Bicycle accessibility of train stations in the Randstad South Wing of the Netherlands: quantifying the use of the bicycle as access mode

Master thesis

Otto Coster
April 2013

Colophon

Master thesis

O. Coster (Otto) BSc
Civil Engineering & Management, master Traffic and Transport
University of Twente
E-mail: otto@ottocoster.com

Keywords

Accessibility, bicycle, public transport, train station, transit-oriented development

Supervisors

Dr. Ing. K. T. Geurs
University of Twente

Dr. Ing. L. C. La Paix
University of Twente

Ing. J. Honning
Programmabureau StedenbaanPlus

Summary

Introduction

In the Netherlands, the bicycle is an important access mode to the train station with a modal share of 39% (Givoni & Rietveld, 2007). The bicycle therefore plays a significant role in the accessibility of a train station. In this research is explored what influences the choice of people to take the bicycle to go to the station. The context in which this research is done is the regional transit-oriented development program of the Randstad South Wing, called StedenbaanPlus. The StedenbaanPlus program is the regional TOD program that aims to densify urbanization around train stations and improve the station accessibility (Programmabureau StedenbaanPlus, 2012b).

Objectives

The goal of this research resulted from both the DBR research program 'Transit Oriented Development in the Randstad South Wing' and the issues viewed in practice by StedenbaanPlus. This thesis aims to fill a gap in the knowledge by using a quantitative approach to determine the explanatory variables of bicycle use as access mode to the train station. For this approach, data sources on the bicycle network, public transport, individual traveler characteristics and the built environment was combined and processed in a spatial and statistical analysis. The main research question of this thesis is: What determines the bicycle accessibility of the train station in the Randstad South Wing?

Methods

The factors that are found to influence bicycle use in the literature can be categorized into individual, (built) environment, station and connectivity factors. For each of these categories, data was collected. Based on the data of the NS (Netherlands Railways) customer survey, which contains the origin postcode and the train station, the routes that travelers take to the train stations in the South Wing were calculated. This was done with GIS software in a spatial analysis using the bicycle network from the Fietsersbond (Dutch cycling association). Data on public transport, socioeconomic characteristics and the built environment was added from various sources, as visible in Figure 1.

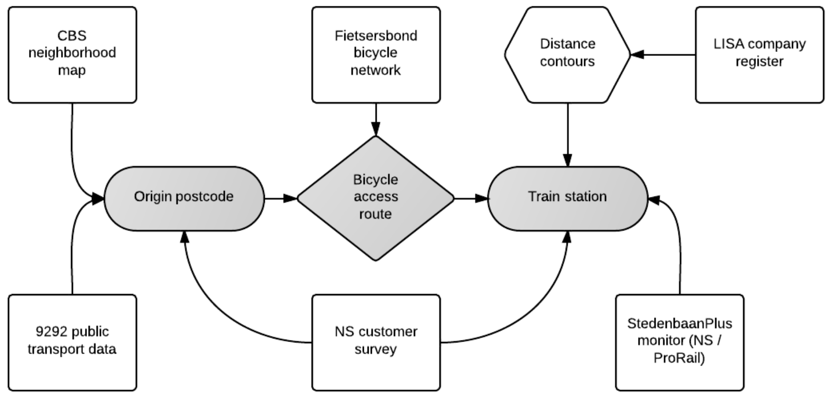


Figure 1: The relations between the data sources for the bicycle access trip to the train station

Results

The spatial analysis resulted in a database, which is used in statistical analysis to quantify the variables that determine the choice for the bicycle as access mode. Three statistical methods were used tot analyze the data. First, a factor analysis was performed to reduce the number of variables to three dimensions: a connectivity, built environment and station component. The factor analysis did not result in a good representation of the variables and therefore the individual variables are used in further analysis.

A multiple linear regression was performed to test the influence of the explanatory variables on the bicycle access share of the Stedenbaan stations. This resulted in a list of 6 significant variables. These include the bicycle parking spaces at the stations, the number of tram/metro lines addressing the stations and the share of non-western immigrants in the origin neighborhood. As the number of cases (36 stations) was very small, a second regression analysis was performed using the individual cases in the customer survey (10403 travelers).

The second regression method used is a binary logistic regression analysis. The analysis identified 24 explanatory variables, which includes variables in all four categories. In the connectivity category, a competition effect between the bicycle and urban public transport was found, the road quality of the bicycle network has a positive effect and a larger distance than 3 km has a negative effect. In the individual category, the type of traveler that is more likely to cycle is a frequent, rush hour traveler that has a work or school motive. The ownership of a car or a student card for free public transport decreases the chance to cycle. Also, a high share of non-western immigrants in the origin neighborhood decrease the chance. In the built environment category, the type of companies in the station area has an influence. Companies in the sectors hospitality and education increase the chance, while retail and other businesses decrease the chance. In the station category, the bicycle parking capacity is significant. A higher number of bicycle parking spaces has a positive effect on the chance that people take the bicycle to the station.

Next, an analysis was performed where the effect of changes in the explanatory variables related to possible policy measures was tested. Found was that the effects of changes in the variables can vary strongly between stations. An aspect that can cause a low bicycle access share of a train station is the competition of urban public transport, especially in the cities of Den Haag and Rotterdam. While this is not positive for the bicycle access share, from the point of view of transit-oriented development this can be seen as a desirable situation. Strongly decreasing the frequencies of bus, tram and metro resulted in a 5% increase in the bicycle access share on average.

A problem at most train stations in the South Wing is the insufficient capacity for bicycle parking. Many stations have occupancy rates above hundred percent, meaning that there are a lot of bicycle parked outside the racks. A test with doubling the bicycle parking capacity at stations has a small effect on the bicycle access share (+2% on average), indicating that merely increasing parking capacity is not sufficient. An optimal road quality also contributes to an increase in the bicycle access share, averaging at 3%.

To see what the best way is to represent bicycle accessibility to train stations graphically, a comparison was made between three types of accessibility measures. From this comparison, the measure that was found the most representative is the potential 'bicycle and train' accessibility measure. This measure combines local accessibility (which train stations can I reach by bicycle within a travel time) and regional accessibility (how many destinations can I reach from my departure station). This is important because travelers often have multiple stations to choose from and base their choice on both access time and station connectivity. The result of this measure is a map with the number of train stations you can reach from a postcode area within a certain travel time.

Conclusions

From reviewing the literature, performing the spatial and statistical analysis and relating the results of this in a case study, it became clear that bicycle accessibility of a train station is hard to quantify. The number of variables that are found significant in the choice of people to choose the bicycle to the station is extensive. However, even with the large number of variables, a large amount of the variation in the bicycle access mode choice remains unexplained. This indicates that there are important variables missing in the statistical analysis used in this research. From the literature, this is though to be mainly related to the individual preferences and attitudes towards bicycle use of travelers.

In short, the aspects that determine the bicycle accessibility of a train station are:

- The amount of bicycle parking space at the train station
- The quality of the bicycle access routes
- The catchment area of a station, determined by the connectivity of the road network, the presence of spatial barriers and the competition with other train stations

- The activity mix in the station environment with the presence of attractive facilities for cyclists
- The position of the train station in the network and the type of travelers it attracts

Further research can improve by focusing on individual preferences and attitudes towards cycling, as this aspect has limited coverage in the data sources used in this research. The quality of the predictions can be improved strongly when individual motives for using a certain access mode are included.

Recommendations for StedenbaanPlus include focusing on stations where improvements are possible, looking at the aspects described above. It is important to keep the individual station profile into account. Also, while local accessibility can determine the choice for the bicycle as access mode, the regional accessibility determines the choice for a train station. Policy measures focused on both these aspects are likely to have more effect in increasing bicycle access shares and train passengers.

An aspect to keep in mind when optimizing bicycle accessibility of the station is the overall goal of the StedenbaanPlus program: increasing the number of train travelers in order to make higher train frequencies on the network possible. Also, the strong competition effect between the bicycle and urban public transport is relevant in how much improvement is possible.

Recommendation for bicycle accessibility improvements that incorporate these aspects include:

- Strongly increase bicycle parking capacity, as the current demand is much higher than the capacity. It can be expected that there is a latent demand, meaning that creating more parking capacity attracts more cyclists. From a cost perspective, investing in bicycle parking is attractive compared to investments in park and ride or urban public transport.
- Measuring the required bicycle parking capacity at the morning rush hour. In this research was found that most cyclists are rush hour travelers with a home-work or home-school motive, so the design capacity should accompany this demand.
- Increasing the catchment area of a station by eliminating spatial barriers. Spatial barriers can be identified by using the maps of the bicycle network accessibility measure. In urbanized areas, the competition of tram and metro is strong. This underlines the importance of direct, fast access routes.
- Investments in the station environment, on lighting, commercial activities or safety, are not only relevant for the cyclist, but also for the other traveler groups. While not specifically target at the cyclists, investments in the station environment help to attract more train travelers.

Preface

Moving from the eastern part of the Netherlands to the west, the differences between the cities of Enschede and Den Haag soon became apparent to me. The numerous tramlines and the massive amounts of pedestrians in the city center of Den Haag made me think about the idea of a transit-oriented city. However, one thing was remained the same: the amount of cyclists on the streets. While Den Haag has adopted the 'shared space' philosophy in the city center, with good intentions, in the real world it means that pedestrians and cyclists are more than often in conflict with each other. Not that in Enschede this is any better by the way.

In the past seven months of my internship at StedenbaanPlus I have seen and learned a lot about how a transit-oriented development programme is done 'the Dutch way'. This means many meetings, collaboration and discussion. It became apparent to me that there is no such thing as immediate policymaking or implementation. Also, it is clear that there is much to do in the South Wing. The Programmabureau StedenbaanPlus is there to make sure policymaking is keeping focus on improving public transport accessibility, even when priorities and funds are becoming more challenging. In the past months I've seen closely why their work is so important. I've come to admire the spirit of my colleagues at StedenbaanPlus for their work.

I have to thank Jan in particular, for the useful discussions about my research and the chain mobility programme we were working on. Besides being a great source of knowledge I've also got to know you as a friendly and inspiring colleague. To you and the rest of the StedenbaanPlus team, I wish you the best for next year and beyond. Furthermore, I'd like to thank Lissy, my daily supervisor, for the intensive feedback I received during our discussions and for never getting tired of my e-mails. And lastly, Karst, our contact was less frequent but each moment helped me to get on the right track and make a large step forward.

For the data I needed for my research, I've got to thank NS, ProRail, the province of South Holland and the Fietsersbond. Your help made it possible for me do my research.

Finally, I've got to thank you, the reader of this, for taking the time to read my thesis. I hope it is interesting and you end up with new insights.

The Hague, April 2013

Otto Coster

Table of contents

List of figures and tables

List of figures

List of tables

1 Introduction

1.1. Transit-oriented development in the Randstad South Wing

The South Wing of the Randstad in the Netherlands is one of the most densely populated areas in Europe with over 3,2 million inhabitants (Zuidvleugelbureau, 2011). These densities result in a high demand for mobility and high quality public transport to accommodate in this demand. In the South Wing there are several programs for the improvement of the public transport network to obtain a regional coverage of high quality public transport. One of these programs is the transit-oriented development (TOD) program StedenbaanPlus.

The StedenbaanPlus program is the regional TOD program that aims to densify urbanization around train stations and improve the station accessibility (Programmabureau StedenbaanPlus, 2012b). This is needed to increase the public transport ridership levels, so that in the end the frequency of the railways can be increased from four to six trains an hour. This is important for the public transport to be a good or better alternative to the car, because with six trains an hour the average waiting time for travelers is so low that it is negligible.

An important aspect of TOD is the focus on non-motorized transport as access and egress mode for public transport. The neighborhoods need to be designed for walking and cycling with pedestrian scale distances to facilities, mixed-use land development and convenient, comfortable and secure transit stops and stations.

The University of Twente has set up a research program that explores the local and regional effects of station area accessibility. Since the economic crisis in 2008, the demand for new land development has decreased strongly and improving transit accessibility can provide an alternative development strategy to increase transit ridership levels. The research program, 'Transit Oriented Development in the Randstad South Wing' is part of a larger, national research program 'Sustainable Accessibility of the Randstad (DBR, Dutch acronym)'. In this program, the TU Delft, the University of Amsterdam and the University of Twente work together to keep the economic most important area of the Netherlands accessible (Geurs et al., 2012).

1.2. The StedenbaanPlus program

The StedenbaanPlus organization has been active since 2003 to implement the StedenbaanPlus concept (literally, it means 'city line plus') in the South Wing. The StedenbaanPlus organization is a partnership of ten parties in the South Wing, including the municipalities of Rotterdam and The Hague, regional government bodies and the railway companies NS and ProRail. The organization has no direct influence on the public transport and spatial developments, but raises awareness for the concept of TOD within the partners and provides them with a yearly monitoring of the progress and gives recommendations for future development. The partners use this information to initiate and influence spatial and infrastructural developments.

StedenbaanPlus focuses on three aspects of TOD: urban development around transit stations, improving the quality of chain mobility and increasing the frequency and quality of the train and light rail network (Figure 1.1). The aspect of chain mobility is primarily related to this research. In short, chain mobility consists of everything a traveler experiences during the access and egress stage of a public transport trip. This includes the accessibility to stations and the station environment, such as the cycling and pedestrian facilities and social safety aspects.

The chain mobility program has four pillars: improving pedestrian and bicycle accessibility and parking facilities, car park & ride facilities, social safety at the stations and travel information facilities (Programmabureau StedenbaanPlus, 2012b). This research supports the chain mobility program in a way that it quantifies the concept of bicycle accessibility, specifically for bicycle use as access mode to the train station.

In the Netherlands, the bicycle had in 2006 a modal share of 39% in the access journey to the train station (Givoni & Rietveld, 2007) and since is increased up to 42% (Bureau Spoorbouwmeester, 2012). The bicycle therefore plays an important role in improving the accessibility of train stations. In this research is explored what influences the choice of people to take the bicycle to go to the station. With this information, StedenbaanPlus has a quantitative basis to identify bottlenecks in infrastructure or land use developments. In the next chapter, the goal of this research will be described in more detail.

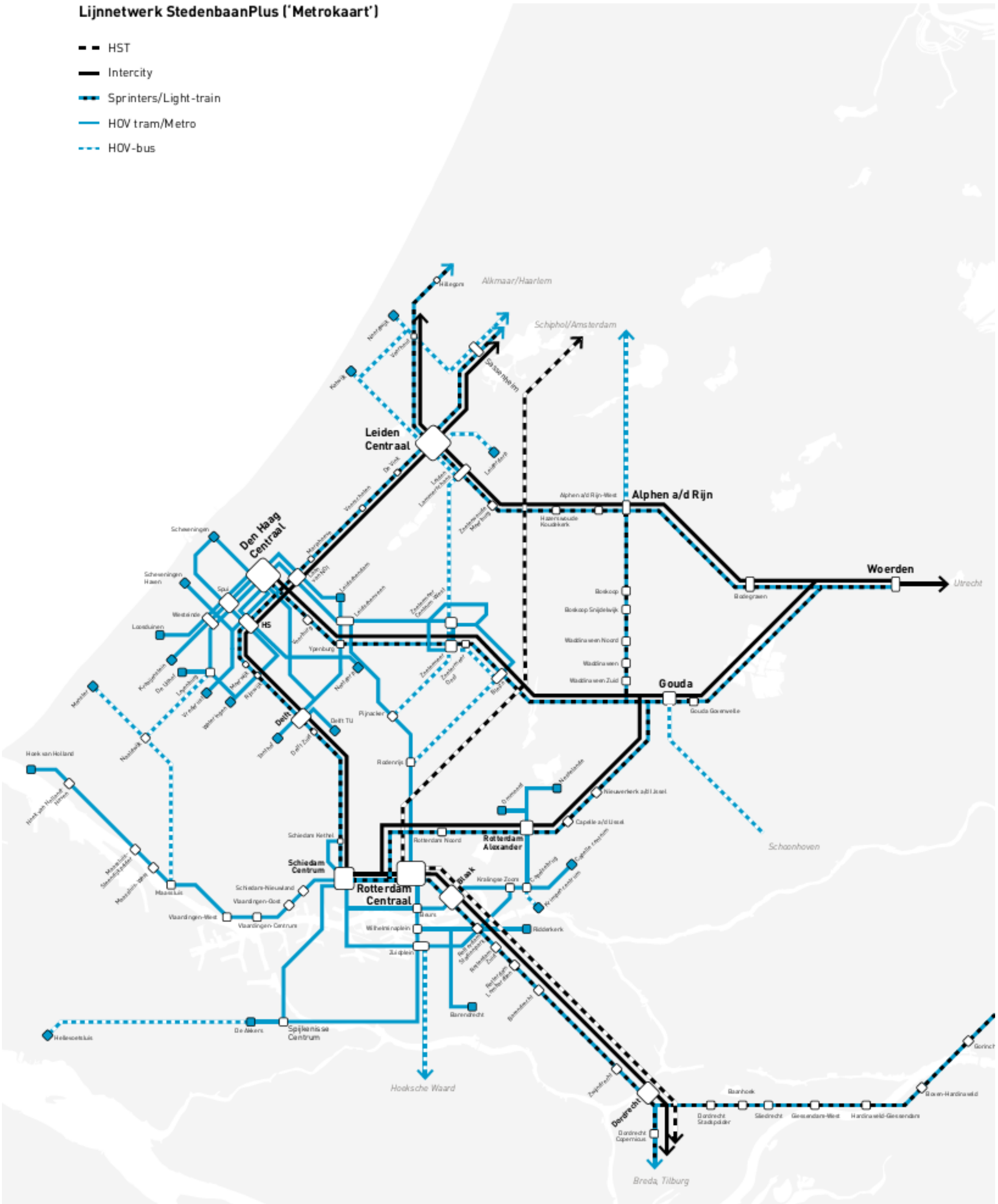


Figure 1.1: Line map of the StedenbaanPlus public transport network in the Netherlands South Wing (Programmabureau StedenbaanPlus, 2012b)

2 Research design

2.1. Research objective and research questions

Current research on bicycle use has been focused on determining the factors that influence bicycle use in Dutch municipalities (Heinen et al., 2010). Research on the role of the bicycle in combination with public transport has been focused on explaining the position of the bicycle as access mode (Rietveld, 2000), the important of bicycle parking facilities (Martens, 2004) and bicycle access routes to the station (Scheltema, 2012).

In this thesis, the focus is on the determinants of bicycle use, specifically as access mode to the train station. This combined bicycle use in general and the influential factors at the train station. The goal of this research resulted from both the DBR research program 'Transit-oriented Development in the Randstad South Wing' and the issues viewed in practice by StedenbaanPlus. This thesis aims to fill a gap in the knowledge by using a quantitative approach.

The objective of this research is defined as:

Further develop the knowledge on non-motorized accessibility by determining the factors that influence the bicycle accessibility of the train stations in the South Wing of the Netherlands.

From this objective, several research questions can be derived. The main research question of this thesis is:

What determines the bicycle accessibility of the train stations in the Randstad South Wing?

The first research question addresses the current state of the literature about bicycle accessibility:

(1) What is known in the literature about bicycle use, bicycle accessibility and its relation to transit-oriented development?

