | 83.28% | 2132 | 82.35% |
| Fast cyclist | 79 | 3.53% | 82 | 3.51% | 45 | 1.66% | 39 | 1.51% |
| Parent–child cyclists | 42 | 1.88% | 36 | 1.54% | 46 | 1.70% | 42 | 1.62% |
| Side–by–side cyclists | 203 | 9.08% | 282 | 12.06% | 118 | 4.37% | 137 | 5.29% |
| Non–commercial cyclists | 49 | 2.19% | 65 | 2.78% | 38 | 1.41% | 43 | 1.66% |
| Commercial cyclists | 5 | 0.22% | 7 | 0.30% | 16 | 0.59% | 11 | 0.42% |
| Mopeds | 149 | 6.66% | 139 | 5.94% | 183 | 6.77% | 180 | 6.95% |
| Stints | 5 | 0.22% | 4 | 0.17% | 2 | 0.07% | 2 | 0.08% |
| Mini-sized vehicles | 3 | 0.13% | 5 | 0.21% | 4 | 0.15% | 3 | 0.12% |
| **Total** | **2236** | **100.00%** | **2339** | **100%** | **2703** | **100%** | **2589** | **100%** |

*Table 4: Overview of the type of users in the morning (06:15 – 11:15)*

Table 4 shows the average ratio of the type of users during the morning. There does not appear to be large differences regarding ratio of the type of users on the 15th and the 24th. There is a small difference on the Fred Roeskestraat. The side–by–side cyclists have increased in absolute numbers, whilst most types have remained the similar in absolute numbers. This translates to a higher ratio for the side–by–side cyclists on the Fred Roeskestraat. Consequently, the percentage of the regular cyclists and the mopeds have decreased slightly, since they both have a relatively large portion of the total number of users.

When comparing the ratios of the Parnassusweg and the Fred Roeskestraat, systematic differences are observed. The Fred Roeskestraat has a higher diversification in type of users. This is mainly due to the higher amount of side–by–side cyclists and non–commercial cyclists. The Fred Roeskestraat has a closer proximity to schools than the Parnassusweg. A location with a close proximity to schools might have a higher diversification of cyclists and attracts non–commercial cyclists and side–by–side cyclists. This will probably not explain the relatively high number of fast cyclists, however it is hard to establish a direct link to the surroundings. It might be a good connection to the network, but it can also be the case that they ignore traffic lights by choosing this route.

The percentages in Table 4 show an average during the morning, however the ratio of type of users can differ over time. In order to give a small impression, the relationship between time and the ratio of the users is plotted in Graph 1. Graph 1 is based on the morning period of the 15th of May on the Fred Roeskestraat. It must be noted there are less than 10 observations until 07:00. This will increase up to 30 observations until 07:30, thereafter the number will increase rapidly. From 06:15 until 07:20, there are only four different types observed, namely the regular cyclist, the moped, the side–by–side cyclists and the fast cyclists.

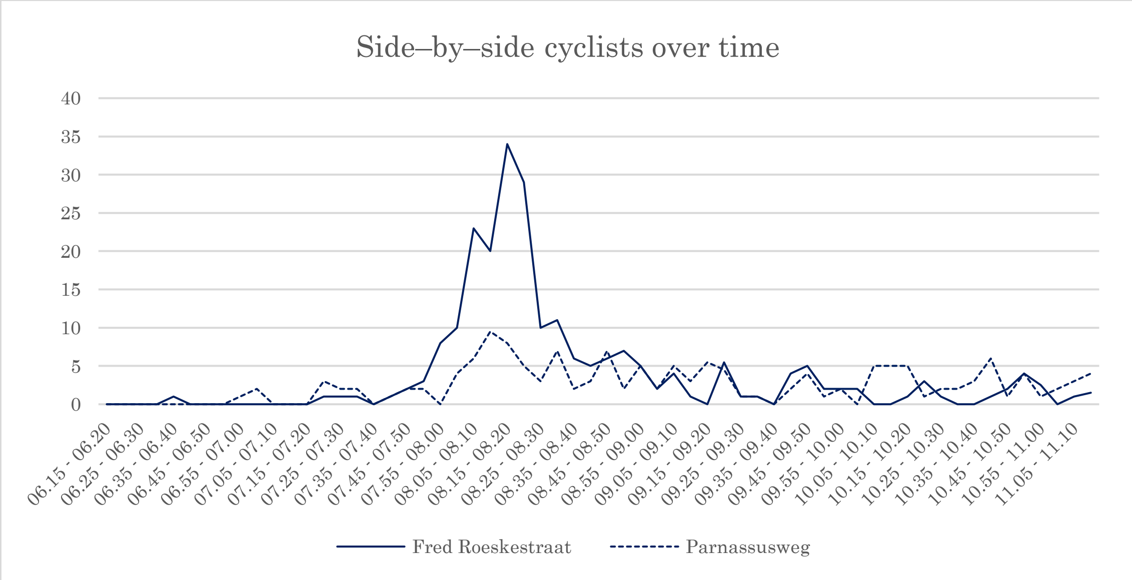



*Graph 1: Ratios of the type of users over time on 15th of May on the Fred Roeskestraat (06:15 – 11:15)*

The category "regular cyclist" has a relatively normal pattern around the 70%. In the beginning it is a bit less, this is thanks to a relatively low number of observations. Whilst the fast cyclist has a relatively high ratio in the early morning, this disappears just before 07:45. Mopeds are relatively have a larger ratio outside the time block from 07:45 until 08:45. It is interesting to see that the parent–child combination is only observed from 07:55 until 08:45. This can be explained by the start of schools. The non–commercial cargo cyclists can be seen during a longer period of time in the morning, but start around a similar time as the parent–child cyclists. They are also counted when there are no kids in them. This is more observed after 08:45. The pattern of side–by–side cyclists seems relatively normal with a relatively small peak, but intense peak around 08:00. There is another peak around 10:45. This can be attributed to a class of kids, which cycled next to each other. This is not representative, since it was not observed on the 24$^{th}$.

The other area graphs in the morning can be found in Appendix III. When comparing Graph 1, Graph 14, Graph 15, Graph 16 (Appendix III), the ratios of the type of users can differ over time. They do not always follow the same pattern. Some type of users, such as the regular cyclists, fast cyclists, parent–child cyclists and mopeds have a similar patterns on both locations. The pattern of the side–by–side cyclists is much more pronounced at the Fred Roeskestraat than at the Parnassusweg. Whilst commercial cargo cyclists are more pronounced at the Parnassusweg. The commercial cargo is more observed after 08:45 than before this point in time.

Since the Parnassusweg generally has more cyclists (Table 3). The pattern of the absolute numbers can give different insights. Therefore the average number of side–by–side cyclists is plotted in Graph 2. The observation from 10:50 – 10:55 on the 15$^{th}$ of May might be a bit high as seen in Graph 1, thus in Graph 2 the average from 10:50 – 10:55 is only based on 24$^{th}$ of May, since this seems to be closer to reality. Graph 2 shows an enormous peak of the Fred Roeskestraat between 08:00 and 08:30. This peak is not present at the Parnassusweg.




*Graph 2: Trend over time of side–by–side cyclists based on the qualitative video analysis*

This difference might be due to the surrounding schools on the Fred Roeskestraat. The high number of side–by–side cyclists might affect the speed of some other types of users, especially with overtaking. It might become harder to overtake since more space is taken. When there are too much oncoming cyclists, you have to adapt to the users in front of you. This has been observed on the video footage, sometimes users slowed down and waited until they could overtake.

The patterns of other types of user can be found in Appendix IV. It must be stated that the commercial cyclists, stint and mini–sized vehicles have not been observed in substantial amounts to draw any conclusions based on their pattern can be drawn. The regular cyclists have a relatively similar pattern, but the peak is later on the Parnassusweg. The mopeds, parent–child and non–commercial cyclists have a similar pattern as well. It was hard to detect any pattern in the fast cyclists.

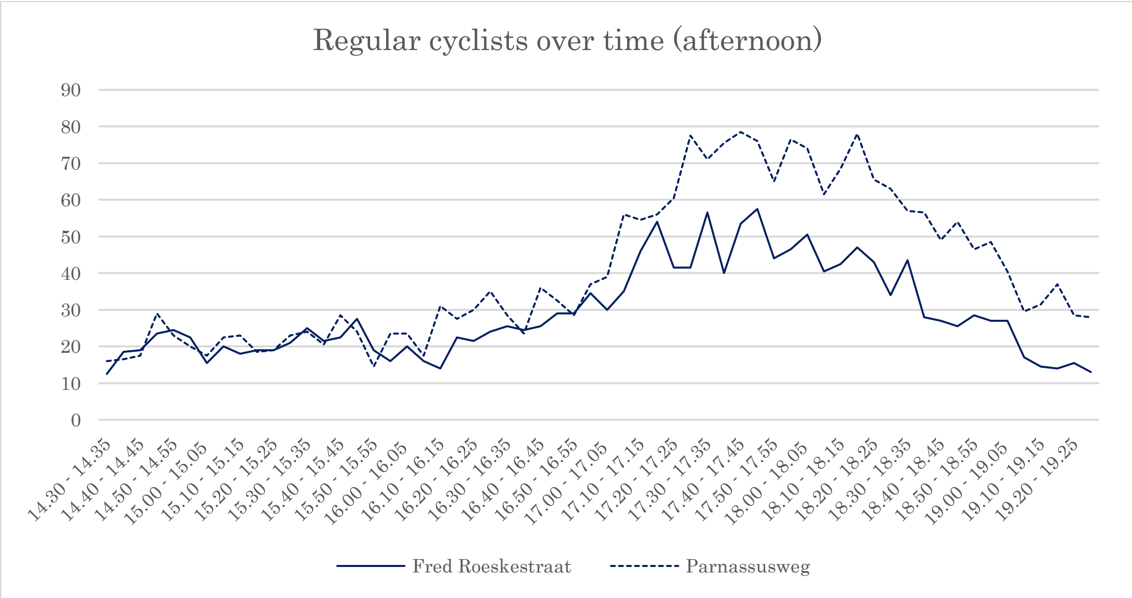
In the afternoon, the overall pattern of users is a bit different. In general there is a higher variation of users, thus relatively less regular cyclists. The number of mopeds is relatively higher than in the morning, especially on the Parnassusweg. The side–by–side cyclists have increased relatively to the morning. A possible explanation might be that there are more leisure activities in the afternoon. The leisure activities might be done in combination with friends. On the Fred Roeskestraat, there were a lot of people observed cycling together wearing tennis or hockey gear. Another possible explanation might be that you cycle home with a colleague for a part of the trip, since we saw a small amount of men in business suits cycling next to each other. As expected the commercial cargo is slightly higher as well. This is mainly thanks to the food delivery services, which are often done by bike. This can also be found in Graph 19 and Graph 20 (Appendix III). It is clearly visible that the commercial cargo is more present than in the morning, especially after 17:00.

| | Fred Roeskestraat *15th of May* | | Fred Roeskestraat *24th of May* | | Parnassusweg *15th of May* | | Parnassusweg *24th of May* | |
|---|---|---|---|---|---|---|---|---|
| | *Total* | *Percentage* | *Total* | *Percentage* | *Total* | *Percentage* | *Total* | *Percentage* |
| Regular cyclist | 1814 | 68.87% | 1655 | 69.65% | 2468 | 76.69% | 2400 | 76.36% |
| Fast cyclist | 81 | 3.08% | 42 | 1.77% | 37 | 1.15% | 68 | 2.16% |
| Parent–child cyclists | 84 | 3.19% | 56 | 2.36% | 34 | 1.06% | 31 | 0.99% |
| Side–by–side cyclists | 386 | 14.65% | 388 | 16.33% | 288 | 8.95% | 284 | 9.04% |
| Non–commercial cyclists | 53 | 2.01% | 56 | 2.36% | 38 | 1.18% | 36 | 1.15% |
| Commercial cyclists | 11 | 0.42% | 5 | 0.21% | 34 | 1.06% | 41 | 1.30% |
| Mopeds | 192 | 7.29% | 161 | 6.78% | 298 | 9.26% | 265 | 8.43% |
| Stints | 11 | 0.42% | 9 | 0.38% | 7 | 0.22% | 4 | 0.13% |
| Mini-sized vehicles | 2 | 0.08% | 4 | 0.17% | 14 | 0.44% | 14 | 0.45% |
| **Total** | **2634** | **100.00%** | **2376** | **100.00%** | **3218** | **100%** | **3143** | **100%** |

*Table 5: Overview of the type of users in the afternoon (14:30 - 19:30)*

When comparing the afternoon of 15th of May and the 24th of May, there are only fairly small differences observed. The most astonishing difference is the fast cyclists, which is on the Fred Roeskestraat is halved on the 24th of May compared to the 15th of May, however they doubled on the Parnassusweg. It is hard to directly point out a cause for this, since the definition of fast cyclists was mainly focused on visual appearance. The ratio of mopeds is higher on the 15th of May compared to the 24th of May at both locations. This difference is less pronounced observed in the morning on the Fred Roeskestraat, but it is not seen at the Parnassusweg. It is hard to state the cause of this difference. The fast cyclists, non–commercial, side–by–side cyclists and stints are more observed on the Fred Roeskestraat than on the Parnassusweg.

When looking at the type of users over time (Appendix III), it is hard to see a distinct pattern. The stints are more observed before 17:00, since they are mostly used by child care institutes and to deliver packages. There is also high percentage of side–by–side and parent–child cyclists observed before 17:00 at the Fred Roeskestraat. In the afternoon people with tennis bags and hockey sticks were seen on the footage on the Fred Roeskestraat. These were often cycling next to each other. But overall it is harder to find a distinct pattern in the type of users, in relative and in absolute numbers. For the regular cyclist, the largest group of the type of users, a distinct pattern can be found. There is a peak during the evening period, which is more distinct at the Parnassusweg than at the Fred Roeskestraat. The pattern is similar for both locations, which can be seen in Graph 3.




*Graph 3: Regular cyclists over time in the afternoon/evening*

A similar trend cannot be found for any other type of users in the afternoon. In Appendix IV the similar graphs can be found for other type of users. Graph 32 (Appendix IV) shows the pattern for side–by–side cyclists. It is hard to detect a trend or a peak for the side–by–side cyclists in the afternoon. This contrasts with the morning period, which is pictured in Graph 2. Then a clear peak is detected. This indicates that the morning peak period is different than the afternoon peak period for side–by–side cyclists.

The afternoon has a higher variation of users, but the morning period has a denser peak period. This can be seen at both locations and can create a different dynamic in both peak periods, therefore it is good to keep the type of users in mind, when analyzing the data of each individual cyclist. Our first hypothesis "*the location of a cycle path contributes to the mix of users*" cannot be rejected based on this data, since substantial difference were observed at the two locations.

### 5.4 Descriptive analysis on dataset Amstelveenseweg

The video footage of the Amstelveenseweg is not available anymore due to privacy regulations. Therefore it is impossible to sketch the type of users observed. When comparing locations, the Amstelveenseweg seems more similar to the Parnassusweg than the Fred Roeskestraat. This is mainly based on the fact that on the Fred Roeskestraat, there are several schools in direct surroundings, whilst there are not that many schools close on the Amstelveenseweg. Therefore we assume that the user profile is more similar like on the Parnassusweg.

This is a one–directional cycle path of 1.8 meters wide. The sidewalk is at the same level on one part of the cycle path and could be used by cyclists when it is overcrowded. The dataset consists out of 2,258 observations on the cycle path. These observations are done on the 10$^{th}$ of May 2017. The maximum temperature was 14.3°C and it did not rain. The dataset covers two main time periods, namely 07:29:24 – 08:45:52 and 13:29:51 – 14:44:08. This is a relatively busy period of time and a relatively quiet period of time. A dummy has been created for the two main time periods.

