Impacts of 4th generation bike-sharing

Case study city of Delft

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TUDelft

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by

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to obtain the degree of Master of Science
at the Delft University of Technology,
to be defended publicly on 13 May 2019.

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Preface

This report marks the end of 5.5 years of studying at the TU Delft. This thesis is about bike-sharing as a new transport concept that will have a major impact on the way people travel in urban areas. This thesis is set up around a pilot implementation of Mobike, the biggest bike-sharing platform in the world, in Delft. The research is based on an experimental method for collecting operational data from the bike-sharing system. This is the first research based on trip data of a dockless bike-sharing system in Western Europe.

Traffic and Transport and information technology always had my interest. After high school I started with the study computer science, inspired through the perspective that IT offers to contribute to solving social issues. During the bachelor I participated with great pleasure in the hyperloop dream team. After graduating my bachelor computer science, I decided to do the master Transport Infrastructure and Logistics. I was triggered through the invitation from Ronald Haverman, the founder of OV-fiets, on his website for a graduation assignment. During our first meeting we discussed the concept of shared bikes and the letter of intent for an open standard. I suggested to do a pilot in Delft, with the perspective of the reconstruction of the Sebastiaansbrug, where the shared bike may offer a quick alternative transport mode. However, this thesis took more time than planned, the effects of the closing of the bridge are no part of the research, since the start construction also was delayed and started last Thursday.

During the research I learned a lot of different aspects influencing a bike-sharing system. Bike-sharing systems seem to be a solution for many social issues, such as more sustainable transport and the reduction of demand for parking spaces, it appears to be difficult to introduce the concept on a large scale. This is a long-term process, like many measures to combat global warming.

I would like thank the representatives of governments and bike-share operators for their cooperation with the interviews, discussions and background information. Inspiring and critical were the discussions with my graduation team: Niels van Oort, Ronald Haverman, Serge Hoogendoorn , Wijnand Veeneman. Especially I would like to thank them for their patience, optimism and ideas.

Sven Boor
Rijswijk, 19th of February 2019

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Introduction

In recent years, growing concerns over climate change, pollution, congestion and unhealthy lifestyles have contributed to increasing attention to sustainable transport modes such as cycling in general and more particularly the bicycle transit combination. As part of the policy to promote cycling, bike-sharing programs were introduced in the past decades. The development of smart bicycle locks in combination with the possibilities of smartphones, made a new type of bike-sharing possible, in literature known as dockless, free-floating or fourth generation bike-sharing [32]. In the new dockless model users are able to start and end their trip at their origin and destination without having to find a nearby docking station. Compared with traditional bike-sharing programs, dockless bike-sharing systems integrate mobile payment and global positioning system (GPS) tracking into the system, these features greatly increase the ease of use and management of the system [53]. These systems have the potential to produce robust travel data generated from the on-bike GPS.

Problem Context

The experience with the dockless bike-sharing concept in the summer of 2017 in the Netherlands showed that the governance is complex since it requires coordination between (commercial) operators, governments, the users, the public and other stakeholders. This thesis is set up around a pilot implementation of the dockless bike-sharing system of Mobike in Delft; what can be learned from this pilot? The research is based on an experimental method for collecting operational data from the bike-sharing system. This is the first research based on trip data of a dockless bike-sharing system in Western Europe.

In literature the following factors are found to be critical for a sustainable dockless bike-sharing system [53]:

- Quantity control; an oversupply of bike sharing causes a series of problems
- Cultural aspects; A positive cycling culture resulting in growing cycling levels and a pro-cycling policy is important.
- Bicycle transit combinations; Bike sharing has the opportunity to serve as a feeder mode for the first and last mile of transit trips.
- Business case; A sustainable bike-sharing system should have a positive business case.

Objective

The objective of this study is analyzing the critical success factors for a sustainable bike-sharing system based on the data of the Delft Mobike pilot. This analysis is followed by recommendations for governance and adjusting the system design to meet the success factors.

Mobike Delft pilot

Mobike was founded in 2015 in China. It was one of the first fully dockless bike-sharing services. Now it's the biggest bike-sharing platform in the world [64]. Mobike started with the Delft pilot in March 2018. This pilot offered an opportunity to investigate the demand for shared bikes in Delft, and in addition, to examine how the use of shared bikes can be regulated best in Delft [16]. In the pilot the focus is on the link between the two railway stations and the TU Campus.

Governance

Stakeholders

For local governments shared bicycles offer opportunities for reaching policy goals. The opportunities are an increase in the modal split of sustainable modes of transport and a possibility of more efficient use of public space [2, 17]. They are worried about uncontrolled introduction of shared bicycles. An oversupply may result in several problems, such as vandalism, mess in the street, occupied public space. This results in a low acceptance by the public, so it is important to avoid these problems.

For Mobike in Delft it's important to have a positive business case. On the operation side the profit is maximized by creating a service that is used as much as possible with as less bikes as possible. As a commercial bike-share-operator Mobike wants no, or as little as possible, regulations and pre-conditions. If needed, they prefer standards, rules that can be applied in different cities, so they have to invest once to comply to the rules for all regions.

Control model

The bike-sharing ecosystem in Delft can be described according to the plan-do-check-act(PDCA-)cycle [25]. The PDCA-cycle is a well-known model for continual process improvement. Two cooperating PDCA circles can be distinguished (see Figure 1). The upper-level consists of the policy management cycle. Scope of this cycle is establishing objectives using bike-sharing as an instrument for increasing modal split of sustainable modes of transport and as a possibility of more efficient use of public space. The policy cycle is in the domain of the government, however for the do phase cooperation with bike-share operators is necessary. The second level is the operational control cycle. In Delft this cycle is in the domain of Mobike.

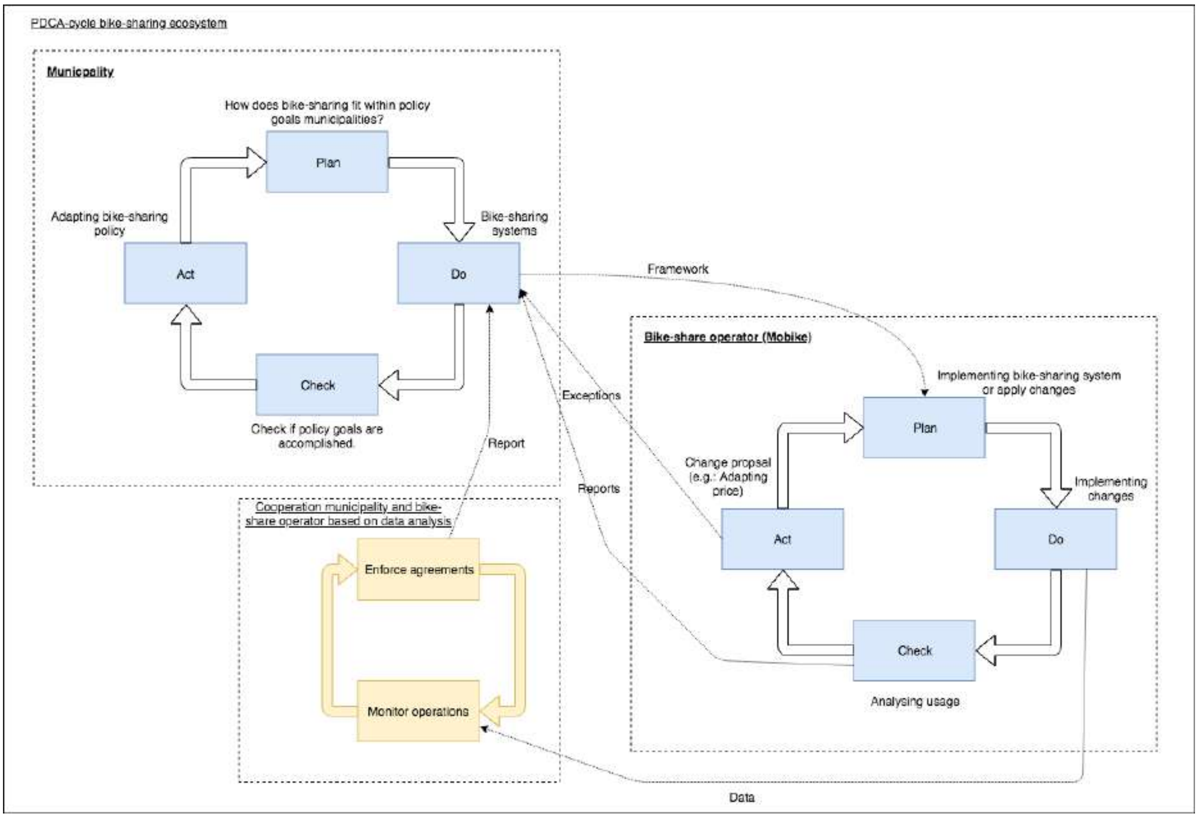

Figure 1: Improved PDCA control model, add the usage of data

Dockless bike-sharing in its current form with commercial operators is largely unregulated [66]. In order to reach government policy goals, a minimal form of regulation is desirable. Even though a municipality does not provide funds to directly support dockless bikeshare, its operation depends on the use of municipality-owned streets, sidewalks, and other public infrastructure. By establishing a permit system, a government is well positioned to commit a bike-share operator and to supply information in order to evaluate the contribution to the policy goals. The PDCA control model provides a framework for regulating dockless bike-sharing on a level which is appropriate for the local situation.

Data play a key role in the PDCA cycle. During the do phase data is gathered to see how effective changes in the system are related to the objectives. The PDCA cycle is supported by quality performance indicators. Quality performance indicators define a set of values against which to measure. The most important indicator is the average daily trips per bicycle. This indicator is relevant for all the different points of view: the profitability of the bike-share operator, the contribution to sustainable transport, the efficient use of public space and limiting the deterioration [53, 66].

Data

The challenge for this study was to obtain data about the usage of Mobike in Delft. The municipality of Delft has no conditions on data sharing attached to the permission for the pilot. Worldwide, commercial dockless bike-share operators do not want to share data anywhere.

An alternative approach has been chosen for this study, by which data can be collected without the permission of Mobike. Starting point for the data collection are the bike position data showed on a map in the Mobike app. To get these data the same HTTP-call performed by the app should be performed by the software that collects the data and write these in a database. To derive how the HTTP-call worked the Mobike app was reverse engineered. By trying out it has been determined that the app shows up to 50 free bikes simultaneously around the GPS position. Only bicycles within a radius of up to 500 meters are shown on the map. Based on these preconditions, the grid around Delft for the sample locations (GPS positions in HTTP-call) of the collection software is determined. Every 5 minutes a complete sample of the city was made, on average a complete sample took 2 minutes and 37 seconds. The data are collected and stored in a database between 28th of May 2018 and 10th October 2018. In total 21152525 detections are stored in the database.

A trip is derived out of the sample data if a bike made a position change of at least 200m in consecutive samples. During the research period 149193 trips are collected in the data set. This by far the biggest free-floating bike sharing dataset ever collected in the Netherlands and gives an unique insight in the performance of this new mobility concept.

Results and analysis

General

The data showed that quite a lot of trips are made with a Mobike in Delft every day, between 1000 and 2100 daily trips. The value for the average daily trips per bicycle in Delft is 1.6. The value can be increased by controlling the quantity of shared bikes in the service area; the average number of trips per active bicycle day by day in Delft is between 2.5 and 3.8. This indicates the average daily trips per bicycle may be increased by controlling the quantity of shared bikes in the service area and by reducing the size of the service areas. The average daily trips per bike worldwide in cities with a docked system are higher than the 1.6 daily trips per bike in Delft. A comparison with dockless systems is not possible, since there are hardly data available.

The average trip great-circle distance is 1.6 km , over the road between 1.7 and 2.3 km, depending on directness of bicycle routes. This rather short average distance corresponds to the distances found in research in the Chinese cities of Nanjing [33] and Beijing [54]; Mobikes are mainly used for distances shorter than 3 km.

Origin Destination

In figure 2 the trips in the period 3 - 7 September 2019, the first college week, are presented on a map.

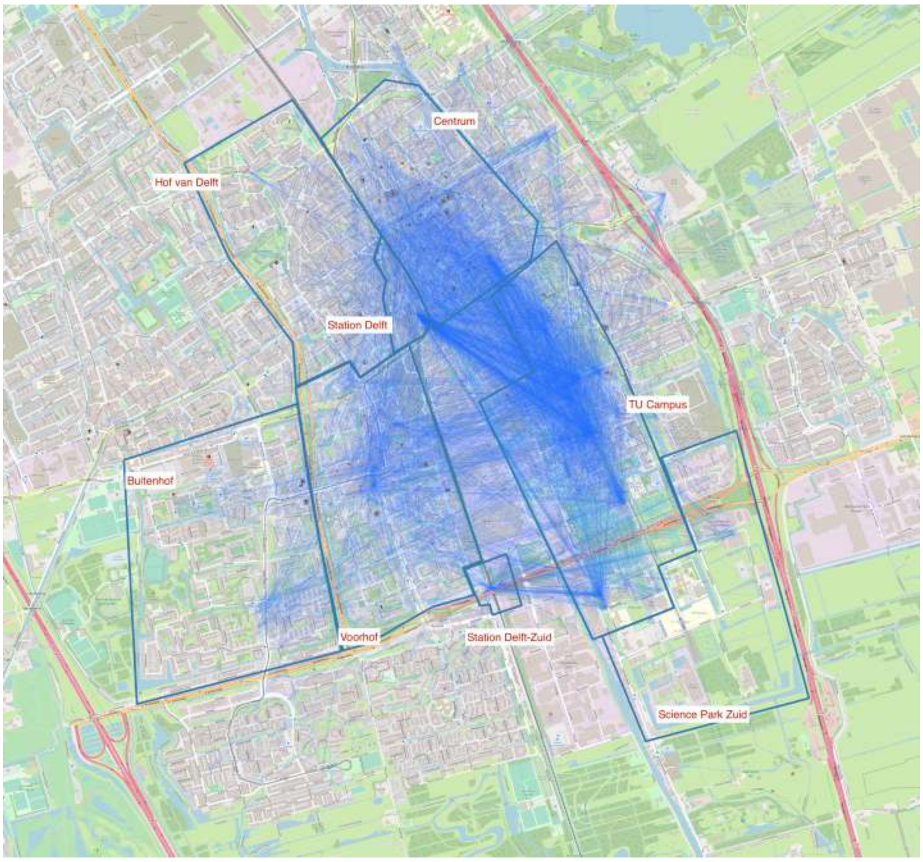

Figure 2: Overview all trips 3 - 7 September 2019 (monday - friday)

Most trips have their origin and/or destination in the campus zone. This indicates that a lot of users are students. Important relations are with the city center, the railway stations and Voorhof. In Voorhof are several large student flats situated.

Bike-sharing and public transport

Bike-sharing as an instrument to strengthen the bicycle-transit combination may give the greatest contribution to the growth of sustainable transport. What can be learned from the data-analysis about this potential?

The share of trips related to one of the railway stations was 18.7%. Especially the number of trips to/from the Delft Zuid station is interesting. In the period between 27 Augustus and 16 September 2018 more then 1000 trips started or had their destination there, that is on average 50 trips per day. This indicates the potential need for shared bicycle bikes here.

In figure 3 the usage of Mobike in Delft is related to the general daily pattern in number of trips with all transport modes in the Netherlands (source: OViN 2014 [5]) on an average working day.

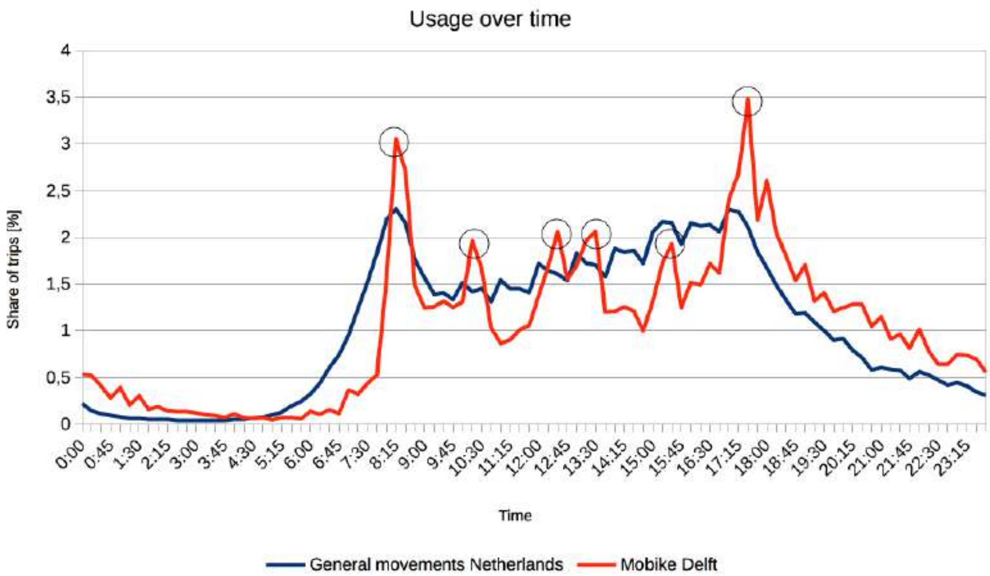

Figure 3: Comparison Mobike Delft usage with general movements Netherlands

During periods without local public transport, for example during the night and during the weekends to and from the TU-Campus, the usage of Mobike is relatively high.

Remarkable in this figure are the peaks in the usage of Mobike Delft, this pattern corresponds more or less with the start and ending times of lectures (08:45, 10:30-45, 12:30, 13:45, 15:30-45, 17:30).

In figure 4 the arriving and departing shared bikes at Delft Station is shown. During the rush hour in the morning there is a peak in the departing bicycles, in the afternoon the number of arriving bicycles is higher. Based on this pattern it's possible to conclude that more people are using Mobike at the activity side than at the home side of a train journey.

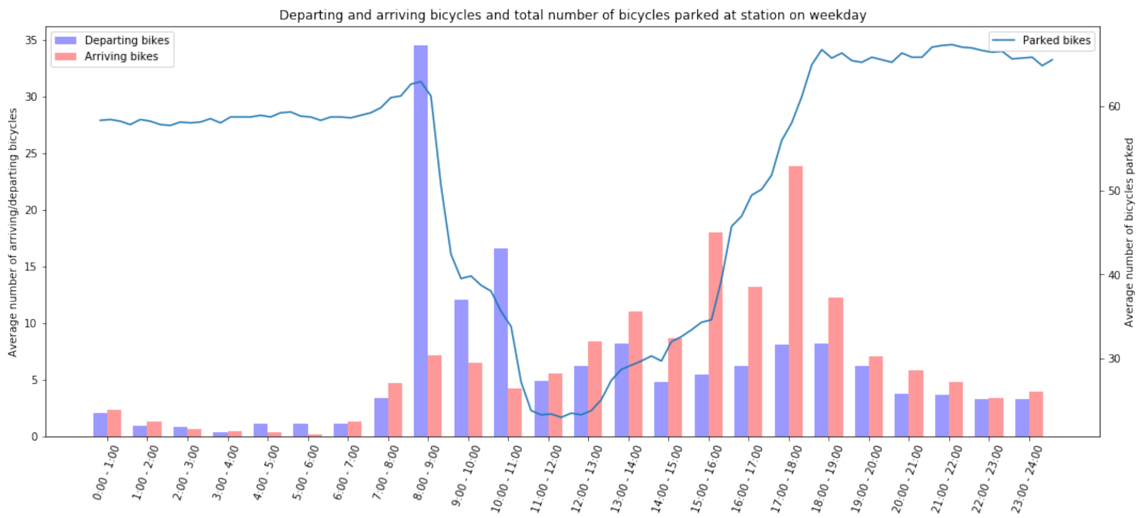

Figure 4: Average number of arriving, departing and parked bikes at Delft Station on workdays in the period 3 September 2018 and 16 September 2018

The Netherlands have a unique issue compared with other countries: the bike use to and from railway stations is very popular and even growing. Despite of years of expansion of the number of parking places at station, bicycle shelters at many large train station remain (over) full [28]. Further expansion of bicycle parking places is often not easily possible in terms of space or involves high costs. KiM concluded that bicycles waiting at railways stations for transport to work, training or another activity (egress) provide 45% of the parking pressure. These bicycles are on average parked for about 2.68 day/train- trip. Bike-sharing may contribute to reducing the bicycle parking pressure at railway stations because shared bikes only need to stand still for a short time.

The blue line in figure 4 shows the average number of parked bikes in het station area during working days. This average varies between 25 and 65. In the period between 8:00 and 11:00 hour on average 60 Mobikes depart from the station area. In this period on average 20 bikes arrive in the station area. In comparison with the usage of second bikes or the OV-fiets at the activity side of a train trip, the use of shared bikes results in less needed parking places during the nights and weekends. During the nights and weekends the occupancy in het railway station bicycle shelters is very high. Regularly the shelter is completely full during the weekends. The higher use of shared bikes at the activity side than at the home side, indicates the potential for further reducing the number of bicycle parking spaces at the railway station. By stimulating the use of a shared-bike instead of an own bike at the home side of a train journey the number of arriving bikes in the morning peak and departing bikes in the evening peak may increase. The use of bike-sharing at the home side can be made more attractive by offering a preferred position in the bicycle parking, close to the access to the train platforms. A guaranteed place gives shorter transfer times with less spread. This, combined with an attractive subscription model, can tempt commuters to use the bicycle at the home side of the train journey.

Bicycles parked for a long time

Figure 5 shows the bicycles parked for a period longer than 5 days on a map.

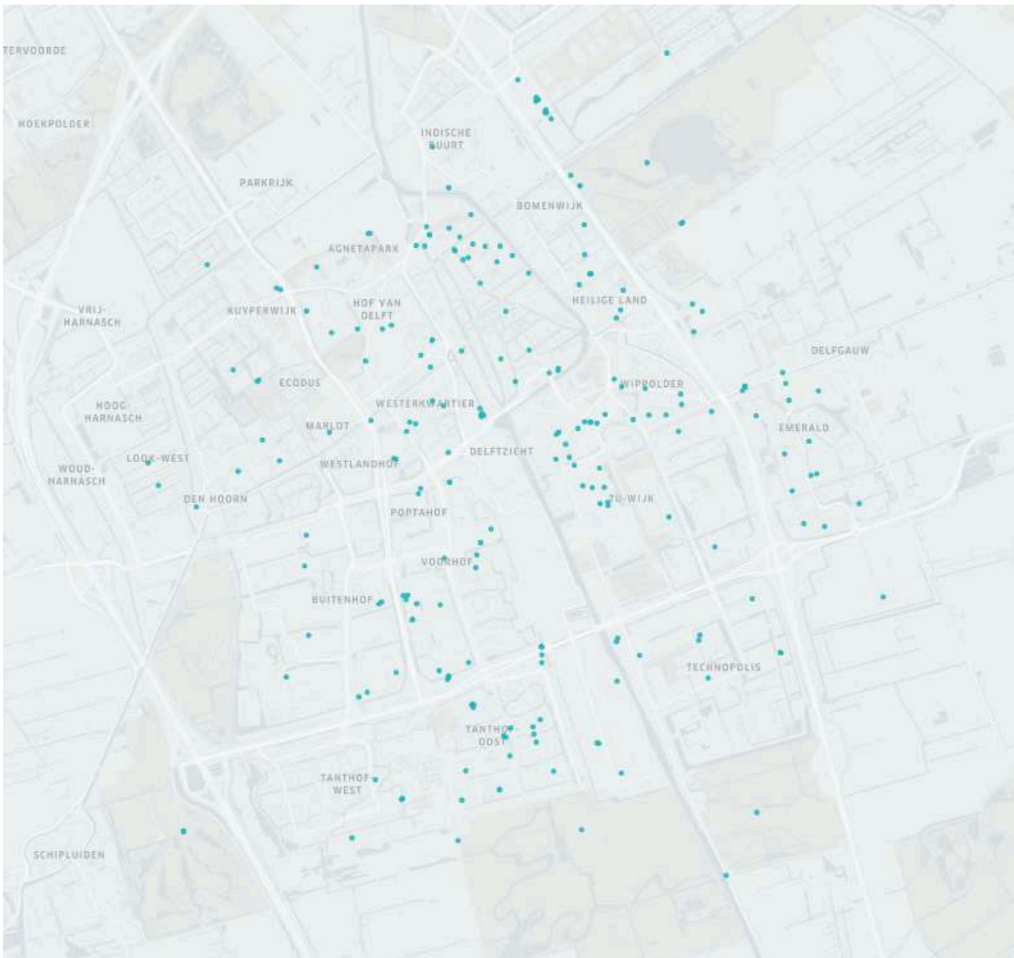

Figure 5: Locations where bicycles were parked for more than 5 days in the period between 27 August 2018 and 16 September 2018

Almost 80% of the bicycles that are not used for more than 5 days are parked in residential areas. Bikes parked for several days at the same place in residential areas, may lead to complaints. Replacing bikes not used several days to locations with a high demand, by street operations, is the most significant operating cost.

Restricting parked bicycles in residential areas can both contribute to reducing the inconvenience for residents and improving the efficiency of the operator.

Conclusion

The challenge is to maximize the benefits of dockless bike-sharing, such as more sustainable transport and efficient use of public space, while minimizing the negative side-effects. The key for more sustainable transport is how to achieve synergy between public transport and bike-sharing. Another key is how to make bike-sharing more profitable.

A possibility to make the bike-sharing in Delft more profitable, is to combine the strengths of free-floating bikes with the higher average usage of docked systems. This can be done by the introduction of virtual docking stations in combination with free-floating use. The virtual docking stations are determined based on the locations and / or zones that are origin and/or destination for many users. In these areas the chance that a shared bike is used again quickly is great.

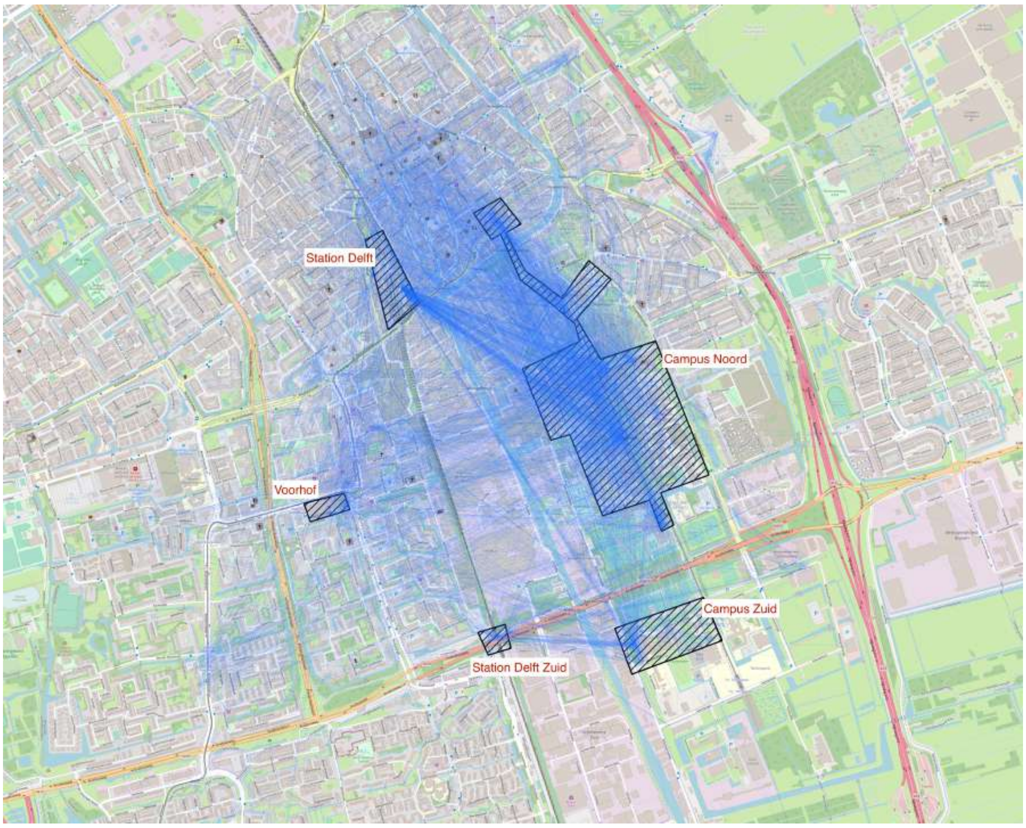

Figure 6: Suggestion for virtual docking areas, based on O-D data.

In the free-floating areas, that is everywhere outside the virtual docking areas (see figure 6), the user remains responsible for the bike under attractive subscription conditions. This means, for example a commuter using a shared bike for the home side of a train journey, parks the bike at home during the night and weekend. This bike may not be used by another user, unless the commuter releases the bike. The expectation of this system design is a reduction of the number of bikes not used for 5 days of longer, a reduction of the costs of street operations, a higher sense of responsibility under the users, less vandalism and deterioration and a better use of public space.

KiM found a latent demand for bike usage at the activity side of the train trip. The challenge is to make bike-sharing attractive on the activity side of a train trip. This may be an alternative for use of second bicycles, which occupy the parking places at railway stations for a long time. The suggestions for making the use of bike-sharing more attractive on the home side also apply for the activity side: Parking places close to the access to and from the train platforms and an attractive subscription model. Ideally, a subscription can be used nationwide. This stimulates the use of bike-sharing as part of a chain trip both at the home side and at the activity side. If there is a balance between the home side and activity side trips, this results in a higher average number of daily trips and a low parking pressure in the railway station bicycle parking place.

Trip data provide insight into the possibilities for improving the efficiency of the bike share operation as well in the effectiveness of measures to achieve synergy between public transport and bike-sharing.

Contracts and permits with bikeshare operators should require them to share real-time data with the city. For every bike in operation data should be made available in a standardized format such as the General Bikeshare Feed Specification (GBFS). Using GBFS makes it easy to show bicycles from different operators on a map. It also offers the possibility to integrate bike-sharing in a public transport journey planner.

1 Introduction

The problem of fuel based car mobility in terms of pollution and congestion is an important topic in urban mobility [26]. Cycling is widely regarded as a very effective and efficient mode of transportation [29]. Walking and cycling are probably the most sustainable urban transport modes. Cycling is not only feasible for short trips, but also for medium-distance trips too long to cover for walking [42]. Public transit and bicycling can be complementary modes of transport. In countries where bicycle use is common, the usage is highest in medium-density areas. However, good transportation policy is needed to realize the potential of bicycle/public transit synergy [23].

In recent decades the bike share of trips in 19 major cities in Western Europe, North America and South America have risen sharply (see figure 1.1). The most dramatic growth has been in cities where cycling had not previously been a regular means of daily travel. In most of the North American cities shown, for example, cycling mode share tripled or quadrupled between 1990 and 2015. Paris, London and Vienna, all without historical cycling cultures, roughly tripled cycling. Also Copenhagen and Amsterdam have shown large increases in addition to already high cycling levels [43].

