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Potential of peer-to-peer bike sharing for relieving bike parking capacity shortage at train stations: an explorative analysis for the Netherlands

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In the Netherlands, many (mainly larger) train stations suffer from capacity shortages for bicycle parking as the result of a large increase in the use of the bicycle as a feeder mode. Sharing of parked bicycles with arriving train passengers who are in need of a bicycle for some time would decrease the number of parked bicycles and reduce the capacity shortage. The paper explores to which extent sharing of these bicycles relieves the capacity problem by investigating the maximum potential for reducing the peak of parked bicycles. This is the potential of the case when all considered participants (bicycle owners and those who are in need for a bicycle) are willing to share. The analyses are based on data of the Dutch National Travel Survey. The main result is that the potential is likely to be modest. The estimated maximum is for the large stations between 13% and 50%, the actual potential is likely to be significantly lower. The large range for the maximum can partly be explained by the uncertainty about the number of arriving train passengers that might shift to the bicycle for the last mile if sharing increases bicycle availability. A second result is that sharing can have a significant effect on the distribution of parked bicycles over the day. The current peak halfway the day can turn into a dip between two peaks in the traditional morning and evening peak hours.

Keywords: *access/egress, bicycle parking, capacity, railway station, the Netherlands.*

1. Introduction

The Netherlands have a long standing bicycle culture. The percentage of trips made by bicycle, 27%, is the highest in the western world (Pucher and Buehler, 2008). Moreover, this percentage has been stable for decades despite a number of adverse trends, like ageing of the population, increased car ownership, and a tendency to travel larger distances (Van Goeverden et al, 2013). Permanent support by authorities since the 1970s contributed to the stability. Initially, bicycle promotion was driven by the national government who financed (part) of some large urban cycle projects and launched a Masterplan Bicycle; the main aim was to create knowledge on cycling issues for promoting cycling by local authorities. This was effective; bicycle promotion shifted to a local level and became an essential ingredient in local transport plans (Van Goeverden et al, 2015).

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Other countries become increasingly aware of the merits of the bicycle. The bicycle relieves traffic problems regarding congestion and sustainability, and cycling contributes to peoples fitness and health (Oja et al, 1998, Cavill et al, 2008). Moreover, the bicycle provides mobility to people who are not allowed or cannot afford to drive a car. A shift to the bicycle is advocated by a number of European countries (ECMT, 2004), the United States (U.S. Department of Transportation, 2010, Pucher and Buehler, 2009), and by other regions in the world (Australian Government, 2013, Medeiros and Duarte 2014). In China, where bicycle use decreased significantly since the late 20th century, the negative trend is being reversed as the result of the introduction of the e-bike, shared bike systems, and a shift in local policies from adverse to promoting (Zhang et al, 2014, Zhao and Li, 2017). Bicycle sharing programs in cities all over the world are booming (Fishman et al, 2014). The bicycle is particularly a convenient and relatively fast mode in cities. Van Goeverden et al (2013) show that in the Netherlands residents of urban areas are more inclined to use the bicycle than those living in the countryside, with the exception of the largest cities where trips can have longer distances and a high quality public transport is provided. Still, the cases of Amsterdam and Copenhagen demonstrate that also in large cities a high bicycle share can be achieved by active bicycle promoting and car restricting policies. In both cities the bicycle market share is 32% (IAmsterdam and Capital City of Denmark, 2014).

The bicycle is in the Netherlands not only important as the main mode for trips, but also as a feeder mode to public transport. In contrast to the stable market share as the main mode, bike use for accessing public transport nodes is increasing. Figure 1 shows the trend of the number of annual bicycle access and egress trips to/from railway stations in the Netherlands in the period 1980-2015. The increase was about 3% per annum and has three components:

- Population growth; comparison of population statistics with the growth of access and egress trips by bike proves that 21% of the latter is explained by this component.
- Increase of train ridership per capita; exploring the data of the Dutch National Travel Survey (NTS) that also made up Fig. 1, the increase explains 53% of the growth.
- Increase of the share of the bicycle in access and egress trips; this explains the remaining 26% of the growth. The bicycle share increased from 32% to 42% at the home-end of trips, and from 7.5% to 11% at the activity-end of trips (NTS data).

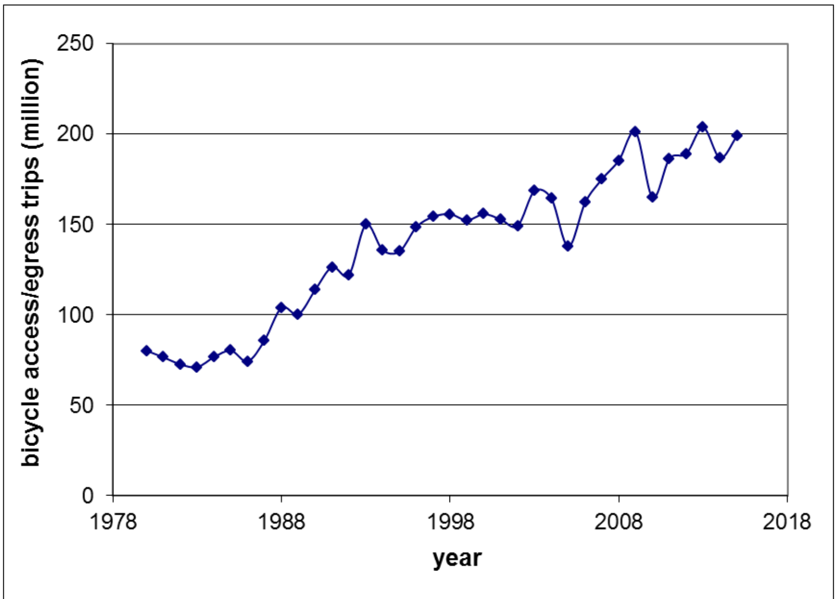

Figure 1. Development of access/egress trips by bicycle to/from Dutch railway stations; source: microdata of the Dutch NTS

The strong increase of bicycle use in access to railway stations caused serious capacity shortages for bicycle parking at particularly the larger railway stations. Large efforts have been made and still are made to increase the capacity at many stations. The number of parking places at the Dutch train stations increased from 183,000 in 1985, to 279,000 in 1999 (Martens, 2007), and to about 450,000 in 2016 (NS, 2017). It is envisaged to be enlarged to 500,000 (Maat et al, 2012). The growth regards predominantly non-guarded places and bicycle lockers. A further increase in train ridership is expected (Ministerie van Infrastructuur en Milieu, 2017) which will be resulting in a still higher demand for bicycle parking places. Therefore the planned extension of the parking capacity might not be sufficient to solve the capacity problems. With growth of cycling worldwide, other countries may be facing the same problem in due time. In the US, bicycle-transit integration is generally increasing (Pucher and Buehler, 2009, Wang and Liu, 2013), in China the increase of public bike sharing "represents an important step towards integrating the bicycle with bus, metro, and rail systems" (Zhang et al, 2014).