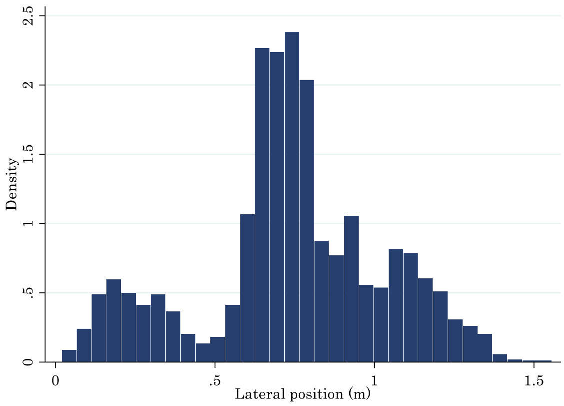
The dataset contains 2,258 observations. Some observations will be dropped. We assume that cyclists cannot cycle slower than 5 kilometers/hour, thus three observations are dropped. We also assume that users cannot exceed above 35 kilometers/hour, thus 12 observations are dropped. The observations cannot exceed the outlines of the cycle path, therefore any detection which is smaller than 0 or exceeds 1.8 meters is dropped. When the lateral position is 0 m, it is equal to the curb. There are 7 observations dropped due to their lateral position. There are still 2,236 observations in the dataset. The descriptive statistics do not extremely differ.

| Variable | | Obs | Mean | Std. Dev. | Min | Max |
|---|---|---|---|---|---|---|
| speed_18m | (km/h) | 2,236 | 19.83746 | 4.120568 | 5.189559 | 34.79397 |
| lateral_position_18m | (m) | 2,236 | 0.7401558 | 0.2887544 | 0.019369 | 1.556066 |
| groupsize_12m_17m | (# cyclists) | 2,236 | 0.8823792 | 0.8736935 | 0 | 6 |
| groupsize_17m_19m | (# cyclists) | 2,236 | 1.155188 | 0.3814196 | 0 | 3 |
| groupsize_19m_24m | (# cyclists) | 2,236 | 0.5299642 | 0.7415421 | 0 | 4 |
| intensity_10s | (# cyclists) | 2,236 | 5.323345 | 3.151167 | 1 | 19 |
| intensity_60s | (# cyclists) | 2,236 | 23.63909 | 11.5172 | 1 | 63 |
| intensity_120s | (# cyclists) | 2,236 | 45.24329 | 21.27632 | 5 | 93 |
| intensity_300s | (# cyclists) | 2,236 | 109.716 | 48.82766 | 17 | 185 |
| Morning | (1 = morning; 0 = afternoon) | 2,236 | 0.8085868 | 0.3935015 | 0 | 1 |

*Table 6: Descriptive statistics after the outliers are dropped*

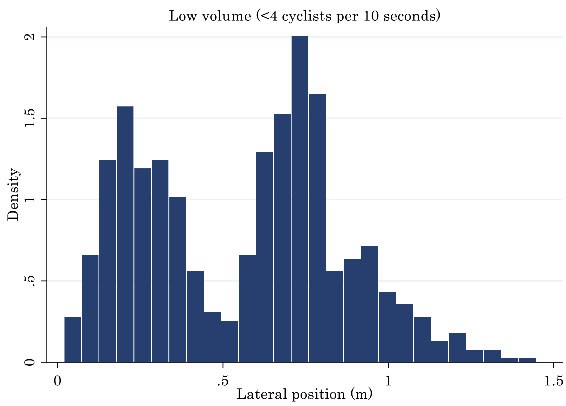
### Lateral position

The lateral position of the cyclists will be taken as the dependent variable. The histogram shows where most cyclists are observed on the cycle path. It shows that there is a relatively high concentration around the mean (74.02 cm). It does not follow a normal distribution, which is not surprising, since cyclists like to leave some space when overtaking. The sample has 2,236 observations, therefore we do not expect non–normality of the error terms to be a serious problem.

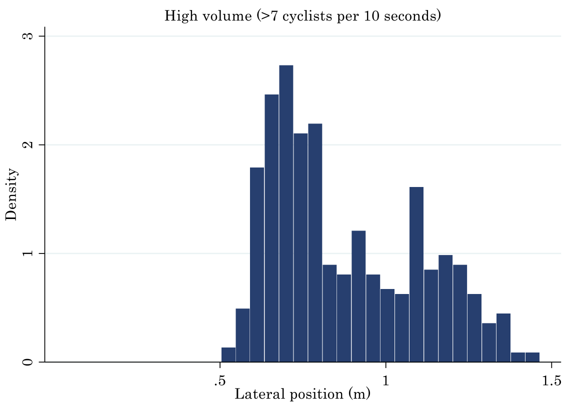



*Graph 4: Histogram of the dependent variable*

The effect of crowdedness will also be tested on the lateral position. Two histograms with different levels of intensity have been composed. A low volume of cyclists is when the intensity within 10 seconds is smaller than four cyclists. There are 746 observations who qualify to this requirement. A crowded cycle path is defined when there are more than seven cyclists crossing the measuring line within 10 seconds. There are 511 observations which follow this definition. When plotting these histograms, a different pattern can be found. During the low volume, there are two peaks. There is one relatively close the curb and one somewhat above 74.02 cm, the mean. This might indicate a lot of side–by–side cyclists. Side–by–side cyclists are presumably more willing to cycle close to each other than overtaking, since they have a similar speed and do not expect to make any weird movements. This is not observed at the high volume cyclists. There they start with a high volume around the normal mean and see cyclists overtaking them.

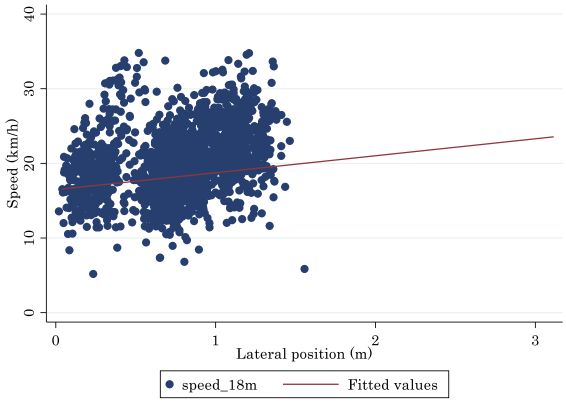



*Graph 5: Histogram of lateral position with a low volume of cyclists*




*Graph 6: Histogram of lateral position with a high volume of cyclists*

When overtaking, one must go faster than the other. In the Netherlands, there are traffic rules established that you must overtake on the left hand. It is expected that there is a trend upwards, however this trend is hard to detect in the scatterplot. The red line does show a small upwards trend.




*Graph 7: Scatterplot of lateral position and speed*

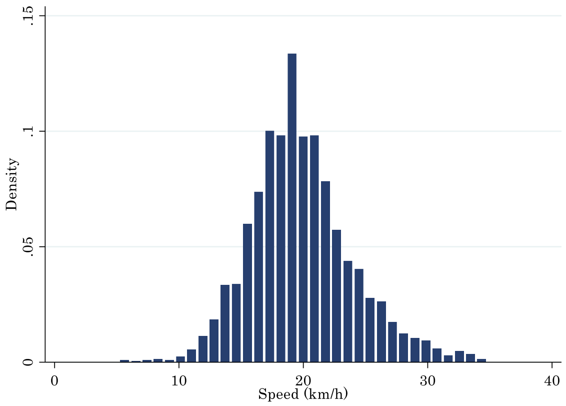
In order to do a regression analysis, it is important to know if there is a high correlation between two variables. One of the OLS–assumption is no perfect collinearity. Perfect collinearity are two variables that have the same variance, and these variables will explain each other. There can also be multicollinearity. This is the case if two variables are highly related and cannot be easily distinguished. In order to control for this a correlation matrix of all the variables in our dataset has been made. There are high correlations observed with the various levels of intensity. This is logical, since within the 300 seconds all the other intensity levels are also included. For example, the correlation between intensity_300 and intensity_120 is 0.9301. The group size between 12 and 17 meter and 19 and 24 meter has a somewhat higher correlation. This is mainly because most cyclists within 10 seconds are detected have just passed the 18 meter line or are about to pass that line. Therefore it would be best if we use the group size between 17 and 19 meters and intensity_10s.

| | speed | lateral_ position | groupsize _12_17m | groupsize _17_19m | groupsize _19_24m | intens ity-10 | intens ity_60 | intensi ty_120 | intensi ty_300 | Morni ng |
|---|---|---|---|---|---|---|---|---|---|---|
| **Speed** | 1 | - | - | - | - | - | - | - | - | - |
| **lateral_position** | 0.3185 | 1 | - | - | - | - | - | - | - | - |
| **groupsize_12m_17m** | 0.0092 | 0.3695 | 1 | - | - | - | - | - | - | - |
| **groupsize_17m_19m** | -0.0329 | 0.2112 | 0.1837 | 1 | - | - | - | - | - | - |
| **groupsize_19m_24m** | -0.0267 | 0.3048 | 0.1646 | 0.1773 | 1 | - | - | - | - | - |
| **intensity_10s** | -0.0813 | 0.4234 | 0.4039 | 0.2296 | 0.4848 | 1 | - | - | - | - |
| **intensity_60s** | -0.0595 | 0.5596 | 0.2847 | 0.1892 | 0.321 | 0.6741 | 1 | - | - | - |
| **intensity_120s** | -0.0515 | 0.5918 | 0.2608 | 0.1681 | 0.2908 | 0.6357 | 0.9196 | 1 | - | - |
| **intensity_300s** | -0.0244 | 0.6192 | 0.2318 | 0.1273 | 0.2709 | 0.5803 | 0.8492 | 0.9301 | 1 | - |
| **Morning** | 0.059 | 0.735 | 0.3861 | 0.0937 | 0.219 | 0.4692 | 0.7053 | 0.7486 | 0.8013 | 1 |

*Table 7: Correlation matrix*

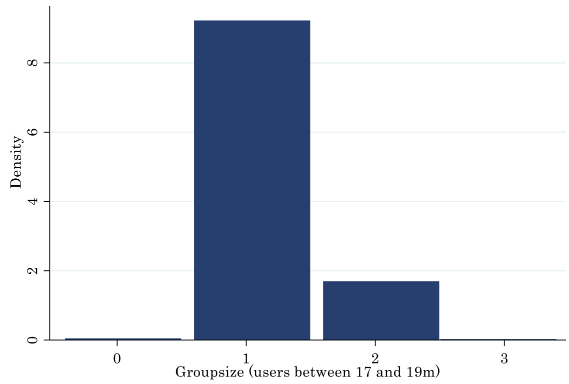
Independent variables

In order to get to more familiar, the distribution of each independent variable has been plotted as a histogram. Table 6 shows that the minimum observed speed is 5.18 km/h and the maximum speed is 34.78 km/h. The speed seems normally distributed.



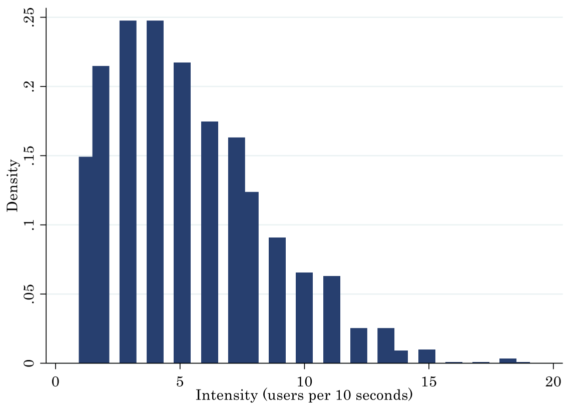
*Graph 8: Historgram of the speed*

The group size has as minimum 1 user and maximum 3 users. Graph 9 displays that the group size of 3 users is not observed frequently. When the group size is 2, it can be a cyclists overtaking other cyclists, but it can also be a pair of side–by–side cyclists. The majority of the group are solo cyclists. When adding this variable in the regression analysis, there cannot be any conclusions about groups larger than 3 people.



*Graph 9: Histogram of the group size*

The intensity levels are more spread. The minimum is one cyclist, namely the detected cyclists itself and the highest observed number is 19 cyclists within 10 seconds. When using the calculation techniques of other papers, this would result in a capacity of the cycle path of 3800[10] cyclists/hour/meter. The average speed was 16.7 km/hour when 19 cyclists within 10 seconds were observed. The intensity is not normally distributed as can be seen in Graph 10.



*Graph 10: Histogram of the intensity per 10 seconds*

[10] We will extrapolate the observation of 19 cyclists in 10 seconds to an hour, which will result in $capacity = \frac{19 \cdot 6 \cdot 60\ cyclists}{1{,}8\ meter} = 3800\ cyclists\ per\ meter\ per\ hour$

### 5.5 Regression analysis on the on the Amstelveenseweg

A regression analysis will be executed, since we suspect that there is some form of correlation between several variables. It is an estimation technique, which enables us to predict a relationship. Since there has barely been any research on a regression model on the lateral position of the cyclists. We will start relatively simple and add each time an independent variables. We will start with a relatively simple regression model.

$$lateral\ postion_i = \beta_0 + \beta_1 speed_i + u_i \qquad for\ each\ i = 1,2,3, \ldots$$

Model 1 has only one independent variable and can be found in Table 8 (page 50). On average if a cyclist cycles 1 km/h faster, the lateral position will be 2.23 centimeters more away from the curb ceteris paribus at a 5% significance level. The model explains about 10.15% of the variance. The lateral position might be influenced by other cyclists as well. Therefore it is important to see what this effect is. There are two variables which express other cyclists, namely the group size between 17 and 19 meter and the intensity of 10 seconds.

First of all, the effect of intensity of 10 seconds is tested in model 2. Table 8 shows the results of model 2. The magnitude of the speed did not change a lot, however the magnitude of the constant did change to 2.56 centimetres and is not significant at a 5% level. The intercept cannot be interpreted, since we excluded all variables with a speed less than 5 km/h. If the number of cyclist goes up one within of 10 seconds of a detection, than the expected lateral position will be 4.14 centimeters away of the curb ceteris paribus at a 5% significance level. This is logical since the chance is higher that a cyclist is going to overtake someone when there are more cyclists in the area. It explains about 30.41% of the variance in the model.

In the third model (see Table 8), the group size between 17 and 19 meters is tested. It is interesting to see that the magnitude of the speed did not change. Second of all, the group size is significant at a 5% level and has a positive sign. If the group size between 17 and 19 meter will become 1 cyclist more the expected lateral position will change with 16.8 centimeters away of the curb ceteris paribus. It must be noted that there were only group sizes between 1 user and 3 users observed. Therefore it is hard to state the effect of a larger group than 3 cyclists. The adjusted $R^2$ is around 0.1499, which seems coherent with the fact that there is not that many difference in group sizes.

In the fourth model we test the effect of the group size and the intensity. The intercept has changed to a negative, however the intercept is not meaningful, since the speed, group size and intensity cannot be zero, since we assume that the speed must be above 5 km/hour. The sign and magnitude of speed has not changed tremendously and is still significant at a 5% level. The coefficient of intensity of 10 seconds has the same sign, namely a positive sign, however the magnitude has decreased slightly. If the intensity of 10 seconds increased by 1 cyclists, the expected lateral position will be 3.88 centimeters more towards the middle, ceteris paribus, at a 5% significance level. The same accounts for the coefficient of the group size. The positive coefficient of group size has a significant effect on a 5% level. The expected lateral position will be on average 9.5 centimeters more towards the middle, when the group size between 17 and 19 meters is increased by 1 cyclists, when holding all the other factors constant.

| | **Model 1** | **Model 2** | **Model 3** | **Model 4** | **Model 5** |
|---|---|---|---|---|---|
| Constant | 0.2973779** | 0.0256285 | 0.0931493* | -0.0727898* | -0.2264715** |
| Speed at 18m | 0.0223203** | 0.0248967** | 0.0228313** | 0.0250225** | 0.0205511** |
| Intensity of 10 seconds | | 0.0414478** | | 0.0388165** | 0.0100510** |
| Groupsize between 17 and 19m | | | 0.1680167** | 0.0951609** | 0.1017882** |
| Morning | | | | | 0.4796728** |
| | | | | | |
| Observations | 2,236 | 2,236 | 2,236 | 2,236 | 2,236 |
| R^2 | 0.1015 | 0.3047 | 0.1507 | 0.3197 | 0.6487 |
| Adjusted R^2 | 0.101 | 0.3041 | 0.1499 | 0.3187 | 0.6481 |

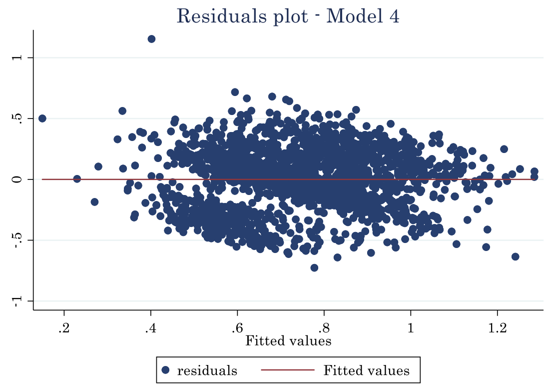
* p<0.05 and **p<0.001

*Table 8: Regression models*

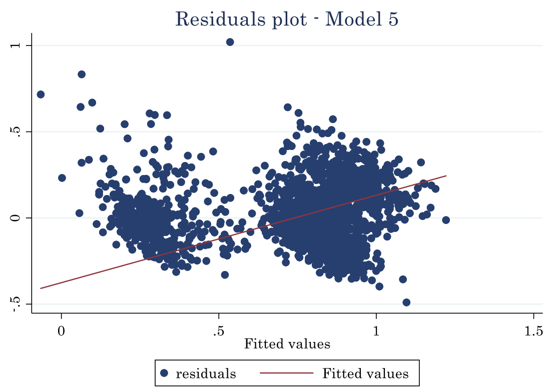
Model 4 seems like a representative model. Nonetheless, our dataset consists of two time periods. One time period is in the morning and one in the afternoon. It would be interesting to create a dummy to see what the effect of a “busy” (morning) or a relatively “quiet” (afternoon) period has. This dummy will capture all the differences between the morning and afternoon period. This will cover not only the time period, but might also enclose the differences in type of users, in level of experiences, in age. Unfortunately it is not possible to test the effect of these variables, since they were not tracked in the data. The analysis on the video footage of the Zuidas showed that there were differences in the types of users observed in the morning and afternoon. There were less regular cyclists and mainly an increase in side–by–side cyclists. If this also holds for the Amstelveenseweg, there will probably be a different dynamic on the cycle path.  We suspect that this might create omitted variable bias in model 5. Since morning and afternoon period do not only include a time variable, but might also include difference in ratios of type of users. Model 5 shows that the behaviour of cyclists is significantly different in peak period than off–peak period.

