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Potential of peer-to-peer bike sharing for relieving bike parking capacity problems at railway stations

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Samenvatting

In Nederland is bij veel grotere treinstations een tekort aan stallingscapaciteit voor fietsen. Dit is het gevolg van zowel een stevige groei in het treingebruik als een toename van het marktaandeel van de fiets in de voor- en natransportmiddelen. In de paper worden de mogelijkheden verkend om het capaciteitstekort te verkleinen door een vorm van fietsdelen in te voeren waarbij door treinreizigers gestalde particuliere fietsen beschikbaar gesteld worden voor andere gebruikers. Deze fietsen staan nu ongebruikt plaats in te nemen; als aankomende treinreizigers die een fiets nodig hebben deze voor beperkte tijd kunnen gebruiken zal het aantal gestalde fietsen kleiner worden en het capaciteitstekort dalen. We duiden fietseigenaren die hun fiets voor enige tijd bij een station stallen aan als 'aanbieder' en arriverende reizigers die voor enige tijd een fiets nodig hebben als 'vrager'. Twee soorten vragers worden onderscheiden: reizigers die nu een fiets gebruiken voor de 'last mile' (actuele vragers) en reizigers die heel goed een fiets hadden kunnen gebruiken maar nu een andere modaliteit kiezen (potentiële vragers). De analyses zijn gedaan met data van de nationale verplaatsingsonderzoeken en betreffen de verkenning van een maximum potentie, namelijk de impact van fietsdelen op de benodigde capaciteit indien alle aanbieders bereid zijn hun fiets te delen en alle vragers particuliere fietsen willen gebruiken. Aannemend dat de werkelijke potentie een stuk lager ligt kan op basis van de analyse geconcludeerd worden dat deze vermoedelijk beperkt van omvang is; voor de grotere stations zou de potentie in de orde van 10% kunnen liggen. Verder onderzoek naar de bereidheid van reizigers om fietsen te delen en naar de mate waarin potentiële vragers door fietsdeelprogramma's overgehaald kunnen worden om te gaan fietsen kan een nauwkeuriger cijfer opleveren. De analyse laat ook zien dat fietsdelen een groot effect kan hebben op de verdeling van de gestalde fietsen over de dag; dit is met name het geval als veel potentiële vragers besluiten te gaan fietsen. Nu is de fietsbezetting overdag redelijk gelijkmatig met een piek rond één uur 's middags. Deze kan veranderen in een verdeling met twee pieken in elk van de beide reisspitsen en een veel lagere fietsbezetting in de tussengelegen periode.

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). In contrast to the stable market share of the bike as the main mode for trips, 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 figures are produced with the microdata of the National Travel Survey (NTS). The large increase has three components:

- Population growth; comparison of population statistics with the growth of access trips by bike proves that 21% of the latter is explained by this component.
- Increase of train ridership per capita; the increase can be derived from the Dutch NTS data and 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).