In this paper we are proposing a possible strategy for tackling the capacity shortage through the sharing of bicycles that are parked at the stations. These bicycles are most of their time idle with no other usage much like in the case of the cars in a parking lot. If bicycles that are parked by the owners for a certain period of time at a station are available for arriving train passengers who are in need of a bicycle for a period that ends before the owners need their bicycle again, the number of parked bicycles would decrease and the capacity shortage could be reduced. The only possibility to share a bicycle in the Netherlands for the last mile stage of a train journey is renting a bike at a train station. Renting became cheaper and simpler by the introduction of OV-fiets (public transport bike) in 2003, a facility that is available for members of OV-fiets. OV-fiets will have contributed to the strong increase of bicycle use at the activity-end of train trips. The number of bicycles rented via OV-fiets increased from 100,000 in 2004 to 2.4 million in 2016 (Wikipedia).

The system that we are proposing to study can be classified as a peer-to-peer bike sharing system. The concept of shared mobility is mostly connected to a fleet of vehicles (bicycles or cars) owned by a company being shared by a group of clients. These systems like the OV-fiets and GreenWheels in the Netherlands have been improving the seamless traveling in public transport (Shaheen and Chan, 2016, Liang et al, 2016, Jorge and Correia, 2013). The concept of peer-to-peer car sharing entails car owners temporarily renting their personal automobiles to others in their surrounding area therefore lowering the costs of auto ownership (Ballús-Armet, et al, 2014). There are several active systems like in San Francisco or Paris. To the best of the authors' knowledge there are only a few experimental start-ups being launched on anonymous peer-to-peer bikesharing systems around the world, at least formally organized as such. One example is the platform CYCLE.LAND which was launched in 2016 and has been experiencing a fast growth (Coleman, 2016). Despite these start-ups no research can be found on this topic. In this paper we contribute with a first analysis on how peer-to-peer bike sharing could be used in the context of first and last mile connection of train trips.

The aim of the paper is to explore the potential of this peer-to-peer bicycle sharing in reducing the number of parked bicycles and therefore relieving the capacity shortage. The analysis regards the Dutch case and is based on data of the Dutch NTS. We will not look at the business model of such peer-to-peer system which would have to be developed at a following stage. In contrast, we provide evidence for its usefulness in bicycle mobility management, particularly in big cities, thus adding to the literature on the important topic of mobility sustainability.

The paper is structured as follows. Section 2 describes the set-up of the study and defines some key concepts. In Section 3 the data are explained and some problems of applying the data for the analyses are discussed. The results regarding the potential for reducing the demand for parking places are presented and discussed in Section 4. Finally, Section 5 gives the main conclusions.

2. Study set-up and definitions

We define the potential of bike sharing for relieving the capacity problem at a railway station as the percentage decrease of the daily peak in bicycle parking as a result of sharing. E.g., a potential of 40% means that the peak of parked bicycles as well as the demanded capacity will be reduced by 40%. The potential can differ for different stations, which means that there could be as many different measures of the potential as there are stations (about 400 in the Netherlands). In the paper we do not intend to estimate the potential for all individual stations, but to get an idea of the order of magnitude for particularly the main stations in the larger cities where capacity problems are most severe.

Peer-to-peer bike sharing in access/egress trips means that bicycles that are parked at railway stations by persons who used them as an access mode to the station are available for arriving train passengers who want to use a bicycle during the day. Three types of bicycle users (or potential bicycles users) are defined:

- Bicycle supplier: this is someone who uses the bicycle as an access mode to the train station, continues the trip by train, returns later at the same day by train, and uses the bicycle for the egress trip. Bicycle suppliers generally start the first trip at home, but they can also start at another location (e.g. work address for a business visit).
- Bicycle demander: this is someone who arrives by train at a station, is using a bicycle for the egress trip, returns later at the same day by bicycle at the station, and continues the trip by train. These persons will also be indicated as *actual* bicycle demanders to distinguish them from the *potential* demanders that are explained next.
- Potential bicycle demander: this is someone who arrives by train at a station, makes an egress trip on a cycling distance, but uses another mode, returns later at the same day at the station (not by bicycle), and continues the trip by train. We define a cycling distance for these users between 1 km and 10 km. Outside this interval the bicycle is not considered as a feasible alternative.

Some groups of bicycle users are excluded from the analyses, partly because of data limitations. These are a) suppliers that park their bicycle for successive days and demanders that need a bicycle for successive days, b) suppliers and demanders that use a bicycle as an access/egress mode to another public transport mode (bus, tram, metro) that stops at the train station, and c) suppliers and demanders aged < 14 years. The two latter groups are marginal compared to all suppliers and demanders at train stations and exclusion will hardly affect the results, the first group is significant.

It is assumed that everyone who uses the bicycle as an access mode to the station parks the bicycle at the departure station, and that every demander who uses a bicycle for the egress trip uses a bicycle that was parked at the arrival station. Reality is slightly different. Sometimes persons go by bicycle to the railway station, take the bicycle with them in the train, and use the same bicycle for the egress trip. Their number is relatively small. Yearly 600,000 tickets are sold for bicycle transport by train in the Netherlands ('Fiets mee in de trein', 2013; the tickets are valid for a whole day); these make up less than 1% of the suppliers and 3-4% of the actual demanders.

Another assumption is that demanders have no preferences for certain bicycles. Still, such preferences will exist. One can conceive that, for instance, women will dislike riding a gents' bike and adults will dislike riding a child's bike. The problem of assigning a child's bike to an adult or the other way around is simply solved by the exclusion of children from the analysis. Gender preferences lower the potential of bike sharing somewhat. This is discussed in Section 4.6.

The analysis of the potential of bicycle peer-to-peer sharing will be performed for the two scenarios: actual bicycle users only, and actual and potential users together. A possible reason for potential users not to be using the bicycle is that they have no bicycle available for their egress trip. Bicycle sharing may increase the availability of bicycles for the last mile and tempt potential users to shift to the bicycle.