The second question addresses the variables that influence the use of the bicycle as access mode to the station:

(2) What are the explanatory variables for the use of the bicycle as access mode to a public transport station?

The third research question addresses the way bicycle access to the train station can be represented by an accessibility measure:

(3) How can the bicycle accessibility of a train station be represented using an accessibility measure?

The fourth question addresses the performance of the stations in the StedenbaanPlus program area:

(4) What is the performance of the StedenbaanPlus train stations on the aspect of bicycle accessibility?

2.2. Research methodology

In order to answer the research questions, the factors that influence bicycle accessibility according to the literature need to be operationalized and processed. In Figure 2.1, a model of the research is displayed.

Research model

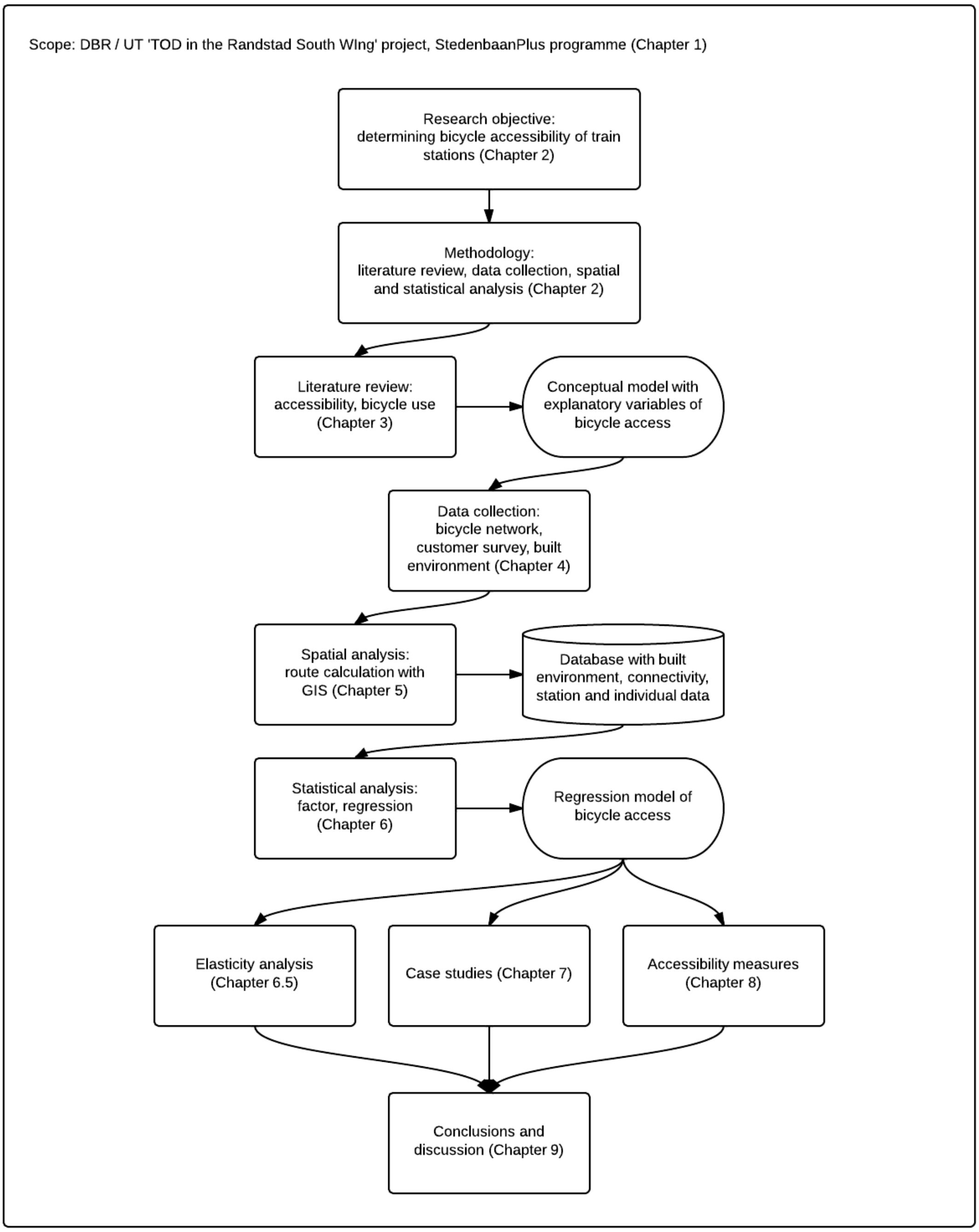


Figure 2.1: The research model, a schematic overview of the research process

The research starts with a literature review, where the current knowledge on accessibility, bicycle use and the relation to public transport is described (Chapter 3). This results in an overview of the influential variables of bicycle use as access mode to the train station. The data on these variables is collected from various sources. This process is described in Chapter 4.

The data that is collected needs to be combined and processed to be used to model bicycle use as access mode. This is done with route calculation and other spatial analysis (Chapter 5). The result of this analysis is a database with socioeconomic data on the travelers to a train station, the route they take and its characteristics, the facilities at their departure station and the characteristics of the station environment.

This database with combined land use, connectivity, station and individual data is then used for statistical analysis (Chapter 6). Using regression methods, the influence of each of the influential variables is examined. The result is a regression model with the statistically significant influential variables on bicycle use as access mode to the train station. With this model, a case study is done to see how the significant variables are represented in reality (Chapter 7). Also, an elasticity analysis is done to see what the effect is of changes in the influential variables.

Then, in Chapter 8 is explored how bicycle access to the train station can be represented with an accessibility measure. Using the results from the statistical analysis, the case studies and the comparison of accessibility measures, conclusions can be formulated on what influences bicycle accessibility, how bicycle accessibility can be represented and what policy aspects can have an influence on bicycle accessibility (Chapter 9).

3 Literature review

In this chapter, an overview of the concepts transit-oriented development, accessibility, bicycle use and their mutual influences is described.

3.1. Transit-oriented development

Transit-oriented development is generally defined as dense, mixed-use urban development linked to high quality public transport in a pedestrian-friendly environment (Cervero, 2004). In TOD, the non-motorized modes (walking, cycling) are used for local mobility, while public transport serves the demand for regional mobility. Primary goal of TOD is to increase transit ridership and stimulate economic development. Secondary goals include improving quality of life, revitalizing declining city centers and supporting smart, and sustainable mobility growth.

The first element of TOD; dense, mixed-use urban development, consists of land development that has a mixture of residential, employment, commercial and recreational uses. High densities are desired to provide a large catchment area for the transit station. The mixed use and close proximity to a station mean that people become less automobile dependent and can reach most destinations by walking, cycling and/or public transport. The second element of TOD is high quality public transport with good accessibility for non-motorized modes. This includes train stations and transit stops which are comfortable for waiting, clean, attractive and safe (Renne, 2009).

In relation to bicycle accessibility, the literature on TOD states the importance of integrating cycling with public transit in order to improve the accessibility of the station. Cycling has the benefit of a travel speed that is three to four times that of walking, increasing the catchment area of a station about a tenfold. Especially in areas with a low service level of urban public transport, cycling plays an important role in accessing the station.

3.2. Accessibility

Accessibility is a key concept of transit-oriented development. Mixed land-use provides many different opportunities for residents. A pedestrian-friendly environment combined with high quality public transport gives quick access to these opportunities. This example shows that accessibility includes different components.

In short, accessibility is the ability for people to access desired goods or services. It consists of four components (Geurs & van Wee, 2004):

- Land-use component; this consists of the number and spatial distribution of the destinations and their characteristics, as well as the spatial distribution of the demand (residential locations).
- Transport component; this consists of the impedance (distance, travel time, costs) between an origin and a destination, and the perception and valuation of this impedance in relation to the destination.
- Temporal component; this involves the constraints in time a person has to participate in an activity, as well as the availability of activities at different times.
- Individual component; this includes the personal abilities and limitations of a person, such as education level or other socio-economic characteristics.

3.3. Accessibility measures

The translation of the concept of accessibility into a performance measure that can be used for planning purposes has got more attention in the literature recently. Whatever the form of the accessibility measure, the key is to measure accessibility in terms that matter to people in their assessment of the options available to them (Handy & Niemeier, 1997). It must be consistent with the uses and perceptions of the residents, workers and visitors of an area.

Another challenge when working with accessibility measures is finding the balance between a theoretically and empirically sound measure and one that is sufficiently plain to be understood and used by different disciplines (Bertolini et al., 2005). The measure should also be visually well represented to enhance understanding and to be able to be communicated in an 'accessible' way (Curtis & Scheurer, 2010).

Accessibility is not only defined by measurable aspects, but also depends on the experience of residents. This can cause problems with calibrating a theoretical measure with real-world data. What people do (revealed behavior) is not always the same as what people would like to do given a set of alternatives (preferred behavior). In accessibility theory, the difference is made between actual accessibility (where do people go to) and potential accessibility (where can people go to).

In the literature, several types of accessibility measures can be identified. The simplest form is the infrastructure-based measure, which describe only the functioning of the transport system, such as the travel speeds or congestion levels. They only incorporate the transport component of accessibility. The other types are categorized as location-based, person-based or utility-based measures (Geurs & van Wee, 2004). These types include more two or more components.

3.3.1. Location-based measures

Location-based measures have both a transport and land-use component and can be divided in three categories:

- Distance-based measures, such as the cumulative opportunities, which is a measure for the amount of opportunities a person can reach given a fixed travel time or distance
- Potential (gravity-based) measures, in which the opportunities are weighted by distance or time
- Balancing factors, which includes competition effects between opportunities and demand

An important aspect of an accessibility measure is the disaggregation level. Accessibility can be measured on a zonal, household of individual level in the spatial dimension. In socioeconomic sense, disaggregation can be made via income groups or other characteristics. The choice of disaggregation level depends on the purpose and intended use of the measure.

Trip purpose represents another dimension of disaggregation. In the current accessibility measures, common purposes are work, shopping or recreation on the destination-end of the trip. The origin is often the residential home. One important aspect of this disaggregation is the fact that destination opportunities actually reflect the needs of the residents (Handy & Niemeier, 1997). This relates to socioeconomic circumstances, but also temporal and physical constraints.

Further, the choice of travel impedance type should be specified. Distance or time are common, but also a combined measures, such as generalized travel costs. This can be divided in impedance per transport mode. Finally, the attractiveness of an opportunity needs to be specified, which can be highly subjective.

3.3.2. Person-based measures

An alternative approach is measuring the accessibility of an individual using a prism-constrained space-time measure. In this type of measure, the individual and all locations are represented as distinctive points in space (Kwan, 1998). The access to opportunities is influenced by an individual's spatial and temporal constraints and incorporates all four components of accessibility. This gives the possibility to account for individual differences and to examine the influence of gender or ethnic differences, for example. A disadvantage of this type of measure is the need for highly detailed individual activity-travel data. The result of the measure can give more information about individual differences in accessibility than aggregated land-use transport accessibility measures.

3.3.3. Utility-based measures

Utility-based accessibility measures give a value to each option in a set of potential choices using a utility function. They include all components except the temporal component and are useful for economic evaluations as they include user-benefit changes. Their general disadvantages are the difficult interpretability and communicability, which is an obstacle in planning situations.

Network-based accessibility measures

In the network-based accessibility measures in the literature, measures that belong to one of the other types (infrastructure, location, person or utility-based) are combined with a form of network measure. This means that the impedance for a node is the sum of the links between origin *i* and first neighbor destinations *j*. The main advantage of this type of measure is that it incorporates the level of connectivity. Well-connected nodes have a better accessibility score than less connected ones. De Montis et al. (2007) used this network-based approach to map accessibility levels for the island of Sardinia, using shortest road distances and the exchange of commuters between municipalities. It gives insight in the relative difference in accessibility between municipalities, which can be combined with other social-economic data for transport policy development.

3.3.4. Conclusion

The literature on accessibility measures discusses various types of measures and dimensions for disaggregation. In Figure 3.1, the options for a 'bicycle as access mode' measure are displayed. Each bicycle access trip starts at the origin location, which is generally the home location. Options can be to measure bicycle accessibility for an individual (taking individual preferences into account), household or zone level.

The destination is by definition, the train station (or a different form of transit). Based on the type of measure, this can be a single station (in case of an infrastructure-based measure for example) or multiple stations (in case of cumulative opportunities). One stage further in the multimodal trip, the choice of a station can also depend on the opportunities you can reach from that station. A train station that can reach more opportunities can be the preferred option, even if the access distance is larger.

The travel impedance of the bicycle access route can also have multiple options, using distance, travel time (with or without delays) or the route quality. A representative bicycle accessibility measure finds a good balance between the relevant influential factors and the complexity of the measure. In chapter 8, several approaches to create a bicycle accessibility measure for the South Wing are described.

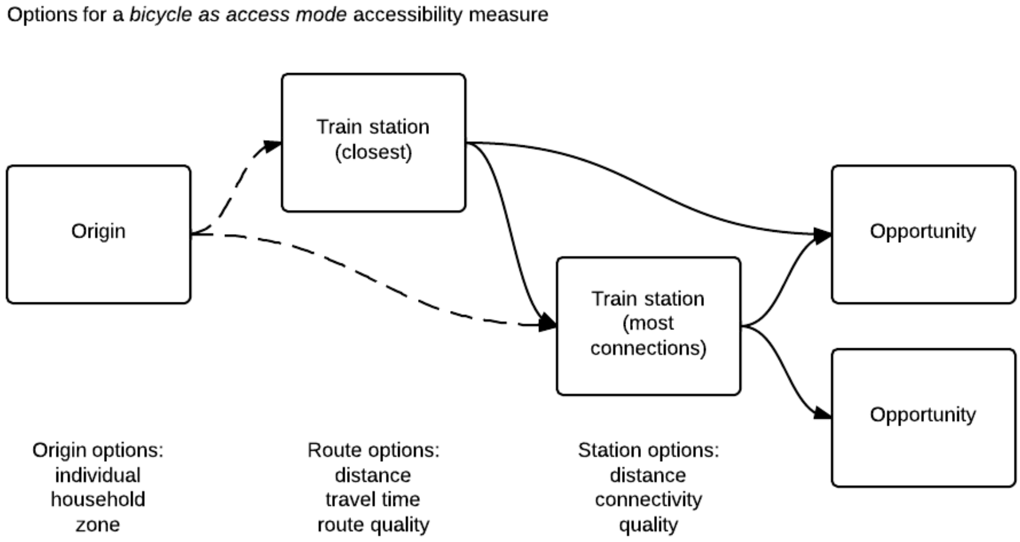


Figure 3.1 - Options for a 'bicycle as access mode' accessibility measure

3.4. Determinants of bicycle use as access mode

The use of the bicycle as access mode for public transport is naturally influenced by bicycle use itself. Factors that influence bicycle use in general can also be relevant for bicycle access trips to a station. Several studies have been done on the factors that influence bicycle use, including Aultman-Hall et al. (1997); Broach et al. (2011); Cervero and Duncan (2003); Cervero et al. (2009); Hadas and Ranjitkar (2012); Handy and Clifton (2000); Heinen et al. (2010); Rietveld and Daniel (2004). The factors that are found to influence bicycle use in these studies can be categorized into individual, (built) environment, station and connectivity factors.

3.4.1. Connectivity

Connectivity relates to infrastructural and transport components of accessibility, which determine how well cyclists are able to access destinations. From the literature, the following variables can be identified:

- Distance / travel time
- Infrastructure (presence and continuity of bicycle lanes, width of the bicycle lanes, width of curb lane, presence of parking lane and occupancy, presence of traffic signals)
- Traffic conditions (traffic volume in curb lane and other lanes, speeds, truck volumes, right-turn volumes)
- Geographical conditions, slopes and hills

In the French-German TOD project 'Bahn.Ville', a key element in supporting rail-oriented development is improving neighborhood mobility, which they define as planning for non-motorized transport to the station, a diversity of urban functions around the station area and urban design principles that stimulate urban vitality (L'Hostis et al., 2010). They worked with frequent users of the stations to examine the quality of the footpaths around the stations. They defined five basic criteria that define the minimum quality standard of a footpath towards a station:

- Atmosphere (environment quality)
- Fluidity (without interruptions, obstacles detours or clashes)
- Security and safety (without any danger)
- Services (minimum amount of shop and services on route)
- Readability (a clearly visible, identifiable destination)

The conclusion of the workshops was that if a deficiency in one of these criteria is sufficient to make a footpath inadequate for the purpose of rail-oriented urbanism. In practice this means that people do not take the route and choose to travel by other modes such as the car. An important finding was also that a single section of a pedestrian route that lacks in one of the five criteria could lead to a whole route to be found inadequate.

Aultman-Hall et al. (1997) analyzed the routes Canadian commuter cyclists take and found that most cyclists divert very little from their minimum path and used mainly the main roads, avoiding slopes and crossings. Interestingly, the dedicated off-road paths where not much used, indicating that these might be unattractive or not on the route from origin to destination. This gives support for better bicycle infrastructure (wider lanes, separate bicycle lanes) along the main roads. For recreational cycling, routes that avoid vehicular traffic are preferred. Broach et al. (2011) did a similar study and found that traffic-calming features such as bicycle boulevards are of high value for the cyclist. The extra value of bicycle lanes was offset by the negative influence of the adjacent traffic, making them no more attractive than a regular low traffic volume street. Commuters were also less sensitive for infrastructural characteristics and more sensitive to distance.

Rietveld and Daniel (2004) did research into the determinants of bicycle use in the Netherlands. They found that, besides physical and social aspects that are related to the cities, also policy-related variables are of influence. Travel time is an important factor, but also physical effort (slopes, frequent stops) plays a large role in the attractiveness of the bicycle as transport mode.

In the Netherlands, the Fietsersbond is an organization that represents cyclists, promotes cycling and tries to make the environment more bicycle friendly. They are one of the supporters of an infrastructural plan to improve bicycle accessibility with fast bicycle routes in the Netherlands. These so-called bicycle highways are direct connections between cities, much like regular highways. They are fast, wide bicycle lanes with a minimum of traffic lights and intersections. The Fietsersbond also maps bicycle lanes in the Netherlands with a specially designed measuring bike, equipped with a video camera, GPS sensor, shock sensor and microphone that measures ambient noise (RTV Rijnmond, 2012). With this bike they examine the quality of the Dutch bicycle network and make suggestions for improvement to municipalities and other policy makers. They have also developed a bicycle route planner (Fietsersbond, 2012) that can be used to plan a quick, comfortable or attractive route, depending on personal preference. A competitive service is the route planner from Google, that recently incorporated bicycle transport in their Maps service (Google, 2012).

3.4.2. (Built) environment

Both the natural and the built environment are found to have an influence on bicycle use. Cervero (2004) categorized the built environment variables that are related to transit-oriented development into three groups:

- Land use density
- Land use diversity (mix of activities)
- Land use design (city block size, street connectivity, environmental quality)

A built environment that has high densities, high diversity in terms of function mix (residential and commercial) is ideal for transit-oriented development. The land use design has to be focused on creating direct and attractive routes for non-motorized traffic. This can be done with a small city block size, well-connected streets with many route options and enough space for pedestrians and good cycling infrastructure.