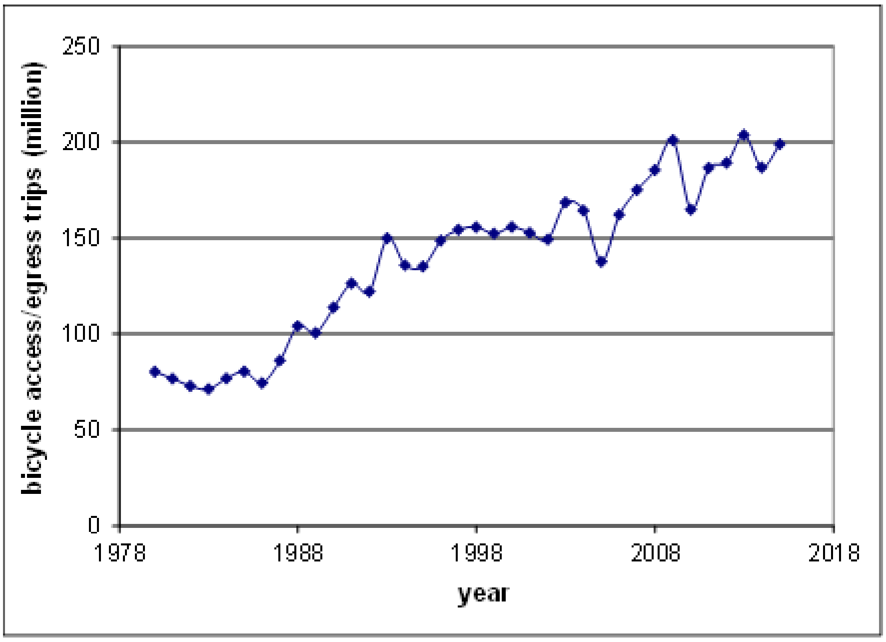

Figure 1: Development of access/egress trips by bicycle to/from Dutch railway stations: source: data of the Dutch NTS

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), to about 450,000 in 2016 (NS, 2017), and 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 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.

This would be a sort of peer-to-peer bike sharing system which is to the best of our knowledge not common. 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 (https://nl.wikipedia.org/wiki/OV-fiets).

The aim of the paper is to explore the potential of this strategy, that is the potential for reducing the number of parked bicycles and so relieving the capacity problem. 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.

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. 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. The hypothesis is that the order of magnitude is similar for stations of a certain type and therefore will not differ strongly between the central stations in the large cities. The data unfortunately does not provide the opportunity to test this hypothesis, as we will explain in the next section, and we assume that the hypothesis is true.

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 part of 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, 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 it is considered that the traveller would not consider to travel by bicycle.

It is assumed that everyone who uses the bicycle as an access mode to the station parks the bicycle at the station, and that every demander who uses a bicycle for the egress trip uses a bicycle that was parked at the 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. However, the number of tickets sold for bicycle transport by train, 600,000 per year in the Netherlands ('Fiets mee in de trein', 2013; the tickets are valid for a whole day), is small compared to those who park the bicycles at the station or use a parked bicycle; they make up less than 1% of the suppliers and 4% of the demanders.

The analysis of the potential of bicycle peer-to-peer sharing will be performed for the two scenarios: actual bicycle users only, and for the 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.

Figure 2 may clarify the different time concepts related to supplier and demander. 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 ts1 and ts2. And if the demander is an actual demander, he/she would have used another bicycle that was parked from the beginning of the day to t_{d1} and is parked again from t_{d2} to the end of the day.

Supplier and demander might agree that the 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. Buffer times will also occur if times are agreed –with or without flexibility– and arriving trains are delayed. If the actual arriving time of the demander (t_{d1}) or the actual arriving time of the supplier (t_{s2}) is later than the scheduled time, a kind of buffer is created that equals the train delay and enlarges the time period of bicycle parking.

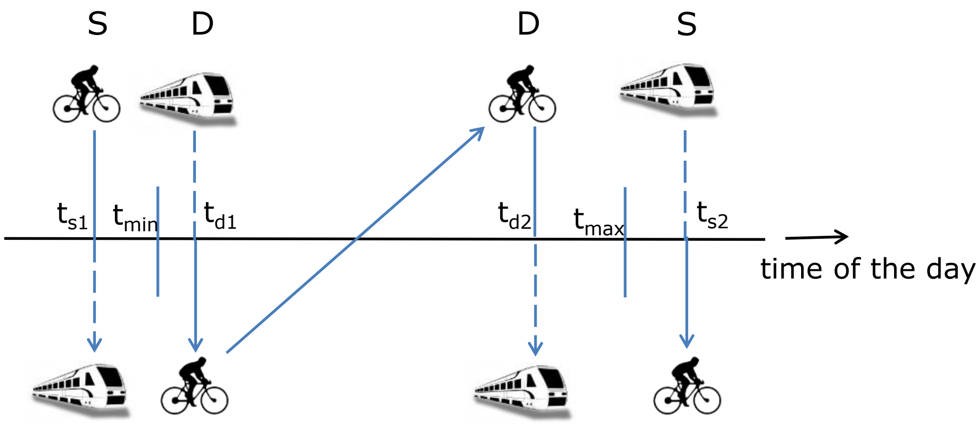

Figure 2: Time scheme with arriving and departing times of supplier (S) and demander (D)

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 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. 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 can be 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.