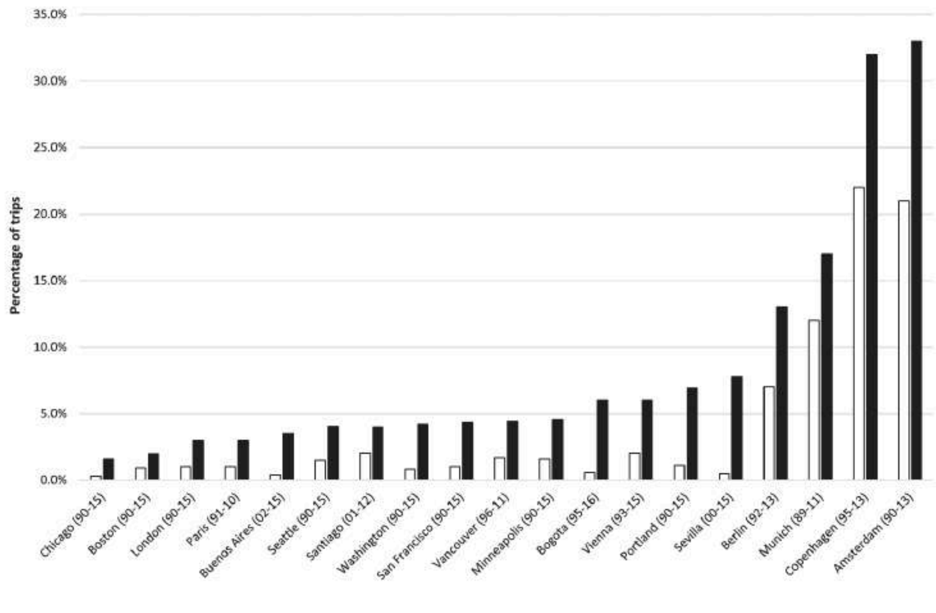

Figure 1.1: Increasing bike mode shares in large cities of Europe and the Americas, 1990-2015. [43]

The expansion, improvement and integration of protected cycling facilities are proven ways to increase cycling levels, improve cycling safety and get more women, children and seniors on bikes [4].

The introduction of bike-sharing systems may give the modal shift an extra impulse. A bike-sharing system is a service in which bicycles are made available for shared use to individuals on a short-term basis. The first generation of bike-sharing appeared in the 60's of the previous century in Amsterdam. In the 90's the attention for bike-sharing systems grew due to new technological developments. The first large-scale automated system was in Lyon in 2005 (1500 bikes). This was the largest 3rd generation bike-sharing program which served as an example for other cities, among which the velib system in Paris. The success of the Paris system generated enormous interest in bike-sharing from around the world [10]. Bike-sharing greatly increases the availability of bikes, the flexibility of routing, and access to and from public transport [42].

In the last years, a new type of bike-sharing is introduced worldwide, the fourth generation of bike-sharing also known as dockless bike share and free-floating bike share in literature [65]. In comparison with earlier generation sharing systems there is no need for staff to hire bicycles nor docking stations are necessary. The new dockless model offers a more flexible bike-share experience because users are able to start and end their trip at their true origin and destination without having to find a nearby station. Dockless bikes are equipped with global positioning systems (GPS), and are found, rented, and locked through the dockless operator's smartphone app. This new kind of dockless shared bikes, with great advantages of accessibility, flexibility, efficiency and cheapness, helps to solve the 'last mile' problem, reduce the travel time, and seems to be very environmental-friendly and sustainable. Compared with traditional bike-sharing programs, dockless bike-sharing systems integrate mobile payment and global positioning system (GPS) tracking into the system, these features greatly increase the ease of use and management of the system [53].

In the summer of 2017 the first free-floating bike-share systems were introduced in the Netherlands. Amsterdam was inundated with thousands of shared bicycles in a short time. Bikes polluted public space and were vandalized. Bike rental companies, aimed at tourists. feared for unfair competition. This resulted in a temporary ban on bicycle sharing in the municipality of Amsterdam. The municipality is working on a come back for shared-bicycles in a more regulated way [2].

Issues such as theft and vandalism, uncontrolled parking and cluttering of public space seem to be generic problems coherent with dockless bike-sharing systems all over the world. These issues are increasingly considered as being impeding the future development of dockless bike-sharing systems. As a consequence, the promise of dockless bike-sharing systems being a means to facilitate sustainable urban travel and reduce carbon emissions is seen as a paradox [1]. How to address these problems is critical to achieve dockless bike-sharing sustainability.

Implementing a dockless bike-sharing program is complex. a variety of stakeholders have been affected with complex interrelationships between them [8, 35]. This thesis is set up around the governance between the parties involved in a pilot implementation of the dockless bike-sharing system of Mobike in Delft. Based on the collection of data about the movements of the shared bikes the impact of a dockless bike-sharing system is determined.

1.1. Problem context

In recent years, growing concerns over climate change, pollution, congestion and unhealthy lifestyles have placed more attention on sustainable transportation alternatives such as bicycles. The bicycle, compared to other kinds of vehicle, has many advantages for both cyclists and society: it is a low-cost, low-polluting, health-improving way to travel [20]. In light of these benefits, cycling has become a major component of visions of sustainable urban transport systems in Europe [19]. As part of the policy to promote cycling bike-sharing programs were introduced in the past decades [37].

In international scientific articles a wide variety of research can be found on the topic of bike-sharing. Several studies are performed on the impact of bike-sharing programs [31]. There is a growing consensus that bike-sharing systems could bring benefits such as mitigating congestion [15, 60], time savings for travelers [13, 52], promoting a healthier lifestyle [14, 38], and reducing air and noise pollution [50]. Whether the political goals of the various projects have been achieved is hardly to find in the scientific literature [31].

A recent study concludes that the sustainability performance of new-generation dockless bike-sharing systems is largely overlooked [53]. The governance of dockless bike-sharing sustainability is complex;

multiple influencing factors and various stakeholders have to be combined. From this study factors that are critical for a sustainable dockless bike-sharing system are derived [53].

1. Quantity control

   An oversupply of bike-sharing causes a series of problems: mess in the street, occupied public space, low acceptance by the public, vandalism. The more bike-sharing services that are supplied, the more supporting infrastructure is needed, the higher the operational costs. However, if too few bike-sharing services are available, this can also lead to a reduction in traffic accessibility. Therefore, the quantity control of bike-sharing services is an urgent challenge for both government and operators.

2. Cultural aspects

   A positive cycling culture resulting in growing cycling levels and a pro-cycling policy is important. Pro-cycling policy contributes to qualitative good cycling infrastructure and good parking facilities.

3. Bicycle transit combinations

   Bike sharing has the opportunity to serve as a feeder mode for the first and last mile of transit trips, potentially making transit and biking easier options to take more often, with mobility and health benefits for individuals and society [10, 11, 44, 63]. How to achieve synergy between public transport and bike-sharing is a key challenge for government and operators.

   Bikes in the Netherlands have a very strong role as access mode of public transport, in the egress mode, the role is much smaller [51]. The share of bicycles in egress transport from the train is 10% and bus, tram and metro it's only 1%, in access transport it's 43% and 13% respectively. By improving the egress of public transport the total public transport network may be strengthened.

   In the Netherlands, with a relative high bicycle usage, a lot of research is done to the bike - rapid transit combination. An important benefit are the greater catchment areas of public transport stops [27]. The increasing catchment areas result in overlapping areas, which give the traveler the possibility to choose between multiple stops [47]. In a choice modelling study different factors, such as bicycle time, train time, parking time and avoiding transfers, which can be influenced by cycling to/from another stop or station, are related [58]. These insights support the design of bicycle and transit networks, incl. parking facilities at transfer points. Another study showed that bus systems with higher frequencies and speeds can attract twice the amount of cyclists on the access and egress sides. It also appeared that passengers accept longer access and egress distances if the quality of the bus operation is higher (higher frequencies, higher speed) [3].

   The KiM (Dutch Institute for Transport Policy Analysis) researched the combination of train and bicycling, especially from the perspective of bicycle parking places at stations. Despite years of expansion of the number of parking places, bicycle shelters at many large train stations remain (over) full [28]. The research concluded that bicycles waiting at the station for transport to work, training or another activity (egress) provide 45% of the parking pressure. These bicycles are parked for about four times as long in a station (average 2.68 day/train trip) than bicycles that are used for transport between home and station (average 0.68 day/train trip). KiM found a latent demand for bike usage at the activity side of the train trip. Bike-sharing may be an attractive solution to respond to this demand.

4. Business case A sustainable bike-sharing system should have a positive business case.

   (a) Principal cost factors include staff needed for operation, service and maintenance; bicycles; the share of the operating the IT system used for reservations, paying and management.

   (b) Income: revenues from the users. If a system is not financially self-supporting a form of financial backing is needed.

   Seeing bike share systems as complementary to the Public Transport system, the benefits may be broader than the economical revenues. The 5xE framework [57] consisting of: environment, equity, economy, efficient city, effective mobility support and quantify the value of public transport extensions.

1.2. Knowledge gap

Not much is known about the potential and use of dockless bike-sharing systems in the Netherlands. Besides the OV-fiets there is no experience with the bicycle transit combination at the egress side. However, the latent demand for bike usage at the activity side of train trips is high. Bike-sharing may be an attractive solution to respond for this demand.

The experience with the dockless bike-sharing concept from the summer of 2017 in the Netherlands showed that the governance is complex since it requires coordination between (commercial) operators, governments, the users, the public and other stakeholders. The challenge is to achieve goals regarding sustainable transport through cooperation between the involved parties. There is a need for practical guidance on how this can be done. Sharing and analyzing data may help to support this governance.

No research is found regarding the performance on dockless bike-share data in any Western European city. With google scholar different combinations of the follow search terms were used "performance indicators dockless bike sharing". In China there are a few researches performed on the GPS data the locks provide [33]. Dockless bike-sharing companies are very cautious with providing data due to the commercial sensitivity. The data may give interesting information about their business models. In this thesis a method is developed to retrieve data about the usage of a bike-sharing system without the permission of the bike-sharing company.

1.3. Scientific & practical relevance

Dockless bike-sharing has the potential to be an important link in sustainable mobility. The method to organize the collaboration between different stakeholders is crucial to be successful. Not much in known how to optimize the cooperation between governments, who want to realize their policy goals, and commercial bike-share operators aiming to increase their profitability.

A framework is provided to facilitate this cooperation, whereby agreements are made about the goals to be achieved and how the progress is measured.

Important contributions of the research are how data from a free-floating bike-sharing system can be collected and how performance can be measured based on this data. Tools developed for this purpose are made publicly available under an open source license, for future research these tools may be re-used.

The research has contributed to the knowledge of data-standards for bike-sharing and the adaption in the Netherlands. The use of the General Bikeshare Feed specification (GBFS) enables researchers to compare bikeshare use across cities and regions, knowing the data is compatible and reliable.

1.4. Objective & Research questions

In the Netherlands dockless bikeshare appeared as an initiative of different market parties. At this moment it's not clear if dockless bike share systems support the policy goals of the government, although there seems potential for dockless bike share as a sustainable mode of transport. Therefore, in this thesis first the policy goals and concerns are explored, a governance model is proposed, indicators to measure the performance of bikeshare systems are defined and research results are presented. The research question is:

What are the impacts of dockless bike-sharing on convenient and sustainable mobility?

This research question is divided into the following sub questions:

1. What are the effects of technological developments on the relationship between bike-share operators and local governments?
2. What's the current policy and what are the ambitions of different government bodies in relation to bike-sharing? What concerns do they have?

3. How can governance be organized to support the collaboration between the main stakeholders?
4. How can data analysis help to find answers to the questions about concerns and opportunities? Based on the Delft bikeshare setup.
5. How is bike-sharing used in Delft?
    (a) General usage
    (b) Origin/destination, especially the relation between railway stations and Science Park Zuid.
    (c) Idle time
6. Which recommendations can be given to several stakeholders based on the data analysis in Delft?

1.5. Methodology

In this section the methodology of this research is presented. An overview of the research approach is presented in figure 1.2. First literature research is used to explore the background and opportunities of bike-sharing. It provides information of different aspects that influence sustainable bike-sharing. It also describes the initiating parties of the different bike-sharing systems in current implementations and in the past. This answers the first sub-question in chapter 2.

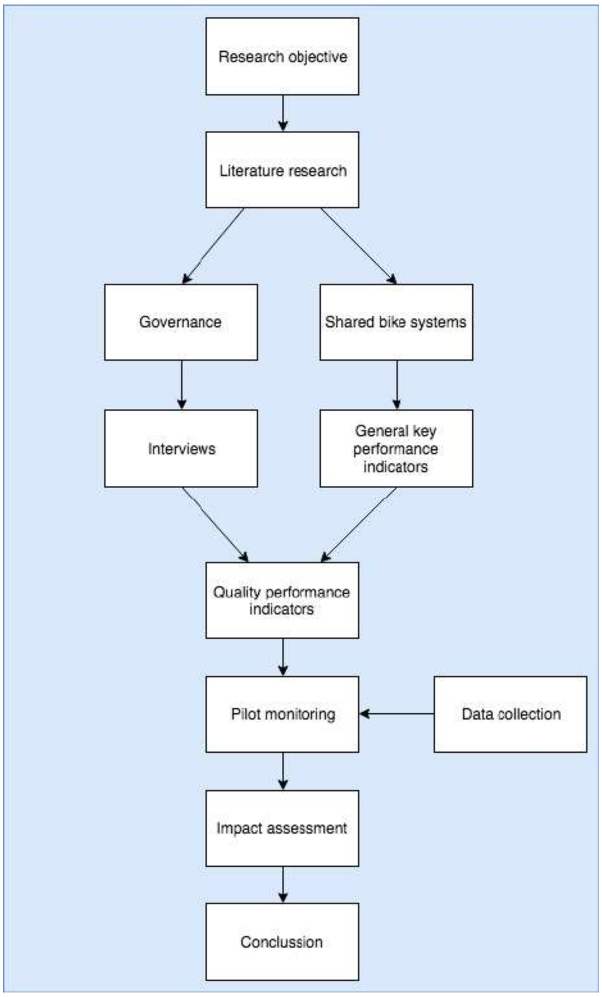

Figure 1.2: Overview research approach.

Literature review in combination with interviewing representatives of governments and bike-share operators is used to explore the contribution of bike-sharing to sustainable mobility and to investigate their concerns, this gives an answer to sub-question 2 in chapter 3.

Models to describe the governance levels and the communication relations between organizations are explored in literature. In combination with opportunities and concerns of the governments a governance model is proposed for collaboration between bike-share operator and local government. This third sub-question is also answered in chapter 3.

Chapter 4 gives answer on the question how can data analysis help to get control over the concerns and opportunities of the local government (sub-question 4). In this chapter performance indicators are defined, based on and derived of existing performance indicators regarding bike-share systems found in literature.

In chapter 5 these indicators are applied to data that was collected during the research. This chapter also gives answer on the sub-question about the bike-sharing usage in Delft.

In chapter 6 the main research question regarding the impacts of dockless bike-sharing on convenient and sustainable transport is answered. This chapter gives recommendations for governance and adjusting the system design to meet the success factors.

1.6. Scope

1.6.1. Mobike in the Netherlands

Mobike is a Chinese startup that was founded in 2015. It was one of the first fully dockless bike-sharing services. Now it's the biggest bike-sharing platform in the world [64]. The mission of Mobike is to "provide an affordable means of shared transportation for convenient short urban trips, while reducing congestion, and our city's carbon footprint. These combined - Mobike improves the quality of city life." [39].

Mobike was the first to introduce a smart lock that combined GPS and telecommunication. In the smartphone app users can locate the nearby bikes and unlock them (figure 1.3). After cycling the user can park their bike wherever they want in the service area (figure 1.4), then lock the bike and the trip is ended automatically. The rental fee is collected automatically.

From March 2018, Mobike extended it's operations to the city of Delft. with a focus on the campus of the university. Bikes are placed on 'prefered' locations at the Stations Delft and Delft Zuid and on almost 20 locations at the campus. This thesis is set up around the introduction of Mobike in Delft.

1.6.2. Pilot implementation Delft

In a letter to the city council the College of Mayor & Aldermen explains the background for a bikeshare pilot in Delft [16]:

As part of the sustainable mobility implementation plan, one of the plans for 2018 was the development of a shared bicycle system. Due to the appearance of bikeshare providers, the need to develop an own system expired. The municipality accepted an offer of Mobike in December 2017 to start a pilot with shared bikes. This pilot offered an opportunity to investigate the demand for shared bikes in Delft, and in addition, to examine how the use of shared bikes can be regulated best in Delft. The pilot was started in March 2018. This thesis is set up around the Mobike pilot in Delft. The shared bike responds to the sharing economy, in which common use of things is central. When sharing a bicycle, it is used more efficiently than when everyone has their own bicycle. In theory, the total amount of bicycles in the city will be smaller and this can have beneficial consequences for the bicycle parking capacity in the city.

The deployment of shared bikes is seen as promising for improving the accessibility of the TU Delft science park. Several companies on the Science Park have a positive attitude towards the shared bikes. The shared bikes may be used in combination with public transport or car for the last mile of a journey and may also be used between different locations within Delft.

With a few exceptions, the shared bike is welcome everywhere in Delft. In the pilot the focus is on the link between de two railway stations and the TU Campus. At the start 100 bikes were placed on strategic

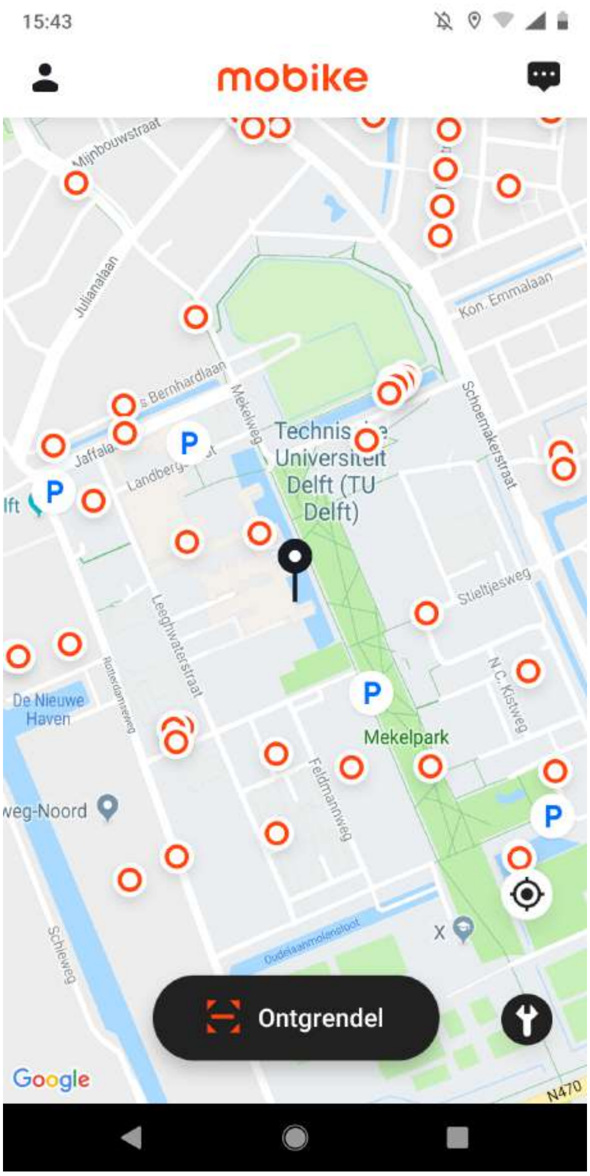

Figure 1.3: Nearby bicycles in app

Figure 1.4: Operation zone in app

points on the route. In consultation with the parties involved was determined at which locations shared bicycles would not be desirable. An example of a forbidden zone are the two underground parking facilities at Station Delft. The shared bikes will be difficult to find at these locations and the parking pressure is already high. As a replacement for this locations a temporary outdoor parking facility is used.

The parties involved consult every month in order to refine the pilot. As long as there is sufficient demand and the shared bikes does not cause inconvenience, the number of shared bikes may increase [16].

This thesis is set up around the governance between the parties involved in het pilot and the collection of data about the movements of the shared bikes.

1.7. Overview report

In the next chapter bicycle-share related literature will be reviewed. In chapter three literature is explored to describe the governance levels and the communication relations between organizations. In combination with opportunities and concerns of the governments a network governance model is developed. In chapter four key performance indicators are defined, in chapter five those indicators are used to analyze the performance of Mobike based on data collected in Delft. In the last chapter the research questions are answered and the research methodology is discussed, also practical and scientific recommendations are given.

2

Bike-sharing history and overview

The first bike-sharing system started more than 50 years ago in Amsterdam [10, 49]. The core idea of bike-sharing has been the same since 1965, but the development of the technique for locking/unlocking bicycles is a continuous force for innovation. These innovations give new opportunities from the perspective of financing and flexibility and the appropriate governance. In figure 2.1 a timeline of the history of bicycle-sharing is presented. With the help of this timeline, an overview of the development of bike sharing systems is presented in this chapter.

2.1. From experimental systems to worldwide phenomenon

The concept of bike share started as a citizen's initiative in the city of Amsterdam during the ’60s of the previous century. There were many bicycles parked without an owner. Luud Schimmelpennink proposed to reuse of all that bicycles by painting them white and making them accessible for everyone. The system did not work because people didn't park them back on the streets. A lot of white bikes were taken in custody by the police because they encouraged theft while they were not locked. It could be seen as an interesting progressive experiment to encourage sustainable mobility during that time, within a city that had many traffic problems. Because it was organized as an experiment by a group of citizens, it was not a sustainable system, and there was no goal of making a profit [49].

More than 20 years later, in 1991, a new experiment was started in Denmark, described in the literature as the 2nd generation [10]. To rent a bike in this system a coin was needed, similar to a coin in a shopping cart. With the introduction of a coin-based system, the hope was that users were more likely to return the bicycle. The system started in the cities of Farsø and Grenå. This system was implemented for the first time at a bigger scale in Copenhagen in 1995. This system had still many problems with bikes that were stolen, because users of the bicycles were anonymous and the deposit was only a small amount (3 euros) in comparison to the value of the bicycles [49].

On the University of Portsmouth in England, the first system with electronic dockings station was applied for renting out the bicycles to students. You had to use a card with a magnetic strip to retrieve a bicycle. The introduction of this system remarks the introduction of the third generation of bike-sharing. Because of the increasing interest in sustainable mobility in cities and the fact that some of the problems with earlier generations where resolved (introduction of payment methods, knowing who your users are etc.) this was the first generation of bike sharing systems that were deployed on a big scale all around the world. The 1st and 2nd generations were deployed in cities where people already used to cycle. The 3rd generation was used to stimulate cycling. A shared bike is seen as an easy method to let citizens get become acquainted with cycling. Other policy goals of the introduction of bike-sharing were the reduction of single occupancy car journeys, reducing traffic congestion, reducing CO_2 emissions and other pollutant emissions, improve public health by increasing physical activity, improving the ’first’ and ’last’ mile, improving road safety for cyclists and improving the image and livability of cities and support the local economy and tourism [46]. The most expensive part of the system was the installment of docking stations; they require a high initial investment.

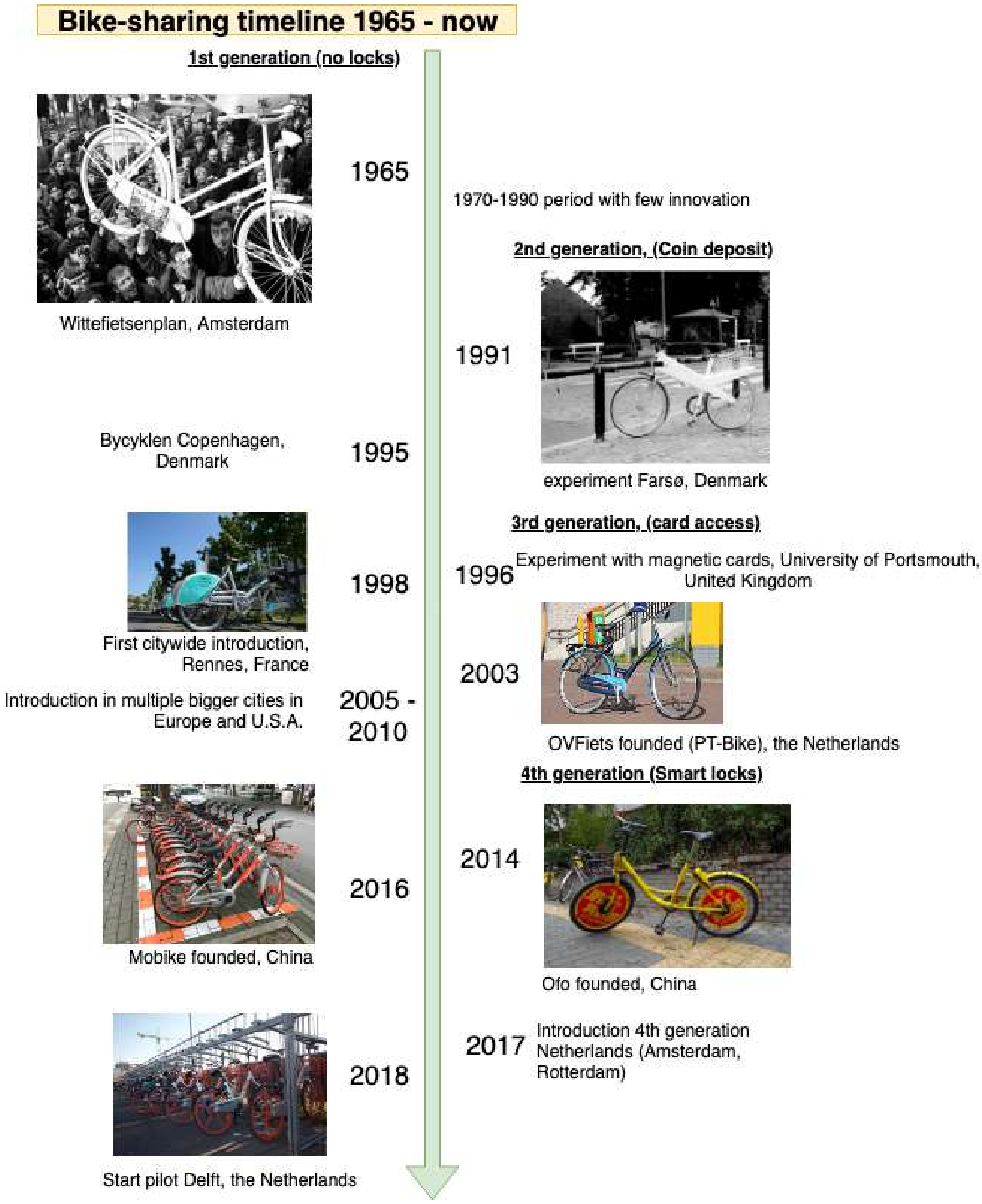

Figure 2.1: Timeline of the history of bike-sharing

In Lyon, the Velib bike-sharing system was introduced in 2005 as part of a deal to place billboards in the public space. The advertisement revenues were used to maintain the bike-sharing system. It became quickly successful, as a result this system was also implemented in Paris in 2007 [49]. Also, here problems with vandalism and theft of bicycles appeared, what resulted in an unsustainable system for the operator (JCDecaux). The Paris system was the first third-generation system where the shared bike was used in the first- and last mile on a significant scale. 28% of the users used the bike to begin or end their transit trip in 2009 [10].

During the same time, the first big nationwide bike-sharing system was introduced in the Netherlands, 'OV-Fiets'. This was an initiative originated by the maintainer of the Dutch railway infrastructure, ProRail. The initial goal of the system was improving the last mile from the train station. The initiative started at ProRail but was continued in a foundation, 5 years after the introduction the Dutch railway corporation (NS) took over the operations of the OV-Fiets and put in more investments to expand the system further. At this moment the system consists of 20500 bicycles, and more than 3 million trips are made every year [56]. The bicycles should always be brought back to the location where the rental started. It is possible to hand in the bicycle at another station for an additional fee. The bicycle is belonging to the user during the rental period. Therefore, there are no problems with the deterioration of the public space. The Dutch Railways also operate the bike parking facilities at the train stations. That gives them a competitive advantage in comparison to other operators. The Dutch Ministry of Transport is working on pilots to give also access to other bike operations at those train stations to break that monopoly position and make fair competition possible.

Systems more comparable with other 3rd generations systems with docks were not introduced in the Netherlands until recently. A possible cause for the absence of those systems in the Netherlands is that there is already for a long time a bicycling culture. Therefore, the introduction can't directly be related to promoting cycling (although it could still be a positive side effect), also there is not much room to place docking stations on the streets in cities like Amsterdam, The Hague and Utrecht due to the historical character of the downtowns of that cities and the other bikes already parked on the streets.

2.2. Recent developments

The fourth generation of bike-sharing was kicked off by the introduction of Ofo in 2014 in China [65]. The development of new techniques made it possible to develop a bike-sharing system without docking stations [32]. The innovation was triggered by the introduction of mobile payments on smartphones and the development of smart locks, including GPS and wireless mobile communication. These locks make it possible to unlock bicycles from a distance and to track bicycles through cities. More than 25 other bike-share operators followed Ofo in China [65], Mobike was one of them. At this moment Ofo and Mobike are the largest operators and the only ones that operate worldwide on a big scale.

The fourth-generation systems opened the possibilities for market parties to initiate bike-sharing systems on their own. This could be explained by the fact that it was no longer needed to construct docking stations. These docking stations are costly and seem to make it difficult to operate a profitable bike-sharing system without subsidies. Due to the fact that no docking stations are needed in public space the local governments have less influence.

Figure 2.2: Bike sharing graveyard

Because the fourth generation of bike sharing was completely introduced by the market, the first years were a race to get as many customers as possible. This race resulted in the deployment of lots and lots of bikes in China. More than were needed, resulting in deteriorated streets. In some cities in China, all bikes were collected and put on a big graveyard (figure 2.2). When public space is scarce, it is not an efficient use of that public space when a lot of different operators are active. Therefore, shared bicycle is not very suitable for governance were complete freedom is given to the different market parties.

Another new trend is the introduction the electrical scooters (step in Dutch), this trend started appearing in the beginning of 2018 in Silicon Valley. Companies as Uber and Lyft understood that these forms of transport are much more efficient and sustainable during rush hours then the traditional cab rides. Some of the companies that supply these scooters, also offer electrical bikes. In the future it's likely that a mix of this modes will be provided. Some of the lessons learned with free-floating bike-sharing can be applied on these new modes as well. An interesting difference between free-floating bikeshare and the electrical scooters is that electrical scooters are every day charged and redeployed by freelance contractors, making the operations very flexible.

Since recent years Moblity as a Service gets a lot of attention. MaaS represents the next evolution in mobility. At its core, Maas relies on a digital platform that integrates end-to-end trip planning, booking, electronic ticketing, and payment services across all modes of transportation, public or private. MaaS platforms let users plan and book door-to-door trips using a single app. The ultimate goal is to make it so convenient for users to get around with MaaS that they opt to give up their personal vehicles for city commuting, not because they are forced to, but because the alternative is more appealing. An important factor in making MaaS a success will be getting all of the players to work together. Private sector participants might join the ecosystem in search of profits, while governments could seek the public policy benefits that stem from reduced congestion: higher productivity, better air quality, fewer traffic accidents, and a smaller urban footprint for parking. Participants will gain these benefits only if they collaborate. Cycling in general and bike-sharing more specifically get a lot of attention as important part in a MaaS ecosystem. Few current platforms, however, include both private and public options and link everything together in a single solution. Even fewer take payments or allow journeys across multiple transportation operators to be paid for in a single transaction. Future iterations of MaaS should create an integrated system of mobility that is more flexible than the existing transportation network, where supply is aligned with actual demand and where more choices are provided to enable travelers to get from point A to point B in ways that are easier, faster, cheaper, cleaner, and safer than those currently available [18].

2.3. Overview literature

There are already several researches performed on data that bicycle share programs generate. The biggest share of research is performed on 3rd generations system, a small number of papers is written about the 4th generation. There are two possible explanations for the lack of research on 4th generation. The systems are relatively new and there is not automatically a lot of data available, most fourth generation systems are market initiatives. In this section an overview is given on the existing knowledge.