In the case of bicycle sharing, a bicycle demander takes a bicycle that is parked at the station by a supplier and returns the bicycle before the supplier needs it again. Figure 2 illustrates the time process of sharing. The first event is the arrival by the supplier at t_{s1}. He/she parks the bicycle and continues the journey by train. At t_{d1} the demander arrives by train and takes the parked bicycle for the last mile. He/she returns at t_{d2}, parks the bicycle and continues the journey by train. The supplier returns by train at t_{s2} and continues the journey by bicycle. There are two parking periods of the bicycle: t_{s1}- t_{d1}, and t_{d2}- t_{s2}. If there was no sharing, the bicycle would have been parked between t_{s1} and t_{s2}. And if the demander is an actual demander, he/she would have used another bicycle. This is in most cases a private bicycle that would have been parked from the beginning of the day to t_{d1} and parked again from t_{d2} to the end of the day. If he/she rented a bicycle, it could have been used by another demander earlier or later in the day.

Supplier and demander might agree that the suppliers' bicycle is available for the demander after a certain time t_{min} ($t_{d1} \geq t_{min}$) that is somewhat later than the general or planned arrival time t_{s1}; and that it should be returned before a later time t_{max} ($t_{max} \geq t_{d2}$) that is somewhat before t_{s2}. This would offer some flexibility to the supplier; he/she has then the opportunity to arrive somewhat later than planned on the outward trip, and arrive somewhat earlier than planned on the return trip and still has the bicycle available. The time periods t_{s1}- t_{min} and t_{max}- t_{s2} are buffer times; these are indicated as the before and after buffer times respectively. Extended parking times will also occur if times are agreed –with or without flexibility– and arriving trains are delayed. If the actual arriving time of the demanders' train (t_{d1}) or the actual arriving time of the suppliers' train (t_{s2}) is later than the scheduled time, an extended parking time for the shared bicycle is created that equals the train delay. We indicate this as buffer time as well.

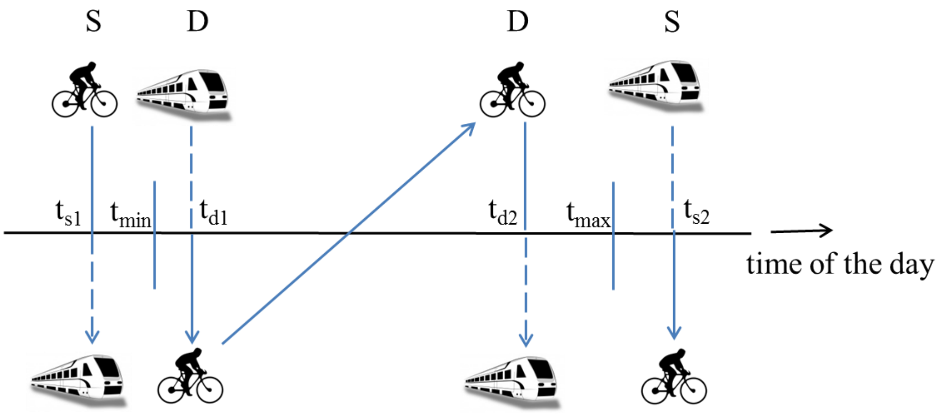

Figure 2. Time scheme with arriving and departing times of supplier (S) and demander (D)

Three concepts of sharing can be considered that differ with respect to how the communication between supplier and demander works out:

- Sharing is organized by bilateral contact between the supplier and the demander; the supplier is the owner of the shared bicycle. Both supplier and demander can be persons who make daily the same trip with the same travel scheme and make appointments about sharing for a longer time period. In that case the supplier may prefer to have some flexibility in arriving times and ask for buffer times. The agreement between supplier and demander can also be incidental, assuming that there is an app that organizes this kind of sharing. The need for flexibility and agreed buffer times is then smaller. Still buffer times can occur due to train delays.

- The supplier makes his/her parked bicycle available for any demander, under the condition that the demander returns at the station before a defined time (t_{max}, which is before or equal to the scheduled t_{s2}). The information about this time is available at the station, cellphone, or at the bicycle itself (technology needed here). Then the bicycle is directly available for demanders after the supplier arrived at the station (t_{s1}) and there is no reason for a before buffer time. Still an after buffer time may be preferred by the supplier.
- Suppliers and demanders use public bicycles. A demander can use a bicycle for an unrestricted period, and a supplier may and is even likely to use two different bicycles for the access trip and the egress part of the return trip. There is no rationale for either a before or an after buffer time. Bicycle sharing systems that now are evolving in Chinese cities are close to this sharing concept; users can take any idle bicycle of a provider and leave it anywhere (Huang and Horwitz, 2017).

The estimation of the potential is based on comparing the distributions of time periods of the parked bicycles in the case of no sharing (t_{s1}- t_{s2}) and the periods of bicycle usage by the demanders (t_{d1}- t_{d2}). The algorithm that attaches supplied bicycles to demanders starts with the demander that needs a bicycle for the longest period and link him/her to an appropriate supplied bicycle if available. Appropriate bicycles are bicycles where $t_{min} \leq t_{d1}$ and $t_{max} \geq t_{d2}$. Then the period for a bicycle need is gradually reduced when attaching supplied bicycles. This might produce somewhat more shared bicycles and a higher potential than a random assignment, because it may prevent that supplied bicycles with a long availability time (t_{min} - t_{max}) are used by demanders for a short period and therefore no supplied bicycle is still available for a demander who wants to use it for a longer time. Still, the algorithm can attach a supplied bicycle to several demanders, in the case the different employment periods do not overlap and fall within the availability time of the bicycle.

In this paper we explore the hypothetical *maximum* potential by assuming that a) all supplied bicycles are available for the demanders, and b) all demanders will use a supplied bicycle if one is available. This is certainly not the reality. However, the upper bound can be used for a more realistic estimation by assuming a share of suppliers who are willing to have their bicycle available for demanders and a share of demanders who like to use a supplied bicycle. The maximum potential will be estimated in both the case that only actual demanders (arriving train passengers that actually use the bicycle for the last mile to an activity) will share bicycles and in the case both actual and potential demanders will share bicycles. The first case is indicated as MSAC (maximum sharing by actual cyclists), the second case as MSAPC (maximum sharing by actual and potential cyclists).