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 demanded bicycles starts with the demanded bicycles that have the longest employment period and link them to appropriate supplied bicycles if these are available; appropriate bicycles are bicycles where t_{s1} + before buffer time ≤ t_{d1} and t_{s2} - after buffer time ≥ t_{d2}. Then the employment period gradually is 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 all supplied bicycles are available for the demanders, and that 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. The station information was mutilated included in the database of 2005 to 2009 and had to be corrected and completed.

The combined 2004-2009 databases include nearly 1,000,000 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), 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. The numbers per station are generally too small for a good description of the distributions of parking and employment periods of supplied and demanded bicycles. 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. If a sample of supplied and demanded bicycles is drawn, there is no guarantee that in the first case a bicycle is available for all demanders in the sample. The expected proportion of demanders that can use a supplied bicycle is less than the actual 100%. As a result, the estimated potential will tend to be too low. The bias will increase when the sample becomes smaller. A kind of opposite effect is not valid for the other extreme. If no bicycle is available for any demander, no bicycle will be available for demanders in a sample as well.
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 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 be overestimated if the distributions of both the parking and employment periods of the bicycles differ for the several stations. However, if the two distributions are similar for all individual stations that are combined, the analysis will produce statistically better results than those obtainable for the individual stations. When stations are combined, preferably stations where the two distributions might be similar should be selected.

4. The potential of sharing for relieving capacity probems

The potential is estimated for a number of cases, defined by selected stations and assumed buffer times. Considering that the calculated potential might be too high if different stations are combined, and tends to be too low for individual stations, both the potential for combined stations and those for some larger individual stations are estimated. In the cases larger stations are combined, the results will be compared with the aggregated results for the same individual stations. This gives an idea to which extent the potential is influenced by combining stations and/or sample sizes. If both influences apply, the potential will be overestimated when stations are combined and underestimated when the results for individual stations are aggregated. In both cases, combining stations will produce a higher potential than analysing individual stations. For the sake of clarity we will again define the concepts of combining and aggregating as we use it:

- 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 if A and B are combined.

- Aggregating (results for) different stations means that the analysis is done on the level of individual stations and that the results are aggregated. Then there is no locational mismatch between suppliers and demanders.

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 Whole country

The first case concerns the whole country. Two potentials are estimated, one by combining all stations in the country, and one by grouping and combining stations by station type. Five station types are distinguished: the central stations of the four largest cities (Amsterdam, Rotterdam, The Hague, Utrecht), the central stations of a number of other large cities, the other main stations, local stations in urbanized areas, and local stations in the countryside. The results by station type are aggregated to a national level. One may expect that when combining all stations the potential will be overestimated, because the distributions of parking and employment times of the bicycles are likely to differ for different stations. For stations of the same type, the distributions might be comparable and combining such stations may produce fairly good estimations of the potential.

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.

Table 1: 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	Aggregation of combined stations of the same type
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)	42,000	38,000
	Sharing between actual and potential cyclists (MSAPC)	166,000	139,000
Peak of parked bicycles	No sharing	222,000	222,000
	Sharing between actual cyclists (MSAC)	180,000 (-19%)	185,000 (-17%)
	Sharing between actual and potential cyclists (MSAPC)	139,000 (-37%)	147,000 (-34%)

The method used has only impact on the results in the case 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 demonstrates that if all stations are combined, the estimated number of shared bicycles and the potential are somewhat higher than if the stations are grouped and combined by type. This is conform to the

expectation. The calculated potential when all stations are combined is likely to be too high. The potential differences are rather small. When bike sharing is limited to the actual cyclists, the calculated potential decreases from 19% to 17%. When potential cyclists are included, the potential decreases from 37% to 34%. 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 by potential demanders, the potential for relieving the capacity problems may increase significantly.
When comparing the peak of parked bicycles in the case of no sharing (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 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 (all stations and aggregation of same type stations). 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).