Whether the political goals of the various projects have been achieved is hardly to find in the scientific literature. However, results have been found on partial aspects. With respect to cycling, bike-sharing appears to increase the frequency in which a bicycle (personal or shared) is used, thus contributing to promote cycling behavior and increase overall cycling levels [34]. Bike-sharing is predominantly used instead of walking and public transport. Findings from several surveys suggest that modal shift from private cars only occurs for a minority of bike share users;

- London BCH, UK – 2% of car trips substituted for [15]
- Vélo'v, Lyon, France – 7% [14]
- Bicing, Barcelona, Spain - 9.6% [48]
- Dublinbikes, Dublin, Ireland - 19.8% [41]

Statistical analysis for Dublin showed that modal shift among higher income earners was most likely to be from car to bicycle or from rail to bicycle, while for lower income groups modal shift to the bicycle was more likely to occur from bus to bicycle or from walking to the bicycle [41]. Recent research performed in the city of Beijing concluded that the dockless bike-share is not an effective alternative for frequent car users [54].

In a review of evidence on impacts of bike-sharing [46] suggest after analyzing several surveys bike-sharing can, at the same time, connect to and substitute for public transport. The exact outcome of this combination is the result of a complex interrelationship among various factors, such as the characteristics of the bike-sharing scheme, its users and the location where it is implemented, including public transport infrastructure attributes and population travel behaviors and preferences.

Research was performed on success factor of bike sharing systems of the third generations [36]. The research identified number of trips per day per bicycle (TDB) as an important indicator for the success of a bike-sharing system. In table 2.1 an overview of the data collected in the research is found. That number of trips per day per bicycle varies between 0.22 and 8.4.

Table 2.1: Trips per day per bicycle for 75 systems [36]

	Main city	Country	Brand name	Operator	Number of stations	Number of bicycles	Trips/day/bike estimate
1	Barcelona	Spain	Bicing	BSM	420	4852	8.4
2	Ljubljana	Slovenia	Bicike (LJ)	JCDecaux	33	252	8.2
3	Dublin	Ireland	dublinbikes	JCDecaux	49	584	8.0
4	Turin	Italy	[TO]BIKE	Comunicare	136	495	7.9
5	Zaragoza	Spain	Bizi	Clear Channel	130	1211	7.3
6	Valencia	Spain	Valenbisi	JCDecaux	276	2403	6.6
7	Vilnius	Lithuania	Cyclocity Vilnius	JCDecaux	33	245	6.0
8	Lyon	France	Vélo'v	JCDecaux	346	3301	5.3
9	Paris	France	Vélib'	JCDecaux	1228	17,151	5.2
10	Milan	Italy	bikeMi	Clear Channel	187	2832	5.1
11	Tel Aviv	Isreal	Tel-O-Fun	FSM GS Ltd.	177	1411	4.9
12	Oslo	Norway	Oslo Bysykkel	Clear Channel	100	882	4.8
13	New York City	US	CitiBike	ABS/Motivate	357	5208	4.7
14	Bordeaux	France	VCub	Keolis	139	1279	4.7
15	Boston	US	Hubway	ABS/Motivate	115	1037	4.2
16	Seville	Spain	Sevici	JCDecaux	260	2203	3.9
17	Nantes	France	bicloo	JCDecaux	102	887	3.8
18	Toulouse	France	VélÔToulouse	JCDecaux	256	2193	3.8
19	Lille	France	V'lille	Keolis	214	2038	3.6
20	Montreal	Canada	Bixi	PBSC/Bixi	421	4044	3.6
21	Nancy	France	vélOstan'lib	JCDecaux	29	245	3.1
22	Washington DC	US	Capital Bikeshare	ABS/Motivate	297	2278	3.0
23	La Rochelle	France	Yélo	RTCR	57	210	2.9
24	Marseille	France	Le Vélo	JCDecaux	123	661	2.9
25	Chicago	US	Divvy	ABS/Motivate	300	2191	2.8
26	Gothenburg	Sweden	Styr & St√§ll	JCDecaux	57	728	2.7
27	Miami	US	DecoBike Miami Beach	decobike	94	601	2.6
28	Nice	France	Vélo Bleu	Veolia Transdev	178	1401	2.4
29	Rennes	France	Le vélo STAR	Keolis	83	779	2.4
30	Rio	Brazil	Bike Rio	Serttel	46	280	2.4
31	Valladolid	Spain	Vallabici	Ingenia Soluciones	29	181	2.2
32	London	UK	Santander Cycles	Serco	748	11,864	2.0
33	Toronto	Canada	Bike Share Toronto	PBSC/Bixi	80	769	2.0
34	Rouen	France	cy'clic	JCDecaux	21	193	1.9
35	Calais	France	Vel'In	Veolia Transdev	36	213	1.9
36	Montpellier	France	Vélomagg'	Veolia Transdev	49	280	1.9
37	Orleans	France	vélo'+	keolis	33	309	1.8
38	Vienna	Austria	Citybike Wien	Gewista	95	1072	1.8
39	San Francisco	US	Bay Area Bike Share	ABS/Motivate	68	611	1.8
40	Mulhouse	France	Vélocité	JCDecaux	40	245	1.7
41	Besancon	France	Vélocité	JCDecaux	30	203	1.5
42	Denver	US	Denver B-cycle	Denver B-cycle	80	569	1.5
43	Belfort	France	Optymo	Optymo	25	201	1.3
44	Amiens	France	Velam	JCDecaux	26	240	1.2
45	Madison	US	Madison B-cycle	B-cycle	32	245	1.1
46	Columbus	US	CoGo	ABS/Motivate	30	225	1.1
47	Brussels	Belgium	VillO!	JCDecaux	323	3708	1.1
48	Sao Paulo	Brazil	Bike Sampa	Serttel	95	571	1.0
49	Minneapolis	US	Nice Ride Minnesota	NRM	169	1399	1.0
50	Saint Etienne	France	VéliVert	Veolia Transdev	33	229	0.92
51	Ottawa	Canada	Capital BIXI	PBSC/Bixi	25	244	0.89
52	Namur	Belgium	Li Bia Velo	JCDecaux	24	190	0.86
53	Houston	US	Houston B-cycle	Houston B-cycle	28	200	0.80
54	Nashville	US	Nashville B-cycle	Nashville B-cycle	21	166	0.79
55	Melbourne	Australia	Melbourne Bike Share	ABS/Motivate	51	546	0.71
56	Caen	France	V'éol	Clear Channel	40	350	0.69
57	Luxembourg	Luxembourg	vel'oh!	JCDecaux	72	684	0.67
58	Pau	France	IDECycle	keolis	22	199	0.66
59	Alacant	Spain	Alabici	Tevaseñal SA	24	120	0.62
60	Charlotte	US	Charlotte B-cycle	Charlotte B-cycle	21	164	0.58
61	Dijon	France	Vélodi	Clear Channel	40	401	0.56
62	Boulder	US	Boulder B-cycle	Boulder B-cycle	22	132	0.55
63	Avignon	France	VéloPop	TCRA	20	173	0.54
64	Fort Lauderdale	US	Broward B-cycle	B-cycle	25	154	0.54
65	Cergy-Pontoise	France	vélO2	JCDecaux	43	318	0.54
66	Chattanooga	US	Bike Chattanooga	ABS/Motivate	33	262	0.47
67	Santander	Spain	TusBic	JCDecaux	15	175	0.46
68	Valence	France	Libélo	Veolia Transdev	20	164	0.43
69	Clermont-Ferrand	France	C.vélo	Vélogik	10	104	0.42
70	San Antonio	US	San Antonio B-cycle	B-cycle	52	388	0.42
71	Brisbane	Australia	CityCycle	JCDecaux	151	1856	0.32
72	Bari	Italy	BariinBici	Comunicare	32	44	0.29
73	Fort Worth	US	Fort Worth B-cycle	FW B-cycle	34	267	0.28
74	Vannes	France	Vélocéa	Veolia Transdev	25	153	0.26
75	Perpignan	France	BIP!	Clear Channel	15	123	0.22

The first 4th generation bike-sharing system in the Netherlands was Flickbike. It was introduced in Amsterdam in the summer of 2017, it operated until October 2017 when all floating shared bikes were forbidden by the municipality. On the introduction of this concept and how it was used research was performed [59]. The research was based on a questionnaire conducted in December 2017, 7.5% of all registered users participated in the research. Main conclusions were that the service was mainly used by young, highly educated man, living in Amsterdam. The reasons people gave to use it was that public transport was too far away and the lack of availability of their own bicycle. It was mainly used as an alternative for transportation by public transport or foot. Weaknesses of the research were that only one company was investigated that operated during a relatively short period and that the research was only based on questionnaires.

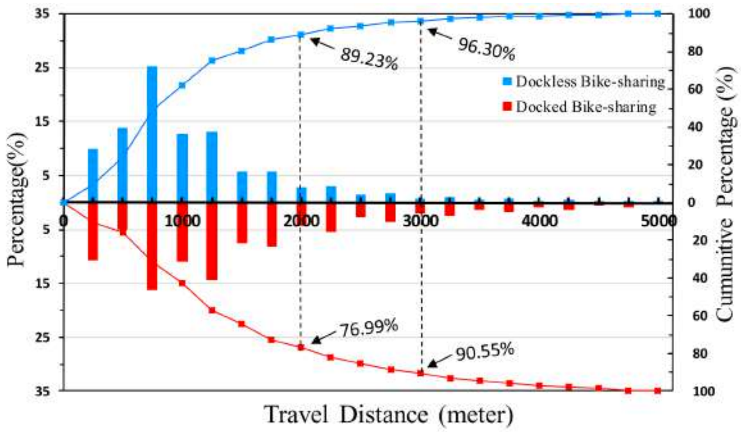

Figure 2.3: Share of trips with a distance shorter than x in city of Nanjing [33]

Research comparing dockless and docked bike-share systems in the city of Nanjing, China revealed that dockless bike-sharing systems are used for shorter distances then their docked equivalent (see figure 2.3) but have a higher usage frequency [33]. Another finding was that people with high-income and people that are familiar with internet technology and online payment are more likely to use dockless bike-sharing.

2.4. Conclusion

The history of the development of bike-sharing summarized is a long first experimentation phase that since the start of the 21th century resulted in exponential growth rates worldwide. This effect was strengthened since 2014 when Ofo started exploiting free-floating bikes in China, directly followed by a lot of other operators. That resulted in the deployment of millions of bikes worldwide. In 2018 this explosive growth seemed to become to an end. A consolidation and reorientation process is started [21, 55]. Ofo has stopped their operations in Europe and the United States. Mobike did the same in the United States and reduced their expansion efforts in other countries outside China.

Table 2.2: Overview of different generations of bikeshare [10], [32]

Generation	Technique	Addition to transport system	Governance
1st (1965) Witfiets	No locks	experimental	Bottom up
2nd (90's) Denmark	Coin based locks	experimental	Local government
3rd (1996 - now)	Dockingstations	supportive to transit	Local government / transit operators
4th (2014 - now)	Electronic locks	integration with transit	Market initiative <>local government

In this chapter, a short overview of the history of bike sharing during the past 50 years was presented. First, we discussed two generations that consist of mainly experimental systems in different parts of West-Europe. During the end of the previous century, with the help of technology a new generation of bike sharing was introduced. In the first ten years of the new century these systems became very successful on various locations worldwide, almost all the systems were somehow subsidized by governments and therefore based on hierarchical governance.

International comparisons show that the share of bicycle in the modal split in the Netherlands is relatively high. In other countries, docked bike-sharing systems were introduced to initiate the use of the bicycle. In the Netherlands there was already a positive attitude towards cycling. Therefore, with exception of the OV-fiets (public transport bicycle), which was introduced to improve the egress of public transport, no bike-sharing systems were introduced on a large scale until a few years ago.

The introduction of the fourth generation of bike-sharing enabled the possibility for market parties to introduce bike-sharing systems; docking stations were no longer needed. All over the world the implementation of dockless bike-sharing systems caused problems such as theft and vandalism, uncontrolled parking and cluttering of public space. These issues are increasingly considered as being impeding the future development of dockless bike-sharing systems. How to address these problems is critical to achieve dockless bike-sharing sustainability.

In the next chapter the goals and concerns of the stakeholders are investigated. An approach is proposed to gain insight into effectiveness and to get a grip on the problems. In chapter 4 the corresponding indicators are presented. In chapter 5 the results of de Delft pilot are presented on the basis of these indicators.

3
Governance

Realizing a dockless bike-sharing system contributing to convenient and sustainable transport, requires a good cooperation between governments and bike-share operators.

In the summer of 2017 the first free-floating bike systems were introduced by market parties in Amsterdam and Rotterdam. The free-floating systems were introduced without any special regulation. After the introduction the same type of problems appeared as in other cities around the world. In Amsterdam a lack of support and trust in market driven operators resulted in a ban.

The experience in Amsterdam made clear the implementing of a dockless bike-sharing system is complex. A variety of stakeholders are involved, a good cooperation between them is a necessary condition for a sustainable bike-sharing system. Chen [7] state that for a sustainable dockless bike-share system it is critical to get government cooperation.

In this chapter first, an analysis of the different stakeholders and their interests is performed. For this chapter information is used from 3 interviews with civil servants of local governments (municipality of Delft and Rotterdam) and national government (Ministry of I&W), also information from interviews with bike-sharing operators is used. Then control models are discussed that local governments can use to influence the way bike-sharing systems are operated.

3.1. Stakeholders

When a new transport service, such as a fourth generation bike-sharing system is deployed in the public space, this affects a lot of different stakeholders. First the involved stakeholders are identified.

The aforementioned study over the critical factors for a sustainable dockless bike-sharing system recognize users, governments, operators, manufacturers and members of the general public as critical stakeholders.

This thesis is about dockless bike-sharing in the Netherlands and focuses especially on the situation in Delft. Problems with the waste problem of amortized dockless bikes, as is common in several Chines cities, are not present here.

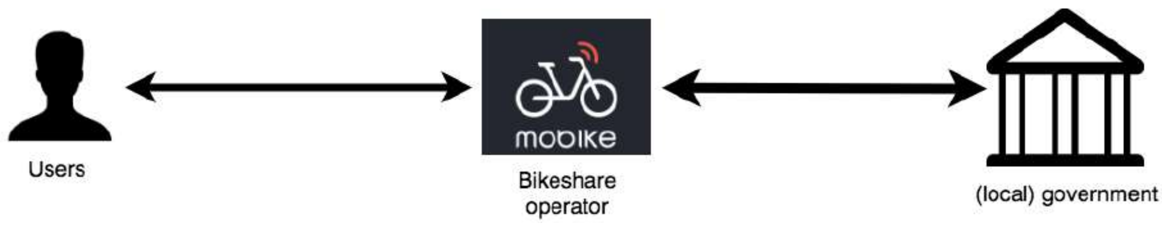

Figure 3.1: Overview most important stakeholders

Dockless bicycles are parked within the public space, a space that is accessible for everyone and which is scarce at many destination points in cities. This means that dockless bicycles compete with other users of the public space. Stakeholders directly affected by the introduction of a bike-share system are local residents and entrepreneurs using the same public space. If a resident can't park his bike in front of his house because there are one or more Mobike bikes, the competition appears immediately. An already existing lack of parking places for bicycles within a municipality, may be negative on a bike-share system. The residents and entrepreneurs may influence the local government directly by addressing or indirect via the city council. The government will also be influenced by the local press with their opinion about the new bike-share service, especially when the new service causes nuisance.

A new transport service as a bike-sharing system may also compete with existing modes of transport. In the situation of Delft, the most direct competitors are swapfiets (lease bikes), bike shops (that sell used bikes) and the local transport companies (Transdev/HTM). Because of its role as public transport concession provider, the Metropolitan Region Rotterdam The Hague is also an interested party. On a higher level the national government has interest in the bike-sharing initiative, successful bike-sharing systems may contribute to their policy goals.

Introduction of structural changes to the public transport network often take a long preparation time, e.g. when introducing a new concession. The local government will include the consequences of introducing shared bicycles on the use of public transport in its policy. The public transport companies, MRDH and other direct competitors in the bicycle industry may influence the policy regarding shared bikes indirectly via the government and aren't approached separately within the scope of this thesis.

The success of a bike-sharing system depends on the usage. Users have their personal reasons for using the bicycles. Users may be citizens of the city or they live in another town and come to Delft as a commuter, for study or as a visitor.

Summarized this thesis will limit itself to 3 important stakeholders: the users, the bike-share operators and the local governments. The general public and the media influence council members with their views and thus indirectly the government. From this perspective in this thesis the users, the government(s) and the operators are recognized as the critical stakeholders and the public transport operators and general public will not be considered separately. Figure 3.1 describes the relationship between the most important stakeholders.

3.1.1. Local government

For local governments shared bicycles offer opportunities for reaching policy goals but can also be a risk caused by negative side effects. To better understand the viewpoint of the local governments, interviews were conducted with the municipality of Delft and the municipality of Rotterdam. Also different policy documents where reviewed from the municipality of Rotterdam and Amsterdam, as input for this paragraph [2, 17].

The offer of Mobike to place bicycles in the municipality was the reason for the start of the project in Delft. Rotterdam offered Mobike the opportunity to place bicycles in the city at the end of 2017 as part of its bike-sharing policy.

The local governments mentioned the following contributions of bike-sharing:

- Bike-sharing as an opportunity to contribute to more sustainable mobility. This means on the one hand bike-sharing system in itself to be sustainable and on the other hand the usage of bicycles on short and medium distances as a replacement for the car.
- Bike-sharing as an extension to the public transport network. Bike-sharing has the opportunity to serve the first- and last mile from metro-, P+R- and railway-stations. Especially at the activity site of a trip, bicycle usage may result in a total shorter travel time to the destination. Depending on the quality of the public transport this may or may not translate in increased ridership. However, integration between public transit and bike-share would contribute to a better, more seamless transportation network, which may also result in a modal shift change to more sustainable transport. The introduction of Mobility as a Service (MaaS) applications may strengthen the public transport bike-share combination.

- Equity, bike-sharing has the opportunity to reduce transport poverty. When any user may pick up a bike in one place and return in it to another, bike-sharing may be an alternative for citizens who dont own or cant afford a personal bicycle. The usages of shared bicycles may give them a bigger chance on the labor market. Also, schools, hospitals and other services come within reach due to reduced travel time.
- Higher utilization of parking facilities at railway stations. At the new station of Delft, a lot of money is invested in two new underground parking facilities. However, during the weekends the capacity is already too low. At this moment a third underground parking facility is build, but due to the high costs it would be interesting to utilize the existing facilities better in the future. Bike sharing is seen as an interesting opportunity to reduce the parking demand significantly. If users both use a shared bicycle at the home side and on the activity side from and to the railway station, the average occupancy of the parking place may be lower, this may give more available places during the day. At the activity side users may use a shared bike instead of a second bicycle, these second bicycles often remain in the railway station parking place during the whole weekend. Replacing second bike use by shared bike trips will also result in a lower average parking place usage.
- More efficient usage of the public space. Shared bicycles may be an alternative for the ownership of 2nd and 3rd bicycles. For bicycles that are normally parked on the street no more public space is needed.
- Bike-share can also contribute to economic development goals, attracting both tourists and businesses, as well as offer an affordable, sustainable transportation mode for visitors to explore the city.

Local governments have the following concerns regarding dockless bike-sharing:

- An oversupply of shared bicycles.

  The oversupply is the reason why the municipality of Amsterdam is focused on preventing the nuisance caused by shared bicycles. The underlying reason is a failed introduction of shared bikes in Amsterdam in 2017. The uncontrolled introduction caused a strong negative public opinion of a small group of citizens about bike sharing. It was seen as another attempt to commercialize the public space, the same way AirBnB and Uber did earlier in their opinion.
- Vandalism and theft

  If insufficient added value is seen by the public for bike sharing and the acceptance is low, the chance for vandalism as throwing bikes away, for example into the canals, is higher. An oversupply of shared bikes reduces the support.
- Occupied public space

  At locations where public space is scarce, remarkably colored shared bikes stand out. The local government requires the bike-share operator to remove the bicycles as quickly as possible in places where they cause nuisance. If this does not happen, this contributes to a bad image for bike-sharing. As mentioned earlier a bad image for bike-sharing may also be caused by to an already existing problem of a lack of parking places for bicycles near home and at important destinations.

Summarized, local governments see the opportunities bike-sharing provides in increasing the modal split of sustainable modes of transport and a possibility of more efficient use of public space. They are worried about uncontrolled introduction of shared bicycles. An oversupply may result in several problems, such as vandalism, mess in the street, occupied public space. This results in a low acceptance by the public, so it is important to avoid the problems.

The challenge for the local governments is to maximize the benefits for the city while minimizing the negative side-effects by setting and maintaining the optimal preconditions

3.1.2. Commercial bike-share operators

For bike-sharing operators like Mobike in Delft, which implements a service for its own account and risk, it’s important to have a positive business case. On the operation side the profit is maximized by creating a service that is used as much as possible with as less bikes as possible. A commercial operator wants to determine its own tariffs without consultation or permission of the government. A commercial bike-share-operator wants no, or as little as possible, regulations and pre-conditions. If needed, they prefer standards, rules that can be applied in different cities, so they have to invest once to comply to the rules for all regions.

A positive attitude under users and citizens regarding the bike-share brand is important. Negative reactions in the press, will result in a negative opinion under the citizens. This may result in a critical city council, as a consequence additional regulation can be entered.

3.1.3. Users

The users of the bike-share system are, for Mobike, the most important stakeholders. Without users the system will not exist. Users want to have a bicycle as close as possible to their origin. This conflicts with the interests of the bike-share operator and government, because to ahave bikes really close available to all users, a lot of bicycles are needed. This may result in a oversupply and the associated problems. The challenge is to find a balance between service level and number of bicycles. A shared bicycle system has a positive impact on the city when the bicycles are in motion, when a bicycle is parked all the positive effects disappear. For the bike-share operators it is also important that the users want to take care of the system, by parking the bicycle correctly and reporting defects and vandalism in the app. The users can be seen as the eyes on the street of the bike-sharing operator, it's important to maintain a good relationship with them.

3.1.4. National government

In addition to the most important stakeholders the policy of the national government is explored. The national government has no direct influence on bike-sharing policies in the different cities, but the national government is following the developments because it fits in their policy goals. To get a better understanding about the role of the national government a representative of the ministry of Infrastructure and Waterstaat (I&W) responsible for chain mobility was interviewed.

The main focus and interest of the national government is to stimulate the usage of the bicycles as a mode of transport and the reduction of CO_2 emission by stimulating sustainable transport. Bicycle sharing supports this ambition, specifically as part of a chain in combination with rapid transit. Other interesting opportunities of bike-sharing are Park + Bike, transfer from car at the edges of the cities, and reducing the needed parking spaces of second bikes at the railway stations.

They encourage market parties to share their data as open data and stimulate interoperability between the different operators. This may reduce barriers to start new bike sharing systems. It is desirable to have bike-sharing options as part of travel advices in journey planners like 9292 and the Dutch Railways app. Interoperability reduces the need of installing a new application in every city a traveler wants to rent a bike. The interoperability is also welcomed from the part of the ministry that's working on the introduction of MaaS.

3.2. Control model

A sustainable bike-sharing system requires a balanced representation of the interests of the various stakeholders. To understand the relations between the stakeholders better, these are projected on the four layer model of economics of institutions [62]. Institutions are systems of established and embedded social rules, that structure social interactions [24]. A bike-sharing system may be seen as such an institution. In figure 3.2 the four layers are presented and examples from the view of a bike-share system are added.

The bottom layer is the transactional layer, this is where the bike-sharing service is provided to the users. Transactions as the reservation and hiring of bicycles and the settlements are part of this level. Relations on this level change continuously. Good experiences resulting in mouth-to-mouth advertising can yield new customers. A bad experience may result in refrain from further use or choosing a competitive service.

The top level is the embeddedness or cultural layer. Institutional settings and cultural roots vary significantly across countries. These aspects determine the context for a bike-sharing system, the positive position of and attitude against the bicycle in the Netherlands [30] is a good departure point for bike-sharing systems. Changes on the cultural level happen slowly, this takes multiple decades.

The relation between the local government and the bike-sharing operator mainly focuses on level 2 and 3. The second layer contains the institutional and legal rules. Legal frameworks apply to all citizens and companies in the Netherlands, including bike-share operators. Relevant for bike-share operators are laws and regulations concerning safety and use of space.

Most of the governance between the local government and the bike-share operator is situated in level 3. This includes contracts and more informal agreements.

A level 2 measure for prohibiting bike-sharing in the Netherlands on the local level is the A.P.V. (general local regulation). In Amsterdam bike-sharing systems were banned based on an article in the A.P.V. that disallows offering commercial services in public space without a permit.

The cooperation between the municipality of Delft and Mobike takes place on level 3. Although the municipality does not formally have a direct contract relationship with Mobike, the municipality does have measures at level 3 as a big stick to Mobike if it does not keep to the agreements.

All the layers of the model do influence each other, for example when a local government decides to prohibit something according to the APV, this limits the municipality in its flexibility to introduce a comparable service.

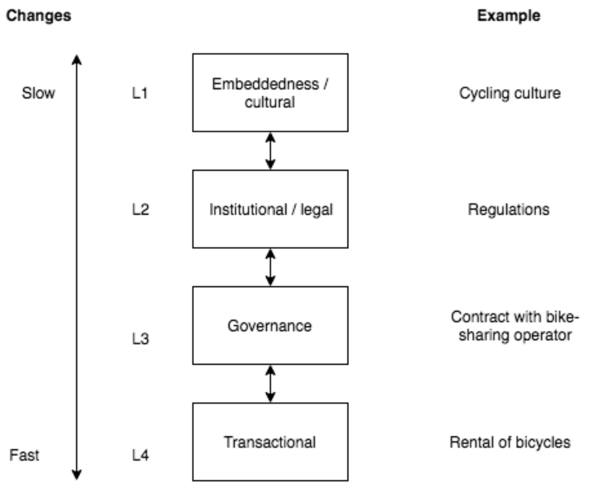

Figure 3.2: Economics of institution shared-bicycles [61]

Powell & Di Maggio provide a different way of how governance can occur; market, hierarchy and network [12]. In figure 3.3 a comparison between the different models is presented. The market model is the most flexible, the user has freedom of choice between different service providers. A good relationship results in a long-term use of the service. If a customer is dissatisfied about the service, another supplier can be chosen. In the Delft situation a customer may change from Mobike to OV-Fiets. A good relationship results in a long-term use of the service. In a market model the government has little influence on the policy of the bike-share operator.

In the hierarchy model the relation is based on rules. In a pure hierarchy model the local government directly controls the bike-share operator or performs the operation itself.

The third mechanism for coordination is known as the network model. In this model there is a mutual dependency between the partners. There is exchange of knowledge and ideas, an open attitude to learn together.

The relation between the municipality of Delft and Mobike can be characterized as network governance. If necessary, in the event that Mobike does not behave according to the informal rules of the local government, the municipality may threaten with more hierarchy.

Table 1. Stylized Comparison of Forms of Economic Organization.

Key Features	Forms: Market	Hierarchy	Network
Normative Basis	Contract—Property Rights	Employment Relationship	Complementary Strengths
Means of Communication	Prices	Routines	Relational
Methods of Conflict Resolution	Haggling—resort to courts for enforcement	Administrative fiat—Supervision	Norm of reciprocity—Reputational concerns
Degree of Flexibility	High	Low	Medium
Amount of Commitment Among the Parties	Low	Medium to High	Medium to High
Tone or Climate	Precision and/or Suspicion	Formal, bureaucratic	Open-ended, mutual benefits
Actor Preferences or Choices	Independent	Dependent	Interdependent
Mixing of Forms	Repeat transactions (Geertz, 1978)	Informal organization (Dalton, 1957)	Status Hierarchies
	Contracts as hierarchical documents (Stinchcombe, 1985)	Market-like features: profit centers, transfer pricing (Eccles, 1985)	Multiple Partners Formal rules

Figure 3.3: Comparison between different models [12]

The governance in the Delft bike-sharing ecosystem, based on the cooperation between the municipality and Mobike, is informal.

3.3. Network governance model in Dutch practice

From the perspective of governance, it is interesting to understand how different local governments react on the introduction of dockless bikes. At the time of the first implementation in the Netherlands, there were no specific regulations anywhere; a shared bicycle was treated in the same way as a normal bicycle. When shared bicycles were becoming a problem for local governments due to deterioration, mainly caused by one of the operators (Obike) that deployed thousands of bad bikes, the government had to intervene to reduce the negative side effects.

Figure 3.4 describes the choices different government bodies made. Amsterdam decided to completely ban shared bicycles. Also, a policy to allow shared bikes under certain conditions was formulated by the local government. At this moment (February 2019, more than a year since the ban) there are no dockless shared bikes on the street. Rotterdam, followed by Delft, decided to start a dialogue with the different market parties, with the goal to collaborate on the implementation and the improvement of dockless bike-sharing. Those governments also saw the opportunities shared bikes can provide. The municipality of Rotterdam and Delft are continuing their experiments, within the network governance they have the possibility to impose rules if necessary.

A good example of collaboration is between RET and Mobike during big maintenance work on the metro network in the city of Rotterdam. During two weeks in the summer holiday, there was maintenance on one of the busiest parts in Rotterdam between Wilhelminaplein and Maashaven [45]. Normally buses are operated to transport between the two metro stations to transfer passengers. Due to the collaboration between Mobike and RET travelers got the possibility to use a shared bike. This gave them the choice to travel by bus, to use a bike to cycle to the other station or to cycle directly to their destination. RET payed a small amount of money to Mobike to hire extra personnel to make sure that at all time enough bicycles were available.

3.4. Conclusion

In this chapter the different aspects of governance are investigated. First the most important stakeholders are identified; the user, municipality and the bike-share operator. For those stakeholders their

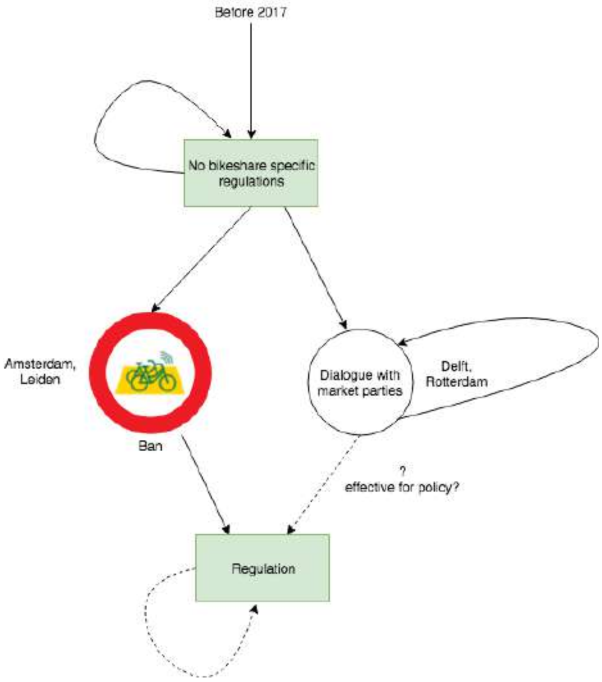

Figure 3.4: To regulate or not to regulate

interests are analyzed. The challenge for the local governments is to maximize the benefits for the city, such as more sustainable transport and efficient use of public space, while minimizing the negative side-effects by setting and maintaining the optimal preconditions.

A sustainable bike-sharing system requires a balanced representation of the interests of the various stakeholders. To understand the relations between the stakeholders better these are investigated in more detail. The network governance is applied in the relation between municipality of Delft and Mobike. This relationship is characterized as informal. If necessary more formal rules can be applied.

For the pilot implementation in Delft this informal network governance is appropriate. In order to achieve policy goals on sustainable mobility on a larger scale, it is necessary to quantify these goals. Even though a municipality does not provide funds to directly support dockless bikeshare, its operation depends on the use of municipality-owned streets, sidewalks, and other public infrastructure. By establishing a permit system, a government is well positioned to commit a bike-share operator and to supply information in order to evaluate the contribution to the policy goals. The plan-do-check-act cycle presented in the next chapter provides a framework for regulating dockless bike-sharing on a level which is appropriate for the local situation.