The analysis is limited to working days outside the holiday periods. The NTS data show that most bicycles are parked by commuters and that the number of parked bicycles is highest on these days and thus the capacity shortages are most severe.

3. Data

3.1. Description of the data

The data source for the analysis are the microdata of the Dutch National Travel Survey (NTS). This survey has been conducted continuously since the start in 1978. The data are stored in annual databases. They include characteristics of the travellers and their households, characteristics of the trips, and characteristics of the trip legs. Information on railway stations where travellers board or alight a train was only collected in the period 2004-2009 and started to be collected again in 2015. Because both station information and a large sample are essential for the analysis, the analysis is based on the databases from 2004 to 2009. The sample of the more recent database of 2015 that includes station information as well is too small. In the 2004-2009 databases, trip leg characteristics are only collected for persons aged ≥ 14. Because leg information is essential for the analyses, children < 14 are excluded.

The combined 2004-2009 databases include nearly 1,000,000 observed trips and 16,000 trips by train. The total number of sampled bicycle suppliers is 1961, where the actual bicycle demanders are 370, and the potential bicycle demanders are 1602. For individual stations these numbers are significantly lower. The main stations in large cities have some tenths of sampled bicycle suppliers (the highest number is 78 for Utrecht Central Station, which is one of the biggest stations in the Netherlands), a number of actual demanders in the order of 10 (the maximum is 19 for both Groningen and Zwolle main stations), and a larger number of potential demanders. The latter is between 50 and 100 for most large stations, but can be significantly larger; the maximum is 225 for Amsterdam Central Station. These numbers are generally too small for a good description of the distributions of parking and employment periods of supplied and demanded bicycles on station level. The low number of actual bicycle demanders is the most important drawback.

3.2. Dealing with insufficient observation numbers

The low observation numbers per station imply that an accurate estimation of the potential for individual stations cannot be made. The results are not only inaccurate but can also be biased. Assume two extreme cases: a station where for all demanders a supplied bicycle is available, and a station where no supplied bicycle is available for any demander. In the first case, for all demanders a bicycle is available under the condition that $t_{min} \leq t_{d1}$ and $t_{max} \geq t_{d2}$. If in this case a sample of supplied and demanded bicycles is drawn, there is no guarantee that the condition is still satisfied for all demanders. The proportion of demanders in the sample that can use a supplied bicycle can be less than the actual 100%, and the estimated potential will tend to be too low. A kind of opposite effect is not valid for the other extreme. If no bicycle is available for any demander, which is the case if t_{d2} always exceeds t_{s2} or t_{s1} always exceeds t_{d1}, no bicycle will be available for any demander in a sample as well. The conclusion is that by drawing a sample the calculated potential tends to be underestimated. The bias will increase when the sample becomes smaller.

The number of observations can be enlarged by combining the data of several stations. Combination of the data implies that the individual stations are assumed to represent one station and includes the implicit assumption that bicycles that are parked and demanded at different stations can be shared. Using this unrealistic assumption, the possibilities for sharing as well as the potential will tend to be overestimated. However, there will be no bias if the distributions of both the parking and employment periods of the bicycles are equal for the individual stations. In that case, the only effect of combining data is an increased accuracy of the results. Therefore, when data of different stations are combined, preferably stations where the two distributions are likely to be similar are selected.

Considering that using data of individual stations tend to underestimate the potential and combining data of different stations tend to overestimate the potential, both types of data handling are applied in the paper. The aggregated results for a number of individual stations are compared to the results when the data of the same stations are combined. The two produced figures for the potential indicate the range of plausible values. Additionally, the relative difference between the two figures gives an idea to which extent the potential is influenced by either the small sample sizes or the combination of station data.

4. The potential for relieving capacity problems

The potential is estimated for a number of cases, defined by selected stations and assumed buffer times. The cases are described in the next subsections. Most cases regard the largest stations; these have both the largest observation numbers in the data and the largest capacity problems for bicycle parking. In line with the discussion in Section 3.2, we selected for these cases stations of a certain defined type and analysed both the potentials for the individual stations and for the combined stations. The results for the individual stations are aggregated and compared with the figures that result from combining data of the same stations. The calculated potentials for the former might be somewhat too low, those for the latter somewhat too high.

For the sake of clarity we will again define the concepts of aggregating and combining as we use it:

- Aggregating results for different stations means that the analysis is made on the level of individual stations and that the results (like number of shared bicycles) are aggregated. Because of the small observation numbers for individual stations, the calculated potentials are not accurate and tend to be too low.
- Combining stations means that a number of stations are taken together and are considered as one station in the analysis; a supplied bicycle that is parked at station A is assumed to be available for someone who demands a bicycle at station B. The higher number of observations assures more accurate results, but the locational mismatch tends to overestimate the potential.

Unless otherwise stated, the presented results regard the period 2004-2009 and assume buffer times of a half hour for both the before and after buffer times.

4.1. The whole country

The first case concerns the whole country. This includes the smaller stations which observation numbers are too small for an analysis on individual level. Therefore, no aggregated figures for the individual stations have been calculated, but instead stations of the same type are combined and the results per station type are aggregated to a national level. Five station types are distinguished: the central stations of the four largest cities (Amsterdam, Rotterdam, The Hague, Utrecht), the central stations of 15 other large cities, the other main stations, local stations in urbanized areas, and local stations in the countryside. The aggregates by station type are compared to the results when all stations in the country are combined. By combining all stations the potential is likely to be substantially overestimated because the distributions of the parking and employment periods of the bicycles may vary significantly between stations. Combining stations of the same type might also produce values that are too high, but the overestimation will be smaller; the distributions of the parking and employment periods are likely to be more similar.

Table 1 shows a number of indicators about bicycle numbers for both methods. The indicated bicycle numbers are produced by expanding the observations in the NTS sample to national totals. The method used has only impact on the result of sharing. The numbers of supplied and demanded bicycles, as well as the peak of parked bicycles in the case of no sharing, are identical for both methods. The table confirms the expectation: if the stations are grouped and combined by type, the estimated number of shared bicycles and the potential are somewhat lower than if all stations are combined. The potential differences are rather small. In the scenario where bike sharing is limited to the actual cyclists, the calculated potential ranges from 17% to 19%. When potential demanders are included, the potential ranges from 34% to 37%.

An important observation is that sharing between actual and potential cyclists produces a significant larger potential than sharing between actual cyclists only. This is connected with the fact that the number of actual demanders is considerably smaller than both the number of suppliers and the summed numbers of actual and potential demanders. If sharing enlarges the general availability of bicycles thus incentivizing its usage, the potential for relieving the capacity problems may increase significantly.