Some estimates of coefficients have remained similar to model 4, namely the speed of a user and the group size. Both estimates are significant at a 5% level. The magnitude of the intensity has decreased to 1.0 centimeter. This implies that the expected value of the lateral position will increase with 1.0 centimeters, when the intensity will increase with one and keeping all the other factors constant at a 5% significance level. The estimate of the peak period is significant at a 5% level. When a cyclists cycles in a peak period the expected lateral position will be on average 47.97 centimeters away of the curb ceteris paribus. This is actually quite high, as said before. There might be a case of omitted variable bias, however it is impossible to test this. This suspicion states that there is an over– or underestimation of the coefficients.

It is important to evaluate the fit of the model to the data and to control if all the OLS assumptions hold. At first sight model 4 and model 5 seem as relatively good models, even though there is a slight fear of omitted variable bias in model 5. First, the fit of the model will be checked by a scatterplot of the fitted residuals and the residuals. When plotting the residuals against the fitted values, a pattern should not be observed. Model 5 shows a linear pattern in Graph 11, whilst model 4 does not show a clear pattern. The non–random pattern in model 5 indicates that model 5 is not capturing all explanatory information.




*Graph 12: Scatterplot of fitted values - Model 4*




*Graph 11: Scatterplot of fitted values - Model 5*

It is hard to determine if there is homoscedasticity of the scatterplots, a Breush-Pagan test will be executed to test for homoscedasticity. The null hypothesis is that there is a constant variance. Model 4 had a Prob>Chi of 0.0000, thus the null–hypothesis is rejected and there is heteroscedasticity. Model 5 had a Prob>Chi of 0.6142, thus $H_0$ is not rejected and we assume homoscedasticity. Model 4 will be tested with robust errors. A test with robust errors will not change the estimates of the coefficients, but only changes the t–values and p–values. The significance levels have not changed for any of our coefficients when estimating the model with robust errors. In order to test our hypothesis, model 4 should be used since model 5 contains omitted variable bias.

The analysis on the Zuidas showed a possible explanation of the omitted variable bias in model 5. The type of users was more diversified than in the morning. The type of users might have an effect on the lateral position as well, however this is impossible to test. The analysis on the Zuidas showed that the morning period and afternoon period had different patterns, but also that over time the patterns varied. The chosen time pattern can have a huge influence on your results. Since model 4 did not capture any time related variable, it seems like the best model. It is an average estimation over two time periods, thus it follows that the expected lateral position of the cyclists can be determined as followed.

$$E(lateral\ postion\ in\ meters_i) = -0.0727898 + 0.0250225 speed_i + 0.0388165 intensity_i + 0.0951609 groupsize_i \quad (9)$$

The second and third hypothesis will be tested based on model 4 (expression 7 & 9). The other models conclude the same regarding the sign, however they differ regarding the magnitude. The second hypothesis *"If the speed of a user is higher, the average lateral position will be more towards the middle of cycle path"* can be confirmed. Each model showed a relationship of 2 centimetres for each increase of 1 km/h., ceteris paribus at 5% significance levels. The third hypothesis "*The average lateral position will be more towards the middle of the cycle path when there is a large flow cyclists compared to a low flow"* is harder to express in magnitude, since it is expressed in two variables group size and intensity. The magnitude is positive, and therefore this hypothesis cannot be rejected.

# 6. Conclusion

The goal of this thesis was to get insights in the interaction between cyclists on cycle paths. The group of cyclists did not only consists of people using bicycles, but also other vehicles that are allowed on the cycle path like Stints, mopeds and mini–sized vehicles. We have used two datasets to gain insights in the behaviour on the cycle path. The results which have been found will be interpreted in this section. First our sub–questions will be answered and afterwards our main research question will be answered. Thereafter our conceptual framework will be adapted based on the outcomes. Furthermore policy implications will be discussed, which facilitates policy makers and designers of infrastructure to make more justified decisions. Following the limitations of this study will be discussed, at last recommendations for future research will be made.

## 6.1 Main findings

In this section, the results will be interpreted. The main research question will be answered based on the sub–questions. For each sub–question a corresponding hypothesis has been composed. First, we will start with insights in different types of users and afterwards we will go into further detail about the relationship of lateral position with speed and other users.

*"What systematic patterns can be observed for different type of users on a cycle path?"*

In order to answer this sub–question, a clear distinction for the different type of users has been composed. A distinction has been made in section 2.5. The users that have be distinguished into nine categories, namely *regular cyclists, parent–child cyclists, side–by–side cyclists, fast cyclists, non–commercial cyclists, commercial cargo cyclists, stints, mopeds and mini–sized vehicles.*

Our analysis found that location and time during the day affect the composition of type of users on the cycle path. These two factors have been proven to affect the composition, however only a small time frame and a limited number of locations have been observed. It would be ambiguous to state the magnitude of the effect.

The corresponding hypothesis of this sub–question was "*The location of a cycle path contributes to the mix of users*". Two different locations were used. One location with a high attraction factor, namely schools and the other location which was more an ongoing route. The distance between the two locations was less than 300 meter. Our analysis showed that the ratio of users differed at the two locations. The location close to the schools has a higher number of side–by–side cyclists and more non–commercial cyclists. There are proportional less regular cyclists and the type of users are more diversified. This was systematically observed during the entire day.

We also observed some interesting differences over time. It was fascinating to see that in the morning the peak was higher and more intense at the location with a high attraction factor, school. This small, but intense peak was only found in the morning. It is expected that this peak is due to the similar starting times of schools, since this peak was not observed in the afternoon. In the afternoon, there was barely a peak observed on the location with a high attraction factor. There was a peak at the Parnassusweg, however this was substantially smaller than during the morning rush hour.

Time did not only affect the number of users, but also the type of users. There are various time patterns observed for type of users. It must be stated that most patterns are found in the morning period. The parent–child cyclists were only seen in the morning between 07:55 until 08:45, the side–by–side cyclists exhibited a peak around 08:30 near the location with the school and earlier around 08:20 on the on–going location. However for the afternoon it was difficult to see a trend in users, except for the regular users. The regular users have an increase around 17:00 and decreased around 18:30. In general, the afternoon was more diversified by type of users than the morning period.

Our second sub–question does not make any distinction between types of users, but focuses on the relationship between speed and the lateral position. There not any other researchers who have estimated this relationship, therefore is it hard to validate our results.

*"What kind of relationship is there between speed and lateral position?"*

When a user increases its speed with 1 km/h, the expected lateral position will be on average 2 centimetres more towards the left ceteris paribus. The magnitude did not change much over different regression models, which indicates that this relationship seems to be solid. This relationship was tested based on the data of the Amstelveenseweg. The corresponding hypothesis was as followed "*If the speed of a user is higher, the average lateral position will be more towards the middle of cycle path.*" This hypothesis cannot be rejected based on our data. The shift in lateral position indicates when there is a high variety of speeds, that the cycle path must have a sufficient width to accommodate enough space for everyone to have a comfortable journey.

We expect that speed not the only factor is which influences the lateral position of the cyclists. We contemplated that other cyclists might contribute the average expected lateral position as well, therefore the following question was composed.

*What are the differences in lateral position due other users on cycle path?"*

Our regression analysis shows that the average lateral position will increase when there are more cyclists on the cycle path. However, there are some small remarks on our regression analysis.

The histograms plotted when there is a low intensity (Graph 5) and when there is a high intensity (Graph 6) seem to show that there is a clear difference when people are cycling next to each other or overtaking. It shows that side–by–side cyclists ride generally closer to each other than when cyclists are overtaking. Greibe and Buch (2016) concluded this as well. It must be noted that our histograms of the lateral position with a low and high volume (Graph 5 & Graph 6) did not resemble their graphs. Since our dataset of the Amstelveenseweg might exhibit more side–by–side cyclists than in Copenhagen, unfortunately this cannot be confirmed by video analysis on the Amstelveenseweg. The analysis on the Zuidas did show a relatively high percentage of side–by–side cyclists. This gives an indication, but not a definite result. Especially since Greibe and Buch (2016) did not state the percentage of side–by–side cyclists that they have observed.

We expect that the side–by–side cyclists will have influence on the magnitude of variables which express the number of users in the regression analysis. Based on our analysis, we cannot reject that the number of users on the cycle path does not affect the lateral position, however the magnitude is not clear yet. Since we expect that side–by–side cyclists will influence the results

When combining the results of our three sub–questions, we are able to answer our main question.

*How do cyclists interact with each other on a cycle path?*

First of all, the cyclists that cycle faster will cycle more left side of a cycle path. If the variation in speed observed on the cycle path is quite large, it implies that a wider cycle path is preferred. Speed is not the only factor that influences lateral position, the other users on the cycle path influence the average lateral position positively as well. It also seems that side–by–side cyclists cycle closer together than when overtaking. This cannot be confirmed by a regression analysis, since the type of users are not taken into account. We seem to think side–by–side cycle close to each other, since the analysis on the Zuidas showed that the type of users was more diversified and especially the side–by–side cyclists were higher in the afternoon than in the morning and the fact that a dummy variable of morning in the regression analysis had a relatively high magnitude. When combining this observations, it seems various type of users might have an effect on the lateral position.

Some interesting insights of types of users have been found as well. This is important. First of all, there was a higher diversification of the type of users for the location with a high attraction factor, namely several schools. In the morning, this created a short, but intense peak in the morning. Various types of users were only observed in a certain time block. At the other location, there was less a peak and a higher percentage of normal cyclists, some patterns could be detected in the morning for various types of users. In the afternoon the type of users are even more diversified than in the morning, especially the side–by–side cyclists have increased in relative numbers. It was harder to find a distinct pattern in the type of users, however we did see some general differences.

It should be noted that these conclusions do not directly apply to other cities and countries as well. Greibe and Buch (2016) did a similar study, so some of our descriptive statistics can be compared. First the average speed differs, it is 21.6 km/h in the sample of Greibe and Buch (2016), whilst in our sample it is around 19.8 km/h. Additionally the ratio of types of users is slightly different. Greibe and Buch (2016) did not have an extensive analysis on the type of users, but have some information. The ratio of the mopeds in Copenhagen was around 0.3%, whilst in Zuidas it is between the 6% – 9%. Mopeds are known for their relatively high speed (van der Horst, de Goede, de Hair–Buijssen, & Methorst, 2013), so the actual speed of the regular cyclists might be even lower than 19.8 km/h. These differences might lead to different results, especially since the type of users are not taken into account in the regression analysis.

## 6.2 Revision of the conceptual framework

A conceptual framework has been composed in chapter 3. This framework was designed to capture the behaviour of the cyclists on the cycle path in a clear way. Since there was not much scientific research done, there were not any positive or negative signs assigned to the relationships. Some relationships have been tested in this thesis, therefore the framework can be altered. Due to the design of this research not all relationships could be tested.

Some relationships which were already tested in the scientific literature, have also been added to the framework. These relationships can be found in section 2.52.6. In our original framework, the relationship between the expected lateral position and the speed was two–sided. We only tested this relationship one–sided, therefore this is adapted in our framework. This is a positive relationship, when the speed increase, the average lateral position is expected to increase as well. We also observed a positive relationship between the number of users and average lateral position as well. These results were based on our regression analysis. For the type of users, we tested if they were influenced by any other factor. We found that there are two influences. These influences are added before the type of users, which are time and location. This was the results of the analysis on the Zuidas. The location can influence the composition of the type of users, however it can differ over time as well. Since this relationship is only tested based on two locations and two days. It is difficult to state the magnitude of this relationship. The relationship between speed and type of users could not been tested due to the design of this research.

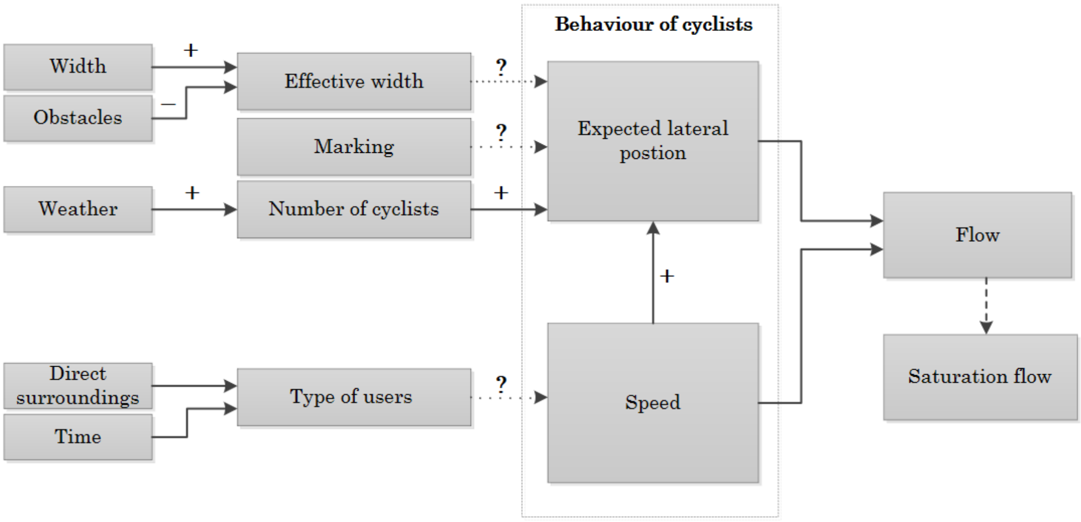



*Figure 25: Revised framework of the behaviour of cyclists*

## 6.3 Policy recommendations

There are a few policy recommendations that can be given based on the outcomes of this thesis. A conclusion of this thesis is that the direct surroundings of a cycle path matter. If there is a high attraction factor which creates a lot of traffic at the same time, such as a schools, university and ferry landings. This will create a high peak, instead of a spread of the rush hour. As a municipality, you need to consider what service level of capacity you want to provide at these locations, since there are sometimes issues regarding traffic safety, especially around schools.

The second recommendation will be regarding the guidelines. Currently design guidelines for cycle paths are based on cyclists/hour. However, there are a few factors which do not make these guidelines representative. First of all, there might be an extreme peak of cyclists within 5 minutes. For example, it can be the case 15% of the total cyclist within an hour are observed in 5 minutes within that hour. It can be a consideration to convert the guidelines towards cyclists per 5 minutes. In this way, various level of services can be determined, since the flow of cyclists is not the same. However when measuring the number of cyclists, it is important that a municipality not only measures five minutes, but a substantial amount of time. It is possible to see a pattern in this way. This information also enables to think more creatively regarding infrastructure, especially during roadworks. For example, if you notice that there is a special time block in the morning is busy with cyclists, but there are less cars, you might want to create more room for cyclists in the morning. In the afternoon, it might be the other way around. This is flexible use of infrastructure.