The margins in bike-share operation are small. Setting up a profitable service requires sufficient scale. It is important that municipalities jointly formulate preconditions / requirements for a bike-sharing system. An example of such a requirement are data standards for integrating in multi-modal journey planning and MaaS.

In the next chapter quality performance indicators are defined using the usage data of the bicycles. These quality performance indicators should give the local government the trust, that they can influence the bike-sharing operating process. In chapter 5 these indicators are applied on the data set of Delft. An analysis is performed to understand what bike-sharing implies for Delft.

4

Quality performance indicators

In this chapter the PDCA cycle is presented as a methodology for measuring and improving bike-sharing systems to meet the goals. An important part of the method is the collection of data.

4.1. Plan Do Check Act Cycle

A way to describe the bike-sharing ecosystem is the use of the Deming cycle [25]. The plan-do-check-act (PDCA-)cycle is a well-known model for continual process improvement. It teaches organizations to plan an action, do it, check to see how it conforms to the plan and act on what has been learned. The PDCA cycle is made up of four steps for improvement or change, see figure 4.1.

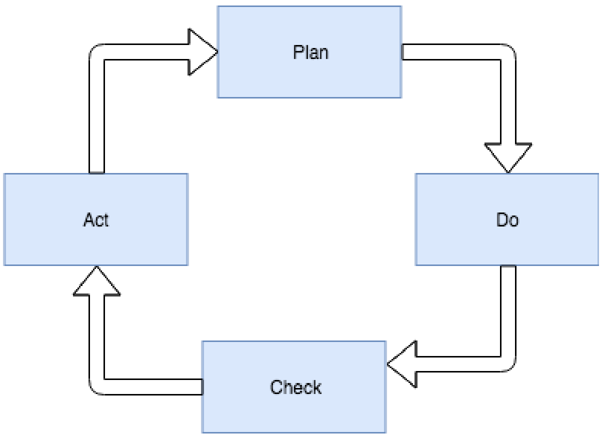

Figure 4.1: PDCA cycle

1. In the Plan-phase opportunities are recognized and the change is planned.
2. In the Do phase the change is tested, the plan from the previous step is carried out. During the do phase data is gathered to see how effective the change is.
3. During the check phase, the data and results gathered from the do phase are evaluated. Data is compared to the expected outcomes to see any similarities and differences. The results are analyzed and learnings are identified. By conducting the PDCA cycle multiple times, trends can be found. This helps to see what changes work and what changes not work.
4. Act: Take action based on what was learned in het check step. If the change was successful, incorporate the learnings from the test into wider changes and standards. If not, go through the cycle again with a different plan.

In the Bike-sharing eco system 2 PDCA circles can be distinguished, see figure 4.2. The upper-level consists of the policy management cycle. Scope of this cycle is establishing objectives using bike-sharing as an instrument for increasing modal split of sustainable modes of transport and as a possibility of more efficient use of public space. The policy cycle is in the domain of the government, however for the do phase cooperation with bike-share operators is necessary. The second level is the operational control cycle. In Delft this cycle is in the domain of Mobike. The interaction between the domains consists of a framework for operation, reports indicating the extent to which the framework is met and proposals for extension or adaption of the framework.

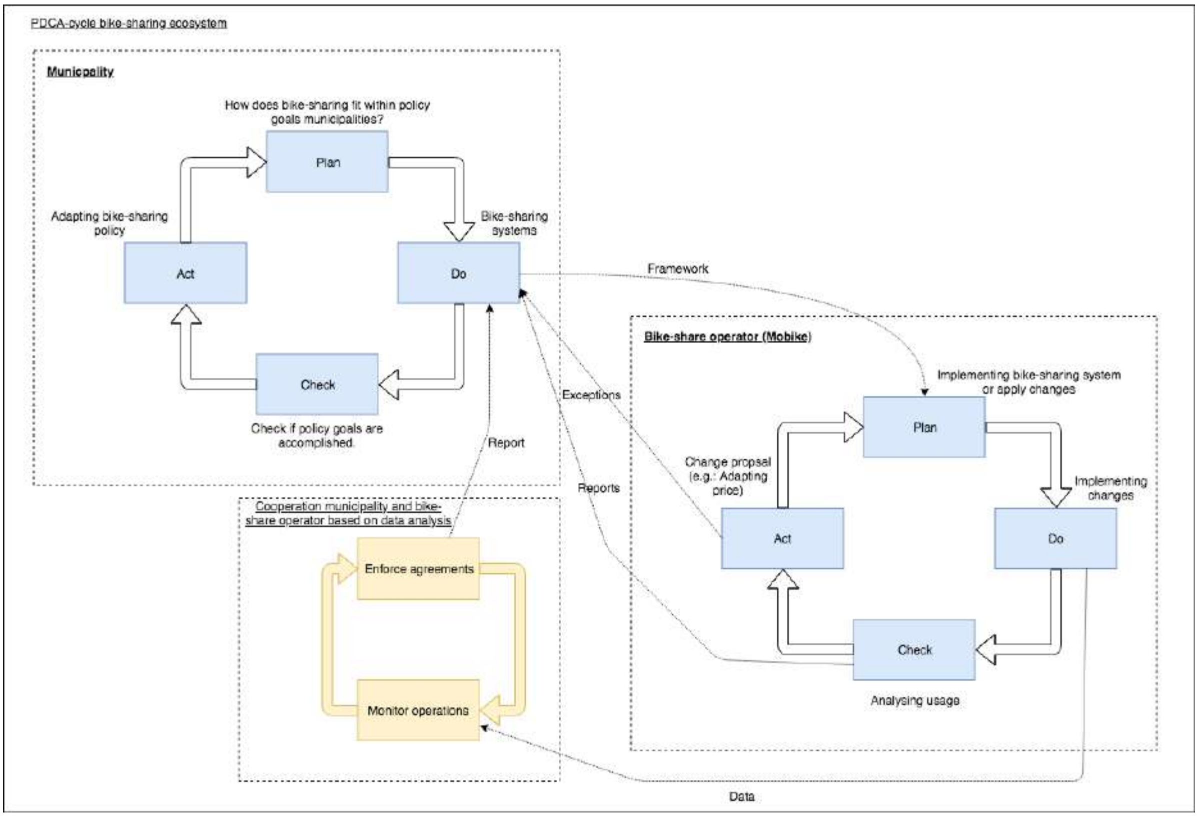

Figure 4.2: Improved PDCA control model, add the usage of data

4.2. Data

Data play a key role in the PDCA cycle. During the do phase data is gathered to see how effective changes in the system are related to the objectives. Before implementing the PDCA-cycle it is important to determine whether the data gathering systems can adequately collect and evaluate data and turn them into useful information.

Dockless bikes with onboard GPS provide trip data. In the PDCA cycle different types of bike-share related data may be distinguished:

4.2.1. Real time usage data

Real time data is used for monitoring the system. During the operation usage data are gathered. Usage data is defined as all data about the use of the bicycle not related to the person driving the bicycle. Based on the usage data questions may be answered as: When and where is the demand for shared bicycles the highest? How often is a bicycle used on average per day? Which routes are travelled most often?

4.2.2. User data

Dockless bikeshare operators collect data about their users at the first registration. For Mobike the minimal registration regards a phone number and bank account or credit card number. Due to privacy protection user data may not be used without the prior consent of the user. However, anonymized user data added to the trip data may give meaningful information, such the number of frequent users in comparison with occasional users.

4.2.3. Additional user surveys

For analyzing the progress of bike-sharing towards achieving government goals, such as change in modal shift to more sustainable transport, the opportunity to reduce transport poverty, reduce use of parking place at railway stations, additional user surveys are needed. In the surveys data should be collected on the demographics of dockless bikeshare users and how and why they use the dockless bikes.

4.2.4. Delft pilot & Data

The process of data collection started by writing an official request for data to the head quarter of Mobike in China. In this proposal we requested for an extensive set of data about the usage of Mobike in Delft, the request can be found in Appendix A. The expectation was that data should be made available, based on the existing collaboration between Mobike in the Netherlands and the TU Delft. That turned out differently, the worldwide policy of Mobike is to provide as less as possible usage data. Worldwide there is almost nowhere data available about the usage of dockless bike-sharing systems.

In cities were the delivery of data is enforced, either the commercial operator is willing to comply or its a reason to abandon implementation.

In Delft there are no agreements about the use and sharing of data. The operational data Mobike has in the IT-system for the management and improving of the operations are not available outside Mobike. On the data request, never an official reply from Mobike was received. Worldwide, commercial dockless bike-share operators do not want to share data anywhere.

As part of this thesis an alternative approach has been chosen, by which data can be collected without the permission of Mobike. Starting point for the data collection are the bike position data showed on a map in the Mobike app. To get these data the same HTTP-call performed by the app, should be performed by the software that collects the data and write these in a database. To derive how the HTTP-call worked the Mobike app was reverse engineered. By trying out it has been determined that the app shows up to 50 free bikes simultaneously around the GPS position. Only bicycles within a radius of up to 500 meters are shown on the map. Based on these preconditions, the grid around Delft for the sample locations (GPS positions in HTTP-call) of the collection software is determined, see figure 4.3. Every 5 minutes a complete sample of the city was made, on average a complete sample took 2 minutes and 37 seconds. The data are collected and stored in a database between 28th of May 2018 and 10th October 2018.

A trip is derived out of the sample data if a bike made a position change of at least 200m in consecutive samples. During the research period 149193 trips are collected in the data set. The quality of the dataset was validated with various sampling methods, comparing the bike-ids on the street with the bike-ids in the database. Each of the samples resulted in a 100% coverage of bikes within the operation area.

Officially all bikes should be returned within the operation area, but there are always users that dont comply with those rules and park their bikes outside this area. For bicycles standing outside the area no data are gathered. This explains why not 100% of all the trips are covered with this approach. Another shortcoming with the sampling approach is bikes moved by street operations. Street operations may move bicycles from places where they stand still for a long time to places with high demand, they also pick up bicycles for maintenance. These replacements are registered as trips, because a trip is detected solely on displacement for a distance for more then 200m. This numbers of moved bicycles is relatively small (maximally 20-30 per day is only 1 - 5% of the total trips during a day). Therefore, these movements only have a small impact on the dataset. A more detailed technical description of

Figure 4.3: Example of all sampled locations during one round of sampling.

the data collection and validation can be found in appendix C, including references to the developed open-source software.

4.3. Data Standards

An important part in the act step is the standardization of satisfactory results [40]. It is recommended to implement data-standards already in use for bike-sharing in the US.

The North American Bike Share Association, a consortium of suppliers and operators of bikeshare systems in the US and Canada, has developed and published GBFS (General Bikeshare Feed Specification), which aims to show bike and empty docking space information on a standardized and real-time basis. Publishing data in the GBFS format makes it easy to integrate bike-share multi-modal journey planners and MaaS applications. GBFS is a standard for bikeshare providers to describe the status of their systems to customers. It is relevant for anyone (e.g. a customer or regulator) who want to know real-time shared bicycle availability.

The Mobility Data Specification (MDS)is a data standard for any mobility provider, such as dockless bikeshare, e-scooters, and shared ride providers. It describes:

1. Mobility vehicle trips and their routes.
2. Location and status (e.g. “available,” “in use,” or “out of service”) of each vehicle, at any point in time and historically.
3. Provider service areas.

MDS delivers both real-time and historical data for enforcement and planning purposes.

During the thesis the development of Dutch standards for an interoperable bike-share platform started.

The progress was lagging behind the planning, one of the causes was that the process was not managed from the general interest. One of the results is the acceptance of the General Bike-sharing Feed Specification in the Netherlands.

4.4. Quality Performance indicators for bike-sharing

The PDCA cycle is supported by quality performance indicators. Quality performance indicators define a set of values against which to measure. In this section general performance indicators regarding bike-share systems are introduced. In the next sections performance indicators related to the three important policy goals of the local government are considered: stimulating sustainable mobility 4.5, efficient usage of public space 4.6 and prevention of deterioration 4.7.

In scientific literature is searched for critical success factors of bike-sharing. A lot of research is about the preconditions for successful introduction of bike-sharing. Curran [9] mentions cycling infrastructure, weather and topography, public attitudes of cycling, safety and security as important preconditions.

One of the few studies that have been found concerning the sustainability of dockless bike-share system itself (profitability, contribution to sustainable transport) [53], describes external factors such as cycling facilities, as well as internal factors within the domain of the bike-share operator.

The most important internal KPIs are [53, 66]:

1. The average daily number of trips per bicycle. Target: 4 - 8 daily uses per bike. This metric indicates how efficiently the bikes are being used. Fewer than four daily uses can result in financial unsustainability for the operator, while more than 8 daily uses can indicate limited bike availability, especially during peak hours. If bikes are not readily available to as many potential users as possible, the system will not be viewed as a reliable mode that may compete with other options, such as private cars. A high number of average daily trips per bike may indicate there are too few bicycles in operation. The operator may consider an expansion of the fleet. If a system has relatively few uses per bike, this might indicate inefficient usage, probably because of a surplus of bikes. A system with many bikes being ridden by a small group of users could result in the perception that bikeshare is not being used enough to justify its use of public space. In this case, the establishment of a cap on the number of bikes may be considered. Alternatively, if there are enough potential users, increasing awareness of the system and marketing, may result in a higher usage.
2. Average daily trips per 1000 residents (in service area). This is a metric of market penetration, that is, how many people in the service area are using the system. A high number of trips spread across residents in het service area is key to increasing more sustainable transport. The market penetration will also have influence on the acceptance of small deterioration a dockless bike-share system always brings with it.

4.5. Stimulating sustainable mobility

From the perspective of local and national government an important policy goal is stimulating sustainable modes of mobility, cycling is one of those modes. The goal is to have more movements by cycling and less by cars. Bike-sharing gives the opportunity to play a bigger role in the first- and last mile of public transport trips (improving chain mobility), and therefore can help increase the share of sustainable modes of transport in the mobility mix. To get a better understanding if this is really happening, the collected data are analyzed and visualized. Visualizations of the trips give an overview of the places that are of high interest for cyclists and may be helpful for policymakers.

In table 4.1 an overview is given of the indicators, these indicators are broken down by time and place from the general number of trips indicator. The indicators make clear when trips are made, what the distance of the trips is, what is the origin and destination and what is the share of trips related to railway stations.

Table 4.1: Overview indicators showing how bike-sharing is used

Indicator	**Definition**
Number of trips per day	The total number of trips that starts on a specific day
Average length of trip	The average length of a trip calculated by summing all as the crow flies distances of trips divided by the total number of trips
Distribution distance of trips	Distribution of the length of trips, a histogram with on the x-axis the length of the trips in bins of 500m and on the y-axis the frequency a trip within that bucket was made.
Relative usage per day of week	Distribution of trips over a week. Calculated by counting all trips that are made on every day of the week and then dividing by the total number of trips made.
Relative usage per hour on working day	Distribution of trips over the day. Calculated by filtering all trips on working days and then grouping the start_trip_time on the hour of the day then dividing it with the total number of trips made during working days.
Relative usage per hour on weekend day	Distribution of trips over the day during weekend days. Calculated by filtering all trips on working days and then grouping the start_trip_time on the hour of the day then dividing it with the total number of trips made during working days.
OD-Matrix	The absolute and relative number of trips between two different zones (with origin and destination).
Share of trips related to train stations	The share of trips that has an origin or destination at one of the train stations.
Average daily trips per 1000 residents	The average number of daily trips divided by the number of residents divided by 1000

Zones OD-Matrix For analysis zones are defined of areas that are specifically interesting in Delft, the zones are indicated in figure 4.4. The city center, TU Campus and Voorhof were selected because of the high numbers of trips between those zones that appeared during the first explorative analysis. After a second round of analysis Buitenhof and Hof van Delft were added as well. The railway stations of Delft and Delft-Zuid were selected in order to explore the role of bike-sharing in the first- and last mile. Science Park Zuid was selected because it was one of the areas the municipality of Delft has a special interest in. One of the goals of the pilot is to investigate if the introducing bike-sharing in this area makes the area more accessible by sustainable modes of transport and may contribute solving congestion problems in that area.

Based on the available trip data it is not possible to detect changes in modal shift. Additional sources are needed for this purpose, such as additional user surveys or monitoring of the total number of movements in a certain area or relation.

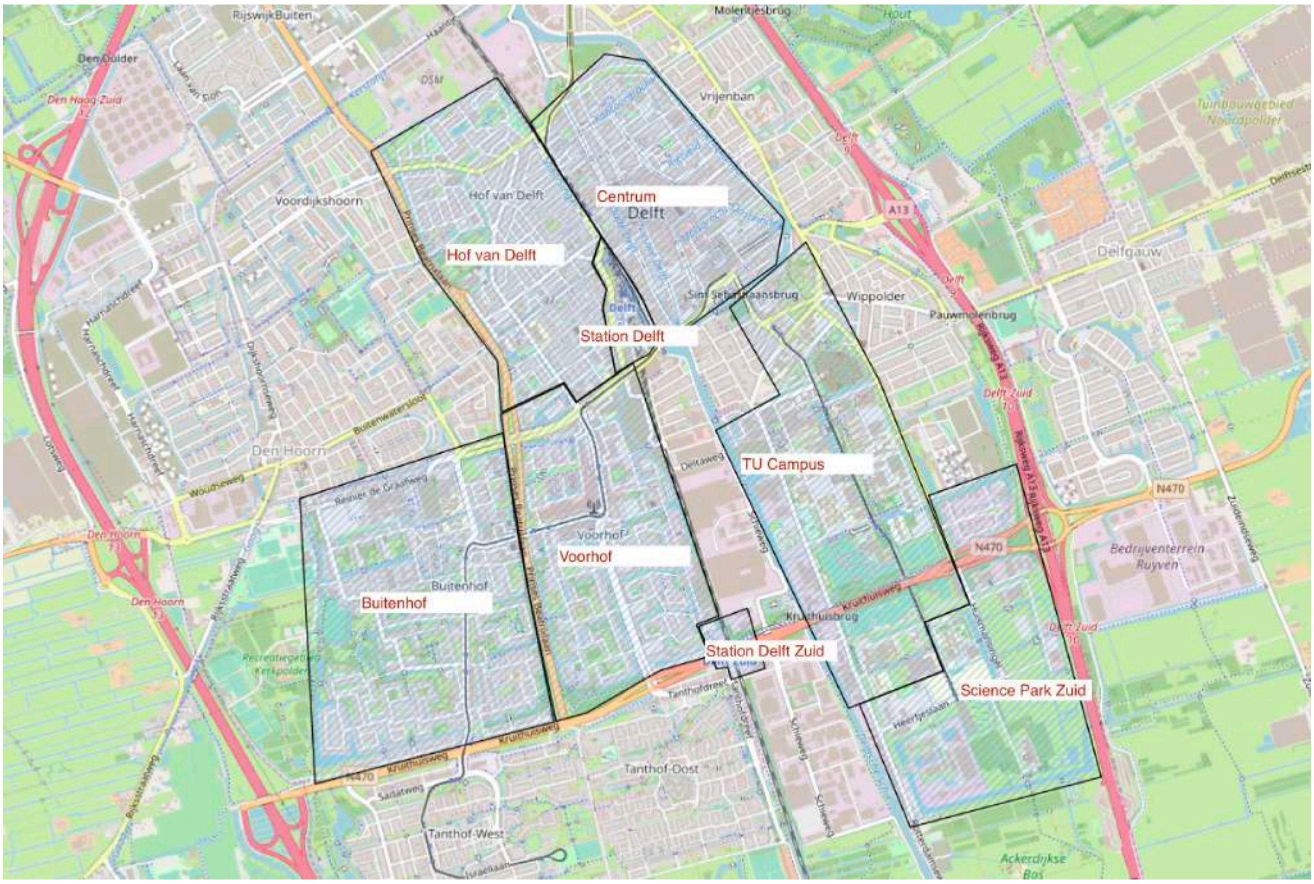

Figure 4.4: The 8 zones.

4.6. Efficient use of public space

Bike-sharing can in theory help to decrease the amount of space needed to park bicycles at train stations and city centers. At the same time, the room shared bikes occupy in public space is a concern. If a bike-sharing system has very low usage numbers when having at the same time many bikes on the street, they occupy space that also could be used by traditional bikes, and that can result in lower acceptance by the public. Shared bikes that are used frequently reduce the need of parking spaces, bikes that are parked for a long time increase the pressure on existing parking facilities. The municipality of Delft sees bike-sharing specifically as one of the solutions for the shortage of bicycle parking spots at the two railway stations and in the city center. Therefore also indicators that focus on specific areas are developed.

The most important indicator regarding the use of public space is the aforementioned average daily trips per bicycle. When the number of trips made per day with a shared bike is higher than with a normal bike it's likely that this results in more efficiently usage of space. The number of trips per active bike per day is added as an extra indicator. In the first exploration of the data it appeared that approximately 30% of the bicycles is not used per day. The bicycles not used have a very negative impact on the average daily trips per bicycle, to explore the potential to increase the average daily trips the second indicator is added. Related to that also a distribution can be made about the number of trips per bike made in the analyzed period.

The average time a bike is parked within specified areas gives an indicator for the efficient use of scarce public space. If this is significantly shorter it's likely that the space occupied by shared bikes is less in comparison to normal bikes. To explore the potential of shared bicycles an indicator for the number of arriving/departing bikes per hour of day on specific locations is added. When the number of arriving and departing bikes is in balance on every hour of the day the potential of the reduction of parking spaces needed is great, because then the bicycles that arrive at the station are immediately rented out to people that depart at the station. If there is an imbalance in the number of people that use the Mobike at their home side and at the activity side, more parking space is needed to accommodate a bike sharing system to store the bikes during the night or day. When the average time between trips is lower than with normal bikes it's definitely more efficient.

Table 4.2: Overview indicators efficient use of public space

Indicator	**Definition**
Average daily trips per bicycle	All trips divided by the number of bikes available
Average daily trips per active bicycle	All trips divided by the number of bikes that made at least one trip
Distribution of trips per day per bike	Distribution of number of trips per bike divided by number of days
Average time between two trips	Sum of all the times between trips divided by the number of gaps between trips
Number of arriving/departing bikes per hour of day on specific locations	Count of the number of arriving and departure bikes grouped by hour of day
Total number of bicycles (Supply Quantitiy)	The number of bicycles on the street.

4.7. Preventing deterioration of public space

The introduction of dockless bike-sharing poses a risk of deterioration of the streets for the local governments. This can happen due to vandalism, lousy maintenance, or bikes that are not used for a long time. Important to notice is that deterioration is very subjective and therefore difficult to measure. The attitude towards shared bicycles could also be different if you compare it with normal bicycles due to the recognizability of the bicycles. When Mobike does receive complaints it's almost always because of bicycles parked for a long time. Another problem is caused by bicycles parked in places where this is forbidden such as the square in front for the station and the market square.

For deterioration some direct and indirect indicators can be defined. Examples of direct indicators are the number of bicycles in canals, number of damages, number of bicycles stolen and the number of complaints. The indirect indicators are defined based on events that are causing annoyance with the public, bicycles that are parked for a longer amount of time or on locations where it's not allowed to park.

The time between trips indicates how long a bicycle is parked. An average of those times is not really interesting, because there is only nuisance due to long parked bicycles. Therefore, it's interesting to look at the number of events a bicycle is parked for a longer amount of time (starting with longer then 24 hours). In the exploration of this indicator multiple thresholds can be chosen, for example 24, 48 or 72 hours, 5 days, 1 or 2 weeks. During weekends the demand for bike-sharing is lower, many bikes are not used more than 48 hours around the weekend..

Another indicator for an event that bothers indirectly is the number of parking violations. That's the number of times a bicycle is detected in an area where a parking ban is in force. This is a good indicator for how good users are following up those bans and may give an indication for how effective those bans are.

Table 4.3: Overview indicators prevention of deterioration public space

Indicator	**Definition**
Number of bicycles in canal	The number of bicycles Mobike restored from the bottom of the canals in Delft
Number of damages	Number of damages Mobike repairs/gets reported in app
Theft	Number of bicycles that Mobike has lost
Number of complaints	The number of complaints the municipality of Delft and Mobike receives
Number of bikes is parked longer then x time events	This indicator is a count of the number of times bikes are parked longer then x hours (i.e. more than x hours between two trips)
Location of bikes that are parked longer then x hours/days	This indicator shows the locations on a map where bikes are parked for longer then x amount of time.
Number of parking violations	The amount of times a bike is parked in an area where a parking ban is in force

4.8. Conclusion

In this chapter several quality performance indicators are presented. The most important indicators found in literature are the average daily trips per bicycle and the average daily trips per 1000 residents. These indicators are relevant for all the different points of view: the profitability of the bike-share operator, the contribution to sustainable transport, the efficient use of public space and limiting the deterioration. The number of trips performance indicator is considered in more detail and further broken down by time and place. In the table below (table 4.4) the indicators and the relevance for the different points of view is summarized.

Table 4.4: Overview quality indicators

Quality indicator	Profitability	Deterioriation	Sustainable transport	Efficient use public space
Average daily trips per bicycle	x	x	x	x
Average daily trips per active bicycle	x		x	x
Total Number of trips per day	x		x	
Total number of bicycles (Supply Quantitiy)	x	x		x
Number of arriving/departing bikes per hour of day on specific locations		x		x
Average length of trips			x	
Average time between two trips	x	x		x
Number of bikes that is parked for longer then x time events	x	x		
Average daily trips per 1000 residents	x	x	x	x

5 Results and Analysis

In this chapter the performance indicators for the Delft pilot are presented and analyzed. The dataset for Delft is collected by reverse engineering the actual bike positions presented in the app for consumers. In chapter 4 the collection method and the validation of the data is described. The data are collected between 28th of May 2018 and 10th October 2018. The main characteristics of the dataset are presented in table 5.1. Most tables and graphs in this chapter concern the period between 27th of August and 16th September. A complete overview, including the period between 11th June and 1th July is presented in Appendix D.

Table 5.1: Overview dataset

Overview dataset (until 10 October 2018)	
Number of samples, the number of times the complete city of Delft was sampled to collect data (every 5 minutes)	46050
Number of datapoints, how many locations of bikes are stored (every 5 minutes the position of all the bikes that appear in the dataset are stored)	21152525
Total number of trips (a trip is detected solely on displacement for a distance for more then 200m between two or more samples (5 minutes)*)	149193
** Not all trips are used in the analysis in this chapter but this data could be used for other research as well.*	

Figure 5.1 contains a screenshot of the dynamic visualization of how Mobike was used on the 17th of September 2018, this gives a good view about the usages of Mobike in general within the city. In the next sections this will be analyzed in more detail.

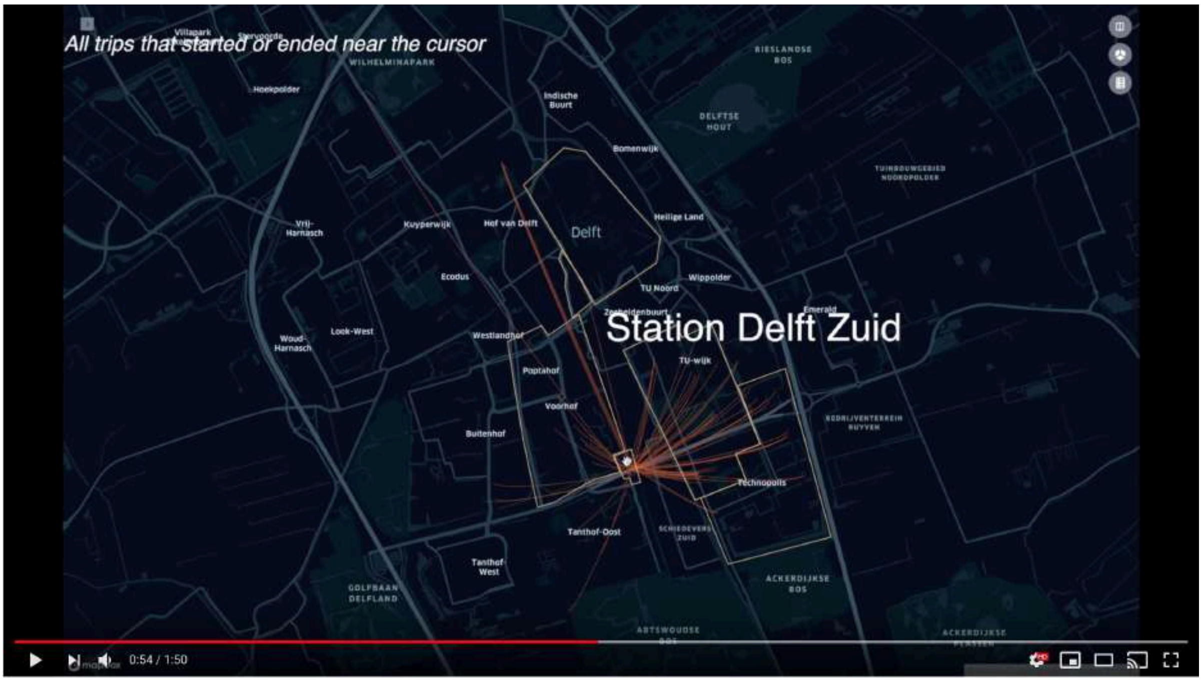

Figure 5.1: Visualisation of how Mobike was used on 17 September 2018 https://www.youtube.com/watch?v=MVqJtJA6_wg

5.1. General performance

The most important overall quality performance indicator is the average daily trips per bicycle. In Delft the value for this indicator is 1.6. The value can be increased by controlling the quantity of shared bikes in the service area; the average number of trips per active bicycle in circulation day by day in Delft is between 2.5 and 3.8. This indicates the average daily trips per bicycle may be increased by controlling the quantity of shared bikes in the service area and by reducing the size of the service areas. The average daily trips per bike worldwide in cities with a docked system are higher than the 1.6 daily trips per bike in Delft. A comparison with dockless systems is not possible, since there are hardly data available. The target value for a sustainable bike-share system according to the 2018 edition of the ITDP Bikeshare Planning Guide [66] is between 4 and 8 daily uses per bike. For a dockless bike-sharing system in the Netherlands contributing to sustainable mobility a target value between 3 and 4 daily uses per bike should be feasible. If the same shared bike is used for home side and activity side trips of a train journey, the daily number of trips is at least 4 during the working days. If the shared bike is not used during the weekends, the average will be around 3 daily trips.