Table 1. Number of bicycles at the stations, whole country

Type of bicycles	Type of cyclists or sharing	Bicycle number on a working day	
		Aggregation of combined stations of the same type	Combining all stations
Supplied bicycles	Actual cyclists	241,000	241,000
Demanded bicycles	Actual cyclists	46,000	46,000
	Actual and potential cyclists	238,000	238,000
Shared bicycles	Sharing between actual cyclists (MSAC)	38,000	42,000
	Sharing between actual and potential cyclists (MSAPC)	139,000	166,000
Peak of parked bicycles	No sharing	222,000	222,000
	Sharing between actual cyclists (MSAC)	185,000 (-17%)	180,000 (-19%)
	Sharing between actual and potential cyclists (MSAPC)	147,000 (-34%)	139,000 (-37%)

When comparing the peak of parked bicycles (222,000) with the total number of parking places at Dutch railway stations (about 400,000, Maat et al, 2012), one may wonder why there are capacity shortages. One explanation is that the number of computed parked bicycles in the table does not encompass all parked bicycles. It regards only the bicycles of the suppliers and demanders as defined before, which are the bicycles that are parked and taken away (suppliers) or taken away and returned (demanders) on the same day. This number is smaller than the actual number of parked bicycles. The later includes additionally bicycles that are parked for several days and orphan bikes. A second explanation is that a capacity shortage is not valid for all stations. There may be many (mainly smaller) stations where part of the places are not utilized. A final explanation is that the number of 222,000 reflects the average for a working day. The actual number of parked bicycles may differ somewhat for different days of the week and may be influenced by weather and climate conditions (Martens, 2004). The peak of parked bicycles on the most busy days will then be higher.

Figure 3 displays in two graphs the time distribution of parked bicycles on a working day for the two methods (aggregation of same type stations and all stations combined). Each graph shows the distribution in the case of no sharing (equal for both graphs), in the case of maximum sharing between actual users (MSAC), and in the case of maximum sharing between actual and potential users (MSAPC).

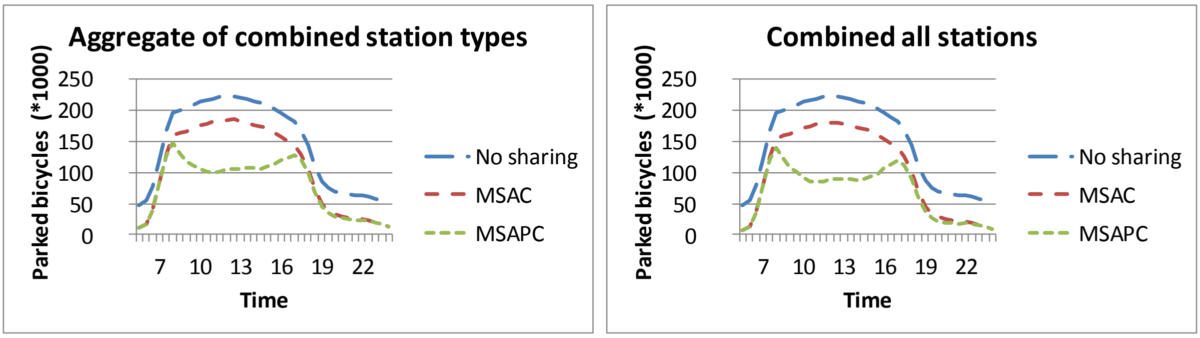

Figure 3. Distribution of parked bicycles over time for different sharing cases, whole country

It can be seen that the curves for MSAC and MSAPC are slightly higher in the case of combining stations that are of the same type. Other observations are:

- The peak of parked bicycles is in the current situation (no sharing) and in the case of MSAC halfway the day.
- The peak of parked bicycles is in the case of MSAPC in the morning at about 8 am while there is a second lower peak in the afternoon at about 5 pm (the traditional morning and evening peaks).
- There is in all cases a steep increase before the morning peak and a steep decrease after the evening peak.
- Sharing reduces the number of parked bicycles in the early morning and late evening (and night) considerably. The reason is that the bicycles used by demanders (either private bicycles or rented bicycles) are not parked any more at the station in these periods.

4.2. Central stations of the four largest cities

The second case regards the central stations of the four largest cities: Amsterdam, Rotterdam, The Hague, and Utrecht. These are all located in the Randstad area which is the most populated in the Netherlands with 7 million inhabitants. The potential is calculated for both the individual stations and the combination of the stations. The results for the individual stations are aggregated.

Table 2 shows that the calculated potentials for both MSAC and MSAPC are significantly higher if the stations are combined than if the results for the individual stations are aggregated. This implies that either the small samples for the individual stations create a substantial underestimation of the potentials, or the combination of stations creates a large overestimation. If the latter is true, the assumption that the distributions of parking and periods of use are similar for the selected stations is not valid.

Table 2. Number of bicycles at the central stations of the four largest cities

Type of bicycles	Type of cyclists or sharing	Bicycle number on a working day	
		Aggregation of combined stations of the same type	Combining all stations
Supplied bicycles	Actual cyclists	28,000	28,000
Demanded bicycles	Actual cyclists	7,000	7,000
	Actual and potential cyclists	73,000	73,000
Shared bicycles	MSAC	3,600	5,400
	MSAPC	26,000	26,000
Peak of parked bicycles	No sharing	26,000	26,000
	MSAC	22,000 (-14%)	20,000 (-21%)
	MSAPC	19,000 (-25%)	17,000 (-34%)

The distribution of parked bicycles over the day is flat between the peak hours in the cases of no sharing and MSAC (Figure 4). In the case of MSAC, nearly all bicycles that are parked in the morning peak will be shared and the bicycle sheds will be rather empty between 10 and noon. This can be explained by the very large number of potential demanders compared to the number of suppliers.