Second of all, the range of speed differences can have influence on the width of the cycle path. If there is a high range of speed differences expected, the cycle path should be wider to maintain a certain level of comfort than if all the users have the same speed. Speed differences will only become greater if the number of electronics bike starts rising, whilst still a large part of the users are using a regular bike. A policy maker has two instruments to ensure comfortable cycle paths: limit the speed differences on the cycle path or to create a wide cycle path. This is a political sensitive considerations, but would contribute to a less crowded cycle path.

Third of all, the type of users should be taken into account when looking at design guidelines. If the ratio of regular cyclists is high, the other type of users are observed in smaller amounts. It would be possible to create a more tailor–made cycle path. In order to reach this goal, there must be further research executed, however a municipality might experiment what the effect different widths is when there is a high percentage of side–by–side cyclists compared to regular users. It is also important that future considerations are kept in mind, since stints are upcoming and frequently used for several activities, such as city logistics and child care. It is important that frequently used routes are taken into account.

All these considerations result in our second recommendation. It might not be as simple to base the design guidelines on total number of cyclists per hour, but it must be extended in further detail to accommodate cycling in a comfortable way. The design guidelines could be based on number of cyclists per five minutes, however the variety of speeds and even type of users observed should be also considered when designing and deciding about infrastructure.

## 6.4 Limitations

This research has some limitations.  The first limitation is the fact that there is not any footage of the Amstelveenseweg due to privacy regulation. This makes it impossible to check the type of users on the Amstelveenseweg. A solution could have been to visually check the Amstelveenseweg in 2018, however there are currently roadworks going on, which limit cyclists to ride their original route. Since we suspected that cyclists took a different route, the visual observation would not have been reliable enough. Therefore, we did make the assumption that it would be similar to the Parnassusweg. This creates less strong conclusions and leaves more room for interpretation.

Second of all, the data of the Amstelveenseweg is of two parts of the day and not an entire day. It makes it hard to see the pattern during the whole day, however we have enough observations of cyclists. It would be nice to have a whole day in our dataset, so that we could see the difference in morning peak and afternoon peak. Additionally the data does not state if this observation is a side–by–side cyclist. This would enable us to express the difference between overtaking and side–by–side cycling in a numeric way.

At last, the effect of the weather on our results is hard to determine. There was only one day observed in the dataset Amstelveenseweg (14.3°C) and two days observed in the dataset Zuidas (23.8°C – 22.9°C). It is hard to state if there is a direct effect on the lateral position and if a specific type of users are not observed anymore.

### 6.5 Future research

First of all, the regression analyses that we have executed could be expanded with type of users. In this way, there will be created new insights in the lateral position of specific type of users, which can be applied for infrastructural decisions. There might be even interaction variables created between speed and type of user. We suspect that there is a difference between overtaking and cycling side–by–side. By adding the type of users, this suspicion can be tested statistically. This also enables researchers to get to know the range of speed within several groups, which makes it easier to make some policy decisions.

Some relationships in our framework not tested with our regression models. One of these relations it the relationship between marking and the lateral position. The original idea was that this would be tested in this thesis as well. Temporary marking was applied with chalk on the 24th of May on the Fred Roeskestraat.

*Figure 26: The chalk middle line applied on the Fred Roeskestraat*

However, the motion–detection algorithm created too many error detections. Therefore it was impossible to use this data in a valid way. Since some cyclists were detected twice, whilst others were not detected at all. When the motion–detection algorithm will become more precise, a similar set–up can be repeated. The chalk was clearly visible during the whole day. It was a safe option and could be applied quickly since a mould was created.

Another possible relationship that was hard to capture, was the relationship between mobile phone use and the lateral position. When the video footage was watched, some cyclists with phones were observed. However, it was hard to see a systematic pattern and the number of cyclists is relatively low which use their phones. It would be interesting to see the effect of mobile phone use on the lateral position of the cyclists controlled with the speed.

It is also not clear if the width of the cycle path influences the speed when overtaking another cyclists or if only more dangerous situations arise. It would be interesting to investigate if it is possible to nudge a cyclists to a specific speed when overtaking depending on the width of the cycle path.

It is also interesting to see the effect of oncoming cyclists, we only measured the effect in a one–directional cycle path. Oncoming cyclists are moving obstacles, but it would be how cyclists react to them, taking various types into account.

The last recommendation is to replicate and extend this research in other geographical areas. This is important to see if the relationship hold in other places in Amsterdam, the Netherlands and smaller neighbourhoods, but also in other places in Europe or even in the world. Since there might be some differences to behaviour of cyclists due to cultural backgrounds and the set–up of the infrastructure.

# 7. Bibliography


Angel-Domenech, A., Garcia, A., Agustin-Gomez, F., & Llorca, C. (2014). Traffic conflict analysis by an instrumental bicycle on cycle tracks of Valencia. *International Cycling Safety Conference 2014*, (pp. 1-19). Göteburg.

Avineri, E., & Prashker, J. N. (2005). Sensitivity to travel time variability: Travelers' learning perspective. *Transportation Research Part C: Emerging Technologies, 13*(2), 157-183.

*Beleidsregel aanwijzing bijzondere bromfietsen*. (2014, December 2). Retrieved from https://zoek.officielebekendmakingen.nl/stcrt-2014-34933.html

Ben-Avika, M. E., & Lerman, S. R. (1985). *Discrete choice analysis: theory and application to travel demand.* MIT Press.

Bernardi, S., & Rupi, F. (2015). An analysis of bicycle travel speed and disturbances on off-street and on-street facilities. *Transportation Research Procedia 5*, 82-94.

Boer, K. (2016). *Verbreden werkt altijd.* Retrieved from Fietsberaad: http://www.fietsberaad.nl/library/repository/bestanden/Fietsverkeer38_Verbreden-werkt-altijd.pdf

Botma, H. (1995). Method to determine level of service for bicycle paths and pedestrian-bicycle paths. *Transportation Research Record 1502*, 38-44.

Botma, H., & Papendrecht, H. (1991). Traffic Operation of Bicycle Traffic. *Transportation Research Record*, 65-72.

Buehler, R., Pucher, J., Gerike, R., & Götschi, T. (2017). Reducing car dependence in the heart of Europe: lessons from Germany, Austria and Switzerland. *Transport Reviews 37(1)*, pp. 4-28.

Button, K. (2006). Transportation Economics: Some Developments Over the Past 30 Years . *Journal of the Transportation Research Forum, Vol. 45, No. 2*, 7-30.

Calvert, S. C., Taale, H., & Hoogendoorn, S. P. (2016). Quantification of motorway capacity variation: influence of day type specific variation and capacity drop, 50(4). *Journal of Advanced Transportation*, 570-588.

Cerema. (2009). *Les pistes cyclables.* Retrieved from https://www.au5v.fr/IMG/pdf/certu_fiche07v-pistes_cyclables.pdf

City of Vancouver. (2017, March). *Transportation Design Guidelines: All ages and abilities cycling routes.* Retrieved from City of Vancouver: http://vancouver.ca/files/cov/design-guidelines-for-all-ages-and-abilities-cycling-routes.pdf

DTV Consultants. (2018). *Capaciteitsbepaling Fietspaden.* Breda: CROW.

Embarq Brasil. (2014). *Manual de projetos e programas para incentivar o uso de biciletas em comunidades.* Retrieved from The city fix brasil : http://thecityfixbrasil.com/files/2014/05/final_relat%C3%B3rio_embarq_maio2014_wireo_site.pdf

Essen, H. v., & Schroten, A. (2010). *Externe en infrastructuurkosten van verkeer.* Retrieved from CE Delft: https://www.ce.nl/publicatie/externe_en_infrastructuurkosten_van_verkeer/1491

FGSV. (2010). *Empfehlungen für Radverkehrsanlagen (ERA) - Neuerscheinung 2010.* Retrieved from https://www.region-frankfurt.de/media/custom/2005_431_1.PDF?1

Fietsberaad CROW. (2008, December 12). *Omzetting van tegelfietspaden in asfaltfietspaden kost 250 euro per meter*. Retrieved from Fietsberaad CROW: http://www.fietsberaad.nl/?section=Nieuws&lang=nl&mode=newsArticle&newsYear=2008&repository=Omzetting+van+tegelfietspaden+in+asfaltfietspaden+kost+250+euro+per+meter

Fietsberaad CROW. (2016). *Design manual for bicycle traffic.* Fietsberaad CROW.

Fietsersbond. (2016). *Fietsen in cijfers*. Retrieved from Fietsersbond: https://www.fietsersbond.nl/ons-werk/mobiliteit/fietsen-cijfers/

Finnish Transport Agency. (2014). *Jalankulku- ja pyöräilyväylien suunnittelu.* Retrieved from Liikennevirasto: https://www.liikennevirasto.fi/documents/20473/102264/Jalankulku-+ja+py%C3%B6r%C3%A4ilyv%C3%A4ylien+suunnitteluohje.pdf/f6f0cd23-4455-4e9c-a8d9-a76e856fcdb0

Gemeente Amsterdam. (2016, april 26). Leiddraad Centrale Verkeerscomissie. Amsterdam.

Gemeente Amsterdam. (2016). *Mag ik mijn gehandicaptevoertuig op de stoep parkeren?* Retrieved from https://www.amsterdam.nl/veelgevraagd/?caseid=%7B12C8605C-695B-4C7A-B9B5-DDBDC425B939%7D

Gemeente Amsterdam. (2017a). *Meerjarenplan Fiets.* Amsterdam: Verkeer en Openbare Ruimte - Gemeente Amsterdam.

Gemeente Amsterdam. (2017b). *Het meerjareninvesteringsprogramma 2018 - 2021.* Retrieved from https://www.amsterdam.nl/bestuur-organisatie/organisatie/overige/coordinatiestelsel/mip-pagina/mip-0/

Gerlough, D. L., & Huber, M. J. (1976). *Traffic Flow Theory.*

Gotschi, T. (2011). Costs and Benefits of Bicycling Investments in Portland, Oregon. *Journal of Physical Activity and Health*, S49-S58.

Gould, G., & Karner, A. (2009). Modeling Bicycle Facility Operation: A Cellular Automaton Approach. *Transportation Research Record: Journal of the Transportation Research Board*, 157-164.

Greibe, P., & Buch, T. S. (2016). Capacity and Behaviour on One-way Cycle Tracks of Different Widths. *Transportation Research Procedia 15*, 122-136.

Heinen, E., Maat, K., & Van Wee, B. (2011). The role of attitudes toward charaterstics of bicycle commuting on the choice to cycle to work over various distances. *Transportation research part D: transport and environment, 16*(2), 102-109.

Hoekstra, A., Twisk, D., Stelling, A., & Houtenbos, M. (2013, December). *Gebruik van mobiele appartuur door jongeren.* Leidschendam: SWOV. Retrieved from Gebruik van mobiele apparatuur door jongeren.

Homburger, W. (1976). *Capacity of Bus Routes, and of Pedestrian and Bicycle Facilities.* University of California, Berkley: Institute for Transporation Studies.

Hoogendoorn, S., & Daamen, W. (2016). Bicycle headway modeling and its applications. *Transportation Research Record: Journal of the Transportation Research Board (2587)*, 34-40.

Jiang, R., Hu, M.-B., Wu, Q.-S., & Song, W.-G. (2017). Traffic Dynamics of Bicycle Flow: Experiment and Modeling. *Transportation Science, 51*(3), 998-1008.

Jin, S., Qu, X., Zhou, D., Xu, C., Ma, D., & Wang, D. (2015). Estimating cycleway capacity and bicycle equivalent unit for eletric bicycles. *Transportation Research Part A: Policy and Practice*(77), 225-248.

Kennisinsituut voor Mobiliteitsbeleid. (2017). *Mobiliteitsbeeld 2017.* Den Haag: Ministerie van Infrastructuur en Milieu.

Khaneman, D., & Tversky, A. (1979). Prospect Theory: An Analysis of Decision under Risk. *Econometrica, 47*(2), 263-292.

Khisty, C. J. (1994). Transportation in developing countries: Obvious problems, possible solutions. *Journal of advanced transportation, 28(2)*, 157-169.

Kircher, K., Ihlström, J., Nygårdhs, S., & Ahlstrom, C. (2018). Cyclist efficiency and its dependence on infrastructure and usual speed. *Transportation Research Part F 54*, 148-158.

Koninklijk Nederlands Meteorologisch Instituut. (2018, May 28). *Langjarig gemiddelden - normale waarden temperatuur.* Retrieved from KNMI: https://www.knmi.nl/nederland-nu/weer/waarschuwingen-en-verwachtingen/normalentabel

Koperberg, A., & Broer, K. (2015, Utrecht). *Zelfstandig Fietsen naar School.* Retrieved from Fietsberaad CROW: http://fietsberaad.nl/index.cfm?lang=nl&repository=Zelfstandig+Fietsen+naar+School

Lancaster, K. J. (1966). A New Approach to Consumer Theory. *Journal of Political Economy, Vol. 74, No. 2*, 132-157.

Landis, B., Vattikuti, V., & Brannick, M. (1997). Real-time human perceptions: toward a bicycle level of service. *Transportation Research Record: Journal of the Transportation Research Board*, 199-126.

Li, Z., Huang, R., Yang, Z., Zhou, W., & Ye, M. (2015). Operational Features in Bicycle Traffic Flow: An Observational Study . *In Proceedings of Transporation Research Board 94th Annual Meeting*, (pp. 1-13).

Li, Z., Wang, W., Liu, P., & Ragland, D. R. (2012). Physical environments influencing bicyclists' perception of comfort. *Transportation Research Part D: Transport and Environment*, 256-261.

Liu, X., Shen, D., & Ren, F. (1993). Operational Analysis of Bicycle Interchanges. *Transportation Research Record 1396*, 18-21.

Ma, L., Dill, J., & Mohr, C. (2014). The objective versus the perceived environment: what matters for bicycling? *Transportation, 41*(6), 1135-1152.

Minderhoud, M., Botma, H., & Bovy, P. (1997). Assessment of roadway capacity estimation methods. *Research Record: Journal of the Transportation Research Board*, 59-67.

NACTO. (2011, April). *Urban Bikeway Design Guide.* Retrieved from Old colonial planning: http://www.ocpcrpa.org/docs/projects/bikeped/NACTO_Urban_Bikeway_Design_Guide.pdf

Navin, F. P. (1994). Bicycle traffic flow characteristics: experimental results and comparison. *ITE Journal*, 31-37.

Rietveld, P., & Daniel, V. (2004). Determinants of bicycle use: do municipal policies matter? *Transportation Research A, 38*, 531-550.