Table 5.2: Comparison of quality performance indicators of Delft with other cities [66]

City	Region	System Type	Operator(s)	Bikem Type	Service Area (km²)	Service Area Population	City Area (km²)	Population Density (persons/km)	Total Bikes	Bike Density (bikes per km2)	Bikes per 1000 Residents	Average Daily Trips (peak month)	Daily Trips per Bike	Trips per 1000 Residents
Tianjin	AS	Dockless	Mobike, ofo	Smart Bike	2771	13245000	2771	4780	300000	108	23	N/A	N/A	N/A
Singapore	AS	Dockless	Mobike, oBike, ofo	Smart Bike	720	5612300	720	7796	30000	42	5	N/A	N/A	N/A
Manchester	EU	Dockless	Mobike	Smart Bike	116	541300	116	4678	2500	22	5	N/A	N/A	N/A
Dallas	NA	Dockless	LimeBike, ofo, Spin, VBikes	Smart Bike	999	1317929	999	1319	20000	20	15	N/A	N/A	N/A
Boston	NA	Docked	Motivate	Traditional	77	535586	125	7300	1600	21	3	6150	11	3.8
New York Cit	NA	Docked	Motivate	Traditional	129	1771173	1.213	7036	9789	76	6	62516	6.4	35
Barcelona	EU	Docked	Clear Channel	Traditional & E-bike	53	1421573	101	15824	6000	113	4	38230	6.4	27
Dublin	EU	Docked	JC Decaux	Traditional	15	120598	115	4811	1600	109	13	9000	5.6	75
Guangzhou	AS	Dockless	Mobike,ofo,Unibicycle	Smart Bike	3843	14043500	3843	3654	800000	208	57	4000000	5	285
Mexico City	NA	Docked	Clear Channel	Traditional & E-bike	54	334806	1.485	6006	6500	120	19	35000	4.6	105
Paris*	EU	Docked	Smoovengo	Traditional	155	3117628	268	15473	23600	N/A	N/A	108117	4.6	35
Rio de Janeir	SA	Docked	tembici	Traditional	80	440394	1.221	5286	1100	14	2	4065	3.7	9
Montreal	NA	Docked	BIXI Montreal	Traditional	213	801877	432	4506	6250	29	8	22595	3.6	28
Washington,	NA	Docked	Motivate	Traditional	175	687928	444	3157	3700	21	5	13291	3.6	19
Vancouver	NA	Docked	CycleHop	Traditional	22	175154	115	5493	1200	54	7	3900	3.3	22
Chicago	NA	Docked	Motivate	Traditional	238	1433915	606	4653	5800	24	4	18287	3.2	13
London	EU	Docked	Serco	Traditional	111	1287842	1572	5590	13850	125	11	36511	2.6	28
Cologne	EU	Hybrid	nextbike	SmartBike	405	1060582	405	2618	1450	4	1	3700	2.6	3
Buenos Aires	SA	Docked	City of Buenos Aires	Traditional	50	945636	203	14237	3000	60	3	6300	2.1	7
Madison	NA	Docked	Bcycle	Traditional	19	57886	244	1037	350	18	6	600	1.7	10
Delft	EU	Dockless	Delft	Smart Bike	20	102230	24.06	4480	994	49.7	10	1540	1.6	15
Minneapolis	NA	Docked	CycleHop	Traditional	82	239744	140	5123	1833	22	8	2927	1.6	12
Boulder	NA	Docked	Bcycle	Traditional	18	37810	67	1614	305	17	8	450	1.5	12
Portland	NA	Hybrid	Motivate	Smart Bike	34	137671	376	1702	1000	29	7	1510	1.5	11
Milan	EU	Docked	Clear Channel	Traditional & E-bike	53	1368590	182	7530	4650	87	3	6000	1.3	4
Atlanta	NA	Hybrid	CycleHop	Smart Bike	32	84423	347	1361	500	16	6	464	0.9	5
Shanghai	AS	Dockless	Dockless Mobike, oBike, ofo	Smart Bike	6341	24152700	6341	3809	1500000	237	62	1000000	0.7	41
Seattle	NA	Dockless	LimeBike, ofo, Spin	Smart Bike	217	704352	369	1908	8000	37	11	2711	0.3	4

In table 5.2 the values for Delft are compared with bike-sharing systems in other countries worldwide. Most of these systems are docked systems, from the dockless systems the performance indicators are scarce available.

The value for the average daily trips per 1000 residents (in service area) for Delft is 15. This is an indicator for the market penetration and is relatively high in comparison to other cities, mainly when the high bicycle ownership in the Netherlands is taken into consideration.

The average daily trips per bike are in cities with a docked system higher than the 1.6 daily trips per bike in Delft. For the smart bike systems, only Cologne and Guangzhou have higher scores. In Guangzhou the market penetration of share bikes is high with 285 trips per 1000 residents in the service area, so this city is not a good reference for Delft.

The system in Cologne is being commissioned by the public transport company and is used as part the public transport network. Both in Guangzhou as in Cologne the fares are relatively low, so this may be an explanation for the higher usage.

5.1.1. Virtual Docking Stations and free-floating

A possibility to make the bike-sharing in Delft more profitable, is to combine the strengths of free-floating bikes with the higher average usage of docked systems. This can be done by the introduction of virtual docking stations. In the current system the chance a bike parked near home is used again by another user is small. At locations with a high demand for shared bicycles in peak hours the supply is too low.

Street operations is needed to transport bikes that are parked for a long to places with a high demand. Street operations is costly and less needed with in a docked system.

The idea for improving the sustainability of dockless bike-sharing by geofencing is also investigated in China. In literature a study for Shanghai was found with a methodology for electric fence planning for dockless bike-sharing systems [67].

In the Mobike app geofencing is used to define areas where the bicycles should be parked, if a bike is parked outside these areas the user gets a fine. Also, areas are defined where parking is not allowed.

The idea for improving the profitability is to define a few virtual docking areas where a bicycle may be parked. These areas should be on locations with a high probability that the bicycle will be used again soon. In the next sections these areas are selected based on the origins and destinations of the trips.

Bicycles may also be used to other destinations outside the virtual docking areas. When a bicycle is parked outside these areas, for instance in residential areas, the rent continues free within the subscription. The user remains responsible for the bike, until the bike is parked again in a virtual docking station. The objective is to make the system as flexible as possible for the user, known from the free-floating system, and limit the disadvantages of these systems of ending rentals at destinations without demand.

It is recommended to stimulate that bicycles do not stand still for more than 72 hours under the responsibility of the same user, for example in the fare structure.

This proposed system design may result in lower operational costs and less bikes that are parked for a long time in places with low demand. This optimized in a way the service level for the users will be more or less the same.

5.2. Role in sustainable mobility

5.2.1. OD matrix

To get a better general understanding about the use of Mobike in the Delft situation, it is interesting to know between which locations people use the Mobike. An Origin-Destination (OD-) matrix is an easy to use analysis tool to quantify the number of trips made between different zones. Tables 5.2 and 5.3 show the OD-matrices of the two different three weeks periods as a percentage of the total number of trips, the OD-matrices with absolute numbers are presented in Appendix D.

Origin/destination	Station Delft	Centrum	TU Campus	Science Park Zuid	Station Delft Zuid	Voorhof	Buitenhof	Hof van Delft	Other	Total
Station Delft	0.1	1.1	2.7	0.3	0.1	1.0	0.3	0.5	1.2	7.2
Centrum	1.1	6.1	6.7	0.2	0.1	1.6	0.3	1.1	4.1	21.3
TU Campus	2.7	8.1	9.4	0.4	0.6	4.8	0.8	1.2	4.3	32.2
Science Park Zuid	0.3	0.2	0.4	0.1	0.6	0.3	0.0	0.0	0.2	2.1
Station Delft Zuid	0.1	0.2	0.7	0.6	0.0	0.4	0.1	0.0	0.2	2.2
Voorhof	0.9	1.3	5.1	0.3	0.4	3.3	0.6	0.4	1.3	13.5
Buitenhof	0.2	0.2	1.0	0.0	0.1	0.5	0.3	0.1	0.4	2.8
Hof van Delft	0.4	0.9	1.1	0.0	0.1	0.4	0.1	0.4	0.5	4.0
Other	1.3	3.3	5.0	0.2	0.3	1.3	0.3	0.4	2.7	14.7
Total	7.2	21.3	32.1	2.1	2.2	13.4	2.8	4.1	14.8	

Figure 5.2: percentage based OD-matrix for period between 11 June 2018 and 01 July 2018

First observation is 32% of the trips have the origin and/or destination at the TU Campus. 22% of the trips is related to the city center. Approximately 10% of the trips are within the TU Campus zone, origin and destination in this zone. This means that a lot of trips are made on the campus and in the city center and between those two zones. This can be explained due to the fact that a lot of users are students. The neighborhood of Voorhof attracts a lot of traffic as well, in this neighborhood multiple big student housing complexes are located.

Origin/destination	Station Delft	Centrum	TU Campus	Science Park Zuid	Station Delft Zuid	Voorhof	Buitenhof	Hof van Delft	Other	Total
Station Delft	0.1	1.0	3.5	0.2	0.0	0.9	0.3	0.4	1.1	7.6
Centrum	1.2	6.2	6.4	0.1	0.1	2.1	0.6	1.1	4.3	22.0
TU Campus	3.5	7.9	9.6	0.2	0.6	5.0	1.2	0.8	3.4	32.2
Science Park Zuid	0.2	0.1	0.3	0.0	0.3	0.1	0.0	0.0	0.2	1.2
Station Delft Zuid	0.0	0.0	0.7	0.4	0.0	0.4	0.1	0.0	0.2	1.9
Voorhof	0.9	1.8	4.8	0.1	0.4	3.2	0.9	0.5	1.3	13.8
Buitenhof	0.3	0.4	1.7	0.0	0.1	0.6	0.4	0.0	0.3	3.7
Hof van Delft	0.5	0.9	1.0	0.0	0.0	0.4	0.1	0.4	0.5	3.7
Other	1.2	3.7	3.9	0.1	0.3	1.2	0.3	0.5	2.8	14.1
Total	7.7	22.0	31.9	1.2	1.7	13.9	3.8	3.8	14.1	

Figure 5.3: percentage based OD-matrix for period between 27 August 2018 and 16 September 2018

An interesting aspect of bike-sharing for policy makers is the role in the last mile. Especially at the egress side of high-quality public transport the use of shared bicycles may result in shorter overall travel times. This strengthens the position of sustainable transport modes in the modal split. The focus for the last mile is mainly on the both railway stations. A trip is considered as related to a railway station when the origin or the destination is in the zone of the Delft or Delft Zuid station.

In the first period the share of trips related to one of the railway stations was 18.5%. In the second period this share was a little bit higher 18.7%. Especially the number of trips to/from the Delft Zuid station is interesting. In the period between 27 Augustus and 16 September more then 1000 trips started or had their destination there, that is on average 50 trips per day. This indicates the potential need for shared bicycle bikes here. At the railway station Delft Zuid are only 4 parking locations for bikes of OV-fiets, so this limited the use of shared bikes from here before the introduction of Mobike. These results confirm the latent demand for bike-sharing usage at the activity side of the train trip KiM has appointed [28]

Origin/destination	Station Delft	Centrum	TU Campus	Science Park Zuid	Station Delft Zuid	Voorhof	Buitenhof	Hof van Delft	Other
Station Delft	0.0	-0.1	0.8	-0.1	-0.1	0.0	0.0	-0.1	-0.1
Centrum	0.0	0.1	-0.3	-0.1	0.0	0.5	0.2	0.0	0.2
TU Campus	0.8	-0.3	0.3	-0.2	0.0	0.3	0.3	-0.4	-0.9
Science Park Zuid	-0.1	-0.1	-0.2	0.0	-0.3	-0.2	0.0	0.0	-0.1
Station Delft Zuid	-0.1	-0.1	0.1	-0.2	0.0	0.0	0.0	0.0	0.0
Voorhof	0.0	0.6	-0.3	-0.2	0.0	-0.1	0.3	0.1	0.0
Buitenhof	0.0	0.1	0.7	0.0	0.0	0.1	0.1	0.0	-0.1
Hof van Delft	0.0	0.0	-0.1	0.0	-0.1	-0.1	-0.1	0.0	0.0
Other	-0.1	0.4	-1.1	-0.1	0.0	-0.1	0.1	0.1	0.1

Figure 5.4: Difference percentage point period 27 August 2018 and 16 September 2018 minus period between 11 June 2018 and 01 July 2018

Comparing the first period with the second period (figure 5.4) there appear some differences in the percentage of trips between OD-zone can be found. All differences bigger than 0.4 percent are marked in yellow. The increase in traffic between the campus and Delft railway station is the most significant. Also, the increase in traffic between Voorhof and the city center is significant and between Buitenhof and the campus. It's difficult to explain these differences by only using this dataset. Probably a group new students at the start of the academic year started using Mobikes. A nice result would be when Mobikes are used instead of second bike use to and from the railway station, however no evidence can be found for this result based on this dataset only.

5.2.2. Average length of trips

Figure 5.5 shows the average length of trips, calculated as the crow flies. The average trip great-circle distance is 1.6 km , over the way between 1.7 and 2.3 km, depending on directness of bicycle routes. This average trip length is shorter than the national average bicycle trip length of 3.8 km according to

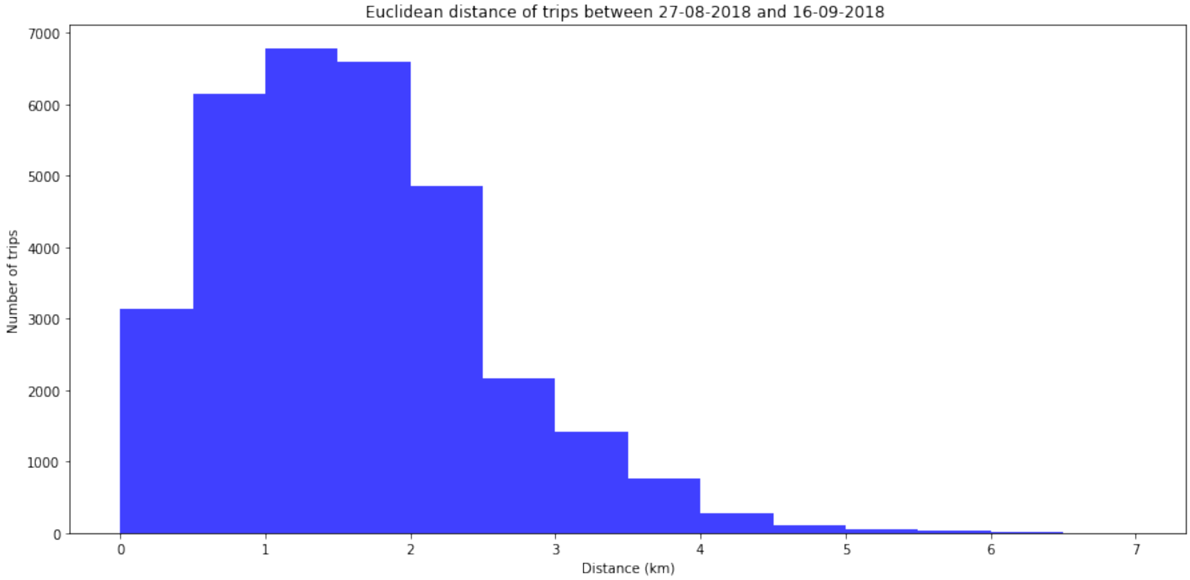

Figure 5.5: Average trip length between 27 August 2018 and 16 September 2018

the OVIN research [22] (Panel based travel data in the Netherlands). This may have multiple possible causes;

- People are not willing to cycle longer distances on a bike with the quality of a Mobike.
- In Delft the average distance of a cycle trip may be shorter than the overall average for the Netherlands.
- The average distance traveled on shared-bicycles is shorter than on normal bikes, in particular if shared bike trips replace walking trips at the activity side of a public transport trip.

The biggest share of Mobike trips in Delft have a great circle distance between the 0.5 km and 2.5 km. Based on the dataset it is not possible to explain this distribution. It may be related to the characteristics of the different zones, but it is also possible there is a maximum distance people want to cycle on a Mobike. The maximum recorded trip distance traveled with a Mobike is 6.5 km. The dataset is not suitable for determining the maximum trip distance, because the sample area was restricted to the city of Delft, trips starting or ending outside Delft are not recorded. Visual observations of Mobikes originated in Delft are done in Vlaardingen, Ter Heijde (5.6) and The Hague. This indicates, certain people are willing to cycle much longer distances, although it's only a small share and officially not allowed by Mobike.

Figure 5.6: Mobike at the beach of Ter Heijde

In research into the usage of dockless bike-sharing in several Chinese cities, comparable short trip lengths and corresponding bike travel times are found. In Nanjing the average trip length is only 1.0 km. [33]. In Nanjing over 60% trips of dockless bike-sharing users last less than 15 minutes, and 97% of trips are shorter than 30 minutes.

A survey under 260 selected respondents in Beijing also shows that in most circumstances the shared bikes are used for a short time and distance. Sixty percent of the respondents finish their trip in less than 10 min. and 91% in approximately 20 min. Two thirds of the users use the dockless bikes for 1 - 3 km distances.

What can be concluded based on both the dataset in Delft and the research of Chinese cities is that Mobikes are mainly used for distances shorter than 3 km.

5.2.3. Special days

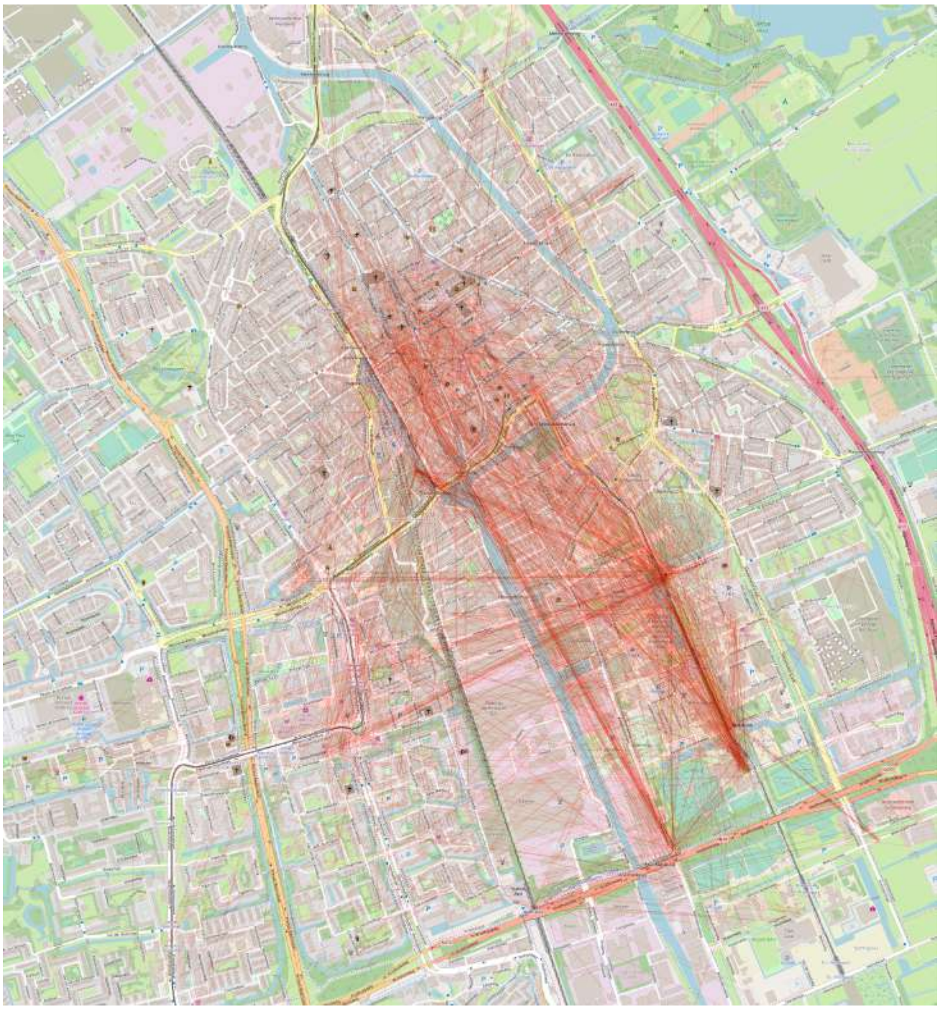

Figure 5.7: Trips Mobike Delft 22 augustus 2018

In figure 5.7 a map is shown of all trips made on a day in the introduction week for students in the city of Delft. This was the most successful day until that moment in Delft with 2445 trips.

The trip patterns on this map correspond with the OD-matrices based on polygons presented earlier in this chapter. However, the exact end- and starting points may differ day by day, depending on activities at attraction point. In the OD-matrices the patterns are aggregated to zones, on this map the real coordinates for begin- and end-point of a trip are shown.

5.2.4. Usage over time

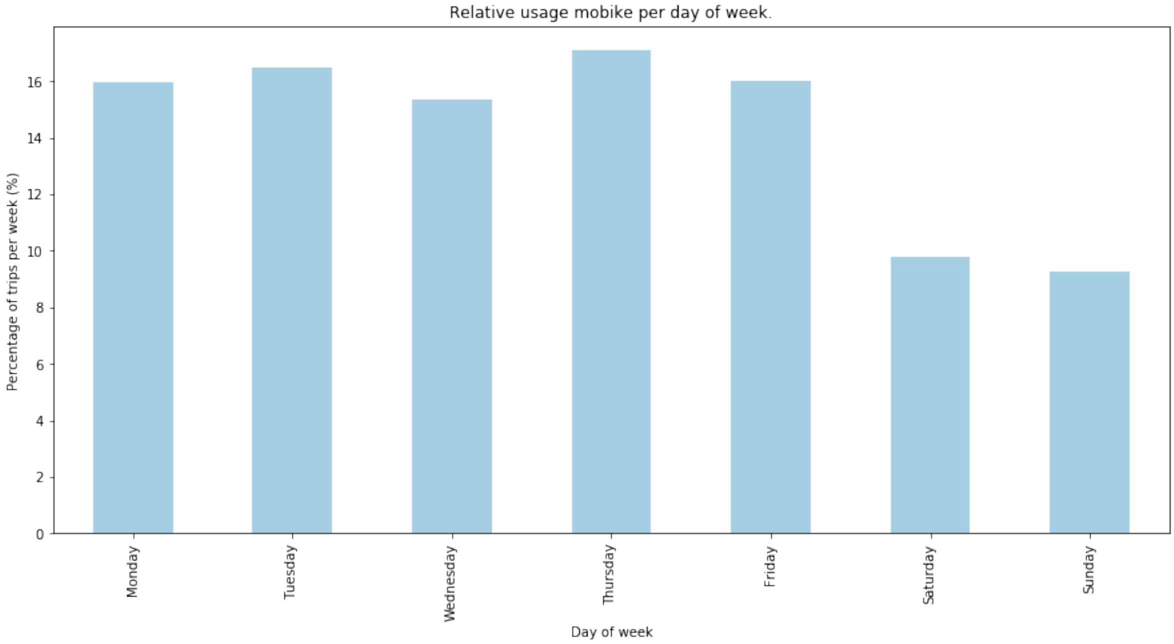

Figure 5.8: Relative usage Mobike per day of week 27 August 2018 and 16 September 2018

The distribution of trips over the period of the day and over the weekdays gives an indication of the travel demand of the users. In figure 5.8 the relative usage over the days of the week is presented. The usage of the bicycles is smaller during the weekend than during the business days. Compared to public transport the usage ratio of weekend days versus weekdays is relatively high for the use of Mobike.

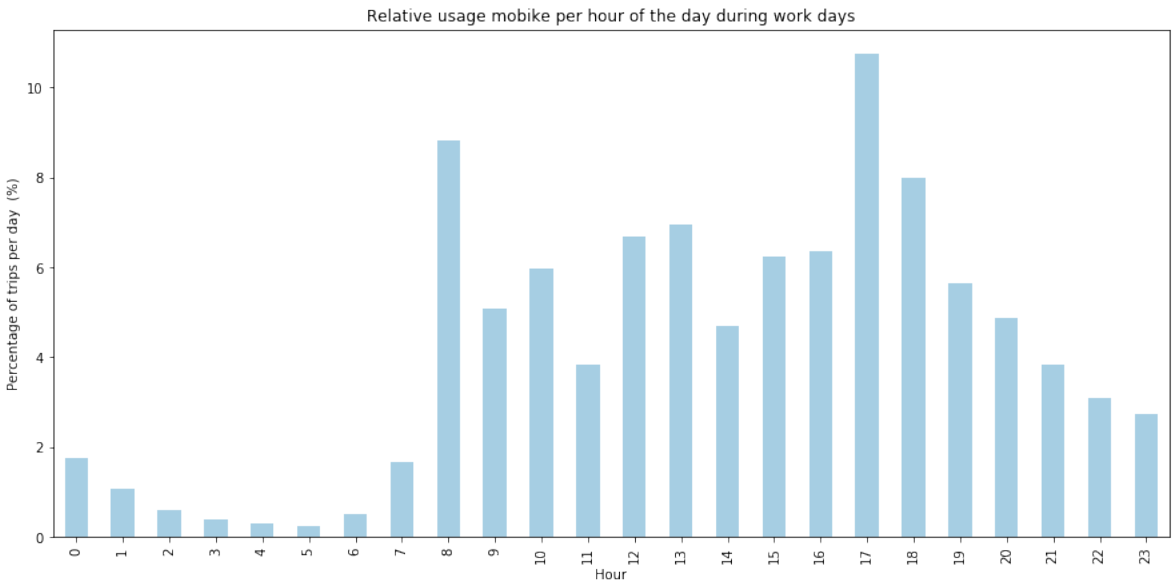

Figure 5.9: Relative usage Mobike per hour of the day during working days between 27 August 2018 and 16 September 2018

The distribution of trips within a day is presented in figure 5.9. In the pattern peaks can be distinguished during the morning and evening rush hours. The evening peak in usage is higher than the morning peak. A possible explanation for this pattern is that during the evening rush hour students often make a short stop on their way home, for instance at the supermarket. This results in two trips during their commute home. Noteworthy is the reduced use in the time blocks from 11-12 and 14-15 hour. This probably indicates a high use by students. In the beginning of September at the start of the new academic year, the Mobike usage pattern corresponds more or less with the start and ending of lectures (08:45, 10:30-45, 12:30, 13:45, 15:30-45, 17:30).

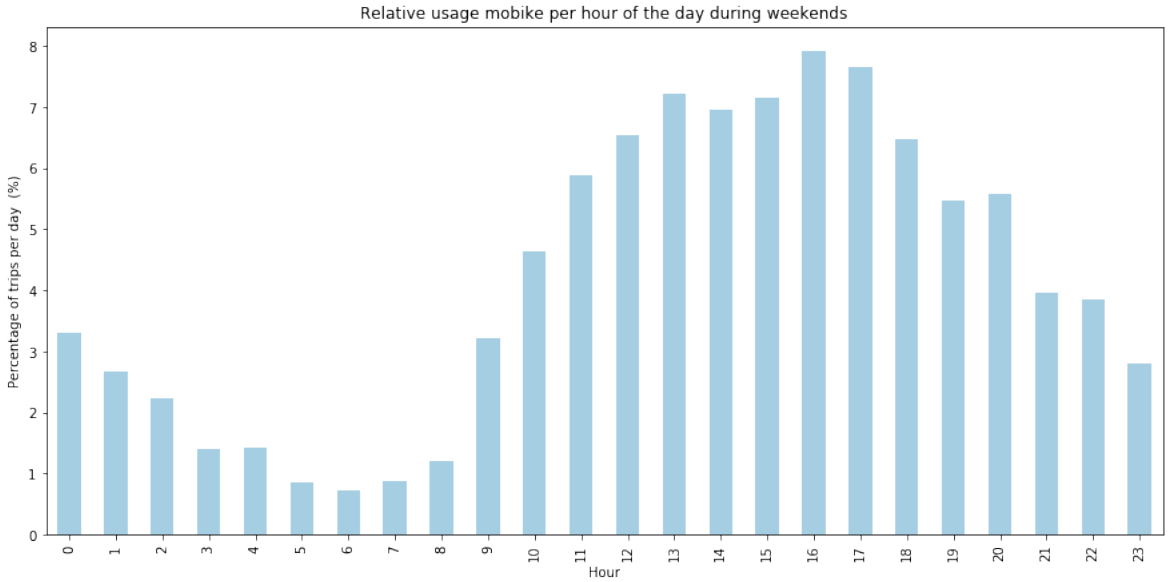

Figure 5.10: Relative usage Mobike per hour of the day during weekends between 27 August 2018 and 16 September 2018

In figure 5.10 the distribution of trips for the weekend days is presented. The usage during the weekends starts later than during workdays and the usage of the bicycles during the night is high (approximately 15% of the trips is made during the night).

5.2.5. bike-sharing and public transport

Bike-sharing as an instrument to strengthen the bicycle-transit combination may give the greatest contribution to the growth of sustainable transport. What can be learned from the data-analysis about this potential?

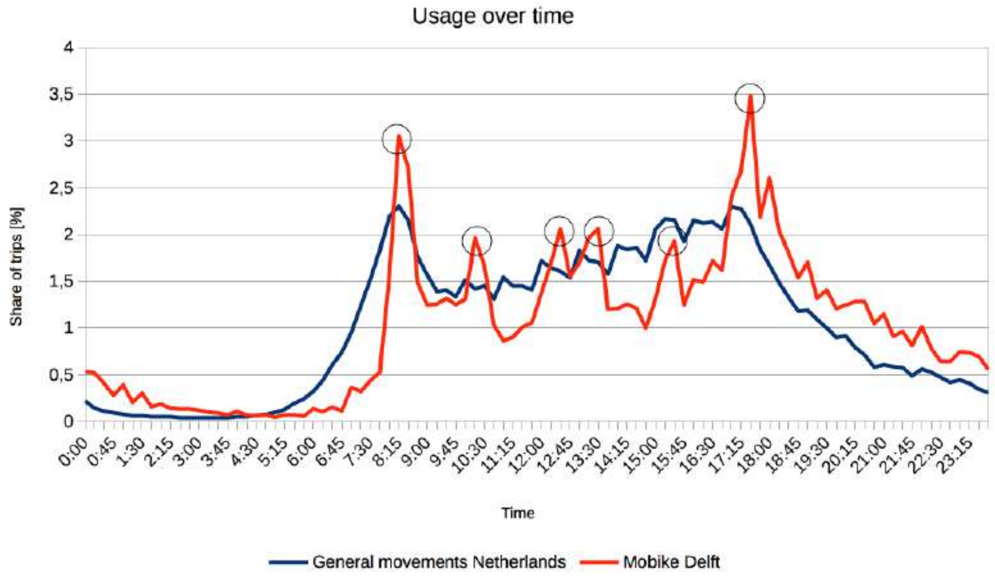

Figure 5.11: Comparison mobike usage with general movements Netherlands

In figure 5.11 the usage of Mobike in Delft is related to the general daily pattern in number of trips with all transport modes in the Netherlands on an average working day (source: OViN 2014 [6]). During periods without local public transport, for example during the night and during the weekends to and from the TU-Campus, the usage of Mobike is relatively high. Probably the users may prefer a bike-share trip compared to a ride with a low-frequency bus line with an interval of 30 minutes or less. Travelling by bike to and from a train gives shorter average transfer times and shorter overall travel times. Further study is recommended how to achieve more synergy between public transport and bike-sharing.

Remarkable in this figure are the peaks in the usage of Mobike Delft, this pattern corresponds more or less with the start and ending times of lectures (08:45, 10:30-45, 12:30, 13:45, 15:30-45, 17:30).

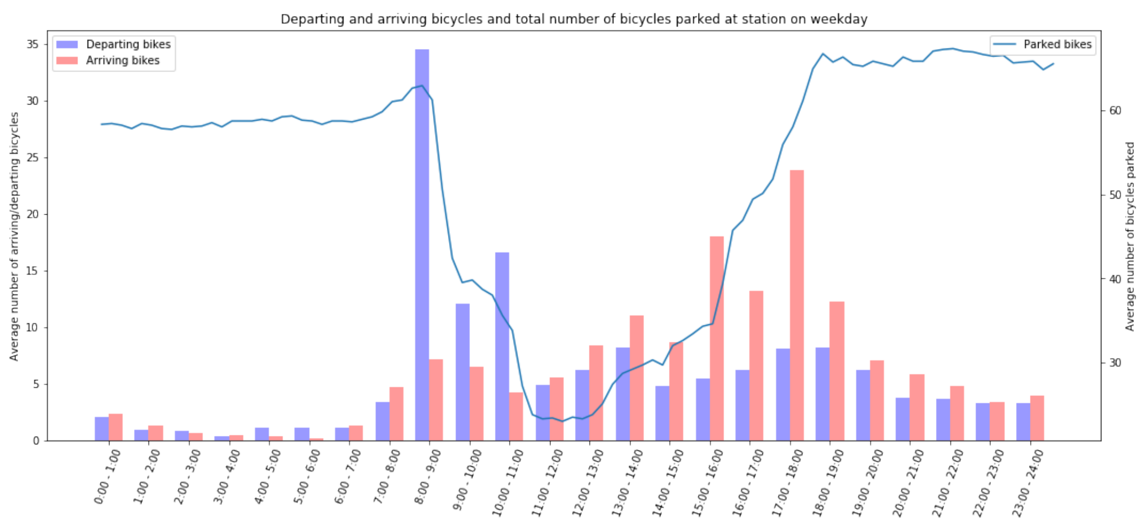

Figure 5.12: Average number of arriving, departing and parked bikes at Delft Station on workdays in the period 3 September 2018 and 16 September 2018

In figure 5.12 the arriving and departing shared bikes at Delft Station is shown during week days. During the rush hour in het morning there is a peak in the departing bicycles, in the afternoon the number of arriving bicycles is higher. Based on this pattern its possible to conclude that more people are using Mobike at the activity side than at the home side of a train journey.