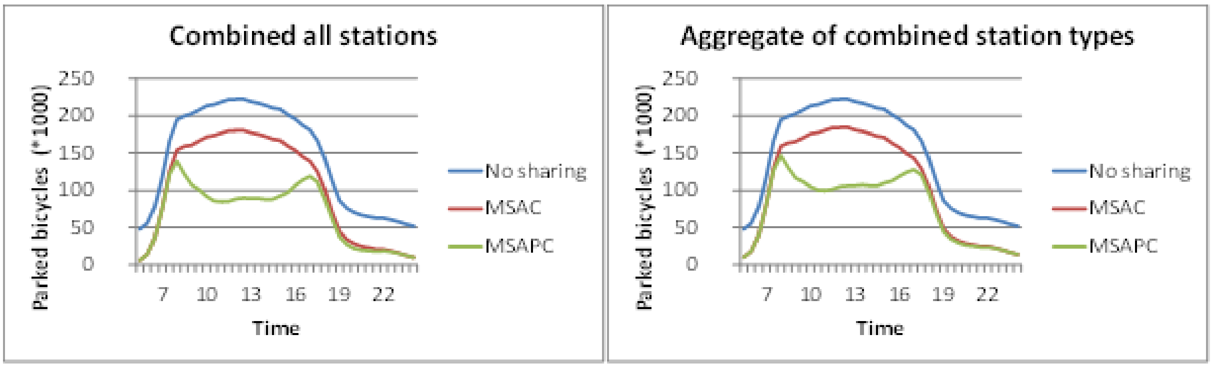

Figure 3: Distribution of parked bicycles over time for different sharing concepts, whole country

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 demanders do not need any more to have their own bicycles parked in these periods at the station.

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. The potential is calculated for both the combination of the stations and the individual 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. Possibly, the assumption that the distributions of parking and periods of use are similar for stations of the same type is not true, at least not for the largest stations. In that case, the estimated potentials for the combined stations could be too high. Another explanation is that the small samples create a substantial underestimation of the potentials for the individual stations. And, of course, both explanations can be valid, each explaining part of the difference.

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	
		Combining all stations	Aggregation of individual 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	5,400	3,600
	MSAPC	26,000	26,000
Peak of parked bicycles	No sharing	26,000	26,000
	MSAC	20,000 (-21%)	22,000 (-14%)
	MSAPC	17,000 (-34%)	19,000 (-25%)

The distribution of parked bicycles over the day is flat between the traditional 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.

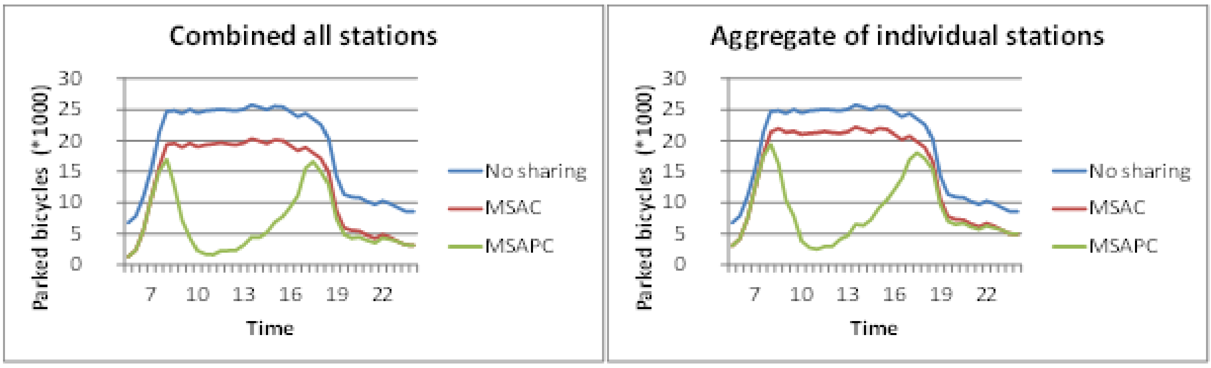

Figure 4: Distribution of parked bicycles over time for different sharing concepts, central stations of the four largest cities

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 differences between combining stations and aggregating individual results are comparable to and slightly higher than those for the four largest stations. A possible explanation for the higher difference is a lower number of observations per station. Additionally, the distributions of parking and employment periods may differ more between 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	
		Combining all stations	Aggregation of individual 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	11,000	7,000
	MSAPC	46,000	25,000
Peak of parked bicycles	No sharing	51,000	51,000
	MSAC	40,000 (-22%)	45,000 (-13%)
	MSAPC	33,000 (-35%)	39,000 (-24%)

Figure 5 shows that in the case of MSAPC the computed number of parked bicycles between the peak hours is significantly smaller when stations are combined than when the stations are analysed individually. 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.