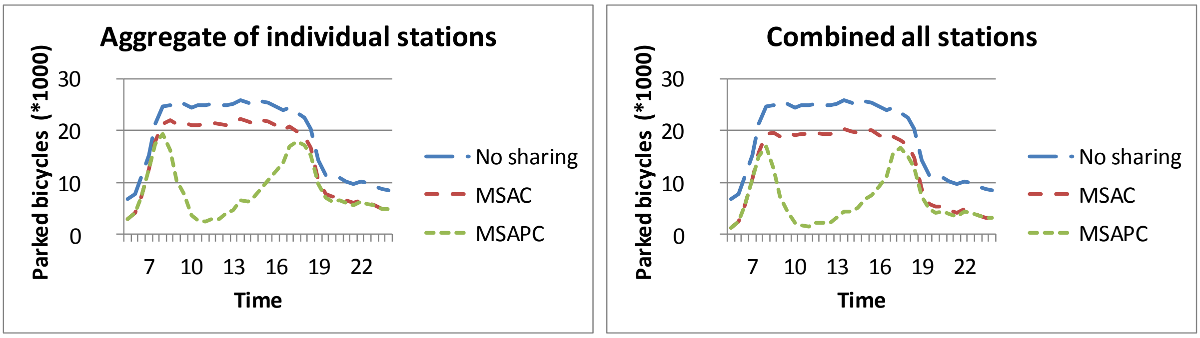

Figure 4. Distribution of parked bicycles over time for different sharing cases, central stations of the four largest cities

4.3. Central stations of other large cities

Table 3 shows the results for 16 other main stations, including the central stations of 15 other large cities and the second main station of The Hague (Hollands Spoor). The city selection is based on 'stedelijkheid' which is an indicator of the degree of urbanization; the selected cities include most older cities that have at least 100,000 inhabitants. The potential ranges are close to those for the four largest cities, but the differences between aggregating individual results and combining stations are slightly larger. Possible explanations for the larger difference are a lower number of observations per station and more deviating distributions of parking and employment periods for the individual stations.

Table 3. Number of bicycles at the central stations of other large cities

Type of bicycles	Type of cyclists or sharing	Bicycle number on a working day	
		Aggregation of combined stations of the same type	Combining all stations
Supplied bicycles	Actual cyclists	55,000	55,000
Demanded bicycles	Actual cyclists	15,000	15,000
	Actual and potential cyclists	73,000	73,000
Shared bicycles	MSAC	7,000	11,000
	MSAPC	25,000	46,000
Peak of parked bicycles	No sharing	51,000	51,000
	MSAC	45,000 (-13%)	40,000 (-22%)
	MSAPC	39,000 (-24%)	33,000 (-35%)

Figure 5 shows that in the case of MSAPC the computed number of parked bicycles between the peak hours is significantly higher when the stations are analysed individually than when stations are combined. It is unclear which result reflects reality best. This difference has no consequence for the potentials because these are determined by the parked bicycles in the peak hours.

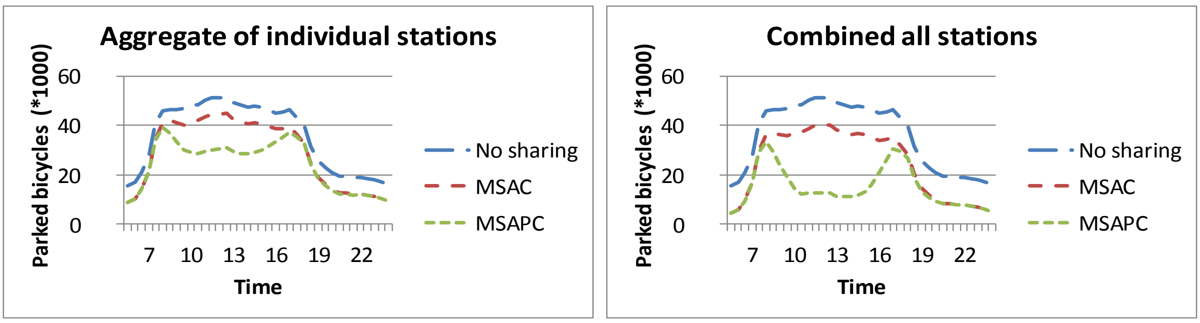

Figure 5. Distribution of parked bicycles over time for different sharing cases, central stations of other large cities

If we compare the calculated peak of parked bicycles for some individual stations with published capacity figures, the peak is generally lower and ranges from ca 50% to 100% of the capacity. The value of 100% is found for Haarlem main station, that suffers from excessive capacity problems (Van Boggelen, 2008). The observation that the calculated peaks are sometimes significantly lower than the capacity for stations that actually have capacity shortages indicate that the bicycles that are excluded from our analysis make up a significant part of all parked bicycles.

4.4. Station type

The analysis in the paper focusses on the main stations in the large cities. This section presents some results for the five defined types of stations (Table 4). The potential columns display the range that result from the analysis on individual level (lower bound) and by combining station data (upper bound). The former are not available for the smaller stations. Concentrating on the values for the combined stations –the only values that are available for all station types–, the calculated potentials are similar for the different types of stations with the exception of the local stations in the countryside. The potentials for the latter are about half of those for the other stations.

Table 4. Potential capacity reduction for different station types

Station type	# of stations in 2015	Peak of parked bicycles without sharing	Potential for capacity reduction	
			MSAC	MSAPC
Central stations of the four largest cities	4	26,000	14-21%	25-34%
Central stations of other large cities	16	51,000	13-22%	24-35%
Regional main stations	35	47,000	?-18%	?-38%
Local stations in urbanized areas	144	41,000	?-18%	?-37%
Local stations in the countryside	201	59,000	?-10%	?-19%

4.5. Impact of buffer times

The preceding analyses assume before and after buffer times of 0.5 hour, as mentioned in the introduction of this section. Lower or higher buffer times will decrease or increase the number of parked bicycles and will likely affect the potential. Table 5 shows the impact of the assumed buffer times on the potential. Four cases are distinguished. The first is the case of no buffer times, which corresponds to the sharing concept where public bicycles are used by both suppliers and demanders. In the second case no before buffer time (BT_{before}) is assumed, and there is an after buffer time (BT_{after}) of 0.5 hour. This corresponds to the sharing concept with suppliers making their bicycle available for any demander who returns in time. The other two cases assume equal before and after buffer times, corresponding to peer-to-peer sharing of bicycles. In one case the buffer times are set to 0.5 hour which was the standard in the preceding analyses, in the other case the buffer times are set to 1.0 hour. For each case the range defined by the aggregate of individual stations (or the aggregate of combined stations of the same type in the 'whole country' cases) –the lower bound– and the combination of all selected stations –the upper bound– is indicated.