The Netherlands have a unique issue compared with other countries: the bike use to and from railway stations is very popular and even growing. Despite of years of expansion of the number of parking places at station, bicycle shelters at many large train station remain (over) full [28]. Further expansion of bicycle parking places is often not easily possible in terms of space or involves high costs. KiM concluded that bicycles waiting at railways stations for transport to work, training or another activity (egress) provide 45% of the parking pressure. These bicycles are on average parked for about 2.68 day/train- trip. Bike-sharing may contribute to reducing the bicycle parking pressure at railway stations because shared bikes only need to stand still for a short time.

The blue line in figure 5.12 shows the average number of parked bikes in het station area during working days. This average varies between 25 and 65. In the period between 8:00 and 11:00 hour on average 60 Mobikes depart from the station area. In this period on average 20 bikes arrive in the station area. In comparison with the usage of second bikes or the OV-fiets at the activity side of a train trip, the use of shared bikes results in less needed parking places during the nights and weekends. During the nights and weekends the occupancy in het railway station bicycle shelters is very high. Regularly the shelter is completely full during the weekends. The higher use of shared bikes at the activity side than at the home side, indicates the potential for further reducing the number of bicycle parking spaces at the railway station. Stimulating home side trips can be done via an attractive subscription rate. It is also important to better align the price for the bicycle parking at the railway station with the shortage of parking spaces at certain times.

However, in the research period only 19% of the trips is related to a railway station, the data-analysis indicates a high potential for a greater share of sustainable transport by improving the bike-share - train combination.

5.3. Efficient use of public space

The most important indicator regarding the use of public space is the average daily trips per bicycle. When the number of trips made per day with a shared bike is higher than with a normal bike it's likely that this results in more efficiently usage of space.

Table 5.3 gives an overview of the usage of the bikes during the two, three week periods in the dataset for the Delft pilot.

Table 5.3: Usage characteristics

Key characteristics		
	11-06 until 01-07	***27-08 until 16-09***
Detected bicycles, detected at least once during the period	647	994
Active bicycles (bicyles that made at least one trip during 3 weeks period*	627	956
Total number of trips detected in the sample area	18737	32339
Average number of trips per day per bicycle**	1.4	1.6

** It is not sure that all active bicycle where the whole period on the streets in Delft.*
*** the total number of trips divided by the number of active bicycles divided by the number of days (21).*

With 1.6 average daily trips per shared bicycle in Delft, this seems to be lower than the trips a commuter makes on his own bike each workday. On first sight space advantage of bike-sharing seems not to be apparent in the Delft-pilot.

Figure 5.13 shows the average number of trips per active bicycle day by day (a bicycle only counts as active for a day if at least one trip is made on that day). Notable in this graph is the increase average number of trips increased significantly from approximately 2.8 to > 3.5 trips per day on active bicycles at the start of the academic year at 3th September 2018.

The number of trips per bicycle is 3.8 on the busiest days with a maximum number of 540 used bicycles on each day (see figure 5.14). On the condition this number of daily trips is reached on a large scale, this should be enough for a profitable bike-sharing system.

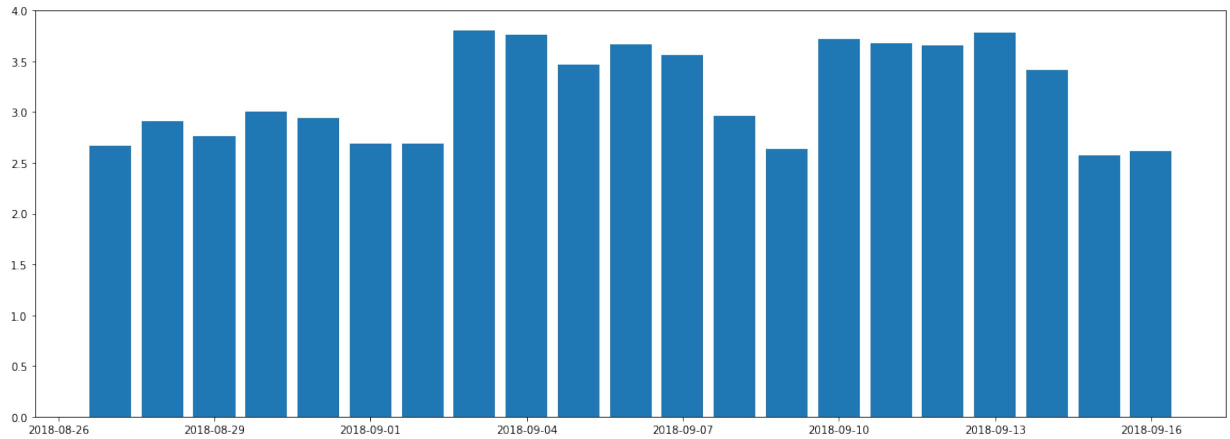

Figure 5.13: Average number of trips per day per bike that made at least one trip on specified date over period 27 August 2018 and 16 September 2018

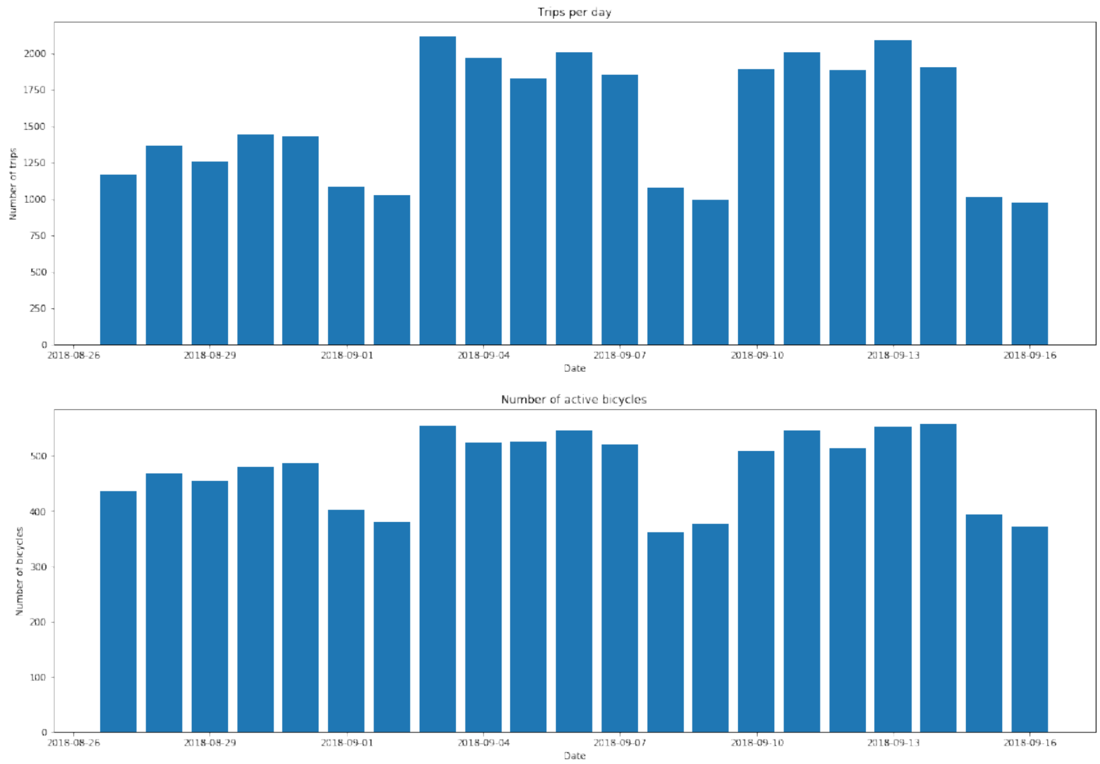

Figure 5.14: Number of trips and number of active bicycles per day over period 27 August 2018 and 16 September 2018

Focusing on the 5 workdays in the busiest week from 3 to 8 September, in total 9762 trips were made on 786 different bikes. This gives a daily average of 2.5 per bicycle. This indicates the daily average number of trips is highly dependent on the total number of active bikes. Reducing pressure on pubic space is the most effective by controlling the quantity of shared bikes in the service area.

Figure 5.13 show the average number of trips per active bicycle day by day (a bicycle only counts as active for a day if at least one trip is made on that day). When this statistic is considered the number of trips per bicycle is 3.8 on the busiest days.

5.4. Preventing deterioration of public space

The longer time between trips a bicycle stands still, the greater the possible effect on deterioration. An indicator for measuring is the number of events a bicycle is parked for a longer time period (starting with longer then 24 hours). The results are presented in table 5.4.

Table 5.4: Amount of times individual bicycles are not used for period longer then:

Number of times a bicycle is not used for period longer then:		
	11-06 until 01-07	***27-08 until 16-09***
>= 24 hours	2004	2653
>= 48 hours	916	1147
>= 72 hours	504	637
>= 5 days	182	242
>= 7 days	73	109
>= 14 days	2	5
Key characteristics		
Detected bicycles	647	994
Active bicycles (bicyles that made at least one trip)	627	956
Total number of trips	18737	32339
Average number of trips per day per bicycle	1.4	1.6

The difference between detected bicycles and active bicycles is the number of bikes didn't detected in a trip in that period. Several reasons may explain why no trips are detected with this bicycle; the bicycle is moved to another service area or depot, someone travelled with the bicycle outside of the measurement area. For this reason in table 5.4 only bicycles with more than 1 measured trip are included, so the the presented numbers maybe a little bit to optimistic.

In the second period the number of bicycles is more than 300 bicycles higher than in the first period. A positive conclusion is that almost no bike was parked on a location longer then 2 weeks. The number of bikes not used for 5 days of longer is considerable. It's not known when people get annoyed by long parked bicycles. If necessary, municipalities may use this indicator to enforce bicycle operators to move bicycles that are parked for a long time to locations with higher demand.

In figure 5.15 the bicycles parked for a period longer then 1 week are visualized on a map. It's interesting to see the difference between the first and the second period. In the first period there was no event of bicycles parked longer than a week in the neighborhood Tanthof, in the second period approximately 30 bikes. Another observation is that there are no events of bicycles parked longer than a week in the southern part of the city of Delft. Around that part of the city a lot of student societies are located. Probably there is frequent a shortage of bicycles around those locations. During the 6-week period only two times a bike was not used for a period longer than a week at one of the railway stations.

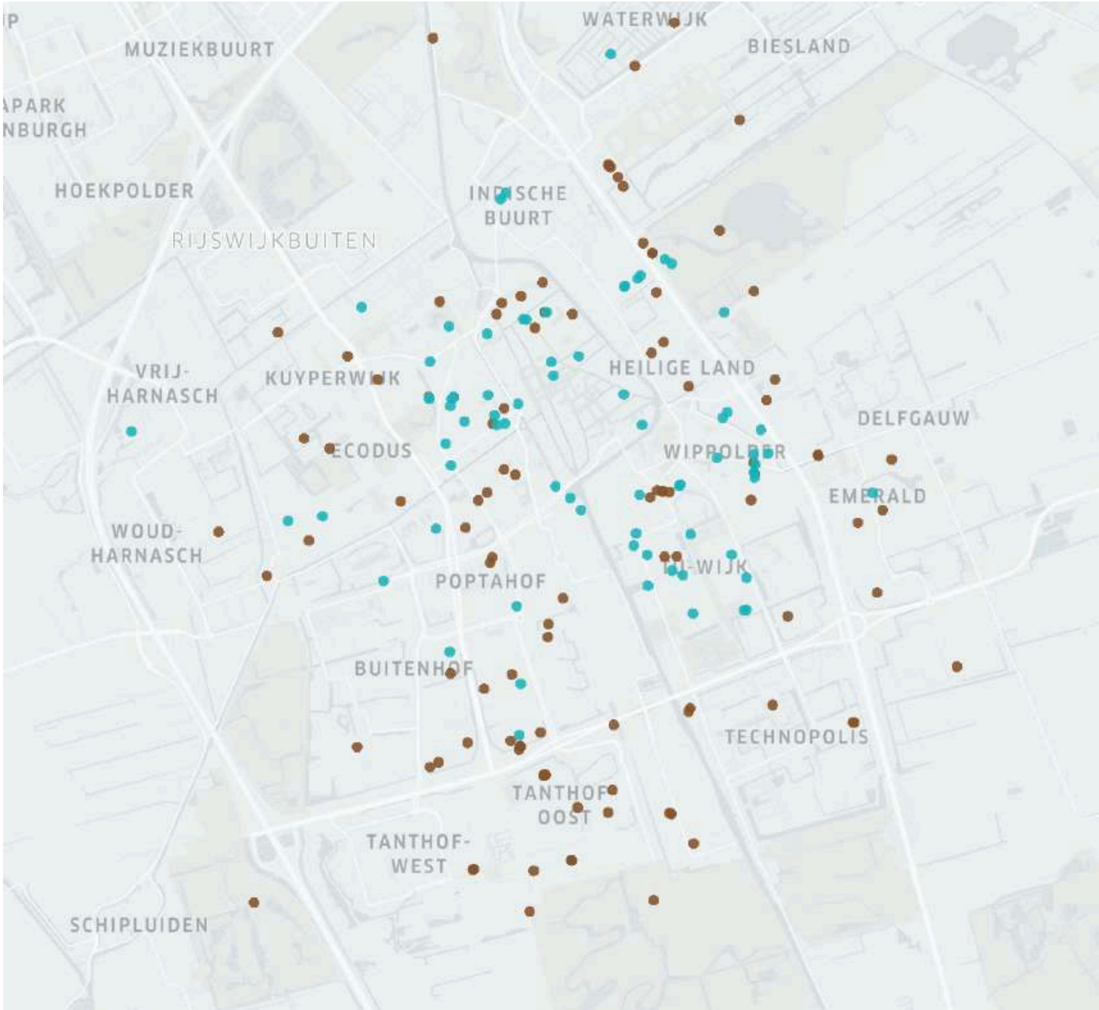

Figure 5.15: Locations where bikes where parked for period longer then 7 days, blue (11-07-2018 until 01-07-2018), brown (27-08-2018 until 16-09-2018)

5.5. Conclusion

In this chapter the performance indicators for the Delft pilot are presented and analyzed. In Delft the largest share of trips on Mobikes is related to the city center and the campus. Voorhof is another zone with many origins and destinations. This is in line with the observation that Mobike is mainly used by students.

Approximately 19% of all the trips in the research period is related to one of the railway stations, this are mainly last mile trips. 60% of these railway related trips have TU Campus or Science Park Zuid as destination. The usage data indicate a high potential for a greater share of sustainable transport by improving the bike-share transit combination.

The most important general quality performance indicator is the average daily trips per bicycle. The average daily trips per bicycle is relevant for several points of view: the profitability of the bike-share operator, the contribution to sustainable transport, the efficient use of public space and limiting the deterioration.

In Delft the value for this indicator is 1.6. A growth to 3 daily trips per bicycle seems to be possible by controlling the quantity of shared bikes in the service area.

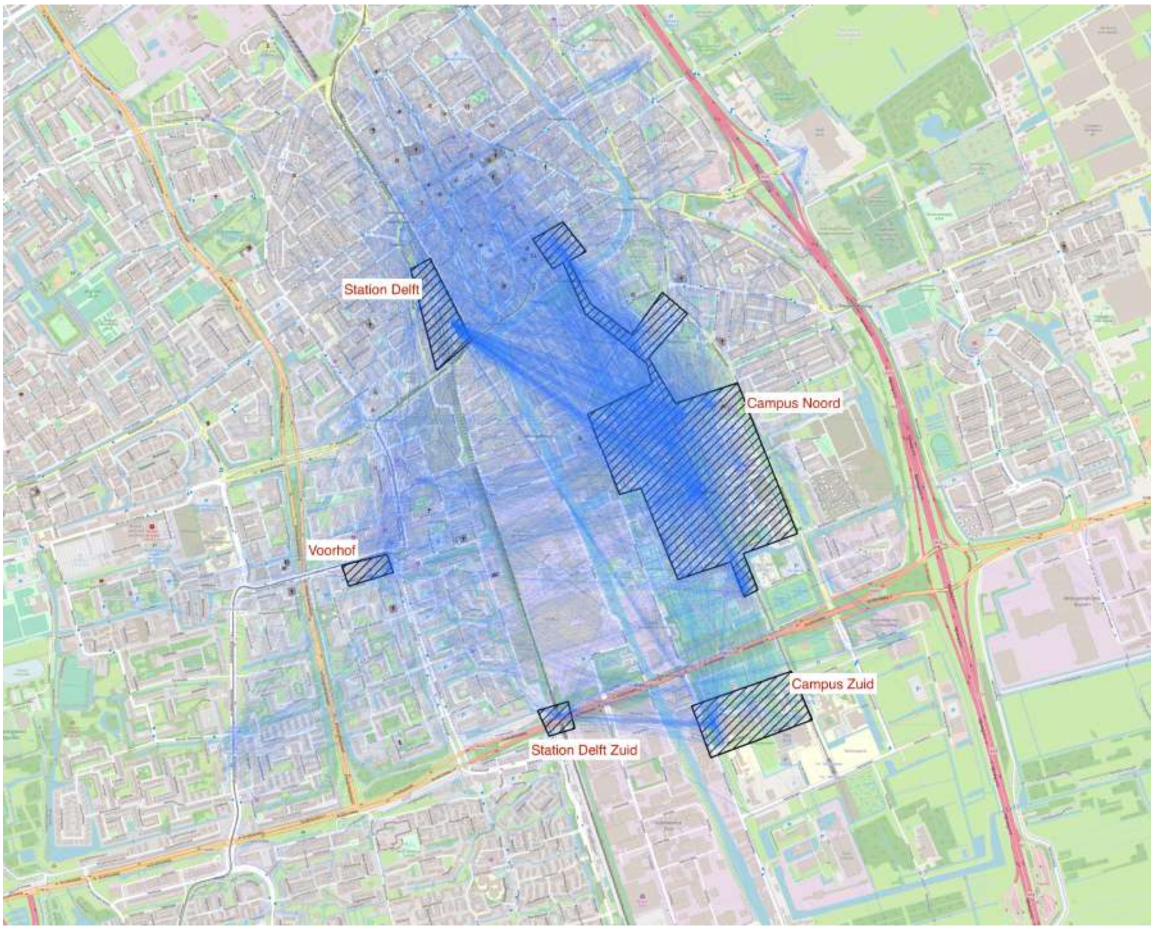

Figure 5.16: Suggestion for virtual docking areas, based on O-D data.

A possibility to realize a growth of daily trips per bicycle, is by combining the strengths of free-floating bikes with the higher average usage of docked systems. This can be done by the introduction of virtual docking stations in combination with free-floating use. In figure 5.16 a possible regime of virtual docking areas is presented, based on the current O-D matrices.

In the free-floating areas, that is everywhere outside the virtual docking areas, the user remains responsible for the bike under attractive subscription conditions. This expectation of this system design is a reduction of the number of bikes not used for 5 days of longer, a reduction of the costs of street operations, a higher sense of responsibility under the users, less vandalism and deterioration and a better use of public space.

This model with virtual docking areas is good for the profitability and may strengthen the bike-share transit combination. The railway stations are both in a virtual docking area. The expectation is that more shared bikes are available in this zone in comparison with the current free-floating model, since users are stimulated to leave the bicycle here. This means, more shared bikes are available for the egress side of a train journey. The availability of shared bikes at railway stations may grow further by stimulating the usage of shared bikes for home side trips. An important additional benefit of stimulating the home side trips, is a reduction of the pressure on the stations bicycle parking.

6 Conclusions, discussion and recommendations

This chapter contains the conclusions, discussion and recommendations from scientific and practical perspective for Mobike and the local government. First the sub-questions will be answered, followed by the main research question.

From March 2018 Mobike introduced shared bikes for a 2 year pilot in Delft. This pilot offered an opportunity to investigate the demand for shared bikes in Delft, and in addition, to examine how the use of shared bikes can be regulated best in Delft. The research questions are answered with the following input:

- Literature, history and state of the art of bike sharing system
- Interviews with local governments and the ministry of I&W regarding the opportunities and concerns of dockless bike-sharing
- Experience of the Delft pilot
- Collected data and data analysis of the Delft pilot.

6.1. Conclusions

1. What are the effects of technological developments on the relationship between bike-share operators and local governments?

   New technologies are the driving force behind new developments in bike-sharing. The third generation of bike-sharing required a natural relationship between bike-sharing operators and local governments due to the required infrastructure on the streets. With the introduction of the dockless bike-sharing this natural relationship disappeared.

   In the Netherlands the local governments reacted in different ways on this development. Amsterdam introduced a ban and in the meantime worked on rigid regulations. Other governments, such as the municipality of Delft, tried an approach based on collaborating with bike-sharing operators. The coordination between Delft and Mobike is shaped by mutual dependency. Mobike and the municipality learn together from the introduction of the fourth-generation bikes. Sharing data, key performance indicators regarding the usage, deterioration and efficient use of public space support the cooperation. In the Delft pilot the network governance is relative invisible, there are no formal agreements with obligations for Mobike, for example concerning data sharing and contribution to policy goals.

   If the government wants to use bike sharing to realize its policy goals, it is necessary to make agreements with the bike-share operator about sharing data in a standardized format, both for monitoring and for integrating bike-sharing in public transport travel information.

2. What is the current policy and what are the ambitions of different government bodies in relation to bike-sharing? What concerns do they have?

   At the start of the introduction of free-floating bikes in the Netherlands there was no policy. The shared bikes were handled in the same way as normal bicycles. When shared bicycles were becoming a problem for local governments due to deterioration, the government had to intervene to reduce the negative side effects. Different government bodies made different choices. Amsterdam decided to completely ban shared bicycles, while regulations were developed by the local government.

   Other cities, such as Rotterdam and Delft, decides, instead of immediately changing the regulations, to have a dialogue with the different market parties active to work on improving dockless bike-sharing. Those governments also saw the opportunities shared bikes can provide. The opportunities are in increasing the modal split of sustainable modes of transport and a possibility of more efficient use of public space. They are worried about uncontrolled introduction of shared bicycles. An oversupply may result in several problems, such as vandalism, mess in the street and occupied public space. This results in a low acceptance by the public, so it is important to avoid these problems.

   Bike-sharing as a mode in the first- and last mile, potentially reducing the total door to door travel-time of trips in combination with public transport, may result in an increase of sustainable transport. Another important aspect for local governments is the potential of bike sharing in limiting the need for new bicycle storage places at railway stations.

   Based on interviews with three different governments the following policy goals were defined:

   - Stimulating sustainable mobility
   - Efficient use of public space
   - Preventing deterioration of public space

3. How can governance be organized to support the collaboration between the main stakeholders?

   The governance of a dockless bike-sharing system is complex since, it requires coordination between governments, (commercial) operators, users, the public and other stakeholders. A sustainable bike-sharing system requires a balanced representation of the interests of the various stakeholders.

   For local governments shared bicycles offer opportunities for reaching policy goals. The opportunities are an increase in the modal split of sustainable modes of transport and a possibility of more efficient use of public space. They are worried about uncontrolled introduction of shared bicycles. An oversupply may result in several problems, such as vandalism, mess in the street and occupied public space. This results in a low acceptance by the public, so it is important to avoid these problems. For a commercial bike-share operator, like Mobike in Delft, it's important to have a positive business case. When the usage is maximized and the number of bikes in circulation is minimized, the profitability is as high as possible. A commercial bike-share-operator wants no, or as little as possible, regulations and preconditions. If needed, they prefer standard rules that can be applied in different cities. So they have to invest once to comply with the rules for all regions. The margins in bike-share operation are very small. Setting up a profitable service requires sufficient scale. It is important that municipalities jointly formulate preconditions / requirements for a bike-sharing system.

   The current pilot implementation is experimental. Main goal is to investigate the demand for shared bikes in Delft, and to explore if and what kind of regulation is needed.

   The network governance is applied in the relation between municipality of Delft and Mobike. This relationship is characterized as informal. If necessary more formal rules can be applied within the framework.

   For the pilot implementation in Delft this informal network governance is appropriate. In order to achieve policy goals on sustainable mobility on a larger scale, it is necessary to quantify and measure these policy goals. Even though a municipality does not provide funds to directly support dockless bikeshare, its operation depends on the use of municipality-owned streets, sidewalks, and other public infrastructure. By establishing a permit system, a government is well positioned to commit a bike-share operator and to supply information in order to evaluate the contribution to the policy goals.

4. How can data analysis help to find answers to the questions about concerns and opportunities? Based on the Delft bikeshare setup.

   The bike-sharing ecosystem can be described according to the plan-do-check-act(PDCA-)cycle. The PDCA-cycle is a well-known model for continual process improvement. Two cooperating PDCA circles can be distinguished. On the upper-level the policy management cycle. Scope of this cycle is establishing objectives using bike-sharing as an instrument for increasing modal split of sustainable modes of transport and as a possibility of more efficient use of public space. The second level is the operational control cycle. In Delft this cycle is in the domain of Mobike.

   Data play a key role in the PDCA cycle. During the do phase, data is gathered to see how effective changes in the system are related to the objectives. The PDCA cycle is supported by quality performance indicators. Quality performance indicators define a set of values against which to measure. The most important indicator is the average daily trips per bicycle. This indicator is relevant for all the different points of view: the profitability of the bike-share operator, the contribution to sustainable transport, the efficient use of public space and limiting the deterioration.

5. How is bike-sharing used in Delft?

   In Delft 32% of the trips have an origin or destination in the TU-Campus zone. The largest relation for Mobikes is between the city center and the campus. Voorhof is another zone with many origins and destinations. This is in line with the observation that Mobike is mainly used by students. Approximately 19% of all the trips is related to one of the railway stations, these are mainly last mile trips.

   The most important general quality performance indicator is the average daily trips per bicycle. The average daily trips per bicycle is relevant for several points of view: the profitability of the bike-share operator, the contribution to sustainable transport, the efficient use of public space and limiting the deterioration.

   In Delft the average daily trips per bicycle is 1.6. A growth to 3 daily trips per bicycle seems to be possible by controlling the quantity of shared bikes in the service area.

6. Which recommendations can be given to several stakeholders based on the data analysis in Delft?

   Data is an important means to create a relation based on trust between government and bike operators. Trust grows by collaborating for a longer time and experiencing that results can be achieved together. By sharing data and being transparent a trust base may arise sooner. Providing data should be an important minimal requirement for deploying shared bicycles in the streets. This data can be used for analysis by the municipality but is also important for scientifically use in order to optimize bike-sharing further.

What are the impacts of dockless bike-sharing on convenient and sustainable mobility?

The challenge is to maximize the benefits of dockless bike-sharing, such as more sustainable transport and efficient use of public space, while minimizing the negative side-effects. The key for more sustainable transport is how to achieve synergy between public transport and bike-sharing. Another key is how to make bike-sharing more profitable.

A possibility to make the bike-sharing in Delft more profitable, is to combine the strengths of free-floating bikes with the higher average usage of docked systems. Analyzing the available trip data gives possibilities how this can be done best. The solution is the introduction of virtual docking stations in combination with free-floating use.

In the free-floating areas, that is everywhere outside the virtual docking areas, the user remains responsible for the bike under attractive subscription conditions. This expectation of this system design is a reduction of the number of bikes not used for 5 days or longer, a reduction of the costs of street operations, a higher sense of responsibility under the users, less vandalism and deterioration and a better use of public space.

Sharing data play a key role on the way to sustainable mobility. Providing data and confirming to open data standards should be a minimal requirement for a bike-share operator.

6.2. Discussion

During the research an experimental method for collecting data was implemented. This was done by reverse engineering the bike position data showed on a map in the Mobike app. It would be more preferable to retrieve the data in a more formal way. That would give more certainty about the reliability of the data in comparison with the limited testing process performed to validate the data. Also, the time resolution of the data would be better. In the current data set trips may be up to 10 minutes longer than in reality due to the 5 minutes sampling interval. In this research the trip duration was no point of interest, but for further research this should be taken in consideration.

What is missing in this research is the experience with dockless bikes from the user perspective. In additional user surveys data can be collected regarding the demographics of the user, how and why they use dockless bikes and how the user travelled before the dockless bikes appeared. Originally an online survey was part of the research plan, the questionnaire would be distributed via the Mobike app. It appeared that distributing the questionnaire via the app was more difficult than suggested and therefor this was cancelled.

This research gives no insight in the change in modal shift after the introduction of bike-sharing. The usage data indicate a high potential for a greater share of sustainable transport by improving the bike-share transit combination. This expectation is derived from the shorter door-to-door travel times when a shared bike is used at the home and/or egress side of train journey instead of walking or using a local bus. There is no evidence for this expectation found in this research.

The suggestion for 5 virtual docking areas in combination with free-floating use outside these areas, is based on the OD-matrices and common sense. This concept is not optimized, for example with a framework to support virtual fence planning. No research is done to the acceptance of the virtual docking concept among users.

6.3. Recommendations

6.3.1. Scientific

For scientific research it would be very interesting to repeat the empirical analysis on a selection of dockless bike systems worldwide (average daily trips per bicycle, average trip length, share of bicycles that is not used per day), a comparable research that is performed in [36]. When doing this comparison on a big scale, some theories can be developed on the important success factors for dockless bike-sharing. Problem at this moment to perform such kind of research is that the data is not available.

Another interesting topic for research is the pattern of the usage of shared-bicycles in comparison to cyclists on normal bicycles. When users of shared-bicycles are comparable to normal cyclists, the data collected for dockless bikes can be used to estimate cycling patterns for the whole city (with a scaling factor).

As mentioned in the discussion section, it would be interesting to distribute a questionnaire under users and do more qualitative research additionally. That can help to understand the motivation for using a dockless shared bike better. Is it replacing an owned bike or is it used as an additional bike? And what modes did users take before the introduction of the Mobike? Did they use another bike, the car, public transport or is it a replacement for walking? There are many more of these kind of questions that can't be answered with only the trip data. It would really help to better understand which role the shared-bike plays in sustainable mobility.

6.3.2. Practical

The main advice for Mobike is to be more open and transparent in relation to local governments by making data available according to the Mobility Data Specification (MDS) and General Bikeshare Feed

Specification (GBFS) data standards. It is advised to make the data available as open data so that a wide variety of interested parties (citizens, scientists, transit operators) can use those data for doing scientific research or to integrate the Mobike in public transport travel advices. In this way the public opinion and trust in Mobike as a company can be improved. Mobike as a Chinese company makes the public opinion by definition skeptical, therefore it's extra important to be as transparent as possible. Making data available is an easy step that can really help. Mobike already signed the OpenBike covenant for the first phase, describing how data should be shared (the GBFS+ format).