A successful TOD project includes a pedestrian-friendly environment. This is essential for ease of access to the transit station and the access to activities around the station. The question is what spatial elements make an environment pedestrian friendly. This relates to the concept of neighborhood accessibility. Neighborhood accessibility is a comprehensive accessibility measure that incorporates the proximity to activities and the availability of reaching them by public transport and non-motorized transport at the neighborhood level. Handy and Clifton (2000) identified the factors that contribute to neighborhood accessibility. They divided these factors into five categories:

- Activity factors (size, quality, density, mix)
- Impedance factors (distance, time, cost)
- Level-of-service factors (crowding, directness of route, information availability)
- Terminal factors (parking availability, intermodal connections, terminal design)
- Comfort factors (traffic speed, lighting, weather, scenery)

One issue with the neighborhood accessibility measure is the generally limited availability of data. Detailed data on the factors is expensive to collect and subject to change. Furthermore, data on pedestrian and cyclists activity is generally not available.

Of the natural environment variables, the weather conditions and temperature are the most important influential variables (Heinen et al., 2010). Precipitation, in particular rain, decreases the attractiveness to cycle. A moderate temperature is considered the most comfortable for cycling.

3.4.3. Station

In a public transport trip chain the bicycle is used in two ways: as access mode and/or egress mode. In the Netherlands, the role of the bicycle as access mode for the railways has been increasing in recent years, from 35% (Rietveld, 2000) to 39% (Givoni & Rietveld, 2007) up to 42% currently (Bureau Spoorbouwmeester, 2012). The role of the bicycle as egress mode is far less important with only a share of 10%. This is highly the result of the unavailability of bicycles at the activity end. For other public transport, such as bus and tram/metro, the percentages are much lower, with a share of 6% and 2.3% (Martens, 2007). Main reasons for this difference are the generally shorter distances travelled by bus and tram/metro and the lack of bicycle parking space at bus stops and metro stations.

Integrating the bicycle with public transport is commonly divided into four options: bike on transit, bike to transit, two bikes and shared bike (Krizek & Stonebraker, 2011). In the US, it is more common to transport the bicycle aboard the transit vehicle, using bicycle racks in or on the outside of a bus. In the Netherlands, this is generally not possible on buses and the parking space on trains is limited, so the bike on transit strategy is not very useful. The most used option in the Netherlands is bike to transit, where the owner's bicycle is parked at the station. Important for the choice to use the bicycle for the access trip to a station, is the availability of bicycle parking space. This is considered the most cost-effective way to increase bicycle use as station access mode. Martens (2004) found that by providing bicycle parking facilities and shelters this generates an increase in the use of the bicycle as access mode.

Martens (2007) found that bicycle parking facilities at the station are very important to cyclists and have a significant effect on the choice to use the bicycle as access mode. On the contrary, research by Givoni and Rietveld (2007) revealed that cyclists do not care much about parking facilities at the train station. This is somewhat surprising and may be due to the fact that on most train stations there is a chronicle shortage of parking places, so people do not count on a parking place when travelling to the station.

The two bikes option is mostly used by people who make the same trip often and park an extra bicycle at their end station, like commuters or students. This provides an extra challenge for the implementation of paid bicycle parking, because the value of the 'egress-bike' is often low and the propensity to pay for secure parking is low. Also, the low valuation of the egress bicycles often forms abandoned bicycles (weesfietsen) that occupy parking space but are not used anymore.

The shared bike option has got moderate success in the Netherlands, with the so-called PT-bicycle (OV-fiets). The PT-bicycle has primarily replaced egress trips by public transport and has caused people to switch from a car to a combined bicycle-train trip. Other initiatives, such as bicycle lease at the egress train station and a combined bicycle lease-bus package have all been canceled because of a lack of interest.

Special attention has to be given to the safety aspect of bicycle transport to stations. Especially during the evening, bicycle routes preferably are located along roads with other traffic, are well lit and clean and don't have socially unsafe locations on the route, such as tunnels or abandoned residential or industrial areas. The destination, the station, have a reputation of social unsafety due to abandonment during night, undesirable activities and groups of people hanging around the station (CROW, 2007).

To conclude, the factors that influence the accessibility of bicycle transport in relation to public transport are:

- Location and catchment area of the public transport station
- Availability of a bicycle at the activity station
- Availability and security of bicycle parking
- Ease of access between parking location and station

3.4.4. Individual variables

Many studies stated the importance of individual variables and preferences on bicycle use. Rietveld and Daniel (2004) found that in cultures where the bicycle is unknown in as transport mode, the probability that the bicycle is included in the choice set is low. This stresses the importance of including culture and ethnicity in the analysis of travel behavior.

Mestrum et al. (2011) also found that the ethnicity is strongly correlated with the modal split of movements in the Netherlands. A high percentage of non-western immigrants in the origin area was strongly positively correlated with the use of public transport and strongly negatively correlated with bicycle use. They also found a correlation between an increase in the number of cars per household and a decrease in bicycle use.

Research voor Beleid (2006) identified several other variables that were influential on bicycle use in Dutch municipalities: the percentage of single households, young people and of non-working people.

The individual variables as identified in the literature are listed below:

- Age
- Physical fitness
- Car ownership
- Socioeconomic situation

- Safety perceptions
- Ethnicity/cultural background
- Attitudes and preferences

3.4.5. Conclusion

In Figure 3.2, a conceptual model of the factors that influence bicycle use as access mode to the train stations is displayed. In this figure, the explanatory variables of the studies that have been done on bicycle use in general and bicycle use related to public transport are combined.

In this research, a combination of spatial and statistical analysis will be used to explore the influence of the variables described in this chapter. For this approach, several data sources were used. This process is described in the next chapter.

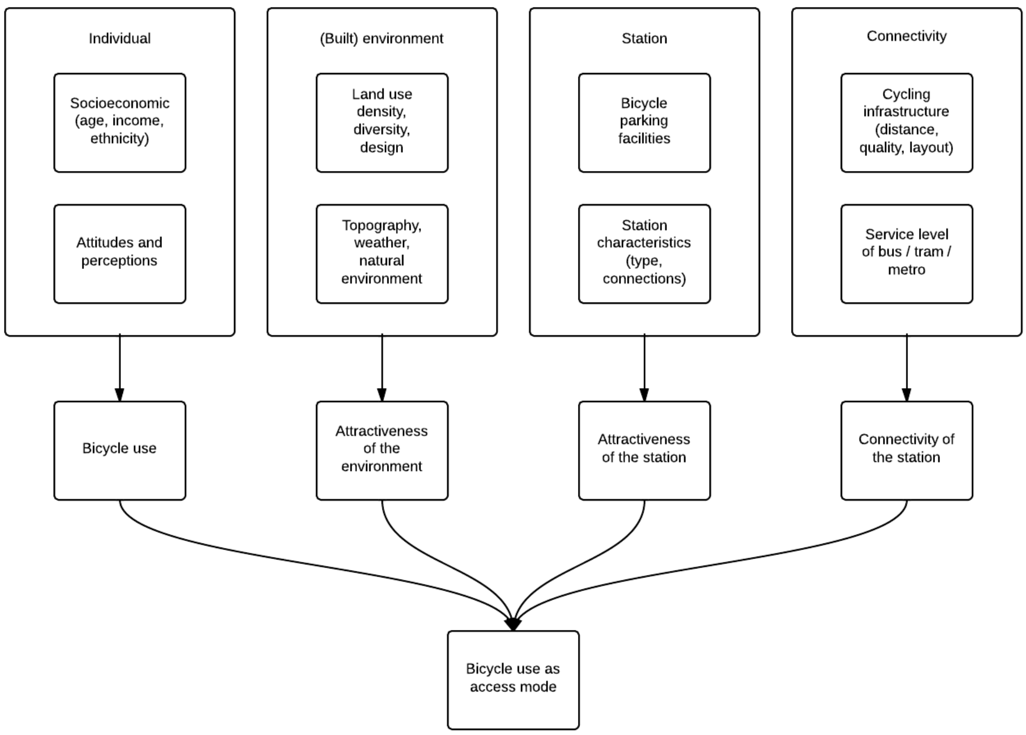


Figure 3.2: Conceptual model of the factors that influence bicycle use as access mode to the train station

4 Data collection

In order to assess the influence of all the variables described in the literature, a large number of data sources is needed. The sources used in this research are described in this chapter. Then, this data was to be combined and processed using spatial analysis in order to obtain a database that can be used for the statistical analysis.

4.1. Data collection

One of the requirements for this research was the availability of high quality, detailed data sources on land use, infrastructural and station characteristics. Especially detailed data about the quality of the bicycle network is often not available on a regional or national level, or has a commercial use. The Fietsersbond (Dutch cycling association) has developed their own bicycle route planner for the Netherlands, free for public use at their website (Fietsersbond, 2012). For this research, the Fietsersbond provided the database of their bicycle route planner for the province of South-Holland.

Another important data source that was used in this research is the customer satisfaction survey database of the Netherlands Railways (NS). This customer satisfaction survey (KTO, Dutch acronym) contains information about the train trips of travelers including and egress modes and the valuation of train trips and station facilities from the perspective of the traveler. This survey is conducted continuously by NS to monitor customer satisfaction levels. NS has made the results of the years 2001 up to 2011 available for use in the DBR research program.

Other data sources are the LISA company register, which was provided by the Province of South Holland and several databases that are publicly available (Figure 4.1).

The available data can be categorized into four groups:

Connectivity

Connectivity includes the variables that influence the route taken from the origin to the destination, the train station. These are mainly related to the bicycle infrastructure. Also, characteristics of the bicycle network density and service levels of public transport in the origin area are included.

Built environment

Built environment includes variables that relate to the spatial area around the station, such as the spatial mix of land use functions and the type of companies.

Station

The station facilities category includes all variables related to the direct station environment and the characteristics of the station itself, such as the type of station and the number of connections.

Individual

From the individual variables, only the socioeconomic variables are included in this research. Data on individuals' attitudes and preferences towards cycling was not available. The socioeconomic variables include all possible relevant variables for bicycle use.

In Figure 4.1, an overview of the used data sources by category is displayed. In this figure, the input sources of the variables are displayed with a connecting line.

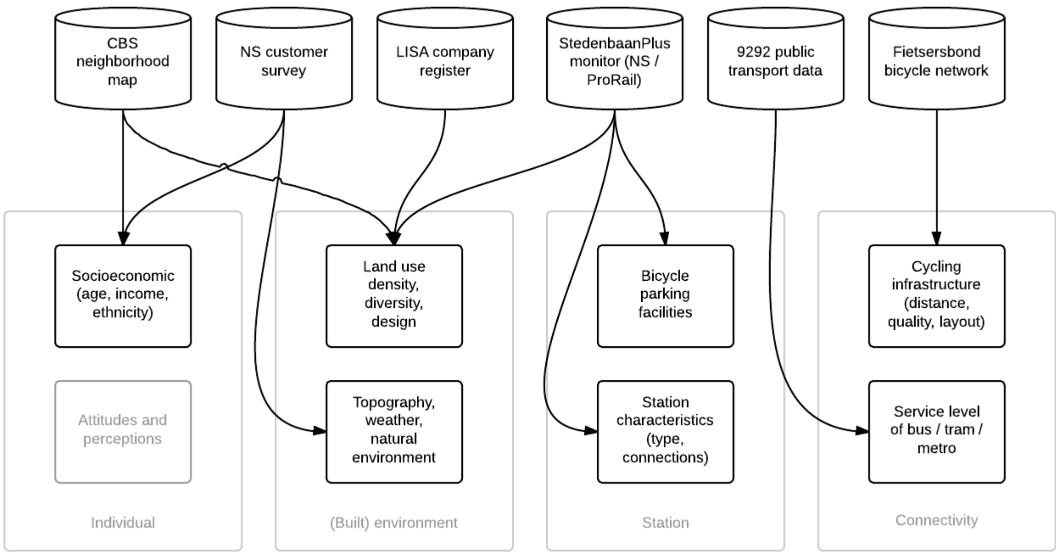


Figure 4.1: Schematic overview of factors and corresponding data source

4.1.1. Connectivity data sources

Fietsersbond bicycle route planner database

The database of the bicycle route planner consists of several files for the nodes, links, entrances of train station and postcode points. The nodes file is used for the routing, but the links file contains the most useful information about the bicycle infrastructure. The characteristics used in this research are listed below:

- Length of the link
- Start and end node
- Road type

- Road surface quality (3-point scale)
- Traffic nuisance along the road (5-point scale)
- Lighting level (3-point scale)

Development of the bicycle route planner database is done by the volunteers of the Fietsersbond. These volunteers are cycling enthusiasts, which aim to map the complete bicycle network in the Netherlands. The database is used for the online bicycle route planner of the Fietsersbond, the most accurate and advanced bicycle route planner in the Netherlands. The volunteers have several methods for ensuring the accurateness of the information in the database. Volunteers are asked to only asses these roads that they are familiar with because of their residence. For unknown roads, they are using different methods, such as photographing / filming the route in combination with a GPS tracker or assessing the roads during the trip using a fieldwork form. Also, the volunteers help each other with corrections and discussion, similar to the editing process at other crowd sourced databases such as Wikipedia. While this does not guarantee complete accurateness, the large number of volunteers, several hundred throughout the Netherlands, and the detailed descriptions of the characteristics provide a level of information that is unmatched compared to the bicycle network in other data sources such as OpenStreetMap (OpenStreetMap, 2013).

Road type

The Fietsersbond bicycle route database distinguishes between several types of roads, bicycle paths and pedestrian paths. On most roads in the Netherlands, you are allowed to cycle on the bicycle (suggestion) lane or there are separate bicycle paths along the road. Residential areas often have no bicycle paths and you are allowed to cycle on the regular road. In the calculation of the access routes to the station, described in Chapter 5, all roads where cycling is allowed are included. Calculation of the routes was done based on distance, no distinction between the types of bicycle path has been made.

Road surface quality

The road surface quality aspect of the network is defined as the maintenance condition and as a result the level of vibration caused by the road surface. The Fietsersbond focuses on the part of the road used by cyclists when assessing this aspect. They distinguish between four possible quality levels:

- Good: A road is considered of good quality if a cyclist doesn't experience any vibrations of the road on a normal city bicycle.
- Reasonable: An asphalt road is considered reasonable if the surface contains cracks and holes, but these don't influence the stability of the bicycle. For clinker brick roads (a road type often found in Dutch residential areas), the quality is considered reasonable if there are vibrations but these don't affect the stability.

- Bad: A road with an asphalt surface is considered of a bad quality if it contains holes, or you experience a constant heavy vibration. A clinker brick road is considered bad when there are a lot of bricks sticking out. Also, the presence of tree roots or loose tiles can be a reason for a bad quality level.
- Unknown: This is the default value for a road that doesn't have this aspect defined yet.

The road quality aspect is unfortunately not defined for a 27% of the access route roads, which makes this variable less reliable as it could have been. An overview of the percentages of the quality levels is visible in Table 4.1.

Note: In Table 4.1, 4.2 and 4.3 only the roads that belong to the bicycle access routes with a maximum distance of 5km to the train stations are included. The maps give an impression of the total road network quality.

Table 4.1: Percentage of bicycle access route roads per road surface quality category

Percentage of bicycle access route roads per road surface quality category	
Good	44,10 %
Reasonable	28,40 %
Bad	0,47 %
Unknown	27,03 %

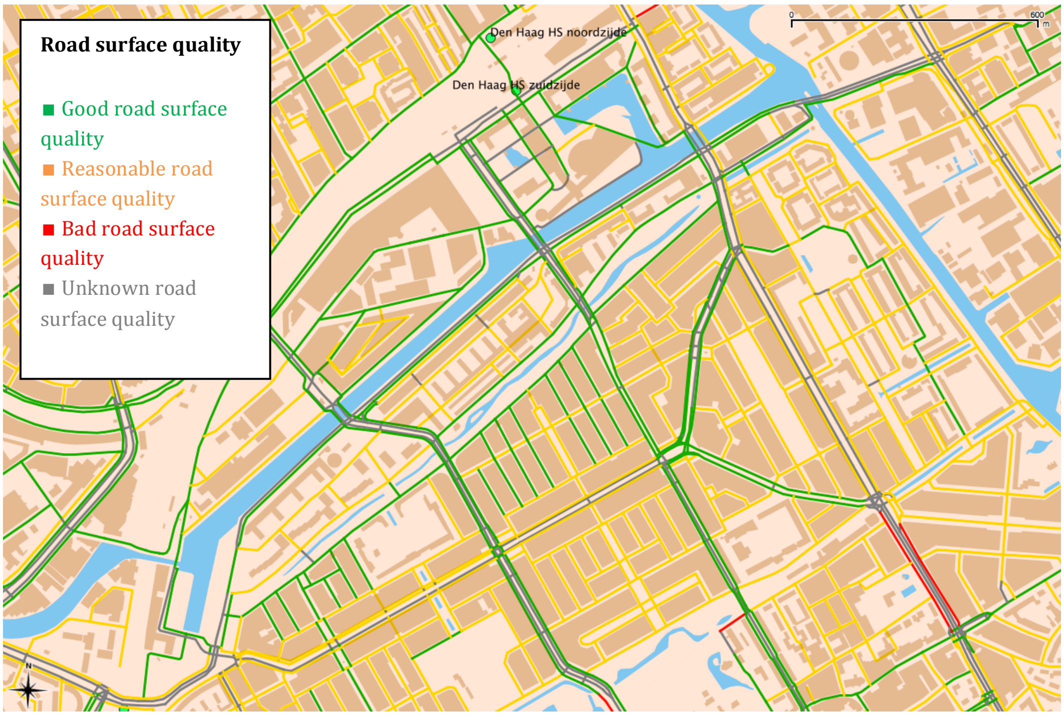


Figure 4.2: An example of the road quality aspect in the Fietsersbond bicycle network. Green roads have a good road surface quality, orange roads have a reasonable road surface quality and red roads have a bad road surface quality

Traffic nuisance

Traffic nuisance is defined as delay and/or danger caused by the presence of other traffic. This can be caused by driving or parked cars, other cyclists, pedestrians or a combination of them. The situation in rush hour is determinative for this aspect. Noise pollution and odor nuisance are not part of traffic nuisance. Because of the importance of this aspect for cyclists, the Fietsersbond distinguishes between five possible values:

- Very little: Roads with very little traffic nuisance are solitary bicycle paths, calm bicycle paths with little sideways and very calm normal roads.
- Little: Normal roads with separate bicycle paths or service roads so that cyclists aren't affected by the traffic.
- Reasonable: Busy, small or curvy roads with bicycle paths hindered by many sideways.
- Much: Reasonable danger or the inability to cycle at the desired speed. No separate bicycle paths. Examples are 50 km/h urban roads without separate bicycle paths, busy 80km/h rural roads or urban bicycle paths with a lot of sideways or loading/unloading traffic.
- Very much: Serious danger that makes it unable to cycle at the desired speed. No separate bicycle paths. An example is a busy regional road.
- Unknown: This is the default value for a road that doesn't have this aspect defined yet.