Table 5. Potential capacity reduction for different buffer times

	BT_{before}=0 BT_{after}=0	BT_{before}=0 BT_{after}=0.5	BT_{before}=0.5 BT_{after}=0.5	BT_{before}=1 BT_{after}=1
Whole country				
MSAC	20-20%	19-20%	17-19%	12-13%
MSAPC	46-51%	43-46%	34-37%	23-25%
Central stations of the four largest cities				
MSAC	22-25%	19-24%	14-21%	6-10%
MSAPC	40-47%	35-39%	25-34%	11-15%
Central stations of other large cities				
MSAC	19-29%	15-26%	13-22%	8-16%
MSAPC	37-50%	30-43%	24-35%	15-23%

The buffer times influence the potential substantially, particularly for the central stations of the largest cities. If there are no buffer times, the potential for the largest stations can be 3-4 times higher than if the buffer times are 1 hour. It is advisable to organize sharing in a way that requires no or short buffer times.

The differences regarding parking times between the two most extreme cases of no buffer times and buffer times of one hour are illustrated in Figures 6 and 7 for the central stations of the four largest cities and the central stations of other large cities respectively. These figures are based on the aggregate of individual stations and correspond to the lower bound figures of the ranges in Table 5.

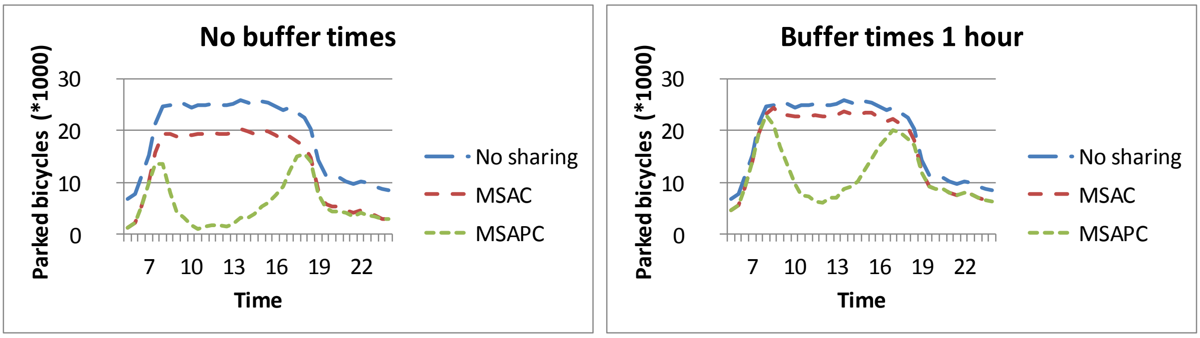

Figure 6. Distribution of parked bicycles over time for different sharing cases, central stations of the four largest cities (aggregate of individual stations)

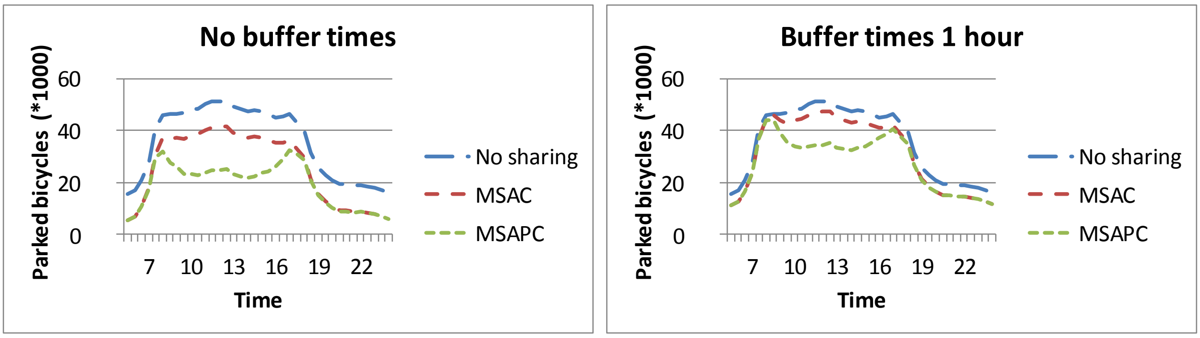

Figure 7. Distribution of parked bicycles over time for different sharing cases, central stations of other large cities (aggregate of individual stations)

It should be noticed that shortening buffer times can have a small opposite effect on the potential. Buffer times increase the reliability of bicycle availability for arriving demanders or suppliers. Shortening buffer times lowers the reliability which might be a reason for storing some additional public bicycles. These can be used when, incidentally, the user of a shared bicycle arrives too late at the station. These additional bicycles need some parking space.

4.6. Impact of gender preferences
The figures displayed in the preceding sections assume that all parked bicycles that are eligible for sharing can be used by all demanders. However, some demanders may dislike to ride certain types of bicycles. Most obvious is the case of women who have no experience in riding a gents' bike and may dislike to do so. We investigated the impact of gender preferences by assuming that both parked gents' bikes are only available for male demanders and parked lady's bikes are only available for female demanders. The shares of men and women in all bicycles suppliers and potential demanders are about equal (close to 50%); the actual demanders are more frequently male (55-60%). Table 6 shows the resulting potentials. The 'men' and 'women' columns indicate the potentials if only the men or only the women are included in the analysis, the 'men + women' column includes both sexes and assumes that gents'/lady's bikes are only available for men/women. Comparing this column with the most right column (no distinction; these figures are taken from earlier tables) informs about the impacts. The reduction of the potential is in most cases 5-15%, but exceeds 20% for the four largest stations if the results for the individual stations are aggregated. The reduction can be significant, but is generally not large. Moreover, the impact will be somewhat overestimated, because the assumption that all men dislike lady's bikes and all women dislike gents' bikes is too strict. Particularly men will generally have no problem in riding a lady's bike.

Table 6. Impact for gender preferences on the potential

	Men	Women	Men + women	No distinction by gender
Whole country				
MSAC	18-21%	13-15%	15-18%	17-19%
MSAPC	32-38%	31-36%	32-37%	34-37%
Central stations of the four largest cities				
MSAC	9-19%	11-16%	11-18%	14-21%
MSAPC	18-29%	25-30%	20-30%	25-34%
Central stations of other large cities				
MSAC	11-23%	7-15%	11-20%	13-22%
MSAPC	15-31%	26-38%	20-34%	24-35%

4.7. Development in time
The possibilities for examination of the development of the potential in time are limited because station information is missing in most years of the survey. Then the potential can only be calculated when all stations are combined. Assuming that the resulting overestimation of the potential will not change in time, the development of the potential on national level can be investigated. Table 7 shows the results for the periods 2004-2009 and 2011-2015. Data of 2010 are left out because the results for this year are quite deviant; in 2010 a new survey design was introduced and the 2010 survey suffered from teething troubles. The assumed buffer times are again 0.5 hour.