For the pilot implementation in Delft the current informal network governance is appropriate. In order to achieve policy goals on sustainable mobility on a larger scale, it is necessary to quantify goals. Even though a municipality does not provide funds to directly support dockless bikeshare, its operation depends on the use of municipality-owned streets, sidewalks, and other public infrastructure. By establishing a permit system, a government is well positioned to commit a bike-share operator and to supply information in order to evaluate the contribution to the policy goals. The plan-do-check-act cycle provides a framework for regulating dockless bike-sharing on a level which is appropriate for the local situation.

The margins in bike-share operation are small. Setting up a profitable service requires sufficient scale. It is important that municipalities jointly formulate preconditions / requirements for a bike-sharing system. Think of data standards for integrating bike-sharing in multi-modal journey planners and MaaS applications.

Bike-sharing has the potential to reduce the need for parking places for bicycles near the railway stations, when a significant group of users start to use a shared bicycle in their first and last mile to the station. By making shared bicycles more attractive than going on an own bicycle to the railway station the first mile bike-share use may grow. One of the options, although sensitive, to make the competition between an own bike and a shared bike fairer is making the parking facilities paid so that all the true costs are paid by the users. The use of bike-sharing to and from the railway stations can be made more attractive by offering a preferred position in the bicycle parking, close to the access to the train platforms. A guaranteed place gives shorter transfer times with less spread. This, combined with an attractive subscription model, can tempt commuters to use the shared bikes both at the home side and at the egress side of the train journey.

There are also some recommendations that are not directly related to the research but based on experiences and ideas that are collected during the period. In my opinion it's interesting to share them as well because they can contribute to more sustainable bike-sharing systems.

Introduction of flexible zones

The biggest costs of a dockless bike-sharing system in a country where the labor costs are high, are the costs for street operations. Therefore, the effort of bike-sharing operators should be on bringing this cost down as much as possible. This should be done in a way that gives as much flexibility as possible to the customers. On the other hand it's preferred that users can only terminate their rent on locations were the likelihood of a new rental of the bike is high, so that the bike doesn't need to be moved by street operations. An idea of a policy that can be introduced by bike-sharing operators, is that they create zones where the bike can be returned on locations, where the likelihood of renting out the bike again is high. In Delft interesting locations for zones could be the railway stations, campus, city center and different student housing facilities. Returning the bikes on these locations is automatically done by closing the lock (you want to require users to stop their rent at stations). On other locations, where the likelihood of a new rental by another user is small, users can park their bike but they remain responsible for the bike. Benefit for users on those locations is that when they want to leave with the bike again they are certain about the availability of the bike. By introducing this system, the situation where bicycles stay behind in remote locations like parks is prevented. This reduces the need for street operations, while still giving users enough freedom. In theory this system may result in lower number of trips per bicycle per day, but the current numbers don't reveal that this results in much less efficiency. At this moment almost 30% of the bicycles is not used on a normal day, with the introduction of this system this percentage may decrease. For users it would be extra interesting if a best pricing model is introduced. You start using a bicycle and the prices are capped to a daily and monthly maximum price. This model can be seen as a crossing between Swapfiets and Mobike.

Level playing field

At this moment there is 'unfair' competition between bike-sharing and public transport. Public transport is subsidized by the government and the VAT tariff for public transport and taxi transport is 9%, while the tariff for bike-sharing systems is 21%. On several locations bike-sharing is a better and cheaper alternative than operating a bus service. Therefore the government should consider to stimulate bike-sharing on specific locations with subsidies or to lower the VAT tariff so that the bike-sharing business becomes more profitable in general.

The shared bicycles of OV-Fiets (owned by the nation railway corporation) have more premium parking locations at railway stations than competing bike-sharing operators. in Delft the OV-Fiets can be parked in the underground parking facility close to the trains while Mobike's has to be parked on a temporary parking facility that is 150m walking from the station. Competing bike-sharing operators should get comparable facilities at stations so that fair competition is possible. For achieving the goal of less need for bicycle parking places at railway stations, it would be preferable to allocate the most attractive parking locations at the stations to bike-sharing operators.

Integrate in trip planners

At this moment shared-bicycles are not integrated in multi modal journey planners like Google Maps and 9292. For people who are not familiar with bike-sharing it's difficult to know where bicycles can be rented and how long the travel time will be in comparison to using other modes of transport. If shared-bicycles are included in the travel advices there is a potential new group of users. These group will not consider this option now, due to the fact that the option is not included in a travel advice.

The General Bikeshare Feed Specification (GBFS) makes real-time data feeds publicly available online in a uniform format. Journey-planners, maps and transportation based apps can easily incorporate this data into their platforms.

The Mobility Data Specification (MDS) is an open standard which makes it easy to share ride data between a Bike share operator and a MaaS providers. Adapting this standard is an important step for integrating Bike-sharing in Mobility as a Service solutions.

A
Data request

In November 2017 Mobike was introduced in Rotterdam, the Netherlands, followed by an introduction of the Mobike 3.0 in March 2018 in Delft. At the Delft University of Technology research is performed on cycling. Despite the long tradition of cycling in the Netherlands, the introduction of shared bikes is relatively new. The introduction of Mobike gives a great opportunity to extend the cycling research to on the one hand shared bike systems and on the other hand cycling dynamics in the Netherlands. With respect to the first, researchers are working on the use and attractiveness of shared bike systems in the Netherlands, among other things as access and egress mode for public transport. Cyclist demand, including origin and destination patterns of cyclists (what are the locations people start and end their trips, how does the demand vary over time (time of day, day of the week, over the year), but also the influence on modal split are of interest. Cycling dynamics relate more to the use of the bike itself: which routes do people choose to cycle, what are the corresponding travel times, which bottlenecks do cyclists encounter are just some of the questions to be answered. Here, we focus on the cyclist behaviour, preferences, and patterns, as well as on the use of the infrastructure.

We believe that the research results could also benefit Mobike in their business operations, and are therefore happy to share our research results. To perform the abovementioned research, we would like to use Mobike data. To get significant statistical results, also with respect to behavioural changes over time, we would like to get data for a longer period of time, e.g. a month or longer. Following upon a sample set we have been given, we would be very interested in the following data:

- Trip characteristics
  - Transaction ID (anonymised)
  - User ID (anonymised)
  - Bicycle ID
  - Transaction date
  - Longitude of intermediate route points (at high frequency, e.g. per 10 seconds)
  - Latitude of intermediate route points (at high frequency, e.g. per 10 seconds)
- Trip origin characteristics
  - Origin time of leasing the Mobike
  - Longitude of origin
  - Latitude of origin
- Trip destination characteristics
  - Destination time of locking the Mobike
  - Longitude of destination

  - Latitude of destination
- User characteristics
  - Socio-economic information (age, gender, origin (local people or traveller)
  - Use of the app (where do people open their apps to search for bikes)
- System characteristics
  - Availability of bikes (locations of available bikes over time)

B

OD matrices

Origin/destination	Station Delft	Centrum	TU Campus	Science Park Zuid	Station Delft Zuid	Voorhof	Buitenhof	Hof van Delft	Other	Total
Station Delft	15	203	529	58	21	185	57	94	235	1397
Centrum	217	1171	1299	36	15	317	66	217	788	4126
TU Campus	528	1569	1816	80	119	919	156	222	830	6239
Science Park Zuid	56	45	83	10	111	59	2	8	41	415
Station Delft Zuid	16	35	132	112	0	70	10	7	40	422
Voorhof	172	243	984	61	76	635	114	78	250	2613
Buitenhof	45	42	197	2	18	89	58	12	71	534
Hof van Delft	86	182	220	8	12	83	22	71	96	780
Other	251	631	961	34	55	244	56	85	521	2838
Total	1386	4121	6221	401	427	2601	541	794	2872	19364

Figure B.1: Trip count based OD-matrix for period between 11 June 2018 and 01 July 2018

Origin/destination	Station Delft	Centrum	TU Campus	Science Park Zuid	Station Delft Zuid	Voorhof	Buitenhof	Hof van Delft	Other	Total
Station Delft	19	319	1139	71	11	298	95	138	365	2455
Centrum	372	1992	2082	28	19	680	179	365	1386	7103
TU Campus	1139	2538	3114	67	204	1619	373	260	1107	10421
Science Park Zuid	72	41	83	12	81	38	0	5	50	382
Station Delft Zuid	7	12	238	119	1	120	20	3	78	598
Voorhof	275	582	1538	36	124	1033	290	145	429	4452
Buitenhof	80	113	541	8	23	186	139	13	92	1195
Hof van Delft	146	302	327	7	1	115	16	123	149	1186
Other	376	1195	1264	43	96	392	109	161	911	4547
Total	2486	7094	10326	391	560	4481	1221	1213	4567	32339

Figure B.2: Trip count based OD-matrix for period between 27 August 2018 and 16 September 2018

C

Data collection

In this appendix the process of data collection is described. The method for collection can be characterised as experimental and unconventional. The data is collected by reverse engineering the way the app for consumers gets it's data to show to the user where they can find the nearest bike. By collecting all the locations of the bicycles every 5 minutes a pattern in the movement of bikes can be derived. Because the method was experimental, validation is an important part of the data collection.

C.1. Data collection

The process of data collection started by writing an official request for data to the head quarter of Mobike in China. In this proposal we requested for an extensive set of data about the usage of Mobike in Delft, the request can be found in Appendix A. Based on the fact that Mobike in the Netherlands and the TU Delft are collobarating the assumption was that it shouldn't be a big problem. That turned out differently, the worldwide policy of Mobike is to provide as as possible usage data. Only in cities were the delivery of data is enforced, Mobike is willing to comply. In the Netherlands both Rotterdam and Delft have no regulations in place that enforce making usage data publicly available. An official rejection of the proposal was never retrieved, but the internal policy of Mobike became clear.

Therefor an alternative approach is developed during the research, so that the data can be collected without the permission of Mobike and made publicly available. This approach is derived from how the Mobike app is showing the locations of the bikes on a map in the app. Every bike shown on the map has a unique id (unique within Mobike worldwide). Based on the movement of the bikes on the map trips could be derived. It would not be feasible to collect this data manually with the app, this should be an automated process. An overview of the complete setup described in this section is represented in figure C.1. import_mobike.py is responsible for collecting the data from the Mobike servers and writes the collected data to an database. With extract_trips.py the raw data is converted into trip data that can be consumed by a variety of data analysis tools. In the remainder of this section this process is explained in more detail.

To automate this process exactly the same data as what is shown in the app, should be retrieved and saved in a database. To get this data the same HTTP-call performed by the app should be performed by a software program that collects the data. To derive how the HTTP-call worked the app was reverse engineered with the help of mitmproxy. Mitmproxy is a man-in-the-middle proxy, by routing all the traffic of a phone through this proxy you can exactly see what HTTP-calls are performed by an app, see figure C.2 for a schematic representation of this process.

Based on this proxy the call that showed the most nearby bicycles was found. The api requested consisted of a lat/lon pair for the location and a radius. An example of the response of that call is displayed in listing C.1. For every bike the distId (bike_id), distX (longitude), distY (latitude) were selected to be stored because that was the minimal ammount of data needed to trip analyzes. As an extra value the biketype (reflecting which generation of Mobike the bike is) was stored, at the moment

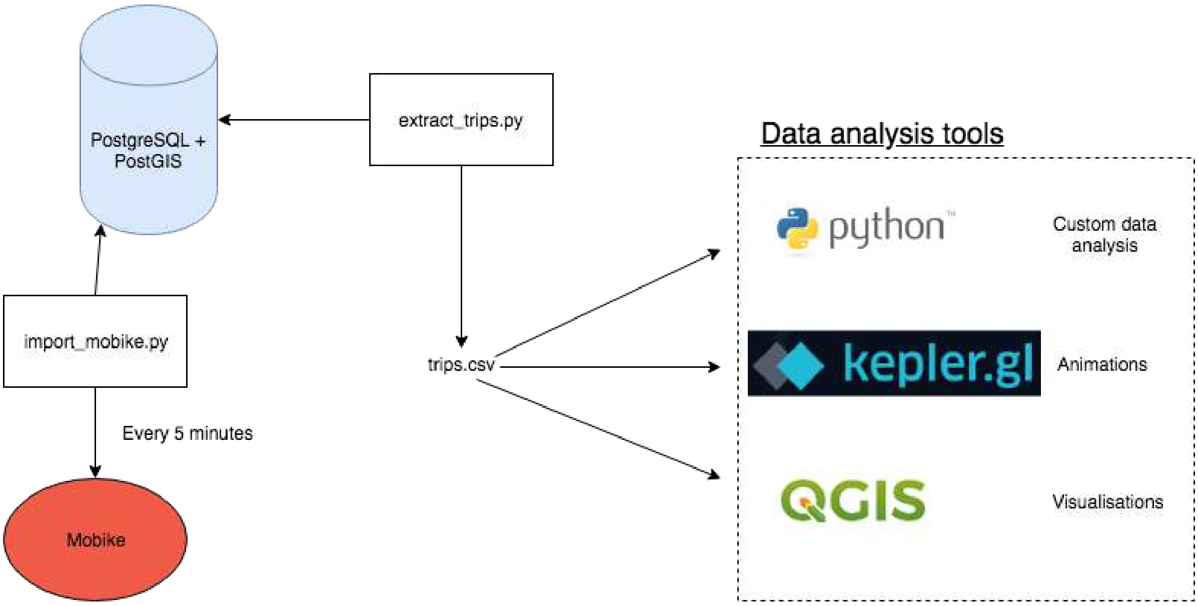

Figure C.1: Overview data collection process

of starting the analysis the only type of Mobike active in Delft was the Mobike 3.0. When new types of bikes are introduced the software is already capable of distinguishing the bikes.

Listing C.1: Example response Mobike server


```
{
"code":0,
"message":"",
"bike":[
    {
        "distId":"A676013702",
        "distX":4.361303,
        "distY":52.000314,
        "distNum":1,
        "distance":"217",
        "bikeIds":"A676013702#",
        "biketype":2,
        "type":0,
        "boundary":null,
        "operateType":2
    },
    {
        "distId":"A676001117",
        "distX":4.362311,
        "distY":52.000392,
        "distNum":1,
        "distance":"247",
        "bikeIds":"A676001117#",
        "biketype":2,
        "type":0,
        "boundary":null,
        "operateType":2
    },
    ..,
    ...
```

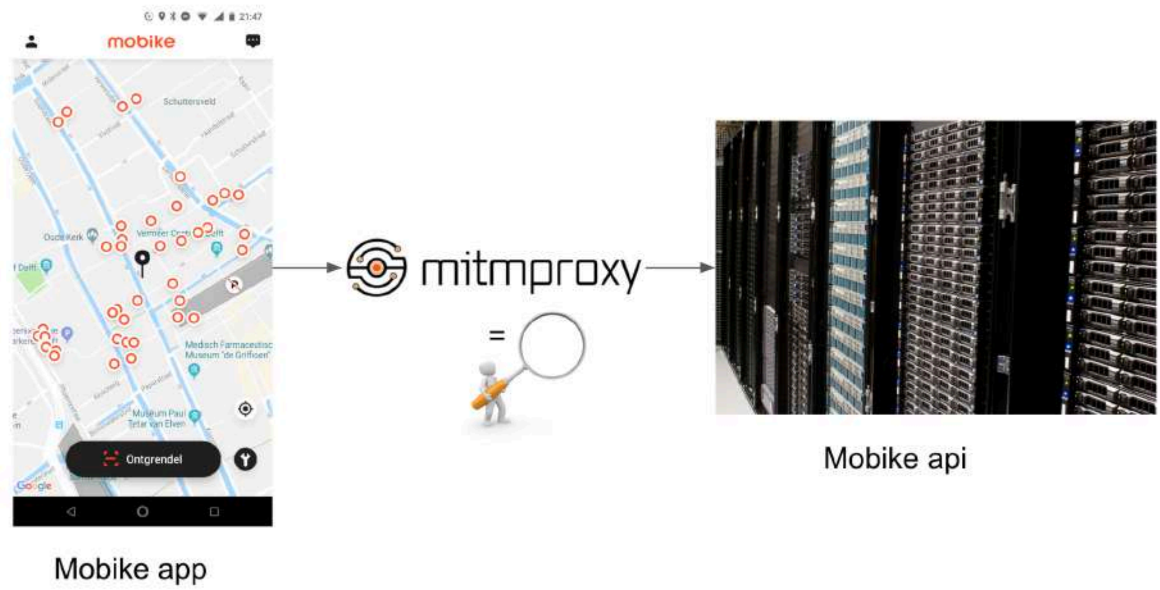

Figure C.2: .


```
],
"biketype":0,
"radius":500,
"autoZoom":false ,
"hasRedPacket":0
}
```


During fiddling around with the api call it appeared that the maximum number of bikes that where returned was 50 and the maximum where withing bikes were returned was 500m. Therefor it was unfortunately not possible to sample with one HTTP-call all the data for the Netherlands. To circumvent this limitation an rectangle grid arround the city of Delft was created, within this grid an HTTP-call every 0.005 degree in latitudal direction and 0.004 degree in longitudal degree was sampled. Additional to that extra samples, with a slight difference in longitudal en latitudal coordinates where performed in areas where there where 50 bikes (the maximum numbers of bikes the api returned) where sampled so that the chance of missing a bike due to that reason is reduced. Figure C.3 is a graphical representation of this sampling strategy. The dimensions of the rectangle are a balance between the time it takes to sample the dataset and the completeness of the dataset.

Every 5 minutes a sample of was made, on average it took 2 minutes and 37 seconds to sample the whole city. Figure C.4 shows the structure wherein the collected data was stored. For every sample a sample record was created with a start_time (the time data collection for sample was started), end_time (the time data collection for sample was endend) and the number_of_bicycles that were detected in the sample. For every bike that was detected in the sample a cycle_measurement record was created containing the sample_id, bike_id, location (lat/lng pair) and the type of bike. The data was stored in a PostgreSQL database with PostGIS extension installed. This database is capable of handling vast amounts of geographical data with good performance.

The source code of the Python software that was used to collect the data is made available, so that the research can easily be repeated for other locations. The software can be found here `https://gist.github.com/sven4all/56bf566e3df3837098962accc2e7dc2a#file-import_mobike-py`.

C.1.1. Trip derivation

To do analyses on the data the raw data should be converted into trips. The first step in the process of deriving trips consists of querying all bike_ids that are detected during a specified period, For every bike

Figure C.3: Example of all sampled locations during one round of sampling.

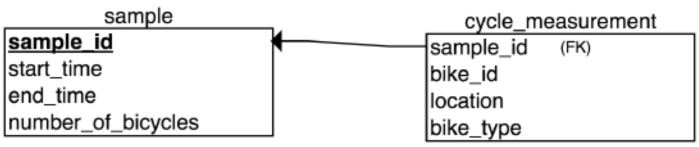

Figure C.4: Database structure used to store samples

all the samples made during the specified period are ordered in chronological order, a small example is shown in figure C.5. When two consecutive samples have a as the crow flies distance longer then 200m the algorithm assumes that the bike made a trip. In figure C.5 is an example of a trip encircled in red, in between those two samples there are 3 samples where the bike was not detected, that's due to the fact that the Mobike app only shows bicycles that are available for rent.

The trips of all the bikes are combined and written to an CSV (comma seperated value) file, this makes it easy to exchange that tripdata with other programs that could be used for analysis, during this research this .csv file was used with QGIS, Python and Kepler. An implemenation for this algorithm that used during this thesis can be found here `https://gist.github.com/sven4all/56bf566e3df3837098962accc2e7dc2a#file-extract_trips-py`, figure C.6 shows an example of output of the algorithm. Every record is a trip containing the bike_id of the bike that has made the trip, the type of bicycle, the start and end location of the trip. And the time that the trip was started and ended.

sample_id	bike_id	latitude	longitude	bike_type
34532	A676013873	51.996308	4.354064	2
34533	A676013873	51.996308	4.354064	2
34534	A676013873	51.996308	4.354064	2
34535	A676013873	51.996308	4.354064	2
34536	A676013873	51.996308	4.354064	2
34537	A676013873	51.996308	4.354064	2
34541	A676013873	52.009931	4.36428	2
34542	A676013873	52.009931	4.36428	2
34543	A676013873	52.009931	4.36428	2
34544	A676013873	52.009931	4.36428	2

Figure C.5: Records of cycle measurement filtered on bike_id and orderered by sample_id

	A	B	C	D	E	F	G	H
1	bikeid	type	start_x	start_y	end_x	end_y	start_trip	end_trip
2	A676001826	2	4,347854	52,007584	4,378792	51,989907	2018-09-13 08:59:20.802744	2018-09-13 09:24:21.140681
3	A676001826	2	4,379041	51,990214	4,364102	52,009248	2018-09-13 17:55:39.113818	2018-09-13 18:15:39.490709
4	A676001826	2	4,364797	52,009044	4,336936	52,010926	2018-09-13 18:30:39.633786	2018-09-13 18:45:39.904923
5	A676013716	2	4,352949	51,995796	4,372868	51,999036	2018-09-13 10:44:22.458682	2018-09-13 10:59:22.669231
6	A676013716	2	4,373929	51,999209	4,353592	51,99632	2018-09-13 12:46:44.757349	2018-09-13 13:06:45.082717
7	A676013716	2	4,353592	51,99632	4,375079	51,989572	2018-09-13 13:11:45.182616	2018-09-13 13:26:45.408756
8	A676013716	2	4,375202	51,989642	4,361461	52,008593	2018-09-13 17:45:38.992886	2018-09-13 18:15:39.490709
9	A676013716	2	4,361413	52,00864	4,369419	52,006004	2018-09-13 19:35:40.795275	2018-09-13 19:45:40.935096
10	A676013716	2	4,369419	52,006004	4,376997	51,995403	2018-09-13 20:20:41.542468	2018-09-13 20:35:41.659608
11	A676013716	2	4,376997	51,995403	4,368192	52,005906	2018-09-13 21:15:42.249574	2018-09-13 21:25:42.421238
12	A676013716	2	4,368192	52,005906	4,37146	51,992466	2018-09-13 22:20:43.230379	2018-09-13 22:35:43.390883
13	A676013716	2	4,371473	51,992525	4,368011	52,00571	2018-09-13 23:40:44.234755	2018-09-14 00:00:44.578455
14	A676013716	2	4,368011	52,00571	4,360523	52,010614	2018-09-14 00:30:44.820123	2018-09-14 00:40:44.998769

Figure C.6: Output of trip derivation algorithm

C.1.2. Validation

The unconvential way of data collection made it necessary to do a validation of the dataset before it is possible to derive any conclusions from this data set. In this section the validation is described and some limitations of the approach used are discussed.

The first step in validating the data was verifying if every bike that was on the street appeared in the data. To do this validation 60 observations of bicycles were performed. For every bike the QR-code was scanned (with the bike_id) or a picture of the bike_id on the frame was taken (C.7). After collecting all the observations it was validated if the bicycle was at the same moment also on that location in the collected data, the results of that was an 100% correct coverage. This was an important first step in validating the correctness of the approach.

Figure C.7: Framenumber on Mobike

The data was also validated against some performance indicators used that originated from a internal Mobike dashboard. With this dashboard it was possible to compare the number of trips and the number of bikes available. Another way of validating the data was during the deployment of new mobikes. A list of the bike_ids that were deployed was available, every time new bike's were deployed within one day all of those bike_ids appeared in the data.

Officialy the operation area (the area where within bikes should be returned) is completely within the rectangle, but there are always users that don't comply with those rules and park their bikes outside of this area. That is the reason why not 100% of all the trips can be covered with this approach. Another problem is that with the sampling approach bikes that are moved by street operations also are registered as trips, because a trip is detected solely on displacement for a distance for more then 200m. This numbers of moved bicycles is relatively small (maximally 20-30 per day) therefor this effect has only a small impact on the data.

C.2. Data analysis

In this section the data analysis tools that are used during this thesis are discussed. The precise analysis that were performed are discussed in a later chapter because the analysis that are performed are based uppon the definition of the quality performance indicators.

For exploration of the data Kepler and QGIS 3 are used to get an quick overview of all the data. For more specific analysis, for example the calculation of indicators and plotting of graphs Python 3 incombination with the Pandas, Geopandas, Matplotlib en Numpy libraries is used. To draw areas of specific interests QGIS is used what exported shapes files that could be easily imported in Python to do further analysis.

For the data analysis two representive periods of each 3 weeks were selected. This made it possible to compare the data between different periods. The first period were the last 3 weeks of June (11 June until 2 July), that period was during the final weeks of the academic year. The second period was the last week of august and the first two weeks of september (27 August until 16 September). That was during the last week of the holliday and the first two weeks of the academic year. Just befor the second period the number of bicycles was increased due to the start of a new college year. Therefor a comparisson between this two periods is extra interesting when looking at the number of trips per bicycle and deteroriation that the bicycles causes.

D

Results of both periods

D.1. Role in sustainable mobility

D.1.1. OD matrix

Origin/destination	Station Delft	Centrum	TU Campus	Science Park Zuid	Station Delft Zuid	Voorhof	Buitenhof	Hof van Delft	Other	Total
Station Delft	0.1	1.1	2.7	0.3	0.1	1.0	0.3	0.5	1.2	7.2
Centrum	1.1	6.1	6.7	0.2	0.1	1.6	0.3	1.1	4.1	21.3
TU Campus	2.7	8.1	9.4	0.4	0.6	4.8	0.8	1.2	4.3	32.2
Science Park Zuid	0.3	0.2	0.4	0.1	0.6	0.3	0.0	0.0	0.2	2.1
Station Delft Zuid	0.1	0.2	0.7	0.6	0.0	0.4	0.1	0.0	0.2	2.2
Voorhof	0.9	1.3	5.1	0.3	0.4	3.3	0.6	0.4	1.3	13.5
Buitenhof	0.2	0.2	1.0	0.0	0.1	0.5	0.3	0.1	0.4	2.8
Hof van Delft	0.4	0.9	1.1	0.0	0.1	0.4	0.1	0.4	0.5	4.0
Other	1.3	3.3	5.0	0.2	0.3	1.3	0.3	0.4	2.7	14.7
Total	7.2	21.3	32.1	2.1	2.2	13.4	2.8	4.1	14.8	

Figure D.1: percentage based OD-matrix for period between 11 June 2018 and 01 July 2018

Origin/destination	Station Delft	Centrum	TU Campus	Science Park Zuid	Station Delft Zuid	Voorhof	Buitenhof	Hof van Delft	Other	Total
Station Delft	0.1	1.0	3.5	0.2	0.0	0.9	0.3	0.4	1.1	7.6
Centrum	1.2	6.2	6.4	0.1	0.1	2.1	0.6	1.1	4.3	22.0
TU Campus	3.5	7.9	9.6	0.2	0.6	5.0	1.2	0.8	3.4	32.2
Science Park Zuid	0.2	0.1	0.3	0.0	0.3	0.1	0.0	0.0	0.2	1.2
Station Delft Zuid	0.0	0.0	0.7	0.4	0.0	0.4	0.1	0.0	0.2	1.9
Voorhof	0.9	1.8	4.8	0.1	0.4	3.2	0.9	0.5	1.3	13.8
Buitenhof	0.3	0.4	1.7	0.0	0.1	0.6	0.4	0.0	0.3	3.7
Hof van Delft	0.5	0.9	1.0	0.0	0.0	0.4	0.1	0.4	0.5	3.7
Other	1.2	3.7	3.9	0.1	0.3	1.2	0.3	0.5	2.8	14.1
Total	7.7	22.0	31.9	1.2	1.7	13.9	3.8	3.8	14.1	

Figure D.2: percentage based OD-matrix for period between 27 August 2018 and 16 September 2018

Origin/destination	Station Delft	Centrum	TU Campus	Science Park Zuid	Station Delft Zuid	Voorhof	Buitenhof	Hof van Delft	Other
Station Delft	0.0	-0.1	0.8	-0.1	-0.1	0.0	0.0	-0.1	-0.1
Centrum	0.0	0.1	-0.3	-0.1	0.0	0.5	0.2	0.0	0.2
TU Campus	0.8	-0.3	0.3	-0.2	0.0	0.3	0.3	-0.4	-0.9
Science Park Zuid	-0.1	-0.1	-0.2	0.0	-0.3	-0.2	0.0	0.0	-0.1
Station Delft Zuid	-0.1	-0.1	0.1	-0.2	0.0	0.0	0.0	0.0	0.0
Voorhof	0.0	0.6	-0.3	-0.2	0.0	-0.1	0.3	0.1	0.0
Buitenhof	0.0	0.1	0.7	0.0	0.0	0.1	0.1	0.0	-0.1
Hof van Delft	0.0	0.0	-0.1	0.0	-0.1	-0.1	-0.1	0.0	0.0
Other	-0.1	0.4	-1.1	-0.1	0.0	-0.1	0.1	0.1	0.1

Figure D.3: Difference percentage point period 27 August 2018 and 16 September 2018 minus period between 11 June 2018 and 01 July 2018