Table 4.2: Percentage of bicycle access route roads per traffic nuisance category

Very little	3,24 %
Little	29,99 %
Reasonable	22,76 %
Much	14,97 %
Very much	2,63 %
Unknown	26,41 %

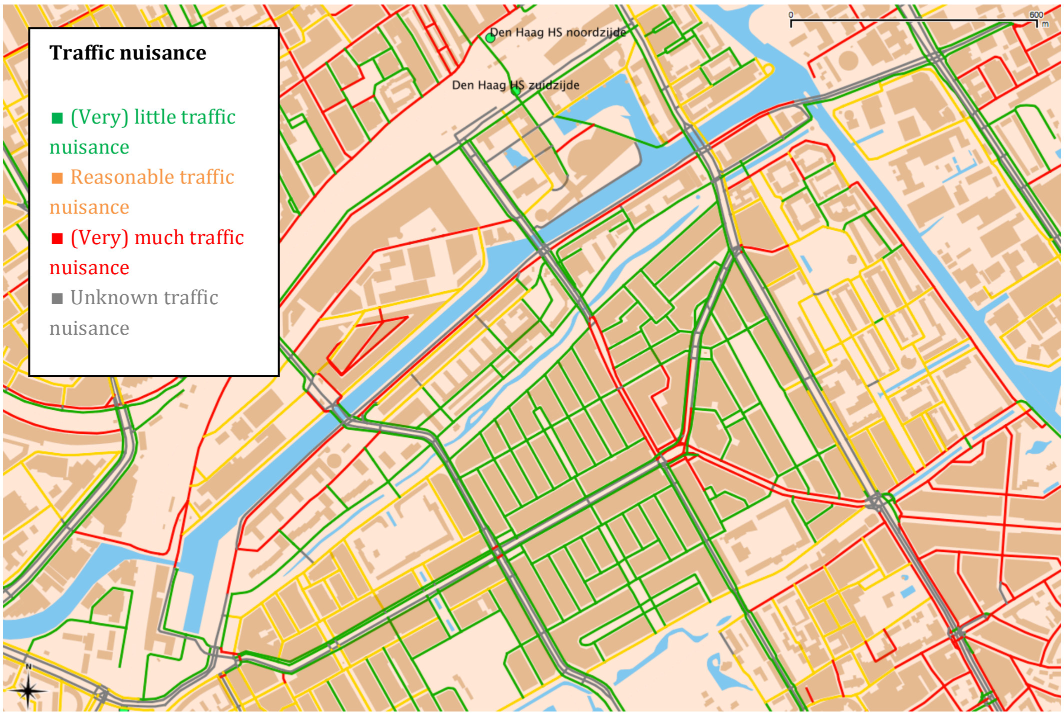


Figure 4.3: An example of the traffic nuisance levels in the Fietsersbond bicycle network. Green roads have very little or little nuisance, orange roads have reasonable nuisance and red roads have much or very much nuisance

Lighting

Lighting is defined as the level of lighting on the road during nighttime. The default value is 'present' for urban areas and 'not present' for rural areas. Three possible values are defined:

- Present: A road has present lighting when there are light posts every 60 meters when they are lower than 8 meters in length, or every 80 meters when they are higher than 8 meters in length.
- Partially present: A road has partially present lighting when the distance between the light posts is larger than above, or there is only lighting present at crossings.
- Not present: A road has no present lighting when there are no light posts, not even at crossings or when you can't see the next crossing because of the distance or bends.

Table 4.3: Percentage of bicycle access route roads per lighting category

Lighting present	89,86 %
Lighting partially present	0,37 %
Lighting not present	5,19 %
Unknown	4,58 %

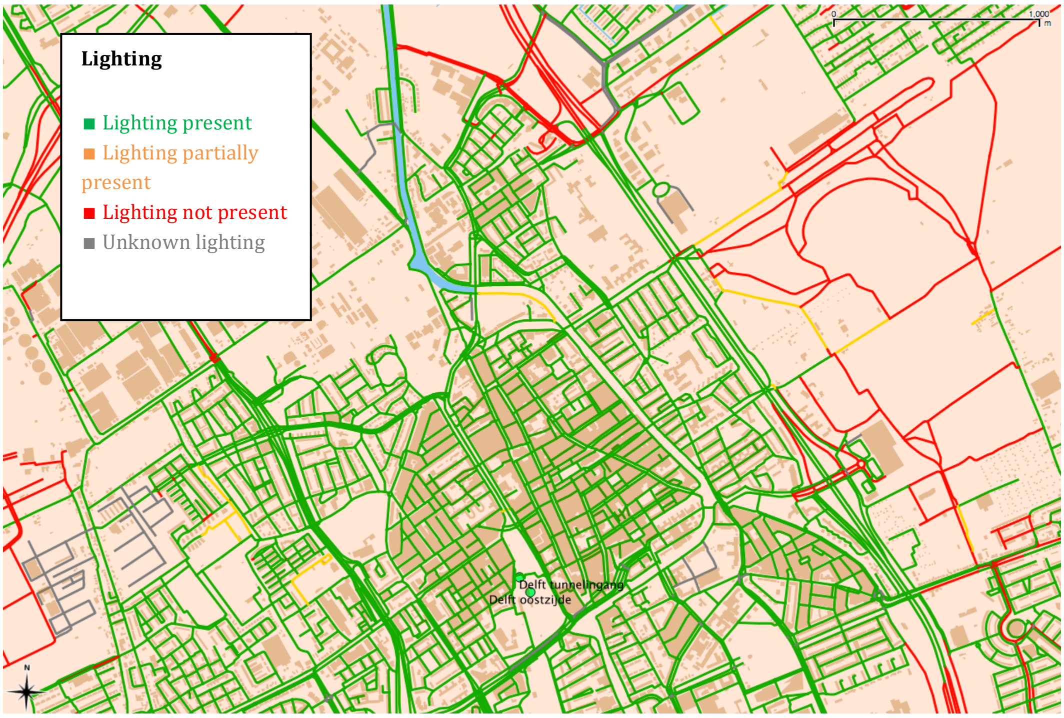


Figure 4.4: An example of the lighting aspect in the Fietsersbond bicycle network. Green roads have present lighting, orange roads have partially present lighting and red roads have no present lighting

9292 Bus/tram/metro data

The 9292 Travel Information Group publishes a route planner for public transport in the Netherlands. In the context of the open data initiative, 9292 has made the schedules and associated geographic information of public transport providers in the Netherlands available (9292, 2012). This data is in the General Transit Feed Specification (GTFS) format. For this research, the information of the schedules was transformed into frequencies for the bus/tram/metro stops and aggregated to postcode level. This information provides a measure for the service level of public transport for each postcode area.

4.1.2. Built environment data sources

Several data sources were used for data on the built environment. These include the StedenbaanPlus monitor and the LISA company register.

StedenbaanPlus monitor

The StedenbaanPlus monitor contains land use data in the influence area around each train station:

- Population amounts
- Number of dwellings
- Number of jobs

The influence area that was used in this data is a 1200m buffer. The data is provided to StedenbaanPlus by the Province of South-Holland and is included in the yearly StedenbaanPlus monitor publication. The 1200m distance limits the information to the direct station environment.

LISA company register

The LISA company register contains information about the location, type of companies and its number of employees. This information is used in the calculation of land use density and diversity.

The companies are classified using the LISA categories into 13 groups (Figure 4.5):

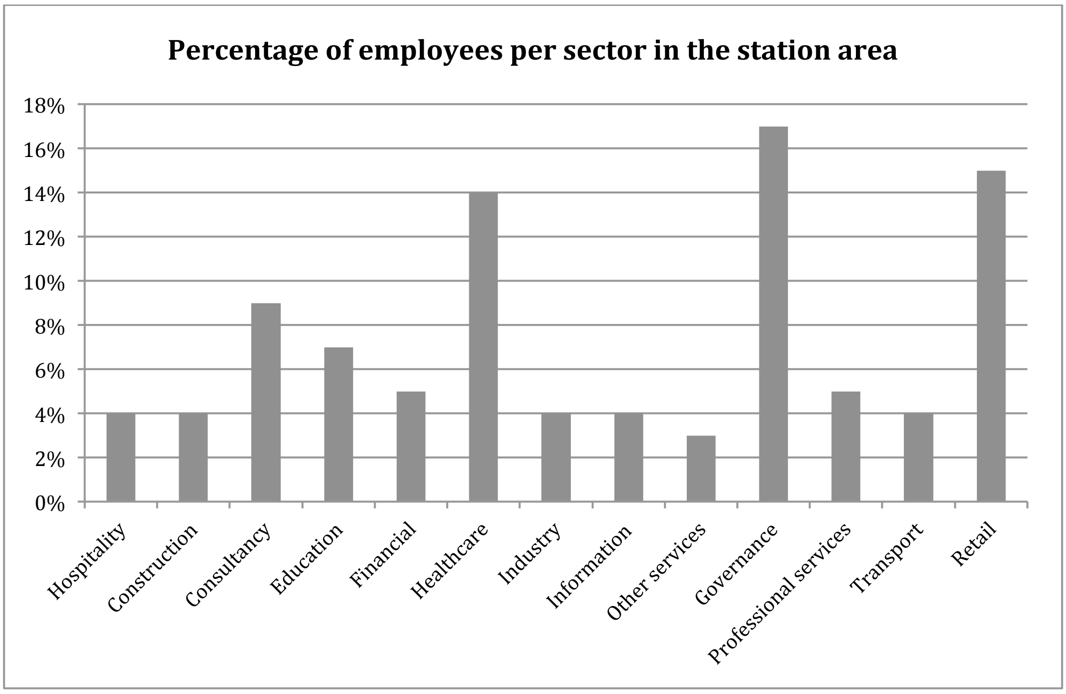


Figure 4.5: Overview of the percentage of employees per company sector, in the influence area of 1200m around the train stations

Kadaster TOP10NL maps

The TOP10NL maps are topographic maps which are available at the website of the Kadaster, the Dutch land registry office (Kadaster, 2012). They contain geographic information about the Netherlands such as buildings, train tracks in vector format used for cartography. This data is used as background in the maps.

4.1.3. Station data sources

StedenbaanPlus monitor

The StedenbaanPlus monitor contains information about the train passengers, bicycle parking spaces and the connectivity with other stations and lower level public transport. The presence of high-speed rail, intercity trains and sprinter trains determine how well a station is connected to other stations. The more stations you can access, the higher the connection value. In this research, the train series (high speed, intercity and sprinter trains) and the bus / tram / metro lines stopping at a station are used for determining the connection value of a station. This information is available on the StedenbaanPlus fact sheets (Programmabureau StedenbaanPlus, 2012a). An overview of the stations can be found in Table 4.4.

Table 4.4: An overview of the StedenbaanPlus train stations with passenger amounts and bicycle parking spaces (Programmabureau StedenbaanPlus, 2012b)

Station name	Station category	Train passengers in 2010	Bicycle parking spaces in 2011
Den Haag Centraal	1	74.957	5.100
Rotterdam Centraal	1	89.562	5.428
Delft	2	24.302	3.416
Den Haag HS	2	44.880	2.517
Dordrecht	2	19.905	3.162
Gouda	2	20.357	4.494
Leiden Centraal	2	58.529	13.485
Den Haag Laan van NOI	3	12.587	708
Rotterdam Alexander	3	16.122	676
Rotterdam Blaak	3	14.509	80
Schiedam Centrum	3	13.622	2.004
Nieuwerkerk a/d Ijssel	4	2.914	1.080
Rijswijk	4	6.699	582
Voorhout	4	2.838	776
Zoetermeer	4	6.859	673
Zwijndrecht	4	5.506	1.630
Capelle Schollevaar	5	2.842	304
De Vink	5	2.162	852
Delft Zuid	5	2.477	1.324
Den Haag Mariahoeve	5	3.071	548
Den Haag Moerwijk	5	1.335	112
Den Haag Ypenburg	5	1.379	244
Dordrecht Zuid	5	1.095	296
Gouda Goverwelle	5	2.549	928
Rotterdam Lombardijen	5	6.736	337
Rotterdam Noord	5	2.147	276
Rotterdam Zuid	5	2.162	80
Voorburg	5	4.173	919
Zoetermeer Oost	5	3.400	860
Barendrecht	6	4.244	1.772

Hillegom	6	1.482	784
Voorschoten	6	2.628	824

NS customer satisfaction survey

The database of the NS customer satisfaction survey contains the results of the survey that is conducted by NS among their train passengers. This database contains information about the train trip the travelers made, the access and egress modes they used and the valuation of train and station aspects. The elements of the database that are used in this research are listed below:

- Departure and arrival train station
- Access mode
- Travel motive
- Availability of a car
- Travel time period (in or outside rush hour)
- Travel frequency
- In possession of student OV-chipcard
- Age
- Residential postcode-4 area
- Weather conditions

4.1.4. Socioeconomic data sources

For the socioeconomic characteristics, the neighborhood map with socioeconomic data of the Statistics Netherlands agency (CBS, Dutch acronym) is used. From previous studies (Mestrum et al., 2011; Research voor Beleid, 2006; Rietveld & Daniel, 2004) is known that several socioeconomic characteristics can have an influence on bicycle use. The neighborhood map data contains an extensive amount of socioeconomic data combined with a spatially detailed map of the neighborhoods (Centraal Bureau voor de Statistiek, 2010). This is later used to attach the data to the bicycle routes and the origin locations of the train passengers.

The following variables were selected for the spatial analysis:

- Population density
- Percentage of single households
- Percentage of non-western immigrants
- Percentage of people not active in the labor force
- Percentage of people age 14-25
- Cars per household
- Income per employee

- Number of supermarkets within 3 km

In Figure 4.6, a map with the population density of the South Wing is displayed. The train tracks are displayed in yellow. Den Haag is currently the city with the highest population density of the Netherlands with about 6000 inhabitants per square kilometer.

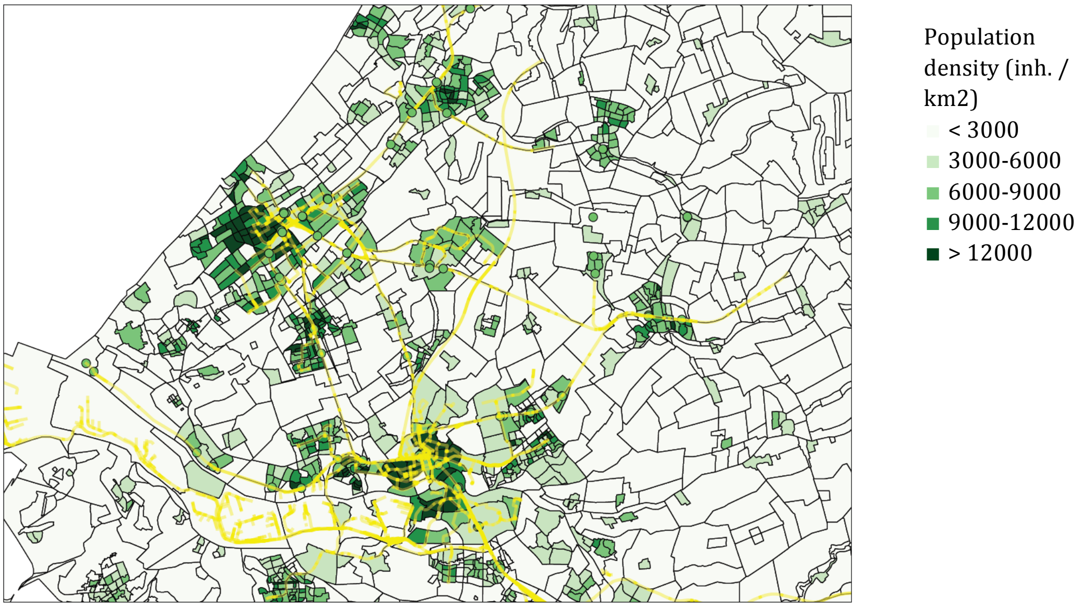


Figure 4.6: Map of the population density of the neighborhoods in the Randstad South Wing (Centraal Bureau voor de Statistiek, 2010)

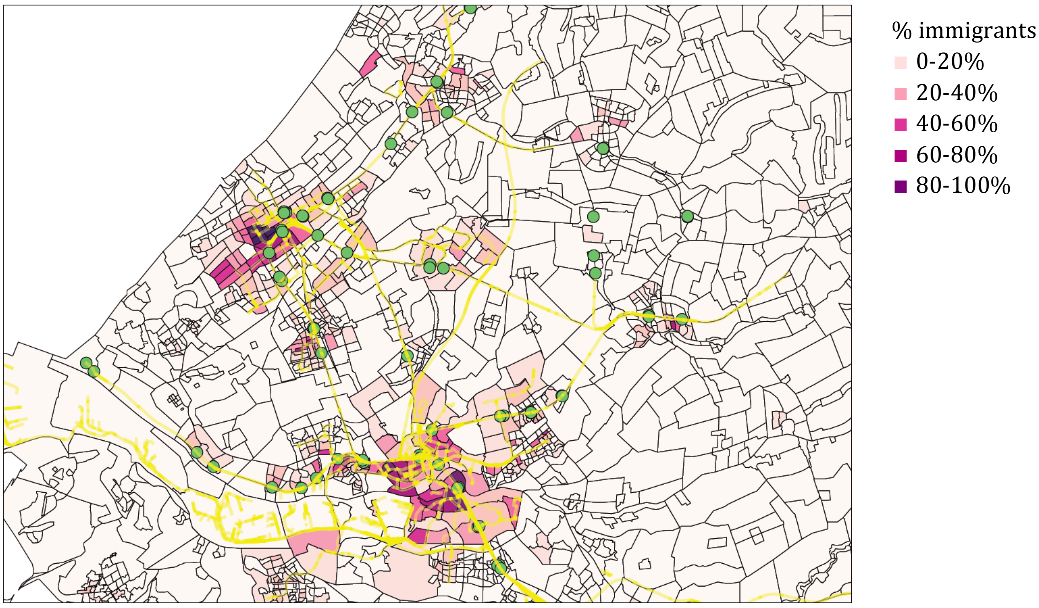


Figure 4.7: Map of the percentage of non-western immigrants of the neighborhoods in the Randstad South Wing (Centraal Bureau voor de Statistiek, 2010)

Figure 4.7 shows a map with the percentage of non-western immigrants per neighborhood in the South Wing. The highest percentages are concentrated in downtown Den Haag and Rotterdam. As non-western immigrants are known to cycle less than average, it can be expected that this also influences the use of the bicycle as access mode in these cities.

Figure 4.8: Map of the number of cars per household in the Randstad South Wing (Centraal Bureau voor de Statistiek, 2010)

In Figure 4.8, a map with the average number of cars per household is displayed. Strongly urbanized areas (Den Haag, Rotterdam, Gouda) have a lower average number of cars per household, as most destinations can easily be reached by walking, bicycle or public transport.

5 Spatial analysis

5.1. Data processing

In Figure 5.1, the relations between the data sources are displayed. The origin postcode of the travelers is known in the NS customer survey and it the starting point of the bicycle access route to the station. The neighborhood characteristics of the origin postcode area are used from the CBS neighborhood map. The data of public transport in the origin postcode area is added.

The departure station of the traveler and destination of the access route is also known from the NS customer survey. This is used to calculate the shortest route using the Fietsersbond bicycle network.