*RVV 1990.* (n.d.). Retrieved from Reglement verkeersregels en verkeerstekens 1990: http://wetten.overheid.nl/BWBR0004825/2017-07-01

Saneinejad, S., Roorda, M. J., & Kennedy, C. (2012). Modelling the impact of weather conditions on active transportation travel behaviour. *Transportation research part D: transport and environment, 17*(2), 129-137.
Schultz van Haegen, M. (2015, Juni 24). *Kamerbrief over drukte op het fietspad.* Retrieved from Rijksoverheid: https://www.rijksoverheid.nl/documenten/kamerstukken/2015/06/24/drukte-op-het-fietspad
Seriani, S., Fernandez, R., & Hermosilla, E. (2015). Experimental study for estimating capacity of cycle lanes. *Transportation Research Procedia*, 192-203.
Smith, D. T. (1972). *Bicycle Circulation and Safety - City of Davis.* San Franciso: De Leuw, Cather & Company.
Sweet, M. (2014). Do firms flee congestion? *Journal of Transport Geography 35*, pp. 40-49.
SWOV. (2015). *Stedelijke Mobiliteit op het Fietspad.* Den Haag.
Thorndike, E. L. (1927). The Law of Effect. *The American Journal of Psychology, 39*(1), 212-222.
Tin Tin, S., Woodward, A., Robinson, E., & Ameratunga, S. (2012). Temporal, seasonal and weather effects on cycle volume: an ecological study. *Environmental Health, 11*(12), 1-9.
TNO. (2017). *Meetmethode: Drukte op het fietspad.* Amsterdam.
Transport for London. (2014). *London Cycling Design Standard.* Retrieved from TFL: http://content.tfl.gov.uk/lcds-chapter4-cyclelanesandtracks.pdf
Transportation Research Board. (2000). *Highway Capacity Manual.* Washington, DC.: National Research Council .
van den Munckhof, L., Zengerink, L., & ter Avest, R. (2017). *Over drukte valt te twisten.* CROW-Fietsberaad.
van der Horst, R., de Goede, M., de Hair–Buijssen, S., & Methorst, R. (2013). Traffic conflicts on bicycle paths: a systematic observation of behaviour from video. *Accident Analysis and Preventioin*, 358-368.
Van Wee, B. (2010). Prospect Theory and Travel Behaviour: a Personal Reflection based on a seminar. *EJTIR, 10*(4), 385-394.
Vejregler. (2012). *Grundlag for udformning af trafikarealer.* Vejregler.
Wegman, F., Zhang, F., & Dijkstra, A. (2010). How to make more cycling good for road safety. *Accident Analysis and Prevention, 44*(1), 19-29.
*Wet Regeling Voertuigen.* (2018). Retrieved February 27, 2018, from http://wetten.overheid.nl/BWBR0025798/2018-01-01#Hoofdstuk5
Wierbos, M. J., Goñi-Ros, B., Knoop, V. L., & Hoogendoorn, S. P. (2017). Bicycle Queue Dynamics: Influence of Queue Density and Merging Cyclists on Discharge Rate at an Intersection. *97th Annual Meeting of the Transportation Research Board*, (pp. 1-11). Washington DC.
Winters, M., Friesen, M. C., Koehoorn, M., & Teschke, K. (2010). Utilitarian Bicycling. *American journal of preventive medicine, 32*(1), 52-58.
Wright, C. L. (1992). *Fast weels, slow traffic: urban transport choices.* Philadelphia: Temple University Press.
Xing, Y., Handy, S. L., & Mokhtarian, P. L. (2010). Factors associated with proportions and miles of bicycling for transportation and recreation in six small US cities. *Transportation research part D: Transport and Environment, 15*(2), 73-81.

Zeegers, T. (2004). *Over breedtes en fietspaden.* Retrieved from Fietsberaad: http://www.fietsberaad.nl/library/repository/bestanden/document000172.pdf

Zhou, D., Xu, C., Wang, D., & Jin, S. (2015). Estimating capacity of bicycle path on urban roads in Hangzhou, China. *Proceedings of the 94th Annual Meeting of the Transportation Research Board.*

# Appendices

## Appendix I. Design standards of two–way cycle paths

| Institute | Year | Country | Width | **Recommendations** *(Cyclists in both directions/hour)* |
|---|---|---|---|---|
| CROW | (2006)[11] | The Netherlands | 2.0 m | 0 – 50 |
| | | | 2.5 – 3.0 m | 50 – 150 |
| | | | 3.0 – 3.5 m | 150 – 350 |
| | | | 3.5 m | > 350 |
| Cerema | (2009) | France | 3.0 m | Not applicable |
| FGSV | (2010) | Germany | 2.5 m | Low cycle traffic[12] |
| | | | 3.0 m | Standard width |
| NACTO | (2011) | Metropolitan cities in the United States and Canada[13] | 2.428 m | Minimum width |
| | | | 3.657 m | Desirable width |
| Embarq Brasil | (2014) | Brasil | 2.4 – 3.0 m | < 1000 |
| | | | 3.0 – 4.0 m | 1000 – 2500 |
| | | | 4.0 – 6.0 m | 2500 – 5000 |
| | | | ≥ 6.0 m | > 5000 |
| Transport for London | (2014) | London, United Kingdom | 2.0 m | < 300 |
| | | | 3.0 m | 300 – 1000 |
| | | | ≥ 4.0 m | > 1000 |
| Finnish Transport Agency | (2014) | Finland[14] | 2.25 – 2.5 m | < 100 |
| | | | 2.5 m | 100 – 150 |
| | | | 2.5 – 3.0 m | 150 – 250 |
| | | | ≥ 3.0 m | > 250 |
| City of Vancouver | (2017) | Vancouver, Canada[15] | 3.0 m | 0 – 750 |
| | | | 4.5 m | > 750 |

*Table 9: Design guidelines of two-directional cycle paths*

[11] The recommendations in the updated version have remained the same (Fietsberaad CROW, 2016).
[12] There was no benchmark defined as what was seen as low cycle traffic
[13] The width was stated in feet, a conversion rate of 0.3048 is used
[14] The number of cyclists was stated per day, a conversion rate of 10% is used for the busiest hour.
[15] The number of cyclists was stated per day, a conversion rate of 10% is used for the busiest hour.

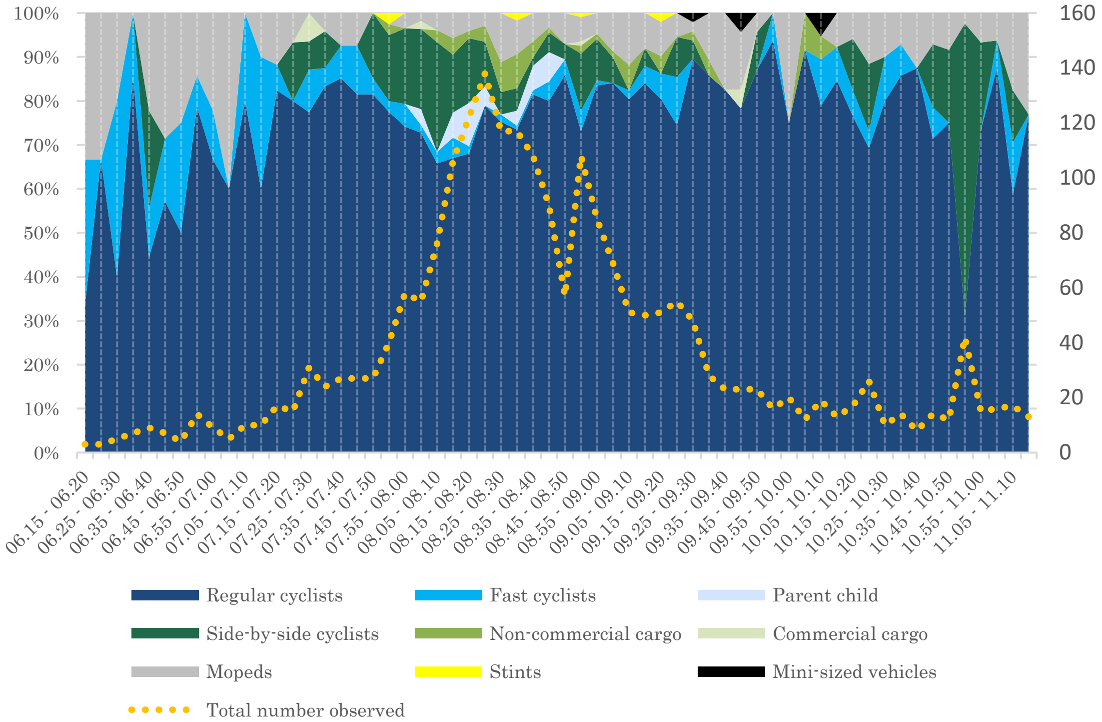
# Appendix II.   Daily weather data

| | Maximum Temperature (degree Celsius) | Maximum Wind speed (m/s) | Duration of sunshine (hours) | Daily precipitation (mm) | The hour when the maximum precipitation was the highest[16] |
|---|---|---|---|---|---|
| 9 May 2017 | 13.2 | 6.0 | 9.9 | 0 | 00:00 – 01:00 |
| 10 May 2017 | 14.3 | 4.0 | 6.9 | 0 | 00:00 – 01:00 |
| 11 May 2017 | 23 | 6.0 | 12.1 | < 0.05 | 00:00 – 01:00 |
| 12 May 2017 | 20.4 | 6.0 | 2.6 | 8.9 | 06:00 – 07:00 |
| 13 May 2017 | 18.2 | 6.0 | 1.7 | 2.5 | 06:00 – 07:00 |
| 14 May 2017 | 20.2 | 9.0 | 9.9 | 2.5 | 13:00 – 14:00 |
| 15 May 2017 | 20.6 | 7.0 | 8.7 | 3 | 16:00 – 17:00 |
| 16 May 2017 | 25.8 | 7.0 | 3.3 | < 0.05 | 00:00 – 01:00 |
| 17 May 2017 | 28.5 | 6.0 | 8.7 | 0 | 00:00 – 01:00 |
| 18 May 2017 | 20.7 | 8.0 | 3.2 | 1.2 | 03:00 – 04:00 |
| 19 May 2017 | 16.4 | 10.0 | 2.0 | 4.6 | 00:00 – 01:00 |
| 20 May 2017 | 17.5 | 6.0 | 11.4 | < 0.05 | 00:00 – 01:00 |
| 21 May 2017 | 19.9 | 4.0 | 9.7 | 0 | 00:00 – 01:00 |
| 22 May 2017 | 24.1 | 5.0 | 12.0 | 0 | 00:00 – 01:00 |
| | | | | | |
| 14 May 2018 | 25.3 | 6.0 | 10.9 | 0 | N/A |
| 15 May 2018 | 23.8 | 6.0 | 14.1 | 0 | N/A |
| 16 May 2018 | 19.5 | 9.0 | 9.2 | < 0.05 | 00:00 – 01:00 |
| 17 May 2018 | 14.2 | 8.0 | 11.6 | 0 | N/A |
| 18 May 2018 | 13.8 | 6.0 | 3 | 0 | N/A |
| 19 May 2018 | 13.6 | 3.0 | 0.3 | 0 | N/A |
| 20 May 2018 | 22.2 | 5.0 | 12.6 | 0 | N/A |
| 21 May 2018 | 24.9 | 6.0 | 10.3 | < 0.05 | 00:00 – 01:00 |
| 22 May 2018 | 22.1 | 6.0 | 0.8 | 0.3 | 10:00 – 11:00 |
| 23 May 2018 | 25.1 | 6.0 | 5.2 | 1.2 | 07:00 – 08:00 |
| 24 May 2018 | 22.9 | 6.0 | 5 | < 0.05 | 00:00 – 01:00 |
| 25 May 2018 | 24.5 | 5.0 | 8.4 | 9.9 | 00:00 – 01:00 |
| 26 May 2018 | 27.3 | 6.0 | 14.1 | 0 | N/A |
| 27 May 2018 | 25.2 | 6.0 | 6.5 | < 0.05 | 00:00 – 01:00 |

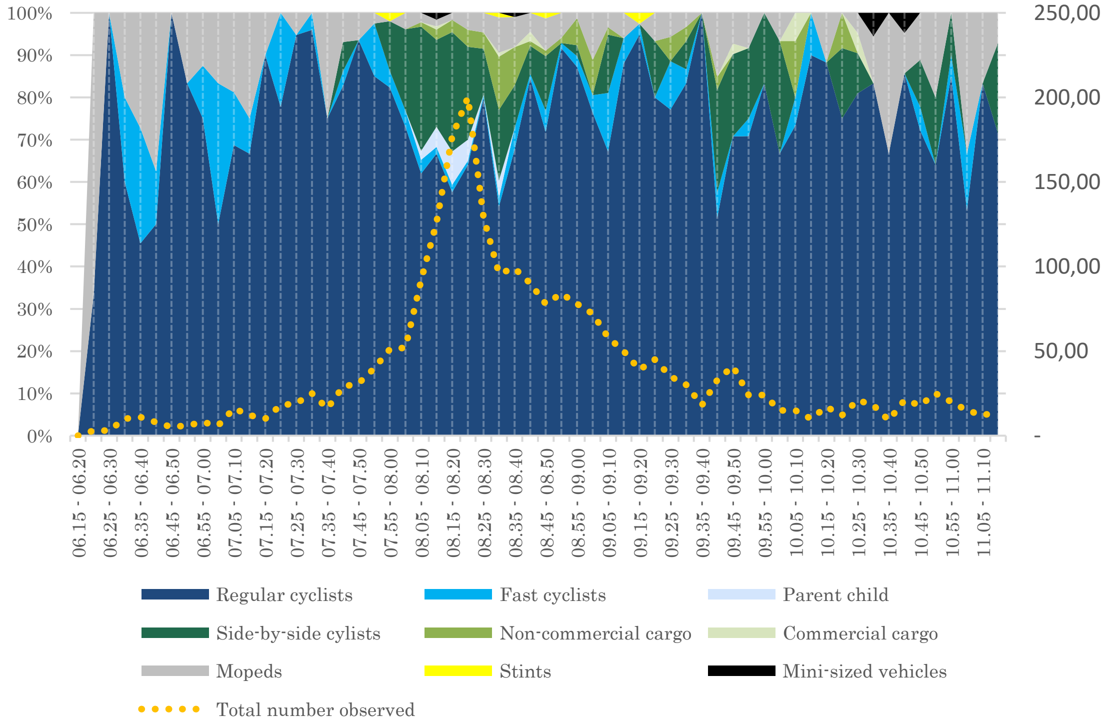
*Table 10: Weather during the research period*

[16] N/A = Not applicable

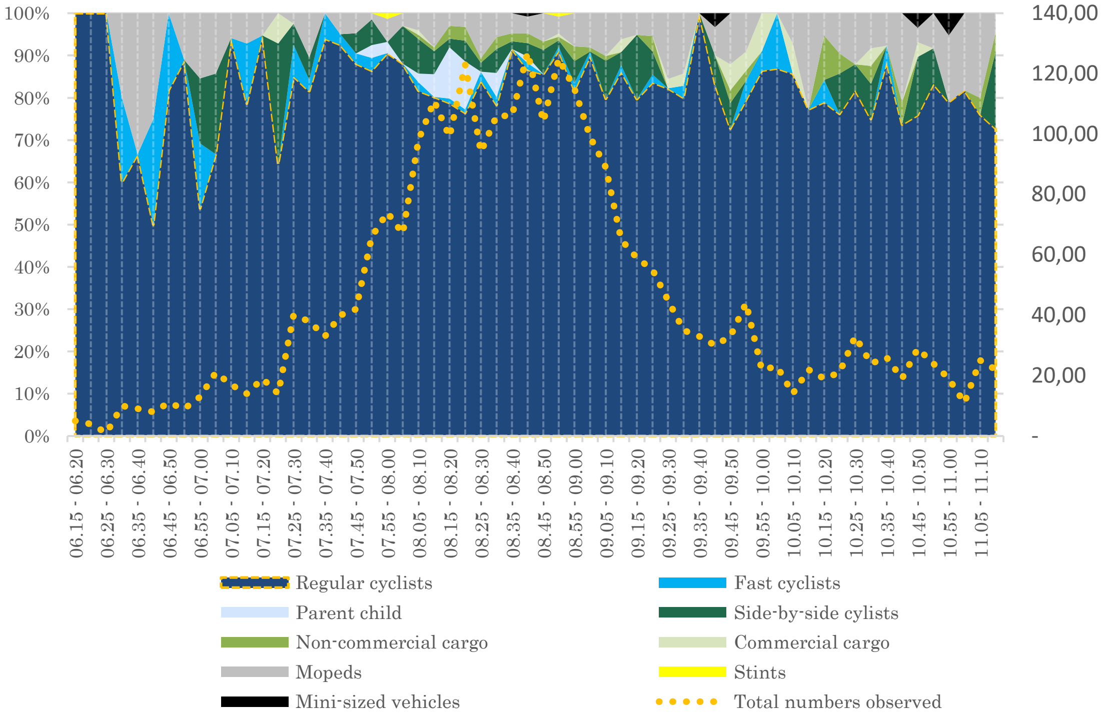
# Appendix III. Area graphs of type of users over time