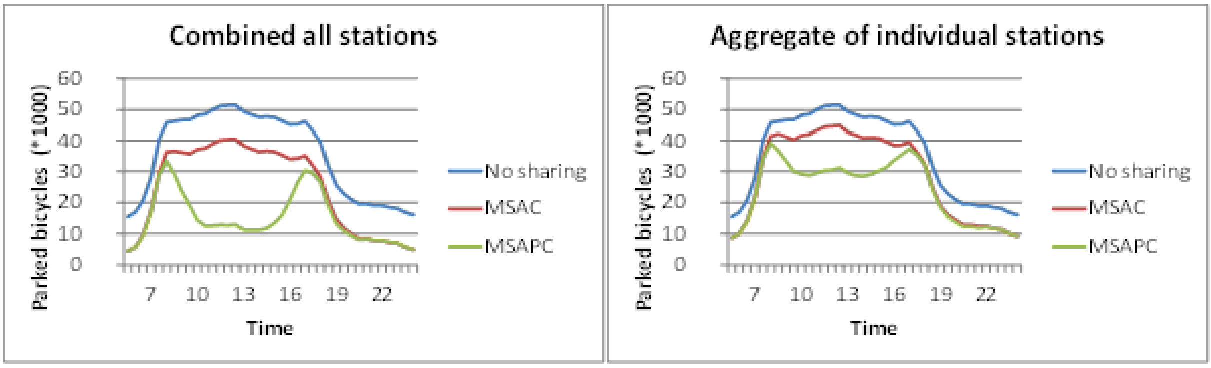

Figure 5: Distribution of parked bicycles over time for different sharing concepts, central stations of other large cities

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 distinguished types of stations (Table 4). The results are calculated for the combined stations of the same type. The calculated potentials are similar for all types of stations with the exception of the local stations in the countryside; they vary between 18% and 22% for the actual cyclists and between 34% and 38% for the actual and potential cyclists. The potentials for the local stations in the countryside are about half these figures.

Table 4: Potential capacity reduction for different station types when stations are combined

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	21%	34%
Central stations of other large cities	16	51,000	22%	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 0.5 hour which was the standard in the preceding analyses, in the other case the buffer times are 1.0 hour.

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, aggregate of combined stations by type					
	MSAC	20%	19%	17%	12%
	MSAPC	46%	43%	34%	23%
Aggregate of central stations of the four largest cities					
	MSAC	21%	19%	14%	6%
	MSAPC	39%	35%	25%	11%
Aggregate of central stations of other large cities					
	MSAC	19%	15%	13%	8%
	MSAPC	37%	30%	24%	15%

The buffer times influence the potential substantially, particularly for the central stations of large 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.