Data from NS and ProRail on the station facilities is attached to the departure stations. The LISA company data is combined with the distance contours to represent the land use diversity in the station environment.

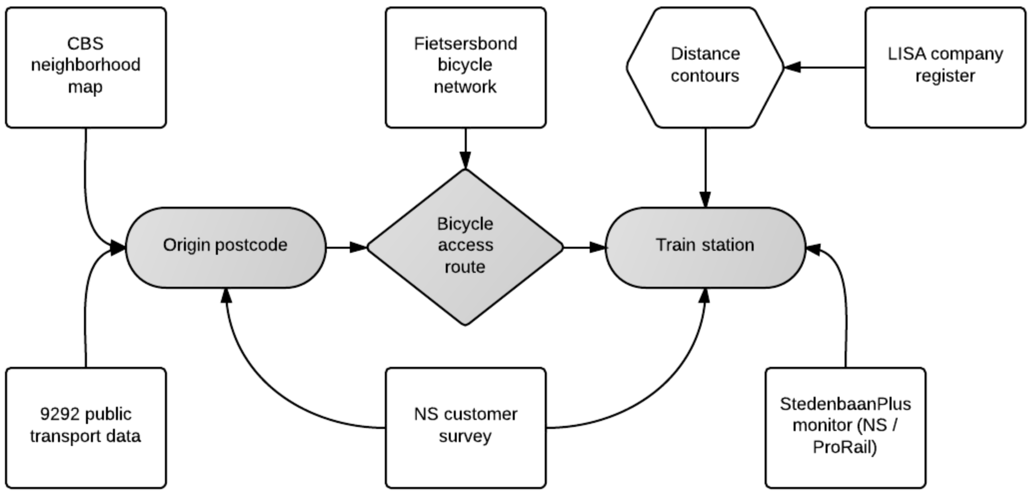


Figure 5.1: The relations between the data sources on bicycle accessibility

5.1.1. Geographic Information System

The data sources from the Fietsersbond, the CBS, and the Kadaster are in Shapefile format, which is regular format for use with geographic information system (GIS) software. GIS combines a database of spatial information with geographic elements such as points, lines or polygons on a map. With GIS software you are able to perform spatial analysis, such as calculating the number of points within a certain radius. The GIS software used in this research is the open source Quantum GIS (QGIS).

For the spatial database PostgreSQL was used in combination with PostGIS, which is a spatial database extension for PostgreSQL. This 'spatially enables' the database to be used for geographic information systems. Route calculation isn't natively supported by QGIS, so this was done using pgRouting, a routing library that extends the PostGIS database to provide geospatial routing functionality. pgRouting provides a number of routing functions, including node-to-node route planning and driving distance calculation with isolines. Both routing functions are used in this research. The route planning function is used for calculating the bicycle access routes to the station, and the driving distance calculation function for generating the stations distance contours.

5.1.2. Access route calculation

To assess the bicycle network from cyclists traveling to the station, the routes from the postcode 4-points to the station were calculated. This was done by first calculating the routes from all postcode 4-points to a station, and then filtering the routes with a length of 5 km or shorter. This distances limit includes nearly all of the bicycle access trips. A figure with the distance decay of the access modes was determined using the NS customer survey data and is displayed in Figure 5.2. The importance of the bicycle in medium distance trips (1.5-3.5 km, where cycling is attractive) is consistent with earlier findings from Rietveld (2000).

The routes are the shortest routes possible over the road network. The code used for calculating the access routes can be found in Appendix 11.2. An example of the bicycle access routes for station Delft is shown in Figure 5.3.

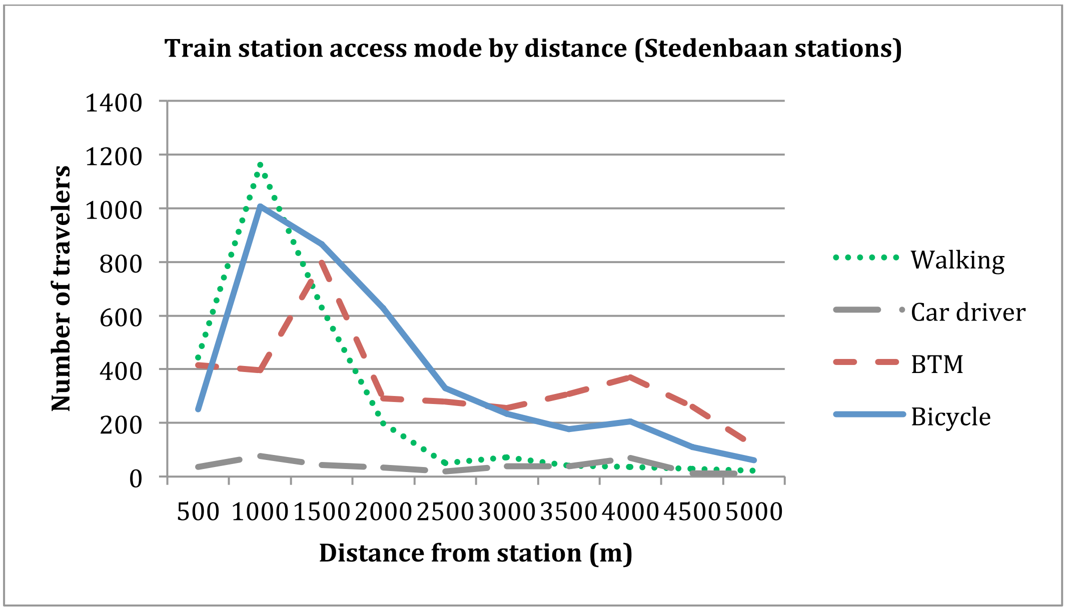


Figure 5.2: Access mode distance decay for the Stedenbaan train stations (N = 12288)

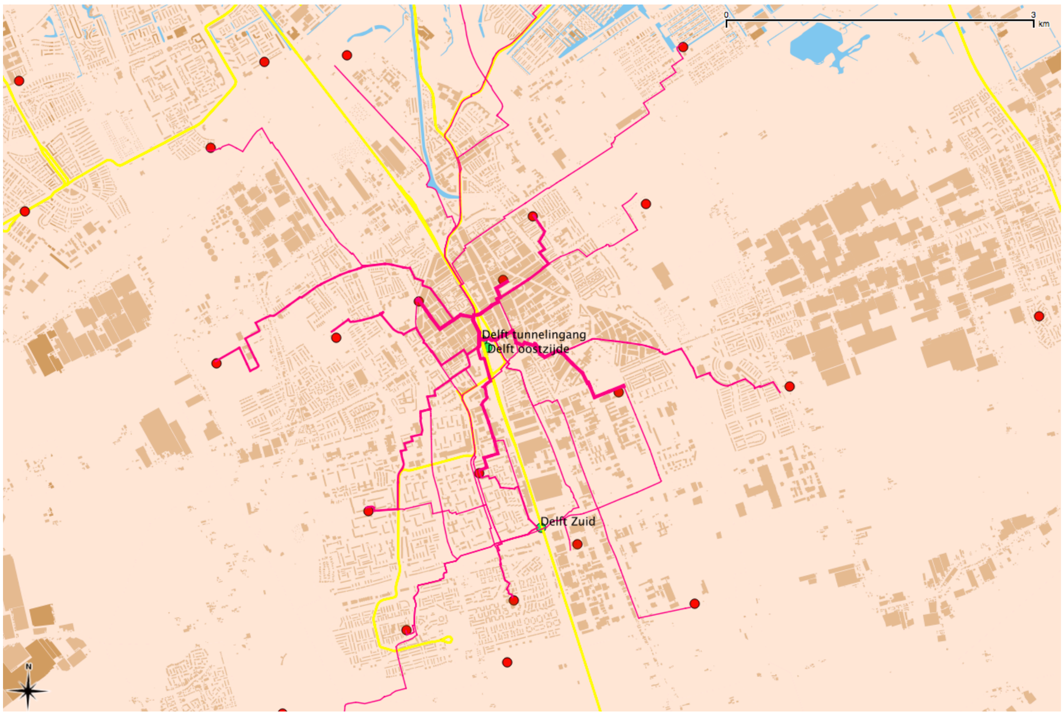


Figure 5.3: A map of Delft with the shortest bicycle routes (pink) from the postcode 4-points (red circles) to the stations Delft and Delft Zuid. The line thickness is proportional to the amount of travelers originating from this postcode

Combination with socioeconomic data

The origin postcode-4 points are used for mapping the socioeconomic characteristics of the people in this area. This information is combined in the statistical analysis with the NS customer survey data, which includes the residential postcode of the traveler. This way, socioeconomic characteristics can be attached to a traveler and the influence on the access mode choice can be determined.

5.1.3. Distance contours

For the mapping of the station environment, distance contours around the train stations were generated. This was done with the pgRouting 'driving distance' routing function using the road network from the Fietsersbond. This function finds the end points within a specified distance from an origin node over the road network.

The contour shapes were created for the area with a maximum distance from the station of 5km over the road network, in 500m intervals (Figure 5.4). The distance contours are used to calculate a number of built environment characteristics within certain distances from the stations, such as:

- Detour factor (the difference between the Euclidean and road distance)
- Bicycle network densities and road quality characteristics
- Company mix and land use function mix

The SQL code used for these calculations can be found in Appendix 11.1.

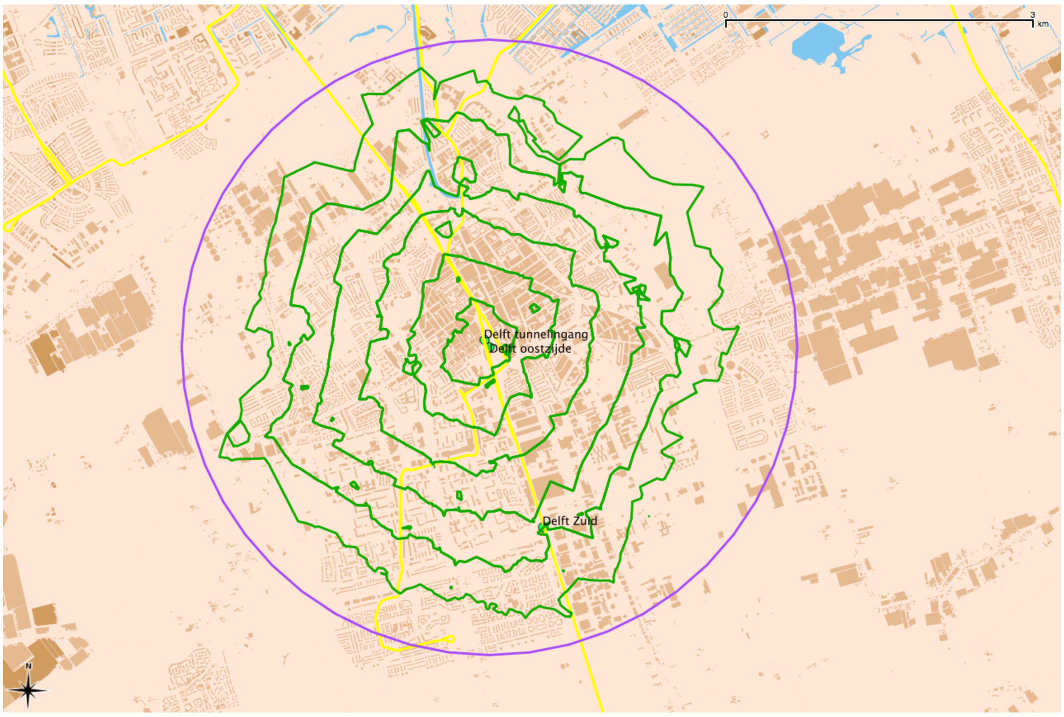


Figure 5.4: The driving distance contours of station Delft (green) in relation to a Euclidean distance of 3km (purple circle). The distance between the contours is 500m over the road network

6 Statistical analysis

6.1. Statistical framework

The quantification of the explanatory variables requires a lot of data and a method to process this data for a statistical analysis. In this research, a combination of spatial and statistical analysis methods was used. With this analysis the influence of the explanatory variables can be tested and compared. The spatial analysis consists of processing and analyzing the data in a geographical information system (GIS). The result of this analysis is a database with variables in the four categories: connectivity, built environment, station and individual variables. This database is then used in the statistical analysis using factor analysis, multiple linear regression and binary logistic regression analysis.

6.2. Factor analysis

The goal of the factor analysis is to bring down the number of variables for the regression analysis. The amount of data available on the various aspects of bicycle accessibility is very large and many of the variables are expected to be correlated. With factor analysis, variables that are strongly correlated can be combined into a single component. The goal of the factor analysis is to bring the number of dimensions down to three: a connectivity, built environment and a station facilities component. These can then be used in the regression analysis to examine the influence of each of the three variables.

The process of the factor analysis started with the variables related to the built environment. These are:

Built environment variables

- Number of companies within a 1200m buffer around the station
- Population amount within 1200m buffer
- Number of jobs within a 1200m buffer
- Number of dwellings within a 1200m buffer
- Number of employees within 500m contours

- Percentage of employees per company category in a 1200m buffer
- Number of jobs per inhabitant in a 1200m buffer
- Number of companies per inhabitant in a 1200m buffer

The first five variables have high loadings on the first component, with around 70% explanation of the total variance in the variables. These variables are all related to the size of a city. The last three variables are not well represented in the component. Especially the employee percentages per company groups have large differences between the train stations and cannot be combined into a single component.

Connectivity variables

- Average road quality level on the bicycle access roads to the station
- Average traffic nuisance level on the bicycle access roads to the station
- Average lighting level on the bicycle access roads to the station
- Density of the bicycle network (number of kilometers bicycle path within 5km of the station)
- Detour factor (the area covered within 5km road distance from the station entrance, relative to a 5km Euclidean distance from the station entrance)

When adding the connectivity variables and running a factor analysis with two components to extract, one representing land use diversity and one representing connectivity, the explained amount of the total variance drops significantly. The road quality variable has a high loading on the second component and the traffic nuisance variable has a high loading on the first component. The bicycle network density and detour factor are also loaded highly on the first component, while the lighting level has medium loadings on both. This indicates that the traffic nuisance is related to the density of a city, while the road quality is not. Denser cities are also related to better connectivity of the road network and a lower detour factor.

Station facilities variables

- Availability and number of Intercity trains connections
- Availability and number of Sprinter trains connections
- Number of train passengers
- Number of bicycle parking spaces
- Number of bicycle parking spaces per train passenger (percentage)
- Number of bus/tram/metro lines

In the factor analysis with the station variables included and three possible components to extract, most variables load highly on the first component, just as the built environment variables. The station variables are all related to the size and importance of the station, and it can be expected that large stations are located in a more densely populated area. The bicycle parking spaces per train passenger variable is not loaded highly on the first component, as the number of bicycle parking spaces often does not increase proportionally to the number of train passengers.

Conclusion

When testing these and other factor structures, it became clear that a solution with a limited number of components did not represent the variables well enough and the total amount of variance explained was too low (< 40%) to use the factor loadings in the regression analysis. Instead, the disaggregated variables are used in the further analysis. Many of the contours variables proved to be highly correlated to the (weighted) averages, so these are used instead of the contour values.

6.3. Multiple linear regression analysis (station level)

The regression model is used to predict the use of bicycle as access mode to the train station, or the bicycle access share, using a number of explanatory variables. The goal of the regression is to determine the influence of the explanatory variables on the bicycle access share and to create a regression model with strong predictive value. This knowledge can help to improve the accessibility of a train station and increase the attractiveness of the bicycle as access mode.

For the regression analysis, several tests were performed to achieve a model with a good predictive value. The stepwise regression method of SPSS was used, a systematic method of entering and removing variables based on significance level. In Table 6.1, the regression model with the highest predictive value (adjusted R^2) is displayed. It contains 6 variables from the individual, built environment and station category.

Table 6.1: Multiple linear regression results (station level)

Coefficients	Unstandardized	Significance
	B	
Individual		
Percentage of immigrants in station influence area	-,001	,245
Built environment		
Percentage of people working in hospitality	1,848	,000*
Percentage of people working in education	,179	,155
Percentage of people working in finance	-,466	,002*
Station		
Bicycle parking spaces per passenger	,369	,000*
Number of rail (tram/metro) lines	-,005	,123
(Constant)	,139	
Dependent variable: bicycle access share per station (2009 - 2011 average)		
R^2 adjusted: 0,737, N = 36		

Significant variables at the 95% level are displayed with an asterisk. Since the number of cases is so small (N = 36), the number of variables that are significant is limited. The variable that is highly significant and makes sense is the number of bicycle parking spaces per train passenger. This is not surprising since there is a constant shortage of parking spaces at most train stations. The other variable in the station category is the number of rail lines serving the train station. The negative sign for this variable suggests a competition effect between the tram/metro and bicycle as access mode. For bus lines, this relation was not found to be significant.

Furthermore, the only individual variable in this regression analysis is the percentage of non-western immigrants living around the station. This has a negative effect on the bicycle access share, which is in line with the theory on bicycle use.

The percentage of people working in the hospitality sector variable is positive, suggesting that a station environment with more people working in this economic sector has a positive influence on the bicycle access share. The same is true for the sector education. The next variable, people working in finance, shows that the financial sector has the opposite effect.

The results of the multiple linear regression indicate that the differences in bicycle access share can be explained by the explanatory variables, but the low number of cases (36) is not reliable enough to base conclusions upon. In addition, a binary logistic regression analysis was performed on the level of the individual traveler. The individual level contains a larger number of cases and is more reliable to test the influence of the variables.

6.4. Binary logistic regression analysis (individual level)

The multiple linear regression analysis was limited to 36 cases (the train stations) and did not include individual variables. Therefore, a second regression analysis was performed using the KTO data on the individual level. This level provides in many more cases and individual variables such as travel motive and individual characteristics could be included. This method used is a binary logistic regression analysis using the choice for the bicycle as access mode as dependent variable. In total, there are 10403 cases used in this regression analysis.

The results of the logistic regression are displayed in Table 6.2.

Table 6.2: Binary logistic regression results (individual level)

Variable	Beta	Significance
Connectivity		
Average road quality of the bicycle access routes	,194	,074
Average headway of bus/tram/metro lines in origin area	,014	,000
Bicycle network length per inhabitant	,002	,025
Access route distance dummy (above 3km)	-,513	,000
Individual		
Rush hour dummy	,297	,000
High travel frequency dummy	,360	,000
Work motive	,313	,000
Business motive	,526	,000
School motive	,219	,003
Percentage single households in origin neighborhood	-,021	,000

Variable	Beta	Significance
Percentage immigrants in origin neighborhood	-,013	,000
Cars per household in origin neighborhood	-,836	,000
Student OV-chipcard dummy	-,286	,000
Car available dummy	-,091	,056
Age 50+ dummy	-,330	,000
Built environment		
Percentage of people working in hospitality	9,328	,000
Percentage of people working in education	3,371	,000
Weather: temperature	,011	,000
Percentage of people working in retail	-2,890	,000
Percentage of people working in other business services	-5,371	,005
Station		
Train passengers	,008	,000
Bicycle parking spaces per passenger	1,307	,007
Rail (tram/metro) lines serving the station	-,059	,000
(Constant)	-,053	,867
Dependent variable: access mode (bicycle or otherwise)		
Nagelkerke's R^2: 0,152, N = 10403		
Model Chi-square: 1215, p < 0,001 with df = 23		

The full model with all variables is able to correctly predict 35% of the travelers that chose the bicycle as access mode, and 88% of those who did not, resulting in an overall correctly predicted percentage of 69%. A chi-square test of the full model against a model with a constant only was statistically significant ($p < 0,001$). The overall correctly predicted percentage of the constant only model was 65%.