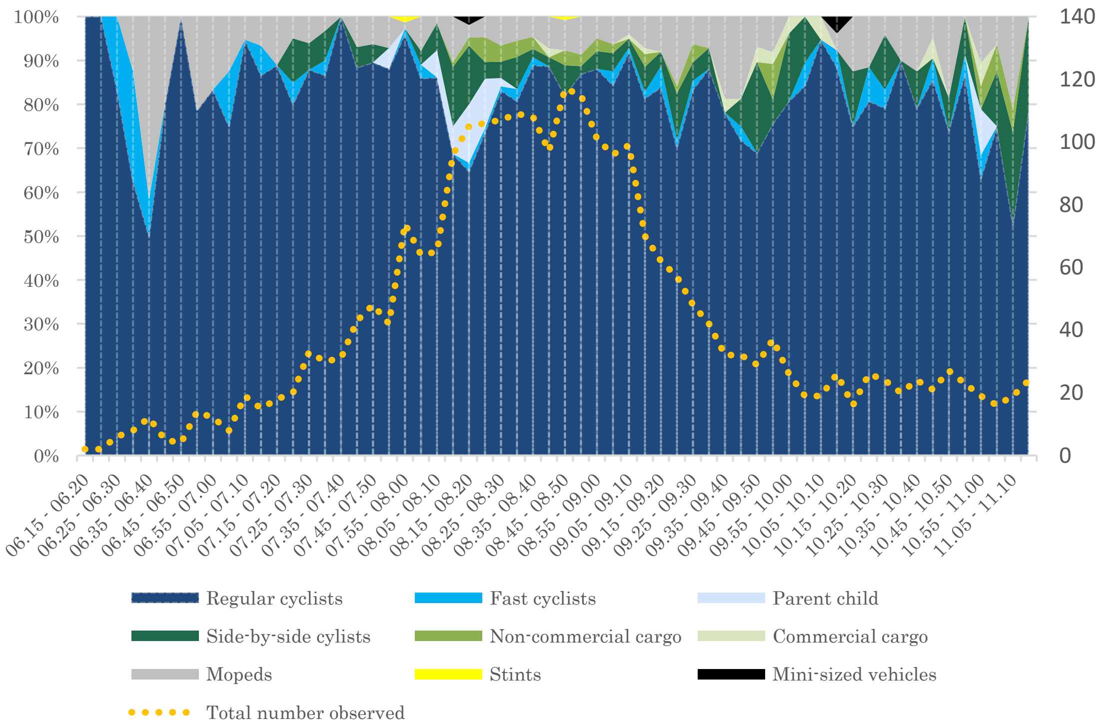

*Graph 13: Ratios of the type of users over time on 15th of May on the Fred Roeskestraat (06:15 – 11:15)*



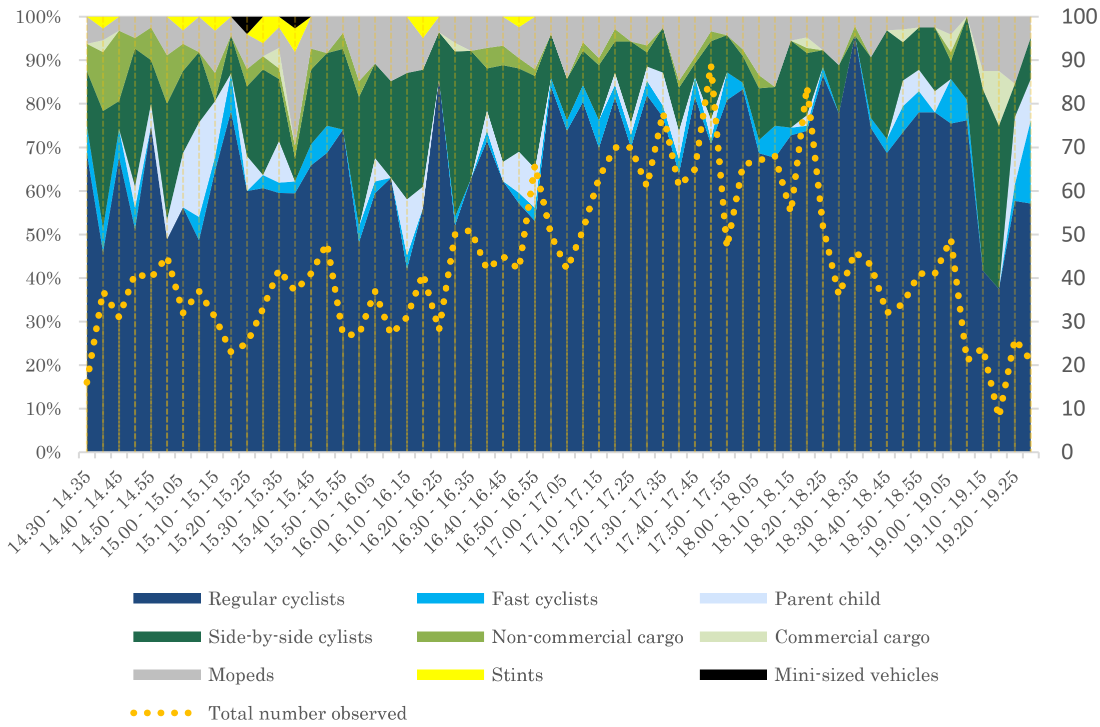

*Graph 14: Ratios of the type of users over time on 24th of May on the Fred Roeskestraat (06:15 – 11:15)*



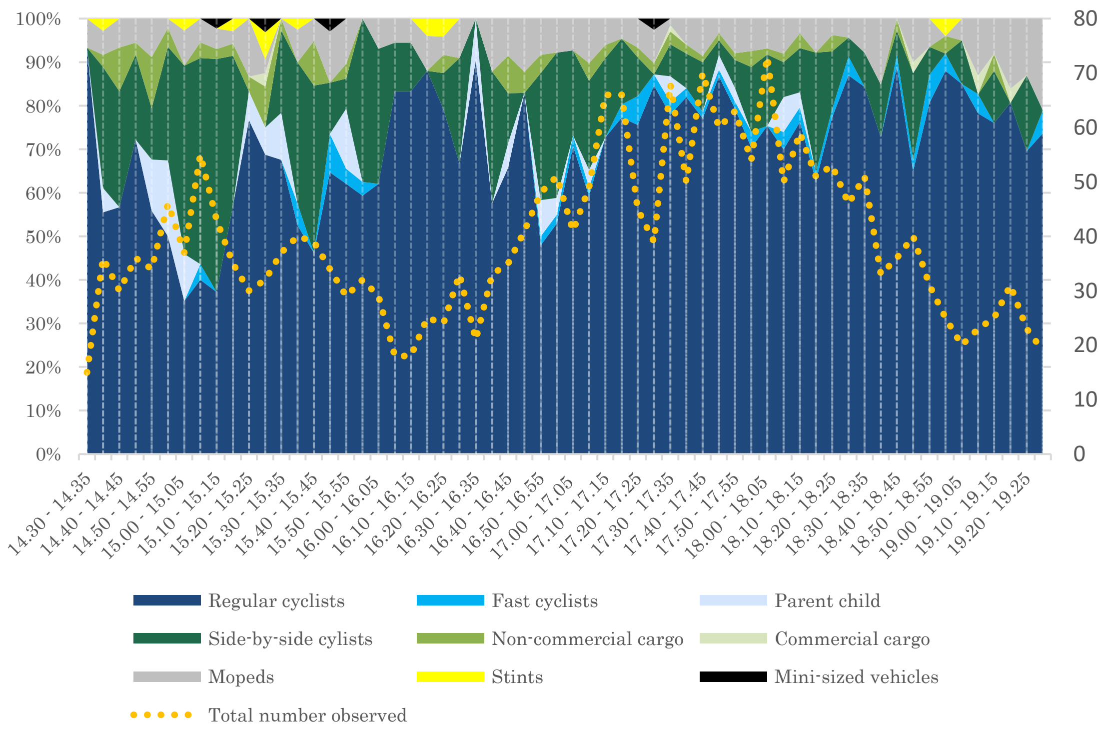

*Graph 15: Ratios of the type of users over time on 15th of May on the Parnassusweg (06:15 – 11:15)*



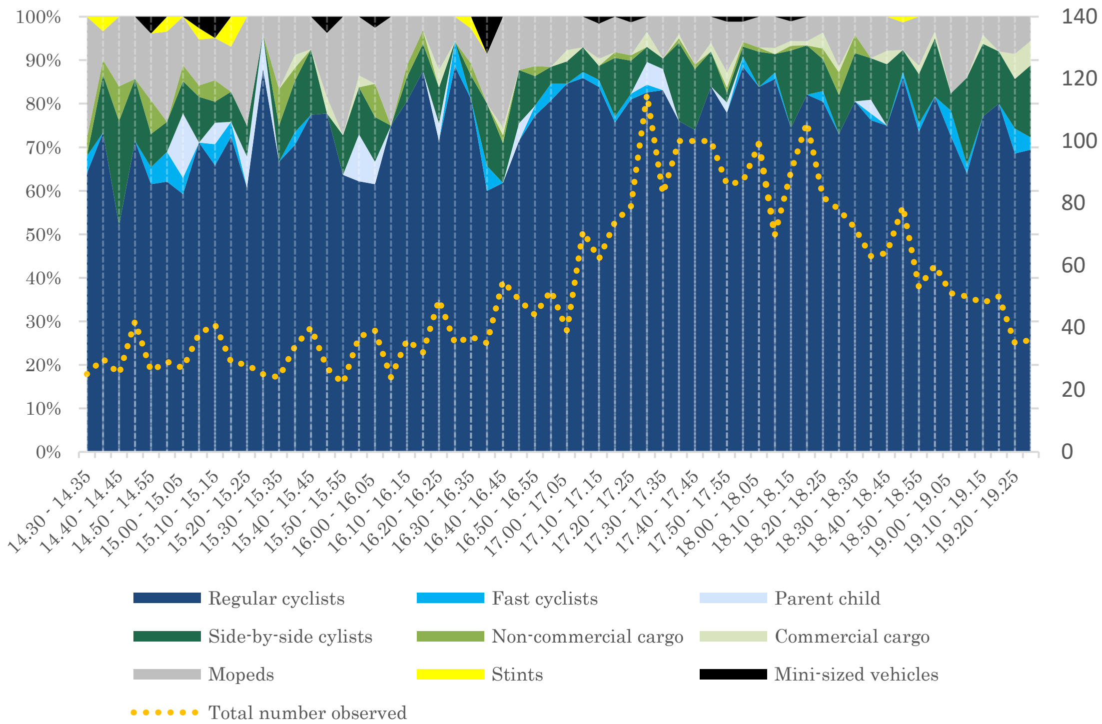

*Graph 16: Ratios of the type of users over time on 24th of May on the Parnassusweg (06:15 – 11:15)*



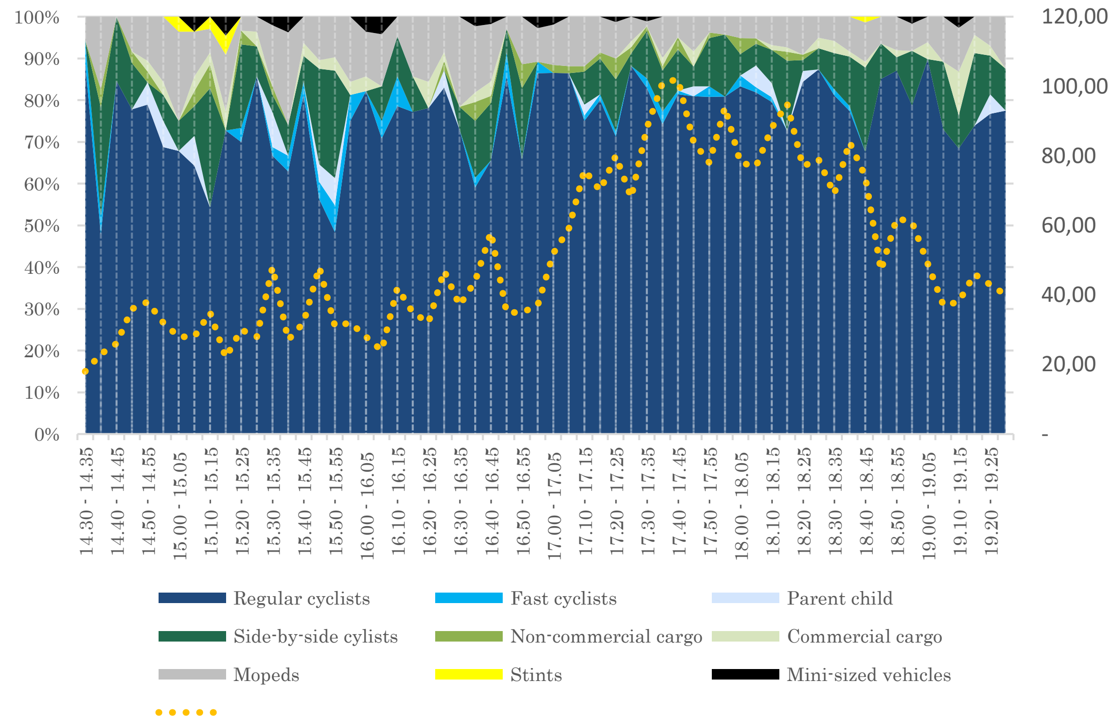

*Graph 17: Ratios of the type of users over time on 15th of May on the Fred Roeskestraat (14:30 – 19:30)*




*Graph 18: Ratio of the type of users over time on 24th of May on the Fred Roeskestraat (14:30 - 19:30)*

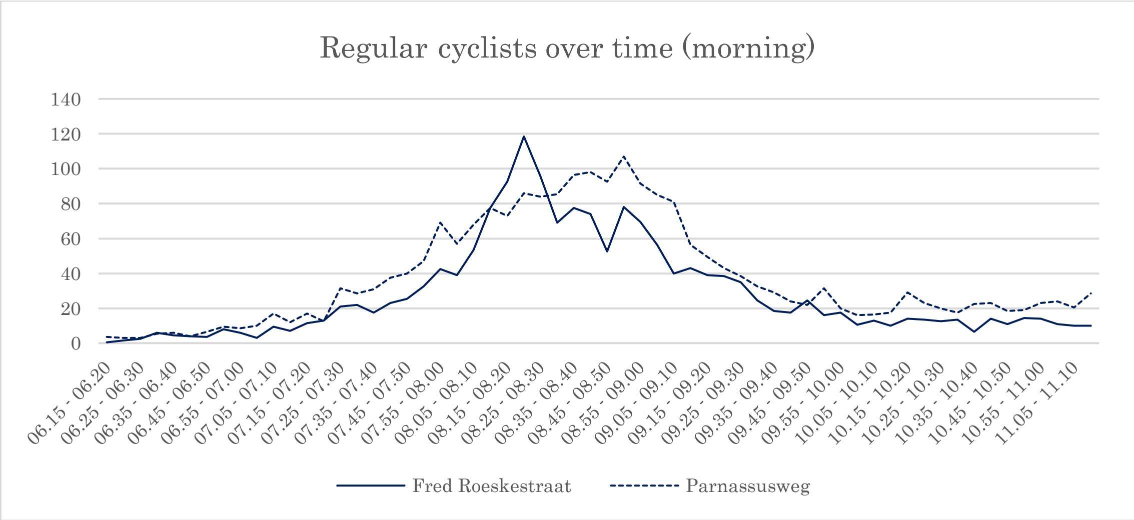



*Graph 19: Ratio of the type of users over time on 15th of May on the Parnassusweg (14:30 - 19:30)*

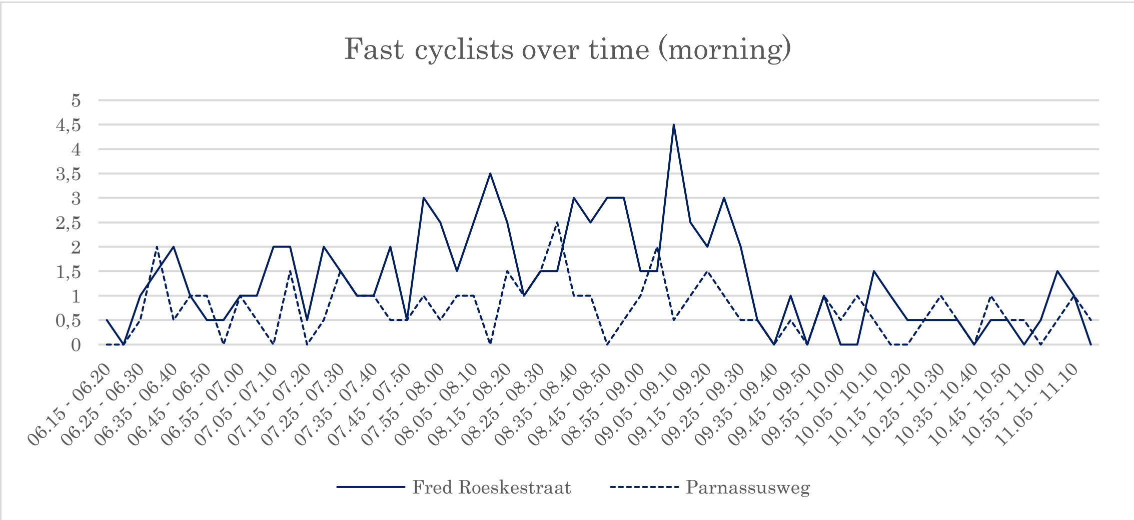



*Graph 20: Ratio of the type of users over time on 24th of May on the Parnassusweg (14:30 - 19:30)*