Table 7. Number of bicycles at the stations, whole country

Type of bicycles	Type of cyclists or sharing	Bicycle number on a working day	
		Combining all stations, 2004-2009	Combining all stations, 2011-2015
Supplied bicycles	Actual cyclists	241,000	204,000
Demanded bicycles	Actual cyclists	46,000	48,000
	Actual and potential cyclists	238,000	211,000
Shared bicycles	MSAC	42,000	47,000
	MSAPC	166,000	162,000
Peak of parked bicycles	No sharing	222,000	190,000
	MSAC	180,000 (-19%)	143,000 (-25%)
	MSAPC	139,000 (-37%)	102,000 (-46%)

An intriguing observation from the table is that the observed number of supplied bicycles and the peak of parked bicycles decreased. This is contradictory to the increasing capacity problems. The explanation is not an actual decrease of parked bicycles, but the change in the design of the National Travel Survey after 2009. This change caused an overall reduction of the registered mobility and a decrease of the registered share of the bicycle in access and egress trips to/from railway stations. The design change complicates the observation of the actual trends. Looking at the individual years, the number of supplied, demanded and parked bicycles increased somewhat in the period 2004-2009, while no clear trends after can be observed, partly because of large annual fluctuations. The number of actual demanders probably increased significantly since 2004; the observed number is even in the new design higher than in the old one. The possible strong increase of actual demanders is connected with OV-fiets. Users of OV-fiets made up less than 1% of all actual demanders in 2004 and 14% in 2015.

The calculated potentials increased significantly between the two periods. The plausible explanation is that the number of actual demanders is growing much faster than the number of suppliers. The success of OV-fiets increased the demand for parking places and hence the capacity shortages. If the users of OV-fiets would share bicycles, this additional demand for parking places would disappear. People will only shift from OV-fiets to peer-to-peer sharing if sharing is more attractive than renting an OV-fiets regarding availability and price. Otherwise demanders who are willing to share bicycles will be predominantly recruited from those who currently do not use OV-fiets. In that case the estimated potentials in Table 7 are too high and possibly there is no increase of the potential over time.

Figure 8 shows that the distribution of parked bicycles over the day is similar in the two periods.

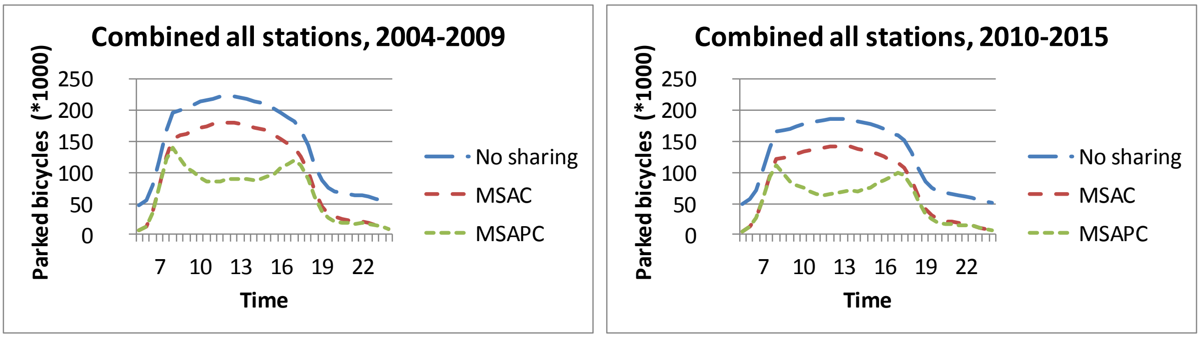

Figure 8. Distribution of parked bicycles over time for different sharing cases, whole country

4.8. Magnitude of the potential

The analysis produced a number of values for the maximum potential, that is the potential of the case when all suppliers and all demanders (actual or actual + potential) are willing to share bicycles. The values range for the larger stations between

- 13% and 29% if only the actual demanders will share, and between
- 24% and 50% if all potential demanders will share as well.

The ranges are taken from Table 5 and include the assumption that the buffer times do not exceed 30 minutes.

The calculated maximum values for the potential are likely to be significantly higher than the potential that actually will be achieved. A number of suppliers may dislike to share their bicycle and a number of demanders may dislike to use (certain) private bicycles from other persons. The proportion of suppliers and demanders that is willing to share bicycles and the attractiveness of sharing for potential bicycle demanders depend on how sharing is organized. Relevant factors are, among others, the ease of the match between supplier and demander, and a possible arrangement about financial compensation to the suppliers for providing their bicycles. Apart from this, buffer times influence the potential significantly, and these are also dependent on the organization. A follow-up study should produce more accurate values for the potential in association with the way sharing is organized.

An important comment is, that the analysis in this paper is limited to suppliers and demanders that arrive and return on the same day. A significant part of the bicycles is parked for successive days and some demanders may need a bicycle for successive days. These bicycles and demanders are not included in the analysis. A part of the long-term parked bicycles are orphan bikes that do not contribute to the potential. The other bicycles could be shared, both with one-day demanders and with persons who need a bicycle for successive days. Sharing of these bikes will have its own potential which may differ from the potential of one-day parked bikes. This could be analyzed in a follow-up study as well.

5. Conclusion

The potential of sharing for the reduction of parked bicycles at railway stations and so relieving the capacity problems depends on a number of factors. Influencing factors are

- The proportion of train passengers that is willing to share bicycles.
- The possible increase of bicycle availability for the last mile as the result of sharing.
- Agreed buffer times between supplier and demander, and buffer times that result from train delays.

All these factors are related to the way sharing is organized. When 'designing' the organization, a relatively high potential will be achieved if a large proportion of cyclists is willing to share, the sharing concept increases bicycle availability for the last mile significantly, and buffer times are short or absent. A demand analysis could produce knowledge on the willingness to share by both actual and potential cyclists, and clarify which elements of the sharing system make people interested in sharing.

A general conclusion of the analysis is that more information is needed for an accurate estimation of the potential, but that still can be said that the potential is likely to be modest. Bike sharing can contribute to relieving the capacity problems, but the contribution is probably limited.

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