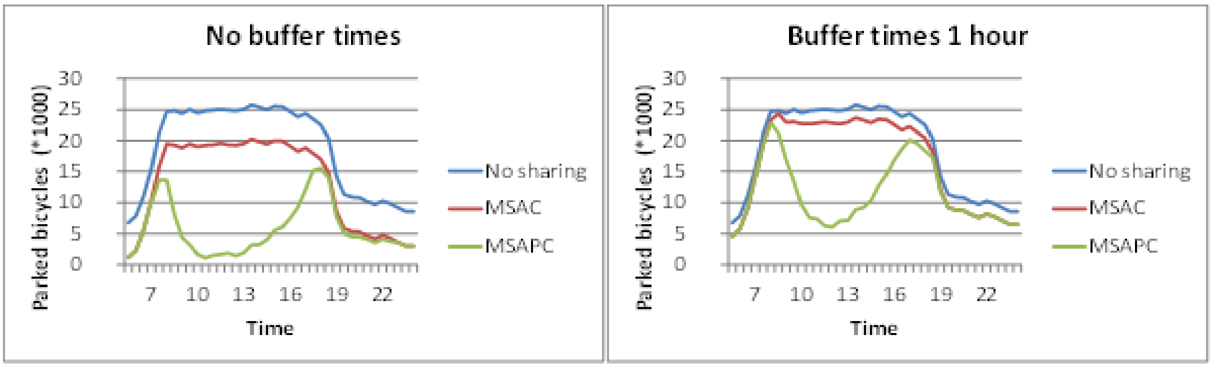

Figure 6: Distribution of parked bicycles over time for different sharing concepts, central stations of the four largest cities (aggregate of individual stations)

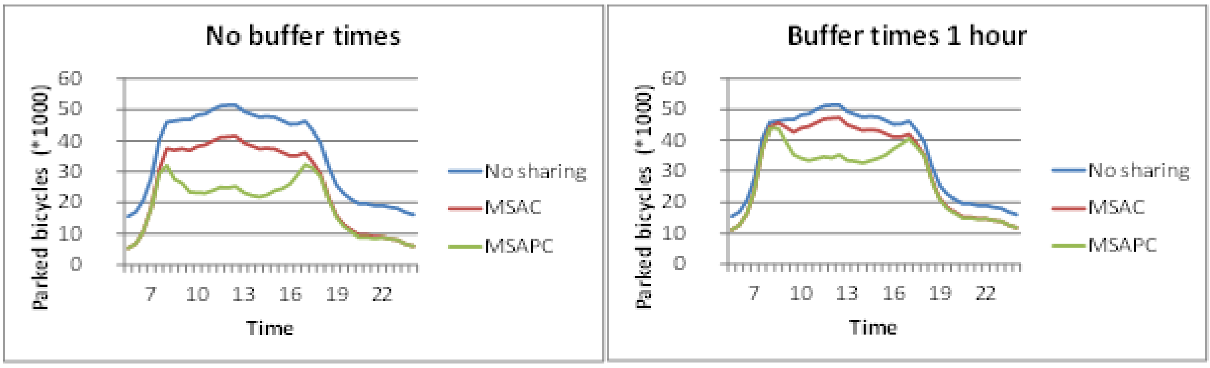

Figure 7: Distribution of parked bicycles over time for different sharing concepts, central stations of other large cities (aggregate of individual stations)

4.6 Development in time

How the potential develops in time cannot be assessed because of missing station information in nearly all databases outside the 2004-2009 period, and the design changes of the NTS that affected the observed mobility. Despite these problems, one conclusion can be drawn when comparing the national data for several years in the period 2004-2015: the number of actual bicycle demanders increased significantly since 2004. This increase will be connected with OV-fiets. Users of OV-fiets made up less than 1% of all actual demanders in 2004 and 14% in 2015. However, it is unclear whether and how this increase affect the potential of bike sharing.

4.7 Magnitude of the potential

The analysis produced many values for the potential. It demonstrated that the potential depends on a number of factors, like the proportion of suppliers and demanders that is willing to share bicycles and the attractiveness of sharing for potential bicycle users. These factors depend in turn on how sharing is organized. Even if there is knowledge about these factors, the available data do not allow to make an accurate estimation. Nevertheless, we think that the results give the opportunity to say something about the order of magnitude of the potential for the large stations. Assuming that half of the suppliers and actual demanders are willing to share bicycles, that sharing increases the availability of bicycles and tempts 25% of the potential demanders to shift to the (shared) bicycle, the potential for the large stations could be in the order of 10%. The potential will obviously increase when a larger number of suppliers and/or demanders is willing to share bicycles. It depends strongly on buffer times as well; in the case of zero buffer times the potential could be closer to 20%, in the case of long buffer times (e.g. 1 hour) 5% is a more likely figure. A reduction of the peak of parked bicycles by 10% is not spectacular, but it is certainly helpful in relieving the capacity problems.

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 due to 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, sharing 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; it could be in the order of 10% for the large stations. Bike sharing can contribute to relieving the capacity problems, but the contribution is probably limited.

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