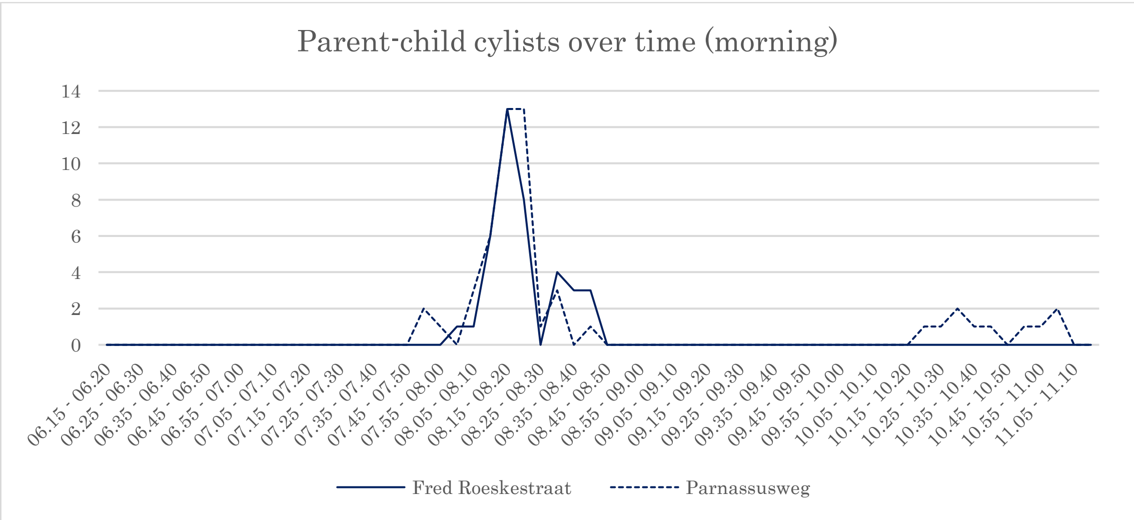
# Appendix IV. Line graphs of type of users over time