The analysis shows that variables in all categories were found to be significant at the 10% level. From the connectivity variables, the distance dummy variable for access routes longer than 3km has a negative effect on the chance to use the bicycle. The bicycle network length per inhabitant (as measure of the bicycle network density) and the road quality of the access routes have a positive effect. An increase in the bus/tram/metro headway (lower frequency) in the origin postcode area is also positive for the bicycle use. This shows the competition effect between the bicycle and public transport as access mode.

From the individual variables, it becomes clear that a relatively young (age < 50) traveler with a work, school or business purpose who travels frequently during rush hour is more likely to cycle. This all is in line with expectations. The possession of a student OV-chipcard has a negative effect. This can be explained by the fact that this card decreases the cost of public transport, making bus/tram/metro more attractive alternative to the bicycle.

The availability of a car and the number of cars per household in the origin neighborhood has a negative effect that can be attributed to competition. Interestingly, from the other neighborhood characteristics, only two variables were found to be significant. The percentage of non-western immigrants has a negative effect, as expected from the theory. The percentage of single households also has a negative effect, for which the explanation is unclear.

From the variables related to the built environment, the presence of several company types was found to be significant. Companies in the sector hospitality (in a station environment these are primarily cafés with refreshments and fast food restaurants) and educational institutions in the station environment have a positive effect on bicycle use, while retail and other business services sector have a negative effect. Interpretation of these results is challenging. The theory on TOD states that the presence of places with social interaction makes an environment more attractive for non-motorized transport. The positive effect of the hospitality variable is in line with this theory, but the negative effect of retail is not. Retail around train stations, mostly found in large city centers, is expected to create a more attractive environment for non-motorized transport. Possibly, this effect is mainly seen in absolute numbers instead of access shares.

An increase in the weather temperature has positive effect, which is consistent with the literature on the effect of weather conditions on bicycle use. The effect of rain however, was not found to be significant although this was expected to have an influence.

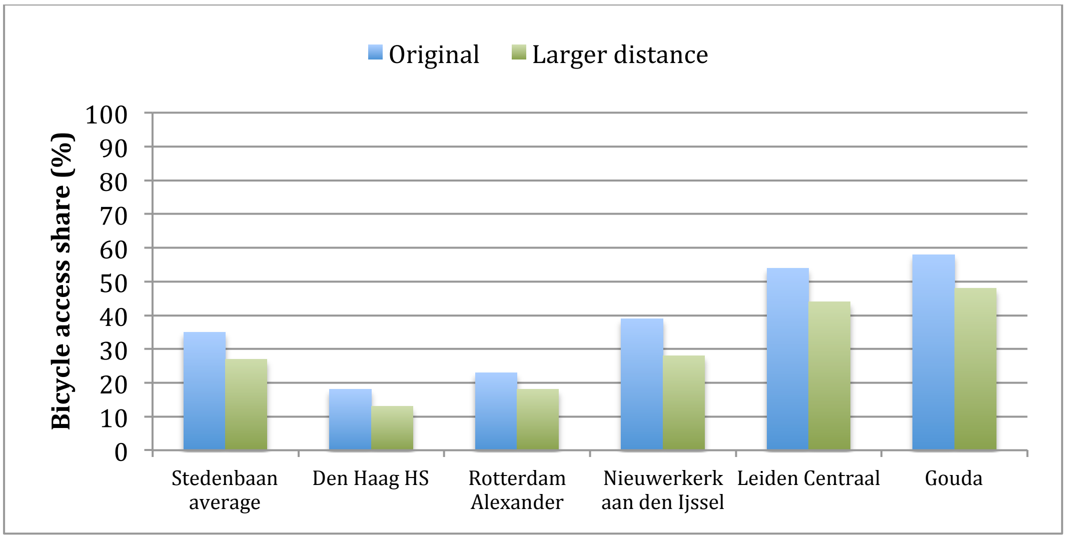
The station category contains three variables. The number of train passengers as measure of the station size has a positive effect. The number of bicycle parking spaces per passenger has a positive effect, which can be expected considering the shortage of bicycle parking space at most train stations in the South Wing. The number of rail lines as measure of the competition between bicycle and tram/metro has a negative effect. The number of bus lines was not found to be significant, possibly because of the lower quality perception of the bus by travelers.

6.5. Effect of changes in explanatory variables

In this section, the effect of changing the variable values on the bicycle access share is explored. This is done to see what the effect is of potential policy measures. Four scenarios were chosen for the analysis: An increase in the access route distance, an increase in the bicycle parking capacity at the station, the improvement of the bicycle road quality and the decrease of the service level of public transport in the origin area. Five train stations were selected from the analysis, based on the variety in the effects of the measures.

Increase of access distance

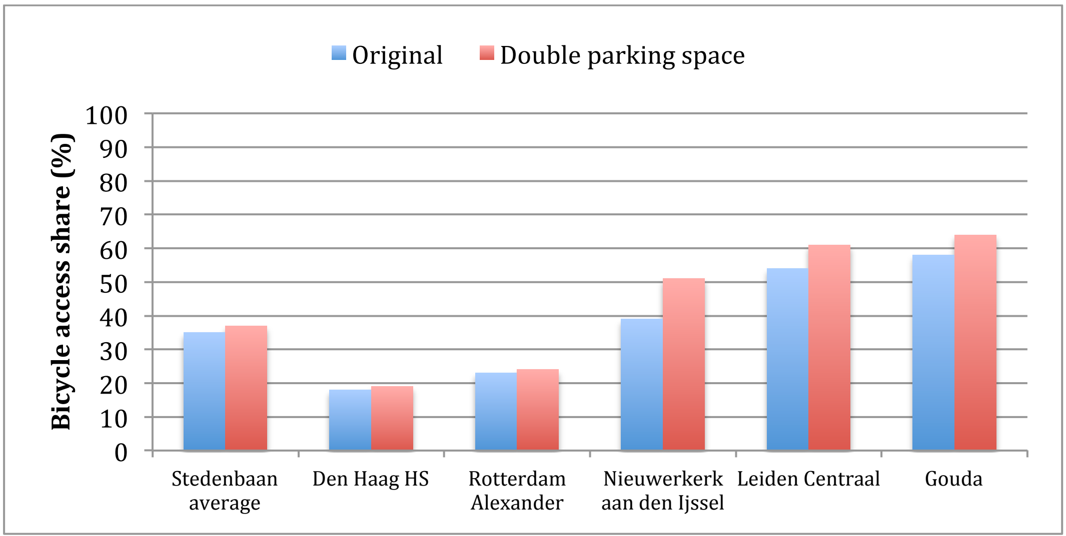
The first scenario tested is an increase of the access distance to the station. In the binary logit model, an access distance dummy for route distances of more than 3km was included. In this scenario, this dummy value was set to represent a route distance of more than 3km for every traveler. This has a strong effect on the predicted bicycle access share, going from an average of 35% to 27%, a decrease of 8 percentage point. For the stations with an above average bicycle share, the effect is even higher. The effect seen here underlines the importance of making the 3km (road distance) catchment area of a station as large as possible.



Doubling the number of bicycle parking spaces per passenger

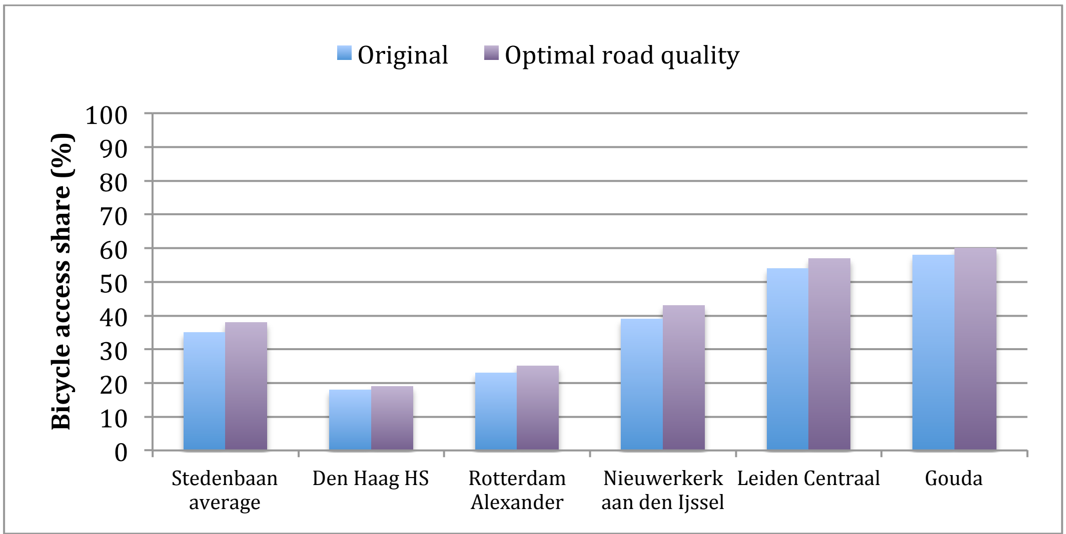
The second scenario tested is the increase in bicycle parking capacity at the stations. This is an interesting topic for discussion as there is a significant shortage of bicycle parking spaces at most train stations. In this scenario, the number of parking spaces per passenger was doubled at each station. This meant that stations that already have a large number of spaces per passenger (Gouda and Leiden: 0,22; Nieuwerkerk: 0,39) get a relatively larger increase than stations with a low amount of spaces per passenger (Den Haag HS: 0,05; Rotterdam Alexander: 0,04).

The effect of more parking spaces is limited on average. The Stedenbaan average increases with 2 percentage point. Den Haag HS and Rotterdam Alexander increase with only 1 percentage point. The increase in the parking space does not make much of a difference. At these stations, increases in the parking capacity do not immediately lead to a higher bicycle access share. Reason for this can be the low amount of spaces per passenger, even after the capacity increase. For example, doubling the parking spaces at Den Haag HS from 0,05 to 0,10 per passenger still is much less than the stations of Gouda and Leiden have. At these stations, the effect is much larger with an increase of 5 percentage point.



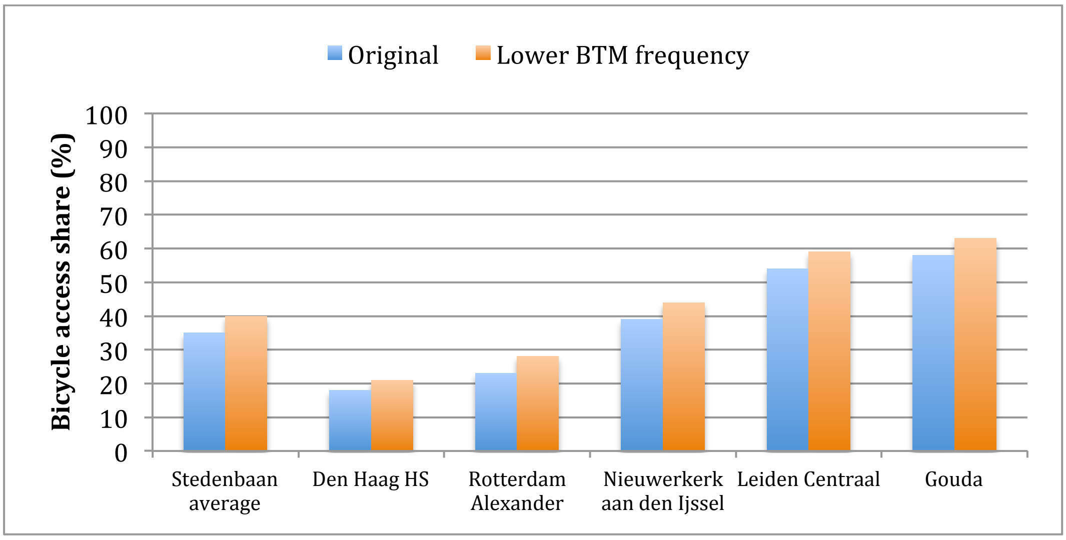
Optimal bicycle road quality

In order to the test the influence of the bicycle road quality, the value for the road quality variable was set to the highest possible value (+1 for all routes). This causes an increase in the bicycle access share of 3 percentage point. The effect is comparable among the stations.



Lower bus/tram/metro frequency

A stronger effect was found when changing the average frequencies of the bus/tram/metro lines in the catchment area. An increase of the headway with 15 minutes causes an average increase in the bicycle access share of 5 percentage point. This is fairly consistent among the stations.



While the effect is clear, it is the question if this is a desirable policy measure. From a cost perspective, a shift from public transport to the bicycle can be interesting if the urban public transport is heavily subsidized. On the other hand, looking at the current shortage of bicycle parking spaces at the stations, a shift from public transport to the bicycle could result in even more problems with bicycle parking. This could make train travel less attractive. When making policy measures to increase the bicycle access share, these consequences should be kept in mind.

7 Case studies

7.1. Relevance

In the statistical analysis is found that variables from all four categories (connectivity, built environment, station and individual) have an influence on the choice to use the bicycle as access mode. The deviation in the bicycle access share of the train stations in the South Wing is large, ranging from a minimum of 14% to a maximum of 61%. In this chapter, a case study of four stations is performed to get more insight into the causes of this deviation and the role of the explanatory variables. With these case studies, the results of the statistical analysis can be validated.

The four stations selected for the case studies are Den Haag HS, Den Haag Laan van NOI, Delft and Delft Zuid. These stations represent a good variety of the types of stations in the South Wing. Den Haag HS is a very large station with many connections, in the middle of a metropolitan area. Den Haag Laan van NOI is a smaller Intercity station in Den Haag with an important transfer function (tram and metro to train). Delft is the main station of the city of Delft, a medium-sized city that provides a connection to Den Haag and Rotterdam. Delft Zuid is a small Sprinter station outside the city, which goal is to attract more travelers. Together, these stations make an interesting case study with varying bicycle access shares and different station environments.

7.2. Station Den Haag HS

Figure 7.1: The entrance of station Den Haag HS (Rudolphous/Wikipedia, 2011)

Description

Den Haag HS (Hollands Spoor) is the second train station of Den Haag, with over 46.000 passengers per day. It is located in the Stationsbuurt, the neighborhood to which the main entrance leads. The south entrance leads to the Laak harbor area. In Table 7.1 an overview of the values of the explanatory variables is displayed.

Table 7.1: Explanatory variable values of station Den Haag HS

Variable	Den Haag HS	South Wing average
Bicycle access share	**23%**	**35%**
Connectivity		
Average road quality of the bicycle access routes	,58	,37
Bicycle network length per inhabitant	4 m	15 m
Average headway of bus/tram/metro lines in origin area	9 min	18 min
Percent of people with an access distance of more than 3km	23%	18%
Individual		
Rush hour dummy	31%	37%
High travel frequency dummy	79%	74%
Work motive	37%	37%
Business motive	6%	8%
School motive	18%	16%
Percentage single households in origin neighborhood	56%	41%
Percentage immigrants in origin neighborhood	35%	18%
Cars per household in origin neighborhood	,57	,84
Student OV-chipcard dummy	28%	21%
Car available dummy	37%	44%
Age 50+ dummy	11%	28%
Built environment		
Percentage of people working in hospitality	4%	3%
Percentage of people working in education	7%	9%
Percentage of people working in retail	14%	17%
Percentage of people working in other business services	3%	3%
Station		
Train passengers	46k	15k
Bicycle parking spaces per passenger	,05	,19
Rail (tram/metro) lines serving the station	11	2

Den Haag HS, data used from years 2009-2011, N = 426

Variables in red have a negative influence; variables in black have a positive influence on bicycle access

Connectivity

The influence area of Den Haag HS is large, with travelers originating from almost all parts of the city (Figure 7.2). This is also seen in the variable for the percentage of travelers originating from more than 3km distance, which is 23%. Interestingly, some neighborhoods located southeast of the station (Schilderswijk and Transvaal) have no travelers originating from. This is thought to be related to the demographic factors (described in section 'Individual' below).

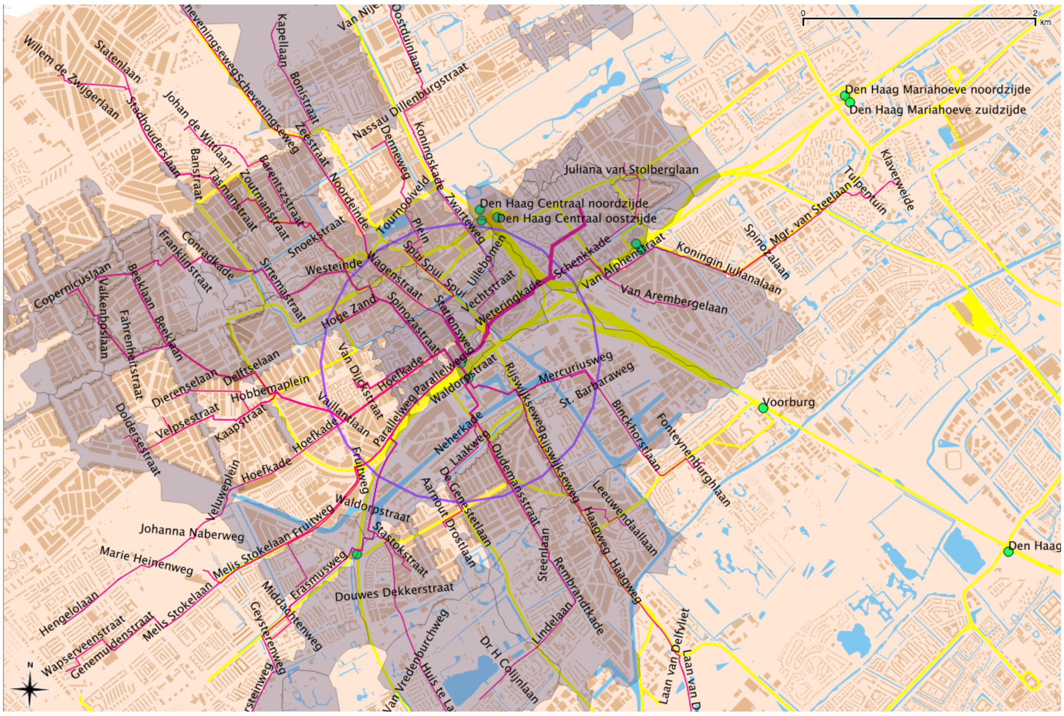


Figure 7.2: Origin zones of station Den Haag HS. A 1200m Euclidean distance circle from the station entrance is displayed in purple. The bicycle routes are pink and labeled with the street names.