□

D.1.2. Average length of trips

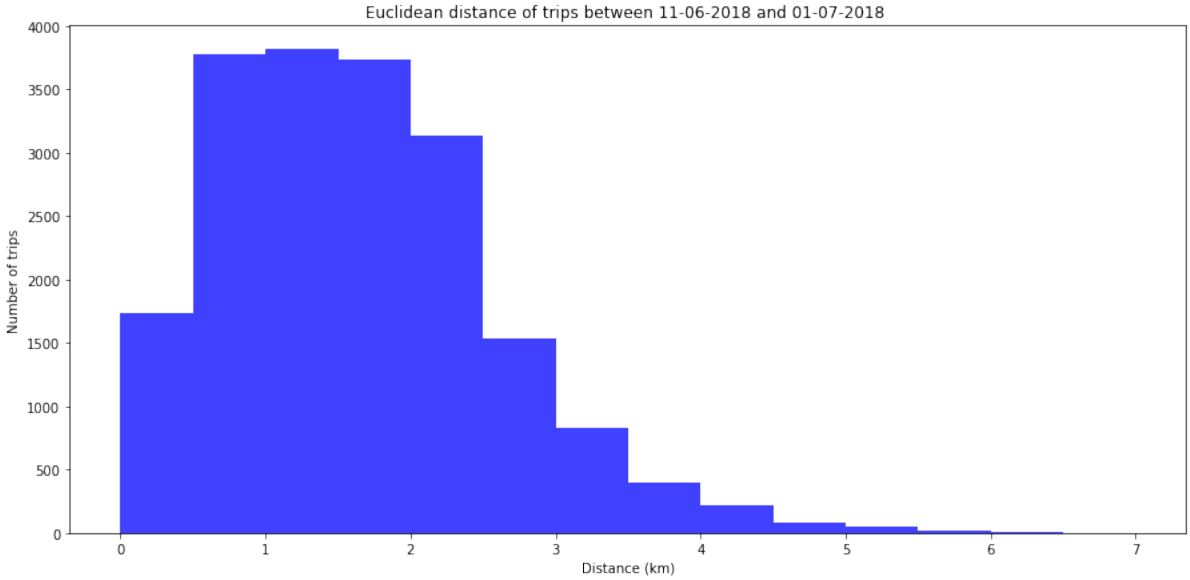

Figure D.4: Average trip length between 11 June 2018 and 01 July 2018

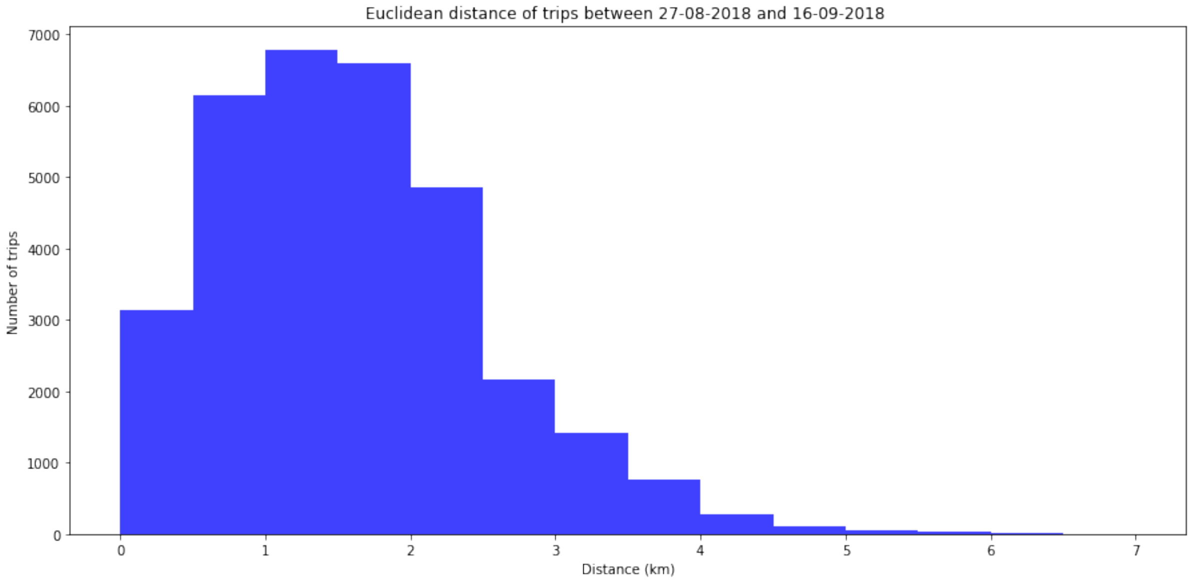

Figure D.5: Average trip length between 27 August 2018 and 16 September 2018

□

D.1.3. Special days

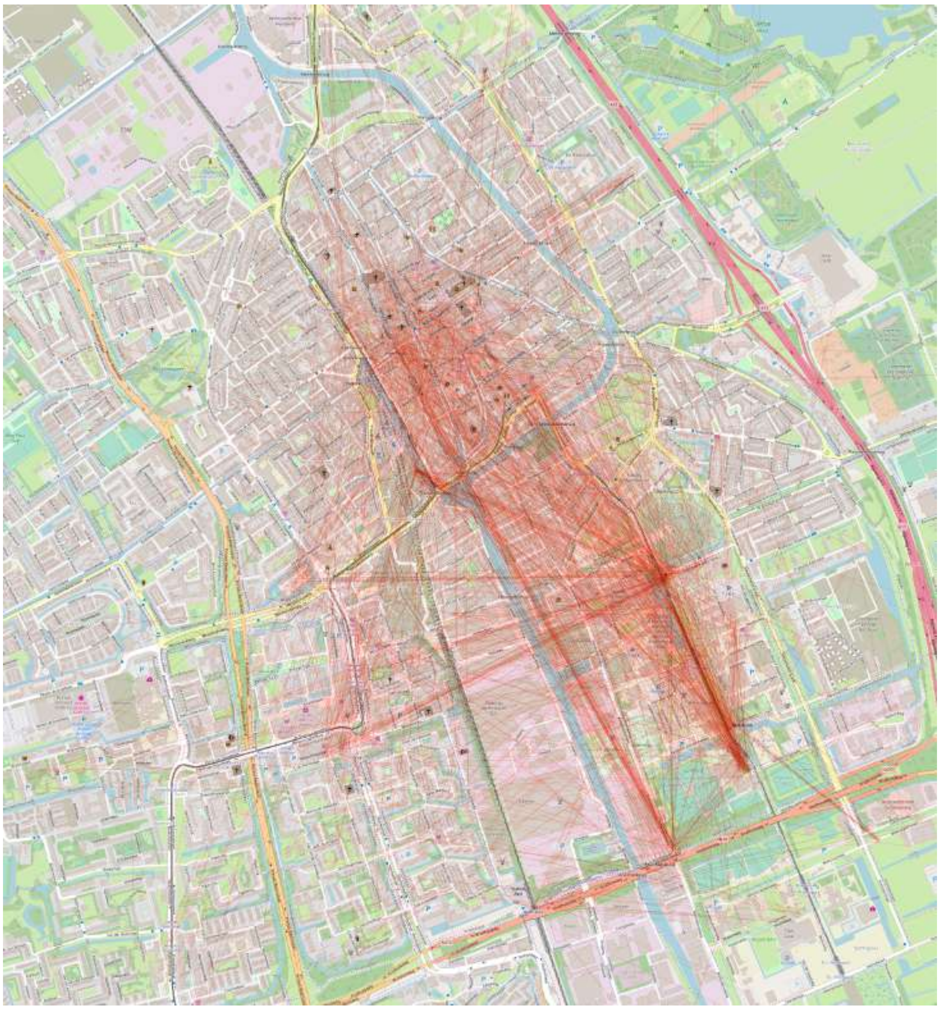

Figure D.6: Trips Mobike Delft 22 augustus 2018

Origin/destination	Station Delft	Centrum	TU Campus	Science Park Zuid	Station Delft Zuid	Voorhof	Other	Total
Station Delft	0	0.53	1.35	0.12	0	0.53	1.06	3.59
Centrum	0.9	9.34	7.21	0.12	0	2.7	7.7	27.97
TU Campus	1.43	10.44	11.88	0.2	0.29	3.69	5.98	33.91
Science Park Zuid	0.53	0.12	0.45	0	0.08	0.12	0.49	1.79
Station Delft Zuid	0	0	0.41	0.25	0	0.16	0.16	0.98
Voorhof	0.25	2.46	4.18	0.12	0.2	1.72	2.38	11.31
Other	0.94	6.67	5.49	0.45	0.16	2.01	4.71	20.43
Total	4.05	29.56	30.97	1.26	0.73	10.93	22.48	

Figure D.7: OD-matrix based on percentages based on the data of 22 augustus 2018

Origin/destination	Station Delft	Centrum	TU Campus	Science Park Zuid	Station Delft Zuid	Voorhof	Other	Total
Station Delft	0	0.81	2.29	0.3	0.07	1.03	2.44	6.94
Centrum	0.52	5.83	4.36	0.07	0	2.14	7.53	20.45
TU Campus	2.22	6.2	6.5	0.22	0.22	4.14	6.06	25.56
Science Park	0.22	0.15	0.3	0.15	0.22	0.07	0.66	1.77
Station Delft	0	0	0.52	0.52	0	0.37	0.37	1.78
Voorhof	0.89	1.03	5.39	0	0.37	4.06	3.91	15.65
Other	1.03	5.54	8.57	0.52	0.66	3.4	8.12	27.84
Total	4.88	19.56	27.93	1.78	1.54	15.21	29.09	99.99
Station Delft	0	11	31	4	1	14	33	94
Centrum	7	79	59	1	0	29	102	277
TU Campus	30	84	88	3	3	56	82	346
Science Park	3	2	4	2	3	1	9	24
Station Delft	0	0	7	7	0	5	5	24
Voorhof	12	14	73	0	5	55	53	212
Other	14	75	116	7	9	46	110	377
Total	66	265	378	24	21	206	394	1354

Figure D.8: OD-matrix based on percentages and absolute numbers for 28 augustus 2018

D.1.4. Usage over time

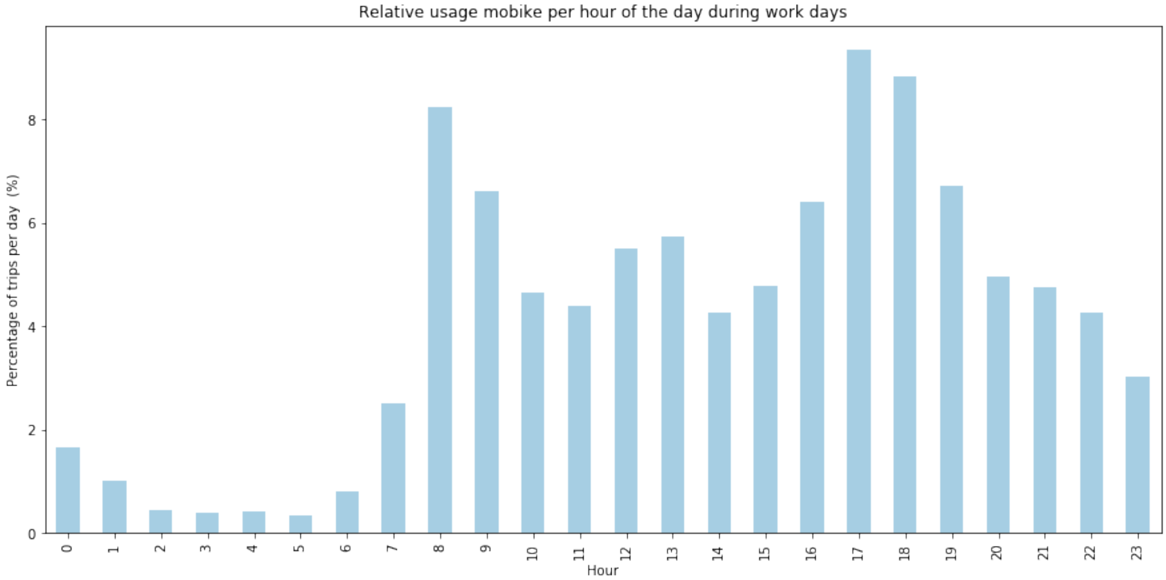

Figure D.9: The trips are started during working days between 11 June 2018 and 01 July 2018

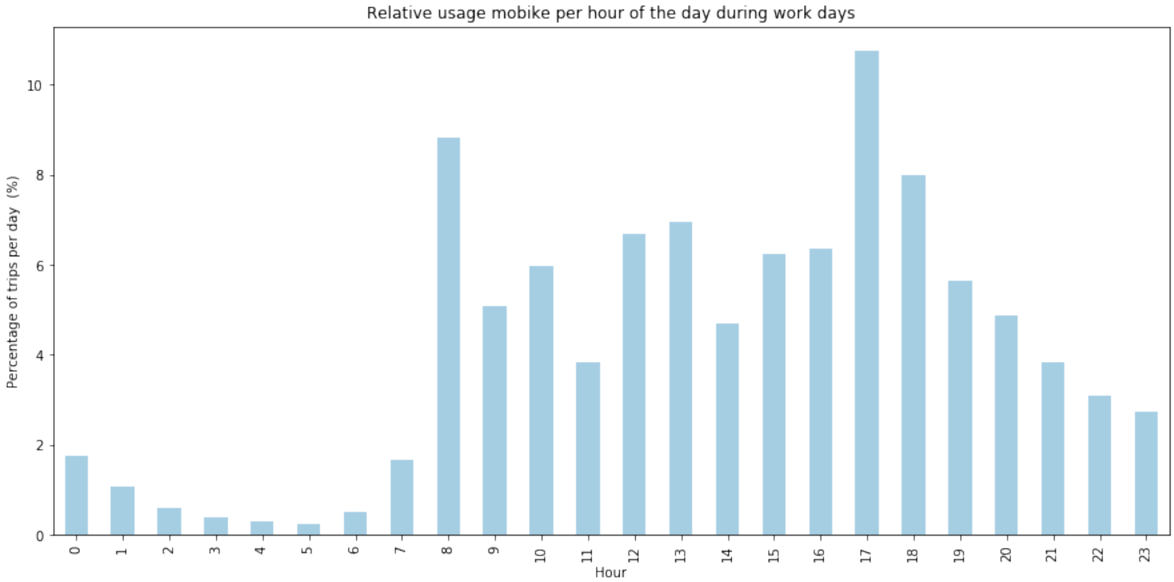

Figure D.10: The trips are started during working days between 27 August 2018 and 16 September 2018

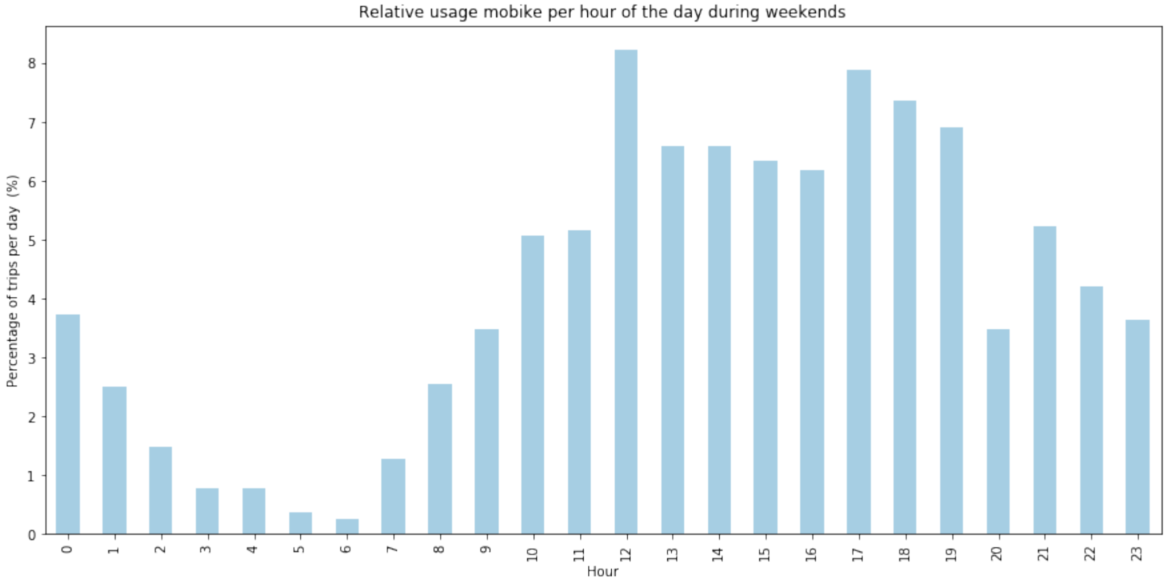

Figure D.11: Relative usage Mobike per hour of the day during work days between 11 June 2018 and 01 July 2018

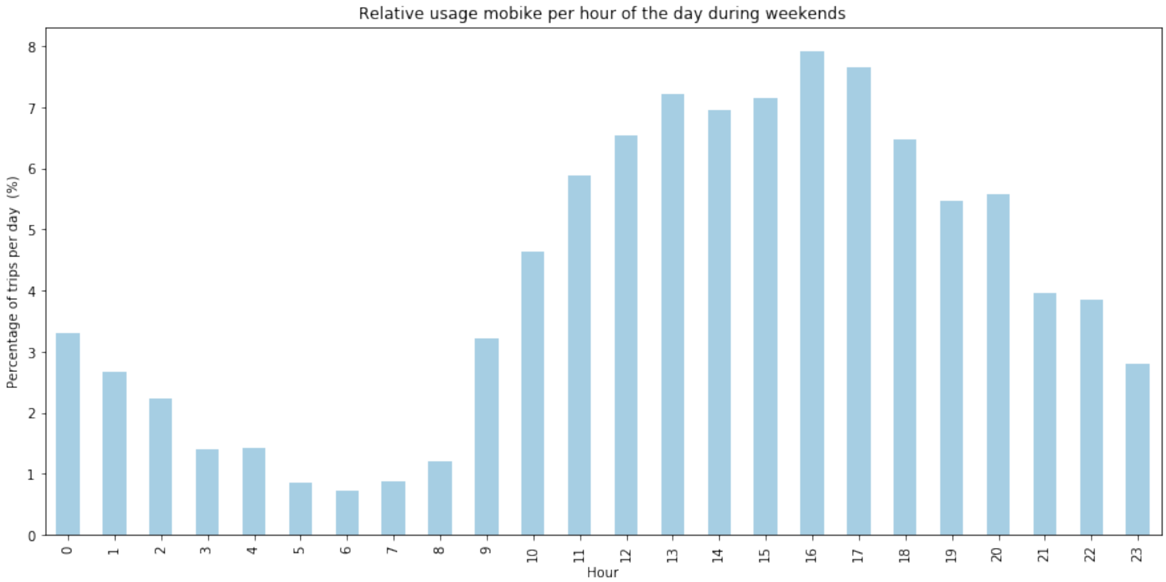

Figure D.12: Relative usage Mobike per hour of the day during work days between 27 August 2018 and 16 September 2018

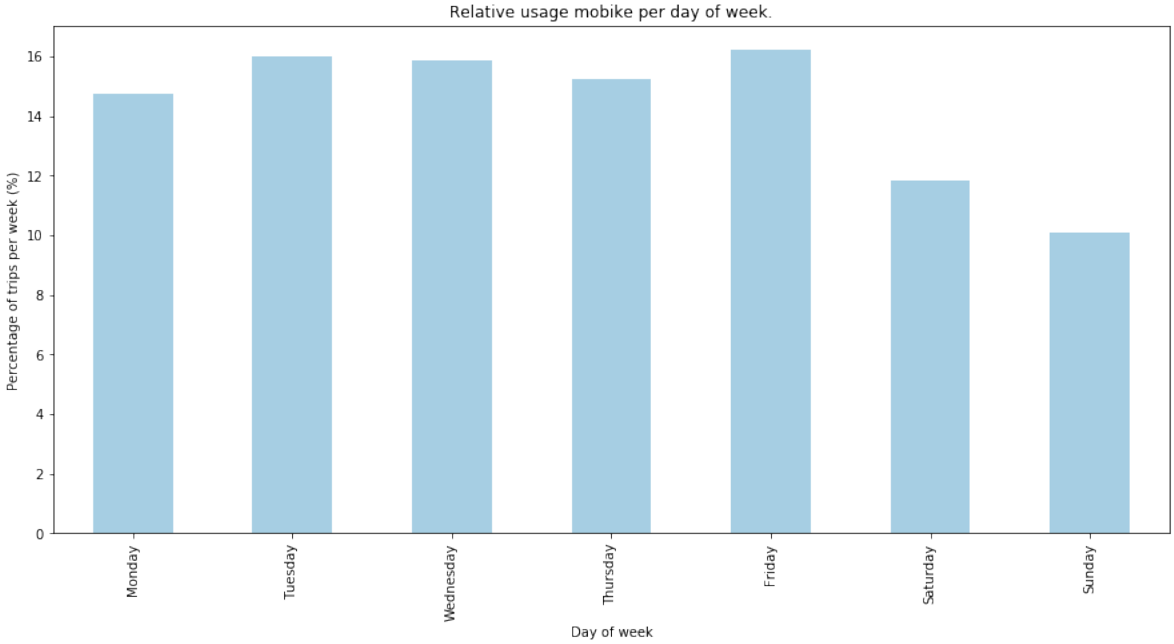

Figure D.13: Relative usage Mobike per hour of the day during weekends between 11 June 2018 and 01 July 2018

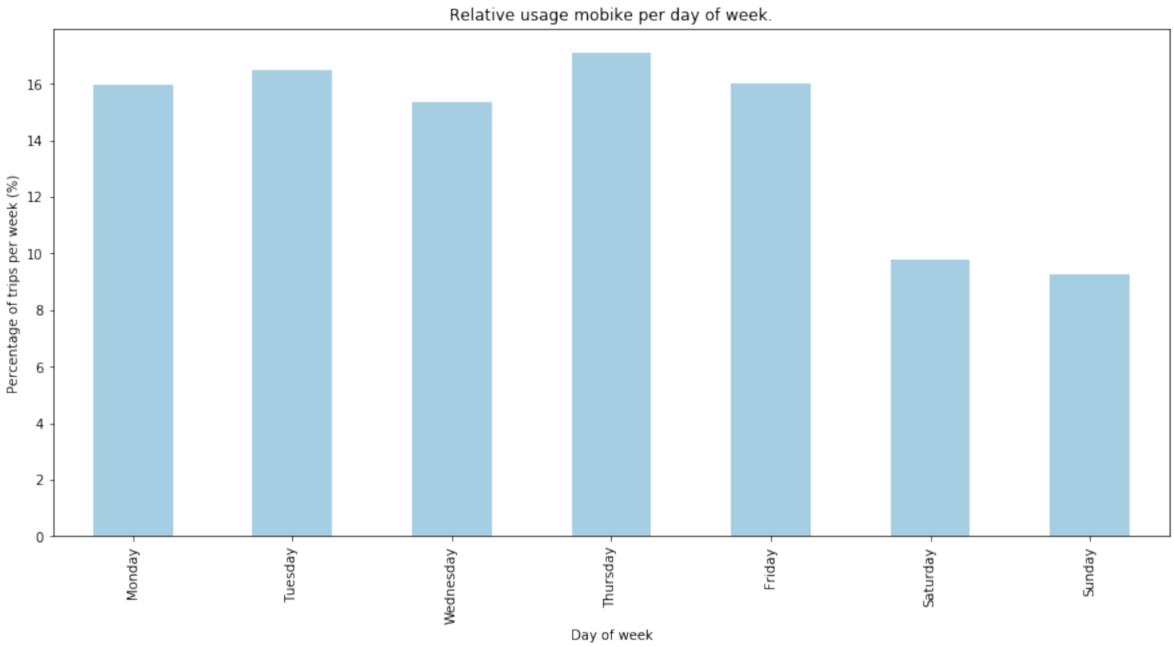

Figure D.14: Relative usage Mobike per hour of the day during weekends between 27 August 2018 and 16 September 2018

D.2. Efficient use of public space

Table D.1: Usage characteristics

Key characteristics		
	11-06 until 01-07	***27-08 until 16-09***
Detected bicycles	647	994
Active bicycles (bicyles that made at least one trip)	627	956
Total number of trips	18737	32339
Average number of trips per day per bicycle	1,4	1,6

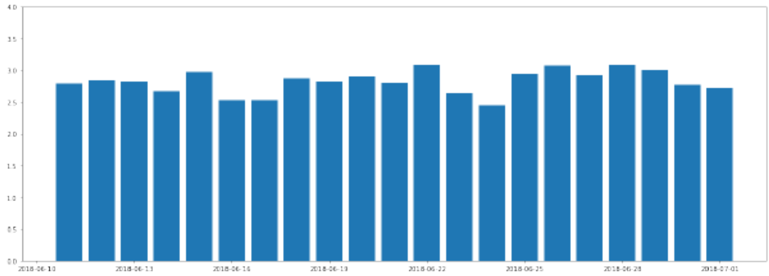

Figure D.15: Average number of trips per day per bike that made at least one trip on specified date 11 June 2018 and 01 July 2018

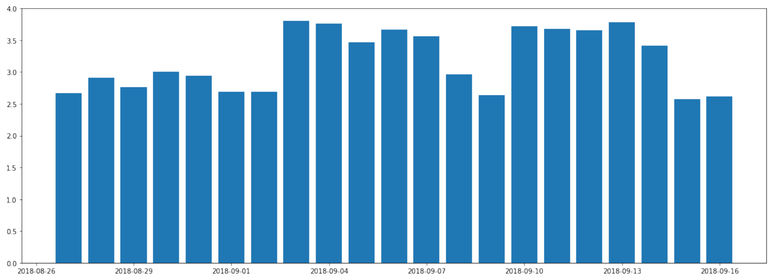

Figure D.16: Average number of trips per day per bike that made at least one trip on specified date over period 27 August 2018 and 16 September 2018

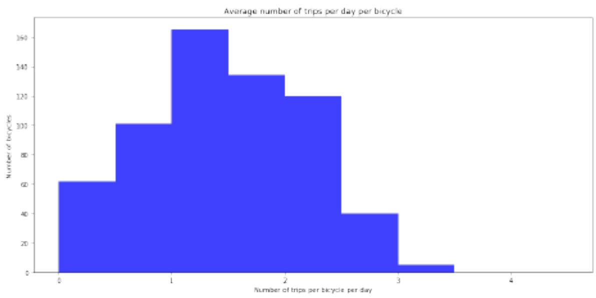

Figure D.17: Average number of trips per day per bike over period 11 June 2018 and 01 July 2018

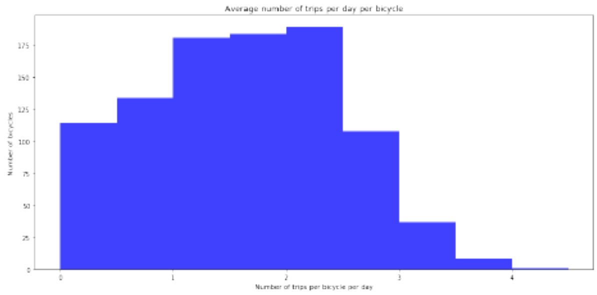

Figure D.18: Average number of trips per day per bike over period 27 August 2018 and 16 September 2018

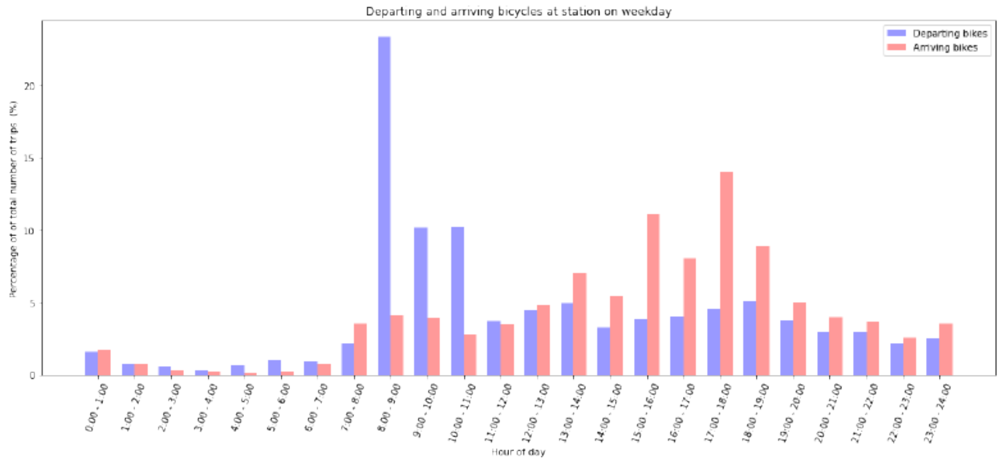

Figure D.19: The share of arriving and departure trips per hour of day on weekdays in the period 27 August 2018 and 16 September 2018

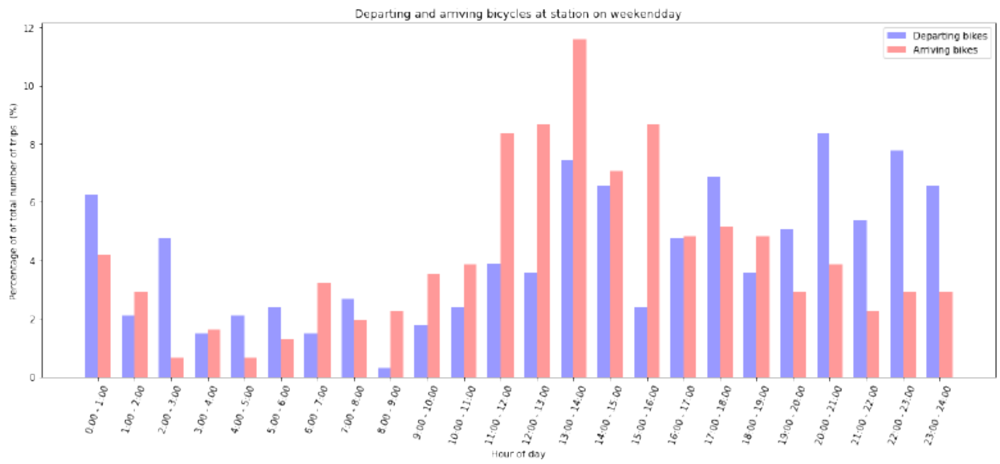

Figure D.20: The share of arriving and departure trips per hour of day on weekenddays in the period 27 August 2018 and 16 September 2018

Table D.2: Amount of times individual bicycles are not used for period longer then

Number of times a bicycle is not used for period longer then:		
	11-06 until 01-07	***27-08 until 16-09***
>= 24 hours	2004	2653
>= 48 hours	916	1147
>= 72 hours	504	637
>= 5 days	182	242
>= 7 days	73	109
>= 14 days	2	5
Key characteristics		
Detected bicycles	647	994
Active bicycles (bicyles that made at least one trip)	627	956
Total number of trips	18737	32339
Average number of trips per day per bicycle	1,4	1,6

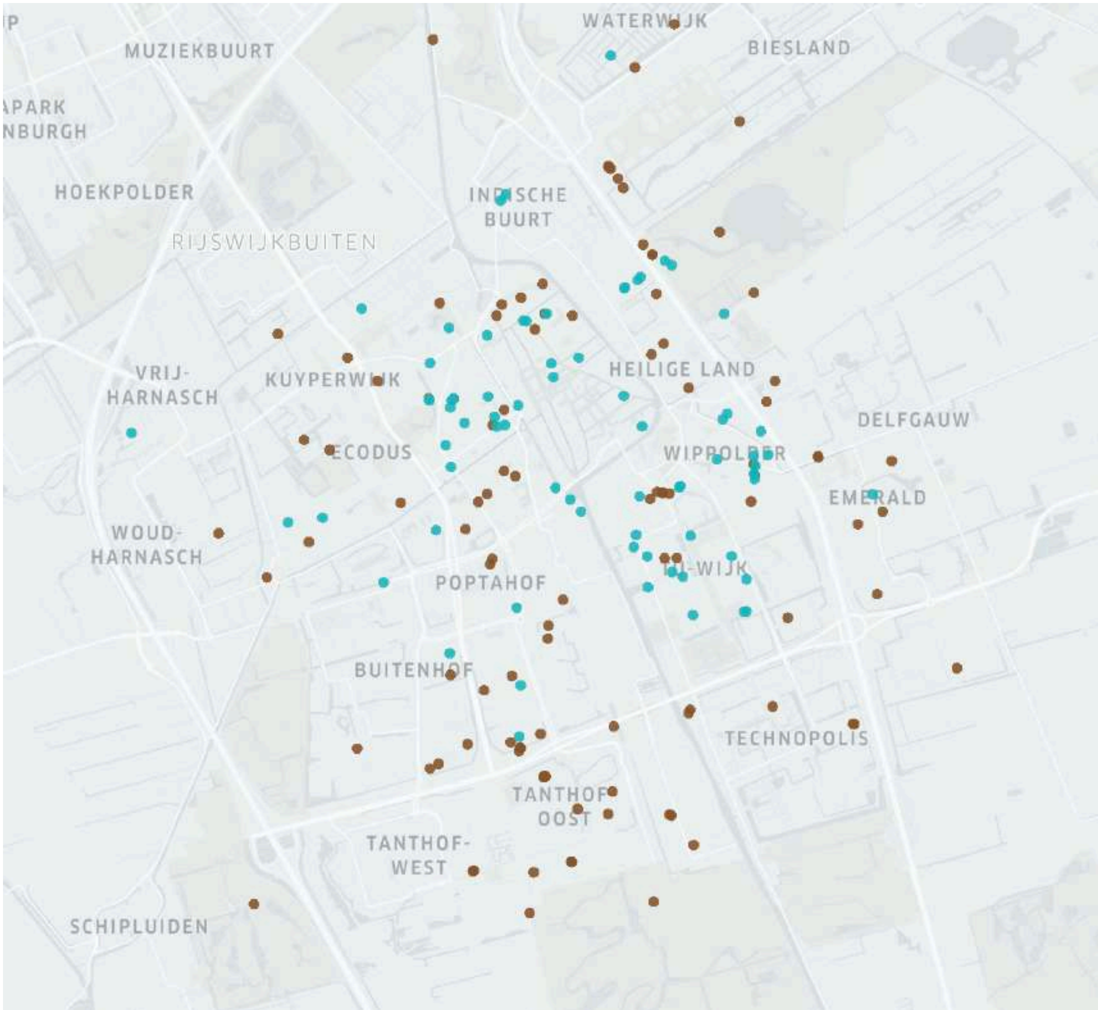

Figure D.21: Locations where bikes where parked for period longer then 7 days, blue (11-07-2018 until 01-07-2018), brown (27-08-2018 until 16-09-2018)

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