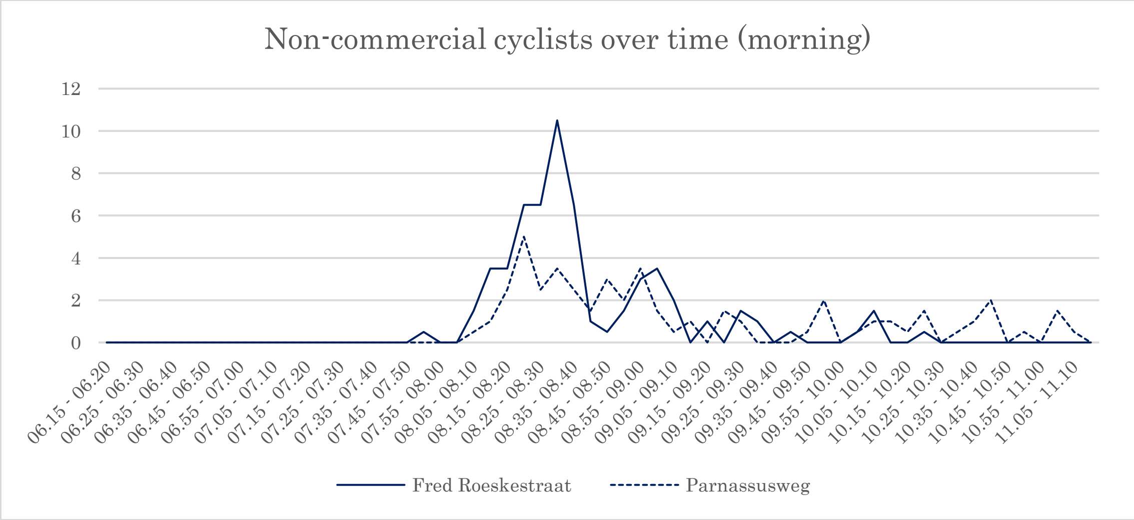

*Graph 21: Average number of regular cyclists over time (06:15 - 11:15)*



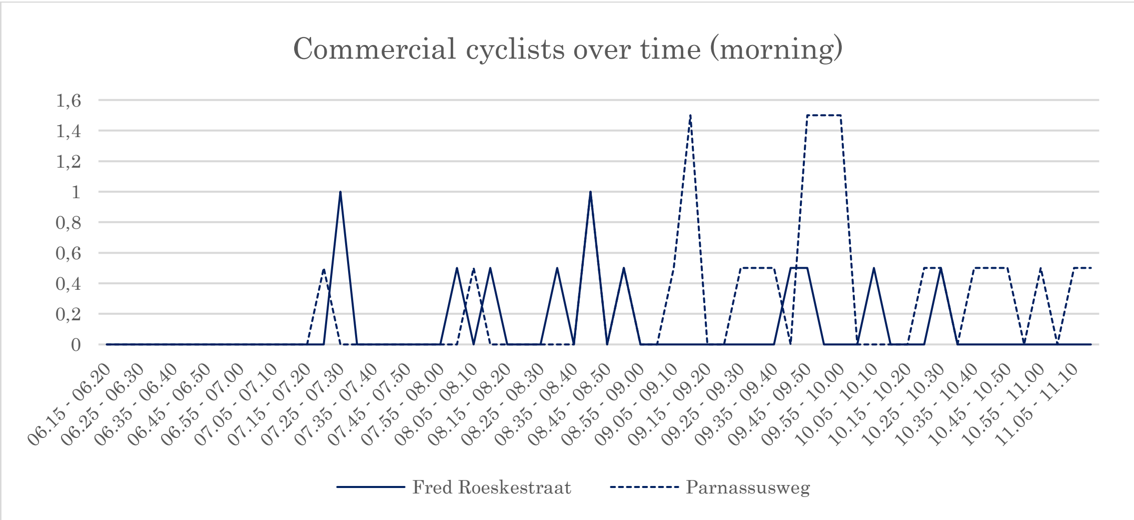

*Graph 22: Average number of fast cyclists over time (06:15 - 11:15)*



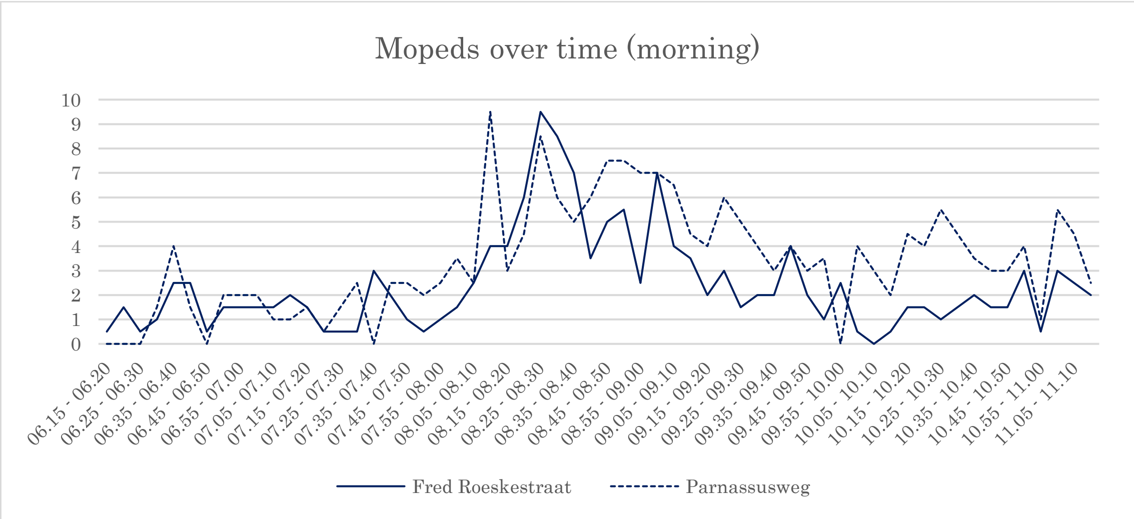

*Graph 23: Average number of parent-child cyclists over time (06:15 - 11:15)*



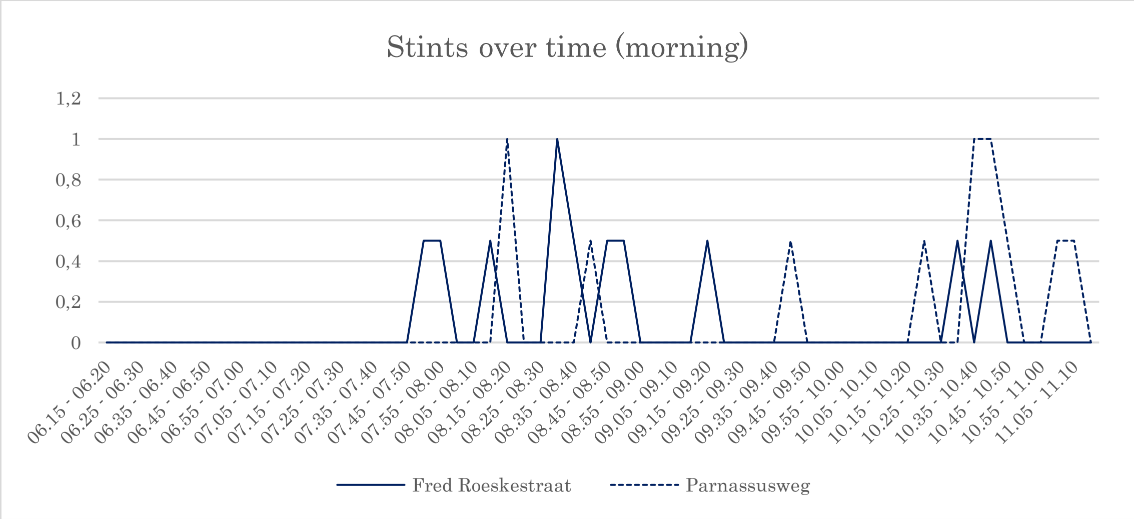

*Graph 24: Average number of non-commercial cyclists over (06:15 - 11:15)*



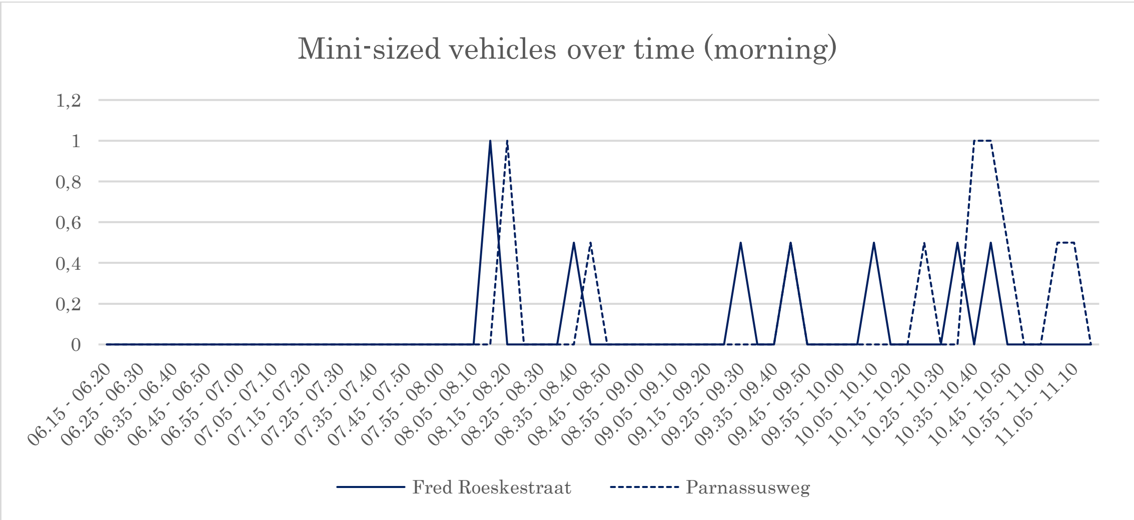

*Graph 25: Average number of commercial cyclists over time (06:15 - 11:15)*



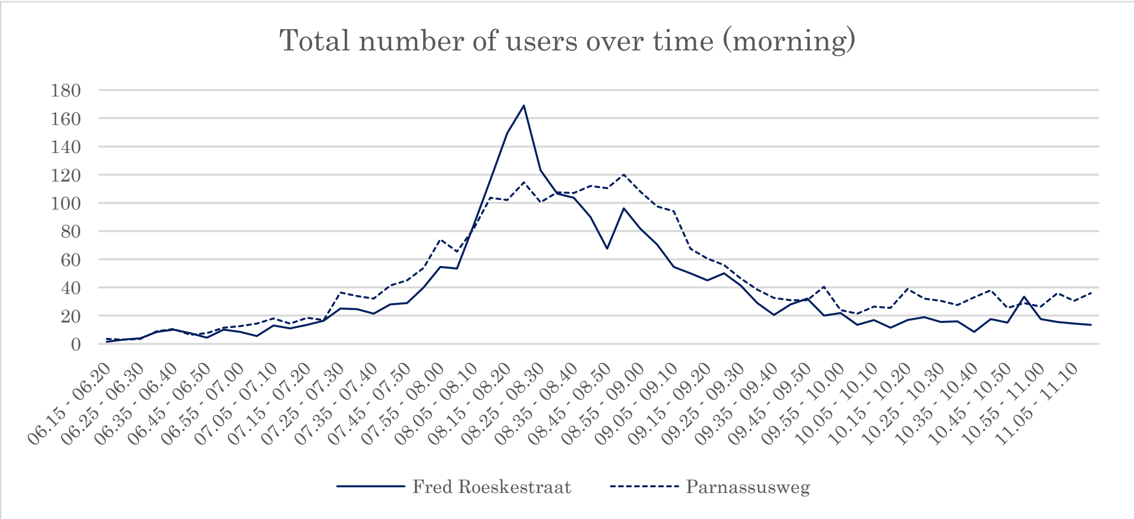

*Graph 26: Average number of mopeds over time (06:15 - 11:15)*



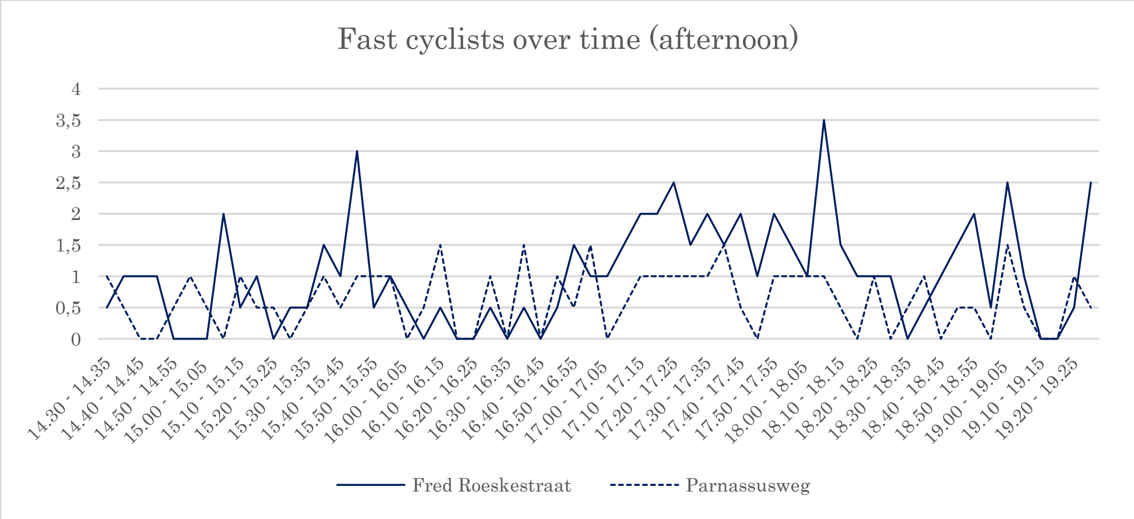

*Graph 27: Average number of stints over time (06:15 - 11:15)*



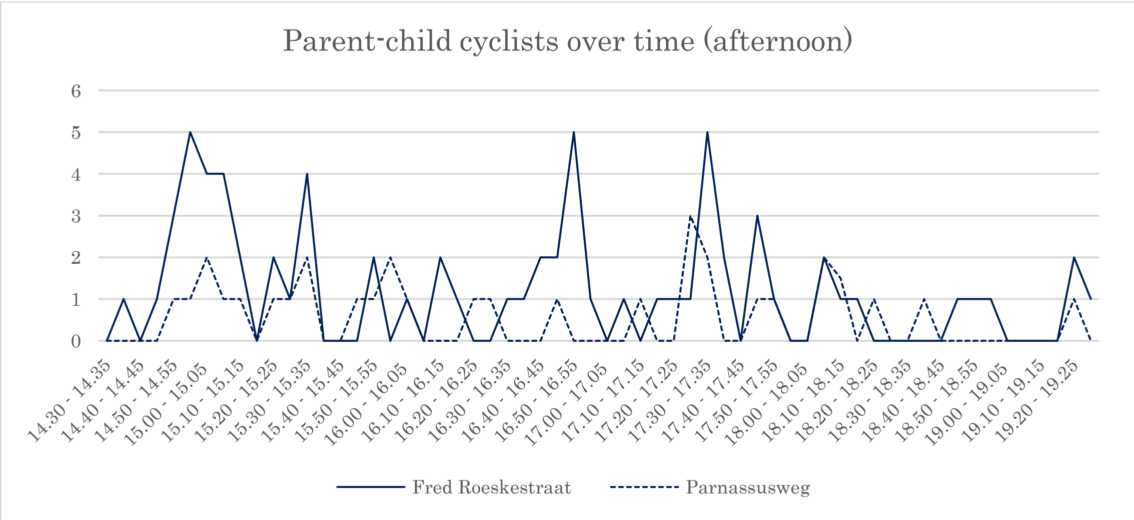

*Graph 28: Average number of mini-sized vehicles over time (06:15 - 11:15)*



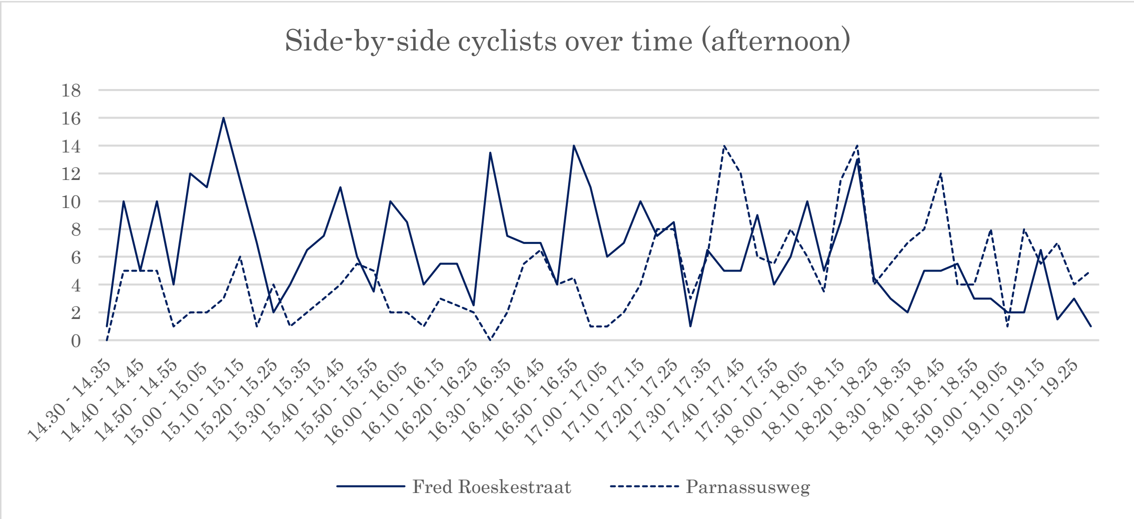

*Graph 29: Average total number of users over time (06:15 - 11:15)*



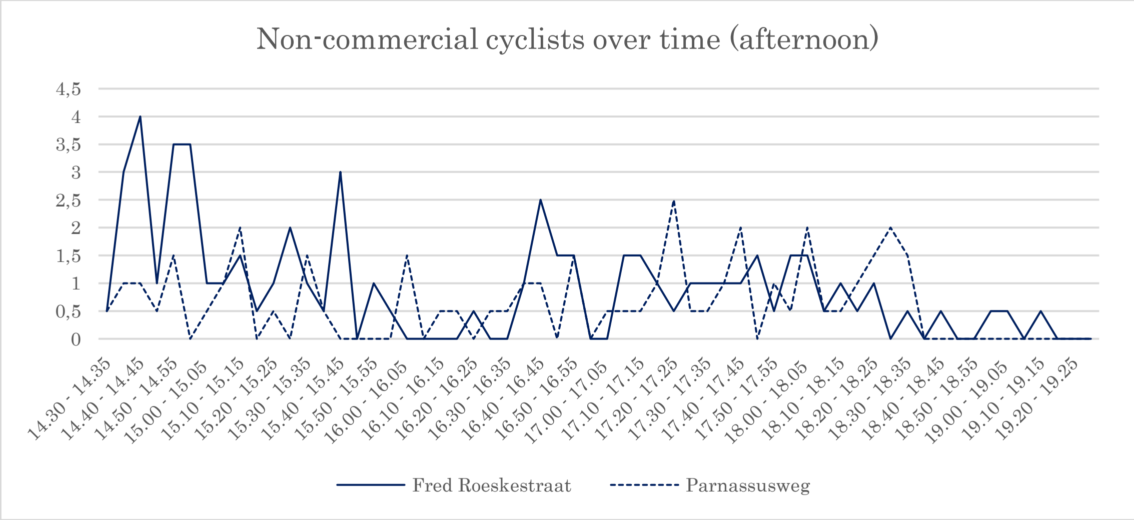

*Graph 30: Average number of fast cyclists over time (14:30- 19:30)*



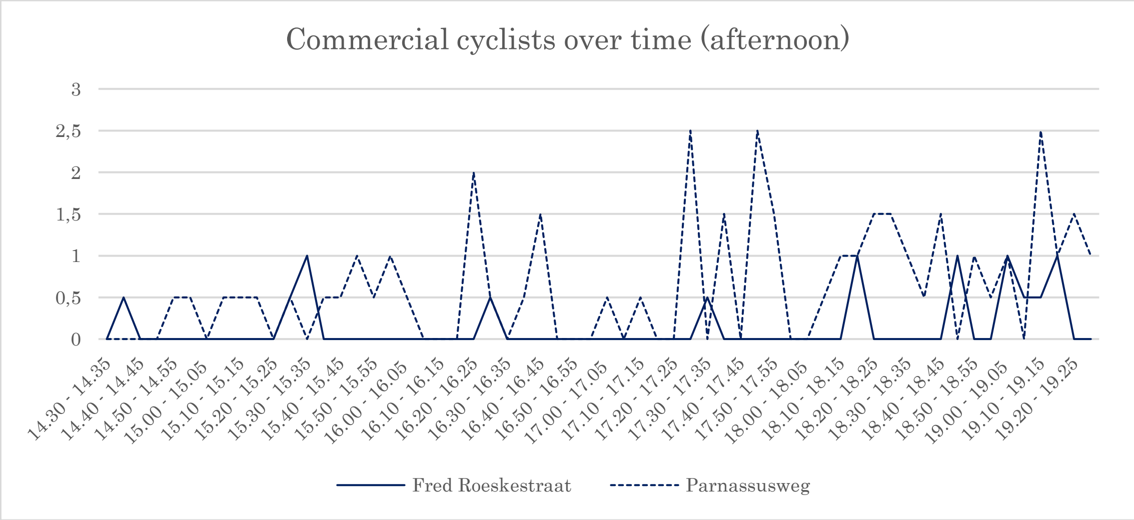

*Graph 31: Average number of parent-child cyclists over time (14:30- 19:30)*



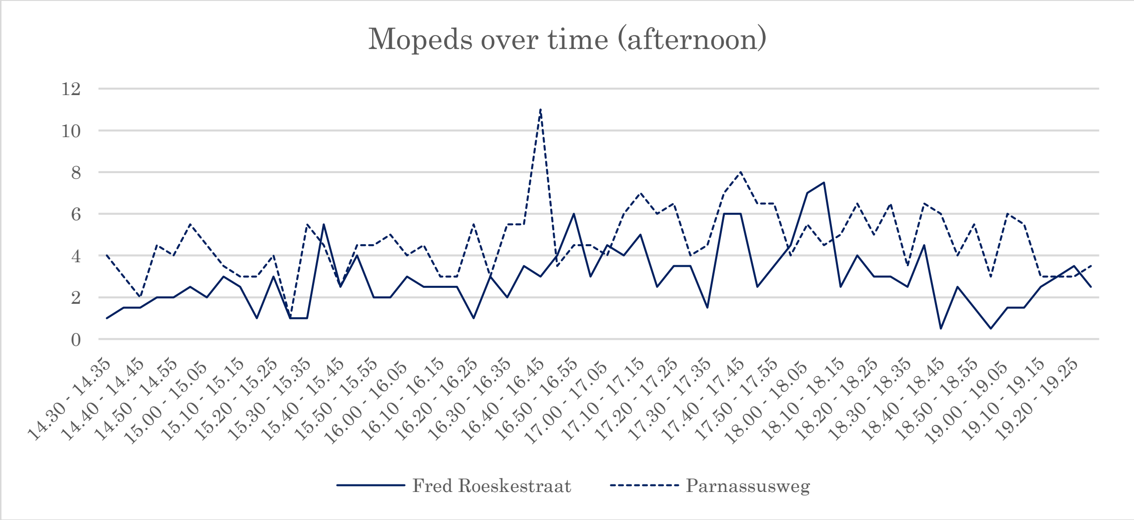

*Graph 32: Average number of side-by-side cyclists over time (14:30- 19:30)*



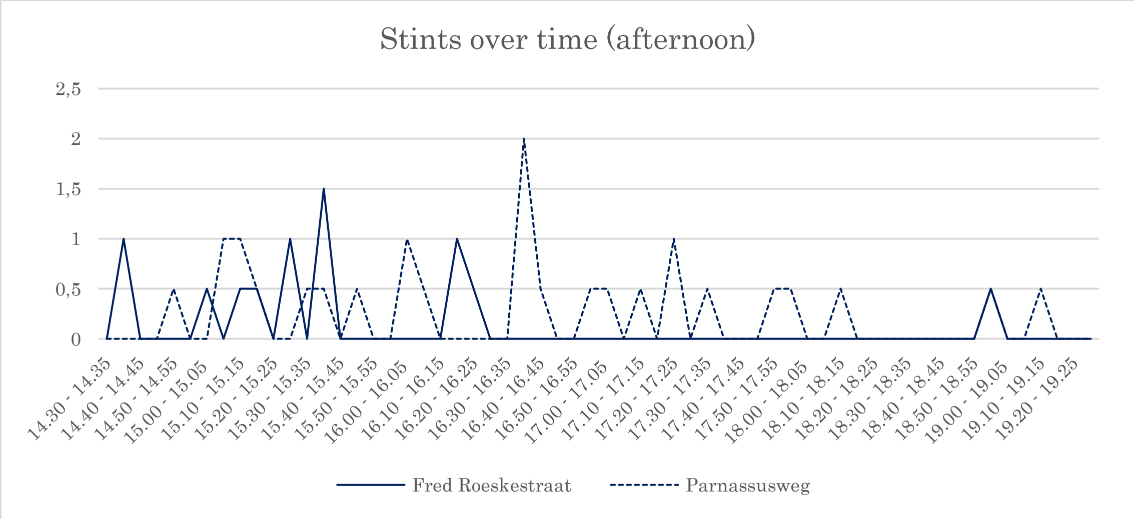

*Graph 33: Average number of non-commercial cyclists over time (14:30- 19:30)*



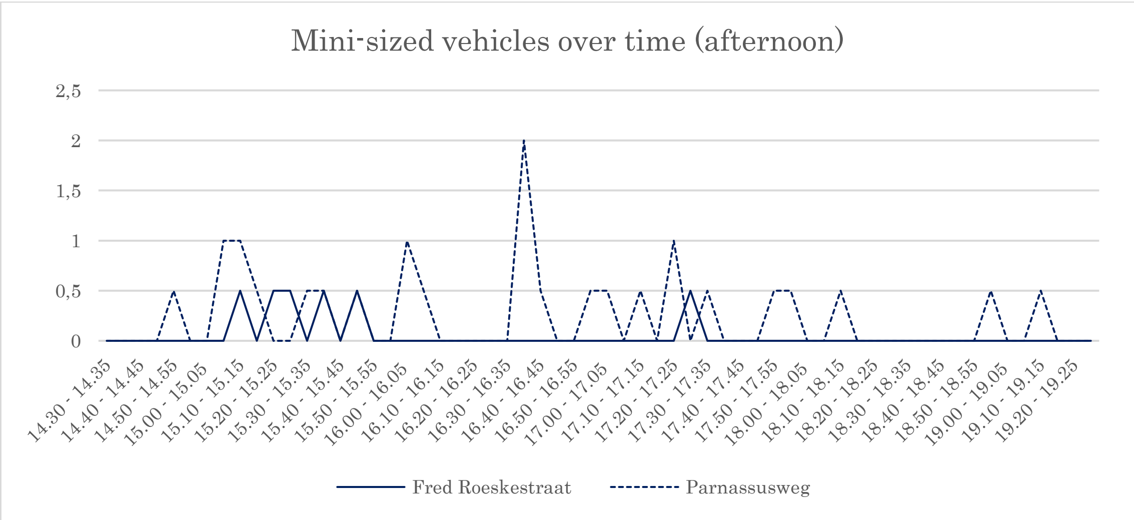

*Graph 34: Average number of commercial cyclists over time (14:30- 19:30)*



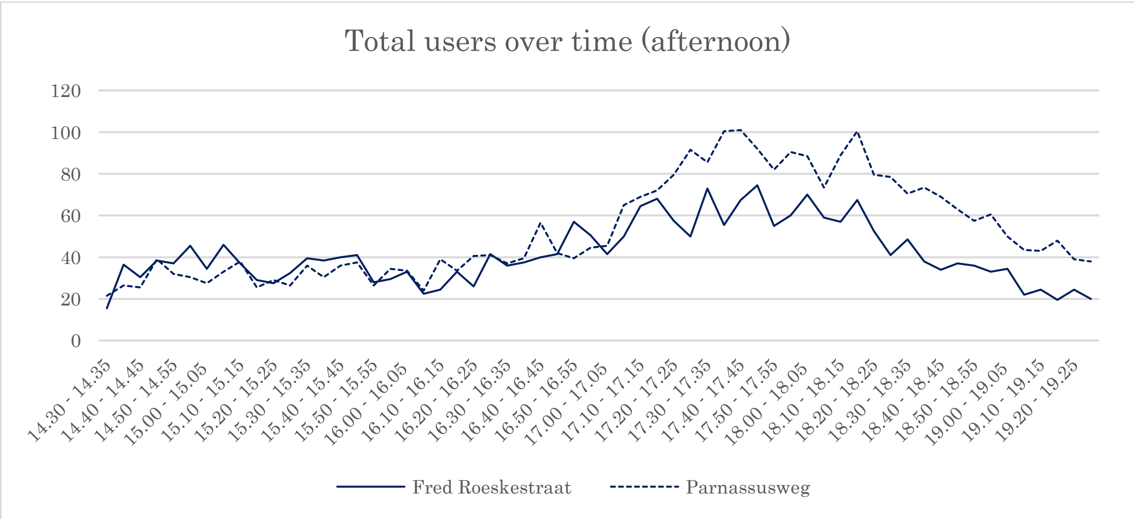

*Graph 35: Average number of mopeds over time (14:30- 19:30)*




*Graph 36: Average number of stints over time (14:30- 19:30)*




*Graph 37: Average number mini-sized vehicles over time (14:30- 19:30)*




*Graph 38: Average number of total users over time (14:30 - 19:30)*