The main bicycle routes, as displayed in pink in Figure 7.3, are located along the Stationweg to the city center and the Parallelweg / Stationsplein, a busy automobile road through the city center of Den Haag. The space allocated for the bicycle lanes is minimal (the bicycle network length per inhabitant is far below average) and there is a lot of traffic nuisance (Figure 7.3, 7.4 and 7.5). The regression model does not identify the traffic nuisance variable as significant, which does not represent the issues viewed in practice. It can be expected that this traffic situation influences a traveler's assessment of accessing station Den Haag HS by bicycle. Two reasons for the absence of this variable can be thought of: traffic nuisance does not influence the choice for the bicycle as access mode, or the traffic nuisance variable does not represent the issues viewed in practice.

Figure 7.3: Conflicting traffic in front of station Den Haag HS (Google Maps, 2013).

The route from the city center (Stationsweg) is also not very bicycle friendly. As visible in Figure 7.5, there are no bicycle lanes and the lanes are very narrow. During rush hour, the traffic volumes are very high and cycling on this road is unattractive.

As the influence area of Den Haag HS is the city center of Den Haag, it profits from good connectivity with the urban tram network. With an average headway of 9 minutes of the public transport network in the origin zones, the competition of pubic transport with the bicycle is very high. This gives another reason for the low bicycle access share.

Individual

Den Haag HS is located in the Stationsbuurt, a neighborhood with a high percentage of non-western immigrants (over 60%). Also the neighborhoods around the station, such as the Schilderswijk and Transvaal, have very high immigrant percentages (80-90%). In the map with origin zones (Figure 7.2) is visible that from these neighborhoods there are no people using the bicycle to the station. This indicates that the location of this train station is an important factor in explaining the relatively low bicycle access share.

Built environment

The main issues of Den Haag HS are the problems with accessibility for non-motorized transport and a neglected urban environment (Gemeente Den Haag, 2011). As visible in Figure 7.3, the traffic flows of trams, cars, delivery trucks, cyclists and pedestrians are conflicting. This mainly results in bad accessibility for the cyclist and pedestrian. The built environment has issues with a high vacancy rate, low quality shops and a socially unsafe environment. With regard to the types of companies in the station environment, the variables do not give much clarification for the low access share.

Station

Den Haag HS is a station with a high amount of passengers, and while the bicycle parking facilities are extensive, the facilities cannot provide enough bicycle parking spaces. The result of this is a high occupancy rate of more than 100%. The bicycle parking share variable shows that the number of parking spaces per passenger is vastly below average. This limits the growth that is possible in bicycle access. This is another important reason for the low access share. Besides this, the connection to public transport is excellent, with 11 tramlines addressing the station.

Figure 7.4: The bicycle access route at the east side of Den Haag HS (Google Maps, 2013)

Figure 7.5: The bicycle route from the city center to Den Haag HS (Google Maps, 2013)

7.3. Station Den Haag Laan van NOI

Figure 7.6: Den Haag Laan van NOI east entrance (Google Maps, 2009).

Description

Den Haag Laan van NOI is a relatively small Intercity station which also provides a transfer to the tram network and the Den Haag – Rotterdam metro line. Its influence area is smaller than that of the other Intercity stations in Den Haag, as seen from number of travelers coming from more than 3km, as well as in Figure 7.7.

Table 7.2: Explanatory variable values of station Den Haag Laan van NOI

Variable	Den Haag NOI	South Wing average
Bicycle access share	**35%**	**35%**
Connectivity		
Average road quality of the bicycle access routes	,25	,37
Bicycle network length per inhabitant	9 m	15 m
Average headway of bus/tram/metro lines in origin area	9 min	18 min
Percent of travelers with an access distance of more than 3km	5%	18%
Individual		
Rush hour dummy	41%	37%
High travel frequency dummy	75%	74%
Work motive	48%	37%
Business motive	6%	8%
School motive	8%	16%
Percentage single households in origin neighborhood	49%	41%
Percentage immigrants in origin neighborhood	12%	18%
Cars per household in origin neighborhood	,74	,84
Student OV-chipcard dummy	17%	21%

Variable	Den Haag NOI	South Wing average
Car available dummy	40%	44%
Age 50+ dummy	13%	28%
Built environment		
Percentage of people working in hospitality	1%	3%
Percentage of people working in education	6%	9%
Percentage of people working in retail	6%	17%
Percentage of people working in other business services	4%	3%
Station		
Train passengers	14k	15k
Bicycle parking spaces per passenger	,05	,19
Rail (tram/metro) lines serving the station	3	2

Den Haag Laan van NOI, data used from years 2009-2011, N = 103

Variables in red have a negative influence; variables in black have a positive influence on bicycle access

Connectivity

Figure 7.7 shows that the origin zones for cyclists are limited to the area located northeast to the Den Haag – Utrecht rail line. This rail line is a spatial barrier for cyclists, as the only possibilities to cross the line is north of Den Haag Centraal or through Voorburg. The figure shows that from the neighborhood Haagse Hout in the north of Den Haag, there are people cycling to the station. Their route, via the Laan van Nieuw Oost-Indië, is a fast and direct connection, which underlines the importance of a good bicycle route.

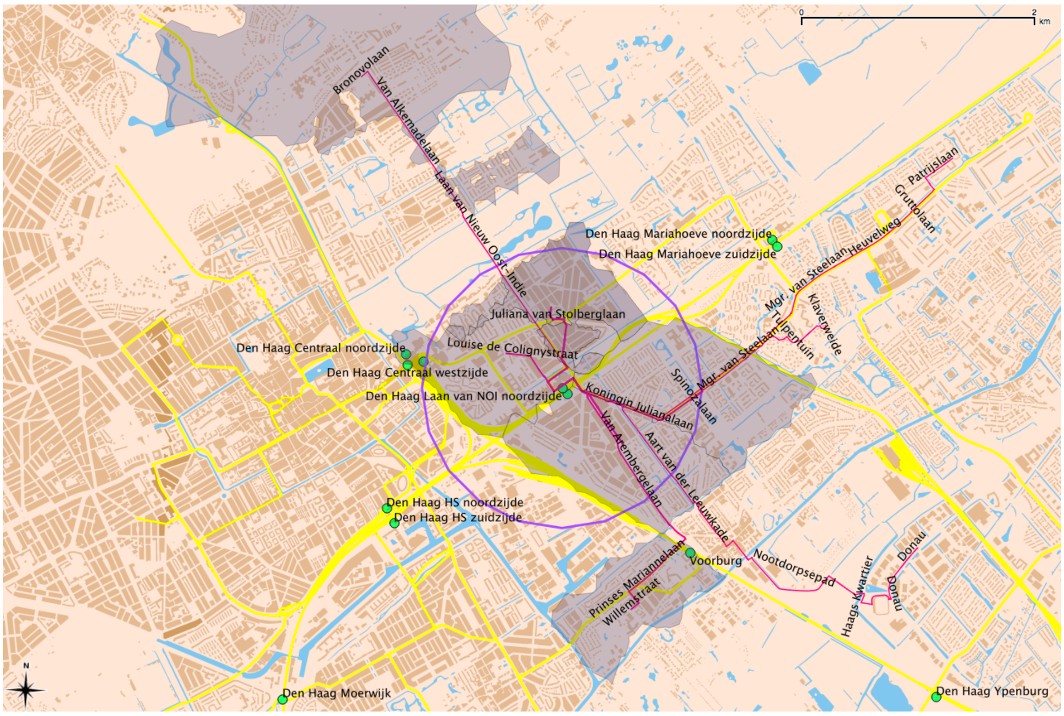


Figure 7.7: Den Haag Laan van NOI origin postcode areas. A 1200m Euclidean distance circle from the station entrance is displayed in purple. The bicycle routes are pink and labeled with the street names.

Individual

The type of passenger that uses Laan van NOI has mainly a work motive. The work motive variable has a highly above average value of 48%. This, combined with the low percentage of non-western immigrants in the origin areas, contributes to a moderate bicycle access share of 35%.

Built environment

Laan van NOI is located between the neighborhoods Bezuidenhout and Voorburg. Bezuidenhout has many office buildings and (semi) governmental organization, while Voorburg is mainly residential. There is little commercial activity in the station environment, also seen in the low hospitality workplaces value (1%). Apart from this, the values for the built environment variables do not suggest a large influence of the built environment on the bicycle access share.

Station

There is little bicycle parking space at north entrance of the station, which is reflected by the occupancy rate of more than 100% and the numerous bicycles parked outside the racks (Figure 7.8).

The Voorburg or south side of the station has substantially more bicycle parking space, with good sheltered facilities. As visible in Figure 7.9, this parking location also has capacity problems. This side of the station has mainly residential dwellings. The station environment is clean but does not welcome non-motorized traffic. It is mainly a large car and bicycle parking space. This station is a good example of a station with a good transport function, but lacks the function of a lively place for accommodation.

Figure 7.8: View on the Anna van Hannoverstraat, at the north entrance of Den Haag Laan van NOI (Coster, 2013)

Figure 7.9: Bicycle parking at the south side of the station (Coster, 2013)

7.4. Station Delft

Figure 7.10: Station Delft overview (Programmabureau StedenbaanPlus, 2012)

Description

Station Delft is currently under construction (Figure 7.10), planned to be finished in 2017. In this research, data from 2009-2011 is used, so this represents the old situation of the station. The bicycle access share of this station is high above the average in the South Wing.

Table 7.3: Explanatory variable values of station Delft

Variable	Delft	South Wing average
Bicycle access share	**46%**	**35%**
Connectivity		
Average road quality of the bicycle access routes	,27	,37
Bicycle network length per inhabitant	5 m	15 m
Average headway of bus/tram/metro lines in origin area	17 min	18 min
Percent of travelers with an access distance of more than 3km	9%	18%
Individual		
Rush hour dummy	28%	37%
High travel frequency dummy	74%	74%
Work motive	18%	37%
Business motive	11%	8%

Variable	Delft	South Wing average
School motive	16%	16%
Percentage single households in origin neighborhood	60%	41%
Percentage immigrants in origin neighborhood	17%	18%
Cars per household in origin neighborhood	,49	,84
Student OV-chipcard dummy	39%	21%
Car available dummy	28%	44%
Age 50+ dummy	15%	28%
Built environment		
Percentage of people working in hospitality	8%	3%
Percentage of people working in education	12%	9%
Percentage of people working in retail	18%	17%
Percentage of people working in other business services	2%	3%
Station		
Train passengers	24k	15k
Bicycle parking spaces per passenger	,14	,19
Rail (tram/metro) lines serving the station	2	2

Delft, data used from years 2009-2011, N = 640

Variables in red have a negative influence; variables in black have a positive influence on bicycle access

Connectivity

The origin postcodes comprise the complete city of Delft, with many people coming from the city center and the University neighborhood (south east of the station). Delft in general has a well-connected bicycle network and routes from all directions are used intensively (Figure 7.11).

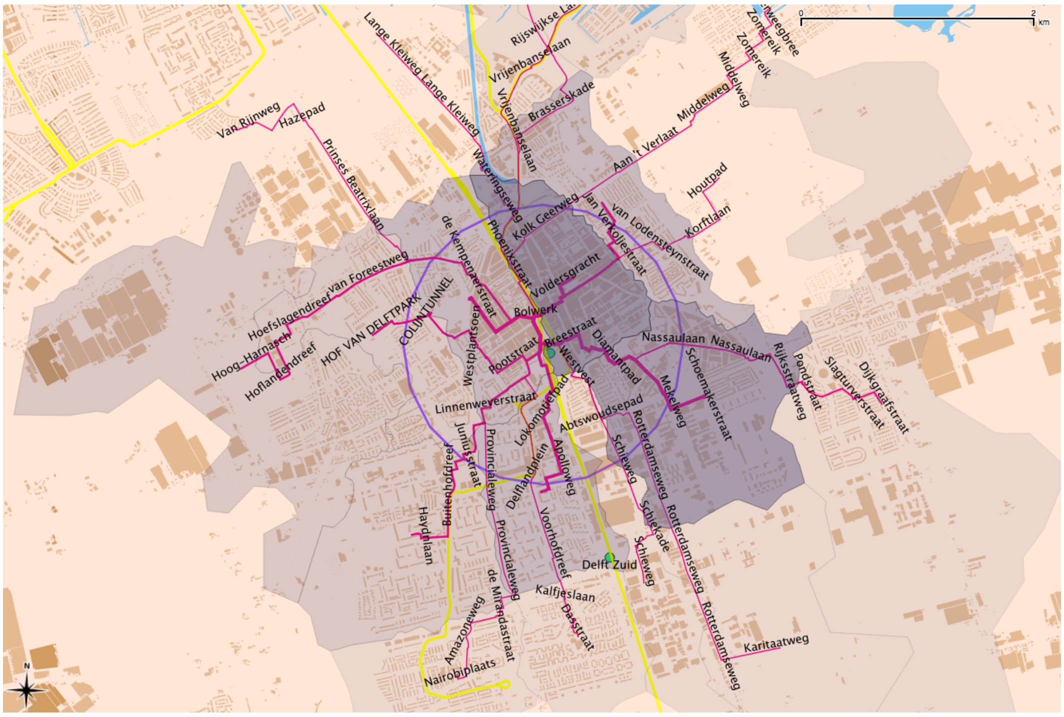


Figure 7.11: Delft postcode origins. A 1200m Euclidean distance circle from the station entrance is displayed in purple. The bicycle routes are pink and labeled with the street names.

The percentage of travelers with an access distance of more than 3km (9%) indicates that most of the travelers of Delft come from a close distance. The city of Delft is relatively compact and a radius of 3km covers most of the city. The competition of public transport is not that fierce in Delft. While two tramlines address the station, these cover only the north-south direction of the city (the yellow lines in Figure 7.11).

Individual

The University of Delft is located in the city, which results in a high amount of students using the station. This is also seen in the share of the travelers that has a student OV-chipcard. Interestingly, this does not have much effect on the bicycle access share. The competition of free (or discounted) public transport is expected to decrease the bicycle access share. An explanation for the absence of this could be the relatively low service level of the urban public transport in the city of Delft. The average headway of the bus/tram/metro lines is still 17 minutes in the origin postcode areas, which is too low to be considered high-quality public transport.

The age group of travelers in Delft is relatively young, which contributes to a higher bicycle access share, but this is comparable to Den Haag HS, which has a low access share.

Built environment

From the built environment variables, both the hospitality and education sectors have high percentages, having a positive effect of the access share. The university is located outside the 1200 influence area, so that does not affect the percentage. The high percentage of people working in the hospitality sector is likely related to the large amount of cafes in the station environment.

Station

The bicycle parking locations at station Delft are extensive, although the parking share is below average. The spaces are in practice fully occupied, often more than 100%. This shows that growth in the bicycle access share is possible if more space is provided. The new station has planned to provide in more bicycle parking space, which is a positive development. Another policy of the municipality is to relieve some of the parking load by stimulating the use of station Delft Zuid instead of Delft. As discussed in the next case study, this will be a challenging issue.

Figure 7.12: Station Delft west entrance with the bicycle parking (Google Maps, 2013)

7.5. Station Delft Zuid

Figure 7.13: Delft Zuid station (University of Twente - LUTI students field work, 2013)

Description

Delft Zuid is a small station located in the south of Delft. It was recently redeveloped to make it more safe and attractive. The station is served by Sprinter trains only. Extensive investments were done to provide more bicycle parking space (Figure 7.15).

Table 7.4: Explanatory variable values of station Delft Zuid

Variable	Delft Zuid	South Wing average
Bicycle access share	**54%**	**35%**
Connectivity		
Average road quality of the bicycle access routes	,52	,37
Bicycle network length per inhabitant	4 m	15 m
Average headway of bus/tram/metro lines in origin area	17 min	18 min
Percent of travelers with an access distance of more than 3km	23%	18%
Individual		
Rush hour dummy	52%	37%
High travel frequency dummy	79%	74%
Work motive	44%	37%
Business motive	12%	8%
School motive	10%	16%
Percentage single households in origin neighborhood	56%	41%
Percentage immigrants in origin neighborhood	22%	18%
Cars per household in origin neighborhood	,50	,84

Variable	Delft Zuid	South Wing average
Student OV-chipcard dummy	32%	21%
Car available dummy	38%	44%
Age 50+ dummy	22%	28%
Built environment		
Percentage of people working in hospitality	1%	3%
Percentage of people working in education	37%	9%
Percentage of people working in retail	14%	17%
Percentage of people working in other business services	1%	3%
Station		
Train passengers	3k	15k
Bicycle parking spaces per passenger	,51	,19
Rail (tram/metro) lines serving the station	0	2

Delft Zuid, data used from years 2009-2011, N = 56

Variables in red have a negative influence; variables in black have a positive influence on bicycle access

Connectivity

The influence area of Delft Zuid has a larger spatial area than that of Delft (Figure 7.14). Mainly travelers originating from the southwest part of the city use the station. The bicycle access share is very high, but absolute numbers are low (Table 7.4). Its location was thought to be attractive to the students from the university neighborhood, but the traveler amounts indicate that this station is not a good alternative to the main station. The reason for this is likely to be found in the fewer connections (no Intercity trains).

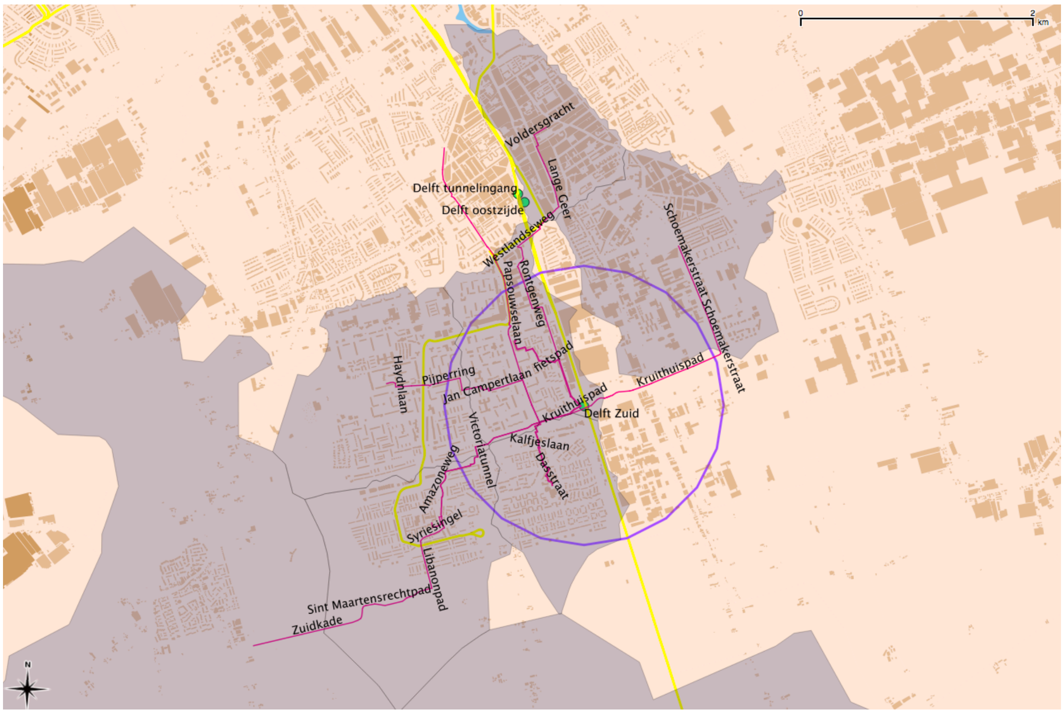


Figure 7.14: Delft Zuid postcode origins. A 1200m Euclidean distance circle from the station entrance is displayed in purple. The bicycle routes are pink and labeled with the street names.

Individual

Both Delft and Delft Zuid have the same population in their influence area, which includes a high share of students (Delft 39%, Delft Zuid 32%). These student shares are the highest of all stations, with Leiden coming third (32%). Delft in general has a young, highly educated population and car ownership levels are low (Centraal Bureau voor de Statistiek, 2010). With the absence of tram and metro lines, the fastest choice to access the station is with the bicycle.

Built environment

The university of Delft is in the influence area of Delft Zuid, which explains the high share of people working in the education sector. Activity of hospitality around Delft Zuid is minimal.

Station

Delft Zuid has one of the highest numbers of bicycle parking spaces per passenger of the South Wing, with an average of half a parking space per passenger. A remark regarding this percentage is very low passenger amount, only a tenth of that of station Delft.

Figure 7.15: Delft South bicycle parking facilities (University of Twente - LUTI students field work, 2013)

7.6. Reflection

From the case studies it is clear that every station has different issues and factors that influence the bicycle access share. No single most important variable can be identified that explains the differences between stations. It is a combination of the factors that determine the bicycle access share of the stations.

The effects of the station and connectivity variables are mostly clear, with logical explanations. The individual and built environment categories are harder to interpret. While these variables are identified as significant in the statistical analysis, it can be unclear why or what the reason behind this relationship is. This gives reason for further analysis on these aspects, mainly the built environment category. Also, the regression model did not identify the traffic nuisance variable as significant. This does not reflect the situation in reality and could indicate that the model is incomplete on this aspect.

8 Measuring bicycle accessibility

8.1. Relevance

The results of the statistical analysis indicated that explanatory variables related to connectivity, the built environment, the station and individual variables are influencing the choice of a traveler to use the bicycle. These results explain the differences in the bicycle access share of the stations. The next step is to develop an accessibility measure that can be used to present the bicycle accessibility of a station graphically in a map. With a map, the geographic situation of a station can be analyzed and compared. In this chapter is explored how this can be achieved.

As described in to the literature review, a good bicycle accessibility measure is relevant, understandable and representative. In this chapter a comparison of three accessibility measures is made, each of them representing different aspects related to bicycle accessibility.

8.2. Infrastructure-based bicycle network measure

The first measure is the most simple, using purely infrastructure to assess the accessibility of a train station. It consists of an infrastructure-based measure with road network distance contours and Euclidean distance of a station. This measure is useful for determining the local connectivity of the station.

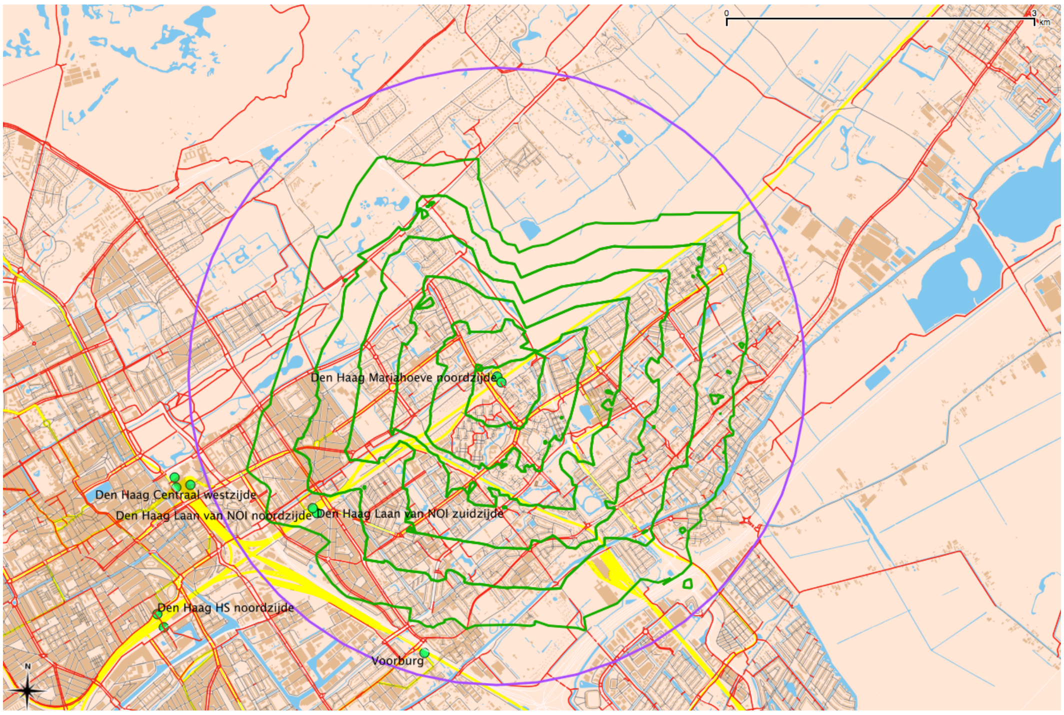


Figure 8.1: Bicycle infrastructure accessibility measure of station Den Haag Mariahoeve

In Figure 8.1, the road distance contours or isochrones are shown in green of train station Den Haag Mariahoeve. The purple circle is the Euclidean distance of 3km around the station. The distance contours represent the area that can be reached over the road network, in 500m intervals. Bicycle paths are colored in red.

This accessibility measure shows the local accessibility of a train station for the bicycle, which depends on the connectivity of the road network. A more complex road network results in a more direct route. More bicycle paths (in red in the figure) provide in a higher quality of the route. In the figure, the area north of the station has low building densities and the road network is very coarse. The result of this is that the route to the station is not very direct and the detour factor is high. This means that the more fine the road network is, the more direct the route.

A negative aspect of this accessibility measure is the limited view it gives of bicycle accessibility. By using infrastructure only, factors that influence the accessibility of a person to reach the station are not considered, such as the option to choose between stations.

8.3. Cumulative job opportunities measure

The second accessibility measure is a centrality accessibility measure with the number of jobs within a station influence area of 5km, using the bicycle access routes. This type of measure is useful for examining the location of the train station within a city. A well-located station, for example in a city center, has a large influence area because the routes cover a large area of the city. A badly located station is on the edge of a city or in a very small city, both limiting the number of jobs one can reach.

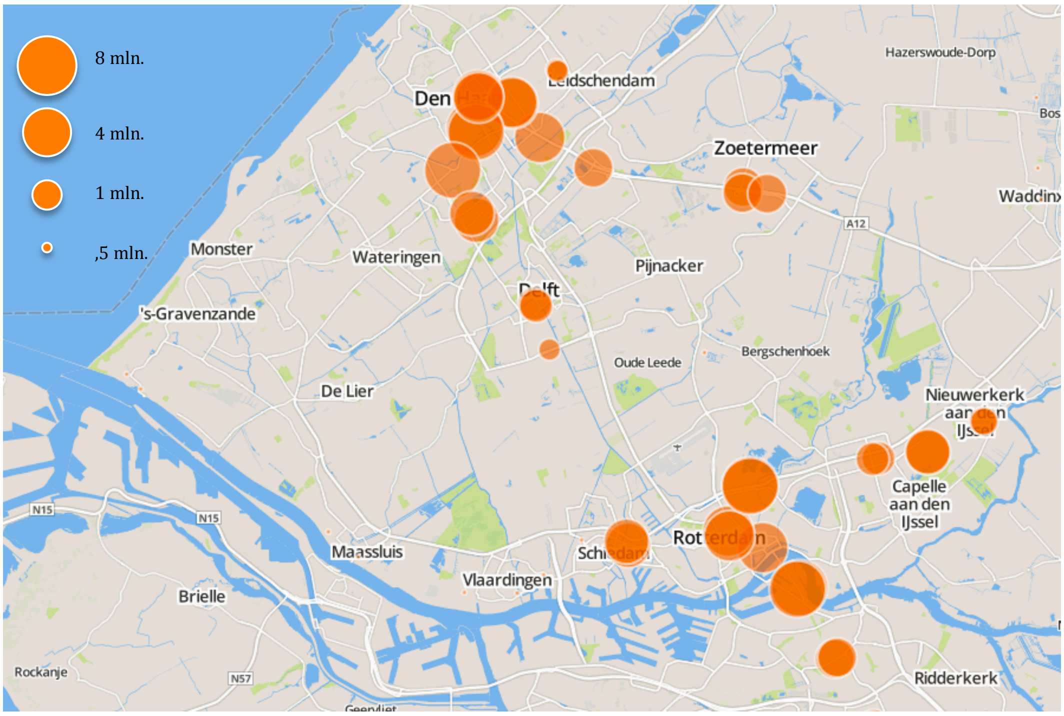


Figure 8.2: A cumulative job opportunities measure of the stations using the number of jobs within 5km network distance, visualized using CartoDB

This type of measure is only slightly related to bicycle use and has limited use as bicycle accessibility measure. In the regression models, the number of job opportunities was not found to be significant in explaining the bicycle access share. It is a measure for the number of people that could potentially use the bicycle as egress mode, but it doesn't address the bicycle specifically. A measure like this is more likely to be used a station potential for the egress part of a multimodal trip. The number of jobs you can reach from a train station within a certain distance is very relevant for the potential amount of travelers you can expect.

8.4. Number of destination stations within 45 minutes travel time

The idea for this accessibility measure is to construct a measure that includes both the access trip by bicycle and the main travel mode, the train trip. The combination of the access and main mode trip provides a measure where local accessibility is linked with regional accessibility. This makes the measure more representative, because in reality the choices in access trip are influenced by the possibilities at the departure station. A train station with more direct, shorter connections is more attractive. This measure incorporates some competition between stations; in the way that the better connected a station is, the more destinations one can reach, even if it is not the closest station to access.

The measure is constructed as a location-based, potential accessibility measure for an origin postcode: the number of destination train stations you can reach within 45 minutes travel time (using bicycle time + train time). This time limit is chosen because it can contain a regular access trip of 10 to 20 minutes and a train trip within the South Wing train network. Of course, the time limit can be set otherwise to represent a different scale.

The travel time for the access trip by bicycle is calculated using the road distance from the origin postcode-4 point to the departure train station. For the travel speed, an average cycling speed of 16 km/h is assumed, which is a moderate cycling speed (Fietsersbond, 2011). The train travel time for each station has been retrieved using the NS API (NS, 2013). Then, a combination of the access travel time and the train travel time is made to a construct trips with a maximum travel time of 45 minutes. This means that a shorter access time (for example, 10 minutes) can have a longer train time (35 minutes) and a longer access time (20 minutes) can have a shorter train time (25 minutes). In the case of multiple departure stations to choose from, the highest value, i.e. station with the most possible destinations, is used.

The result of this combined bicycle and train accessibility measure is shown in Figure 8.3. The origin postcode-4 areas are colored according to the number of stations that can be reached. The value itself is also displayed in the area.

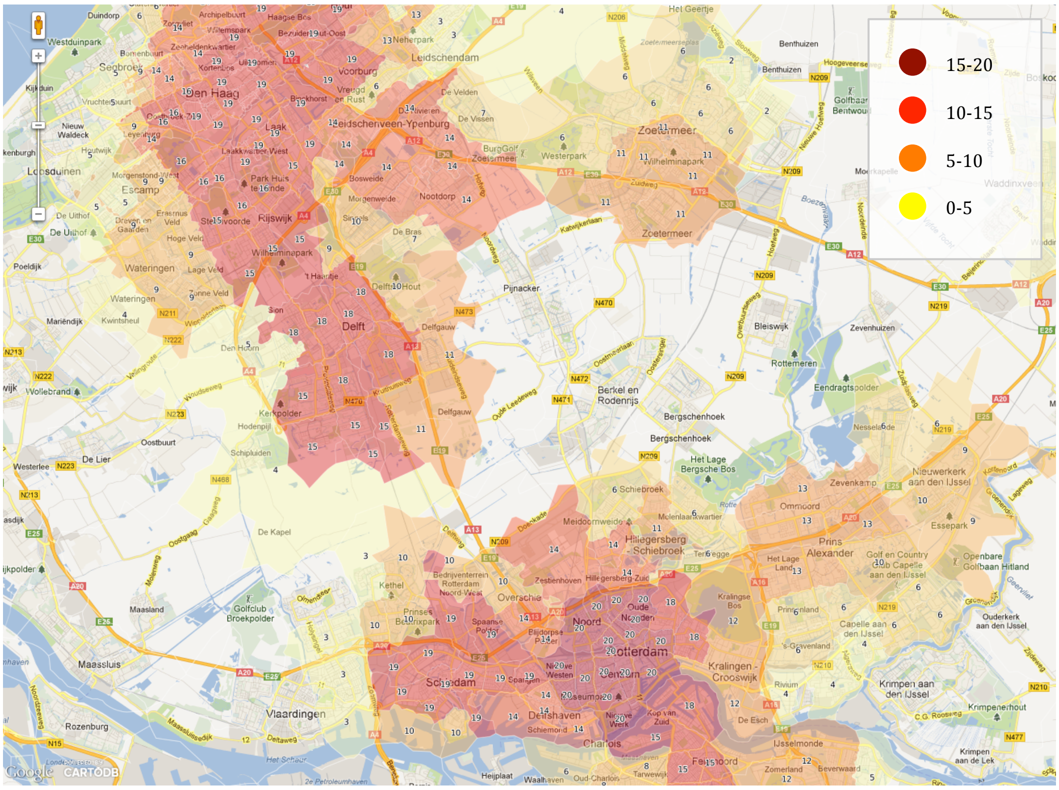


Figure 8.3: The number of train stations accessible within 45 min travel time, using bicycle access and train, visualized using CartoDB and Google Maps. The numbers represent the number of destination train stations accessible from that area.

8.5. Comparison of the accessibility measures

To see what the best way is to represent bicycle accessibility to train stations, a comparison was made between three accessibility measures. An infrastructure-based bicycle network measure using the road network distance and the Euclidean distance, a centrality measure using the number of workplaces in a station's influence area, and a potential destinations measure with the number of train stations you can reach within 45 minutes travel time.

The measures represent different components of accessibility and each has their use. The first measure, the bicycle network measure, uses merely the transport component and is primarily a measure for the density of the road network. This type of measure is most suitable for identifying badly connected areas around the station.

The centrality measure uses the number of jobs as measure for the potential amount of travelers that can reach a station within 5km. This measure is focused on a travelers potential and has no direct relation to bicycle use. Station which are located close to a commercial area have a large number of potential travelers that have the option to cycle since the distance is suitable to cycle.

From this comparison, the measure that was found the most representative is the potential 'bicycle and train' accessibility measure. This measure combines local accessibility (which train stations can I reach by bicycle within a travel time) and regional accessibility (how many destinations can I reach from my departure station). This is important because travelers often have multiple stations to choose from and base their choice on both access time and station connectivity.

9 Conclusions and discussion

In this chapter, the research questions of this thesis are answered, recommendations for effective policymaking are given and suggestions for further research are discussed.

9.1. Summary of results

(1) What is known in the literature about bicycle use, bicycle accessibility and its relation to transit-oriented development?

A limited amount of studies have been done on bicycle use in combination with public transport, in the Netherlands or abroad. The importance of the bicycle in the accessibility of transit stations in frequently underlined, indicating that the bicycle is able to vastly increase the catchment area of a station. However, studies that discuss the variables that influence bicycle use as access mode to the station are mainly qualitative of nature.

From the literature, many potential explanatory variables of bicycle use as access mode are identified. These include variables in the built environment, connectivity, station and individual category. Mainly due to a lack of data, empirical research that assesses the influence of these potential explanatory variables is limited. This research aims to fill this gap in the knowledge by combining various data sources to model bicycle access to the train station.

(2) What are the explanatory variables for the use of the bicycle as access mode to a public transport station?

Using spatial and statistical analysis, several data sources were combined and a regression analysis was performed to identify and quantify the explanatory variables. This resulted in a binary logistic regression model with as dependent variable the choice of the individual traveler to use the bicycle as access mode.

The individual regression model identified many variables, in all four aforementioned categories to be significant. In the connectivity category, the characteristics of the bicycle route (road quality, density) are found to be significant. Also, a strong competition effect between the bicycle and urban public transport (bus/tram/metro) was found.

The type of traveler (frequency, time of departure, possession of student OV-chipcard, availability of a car) is also found to be significant. Significant socioeconomic variables that are not directly attached to the individual, but are averages of the origin neighborhood, are the percentage of non-western immigrants and the share of single households.

In the station category, an important explanatory variable is the number of bicycle parking spaces per passenger. As expected, more parking capacity has a positive effect on the choice for the bicycle as access mode. In this category the competition effect of urban public transport is seen.

The built environment category consists of four types of companies, from which the hospitality and education sector have a positive effect, and the retail and business services sector have a negative effect. The cause of this relationship remains unclear, also looking at the case studies.

(3) How can the bicycle accessibility of a train station be represented using an accessibility measure?

In the theory on accessibility, the opportunities one can reach from a certain location is an important aspect. For a train station, the bicycle is a fast access mode that creates a large catchment area. A bicycle accessibility measure should represent this catchment area. In this research, it is shown that there is a strong decrease in the number of cyclists when the access distance is more than 3km. The catchment area of a station is strongly influenced by the layout of the road network, spatial barriers and competition of other train stations. This aspect can be represented using an accessibility measure. Using a comparison, the options for representing bicycle accessibility of a train stations have been explored.

In a comparison of three different types of accessibility measures (bicycle network, job opportunities and train station destinations) related to bicycle use and station accessibility, it became clear that bicycle use specifically as access mode to the train station is difficult to represent in an accessibility measure. A simple, network based measure is useful for determining the local accessibility of a train station using the road and bicycle network. While this measure gives a good representation of the bicycle aspect, the station aspect is not present in the measure. The job opportunities measure is useful for determining the general egress potential, not so much as measure of bicycle access.

An accessibility measure that combines both bicycle access and the station aspect is the measure of how many train station destinations you can reach within a fixed travel time, using both bicycle access and train travel. The form of this measure is a map with the number of train station destinations one can reach from an origin postcode-4 area.

To answer the question: bicycle access can be represented on different scales. On a local scale, a network measure gives a detailed view of the accessibility of a station. On a regional scale, the choice for a station is also influenced by the location of the station in the rail network. A train station destinations measure that uses a combination of travel time is the most representative measure.

(4) What is the performance of the StedenbaanPlus train stations on the aspect of bicycle accessibility?

The StedenbaanPlus train stations used for this research have highly varying bicycle access shares. The share ranges from very low (9%) to very high (40%). With the regression model, an explanation can be given for the differences between the stations. In general, the train stations in the StedenbaanPlus network are very well accessible by bicycle. The spatial distribution of the stations is very good, with few residential areas located outside the catchment area of a train station. Even the suburban areas, which sometimes do not have their own train station, are well served onto the network by the regional light rail connections. While not included in this research, these stations have comparable bicycle facilities to a train station.

An analysis was performed where the effect of changes in the explanatory variables related to possible policy measures was tested. Found was that the effects of changes in the variables can vary strongly between stations. An aspect that can cause a low bicycle access share of a train station is the competition of urban public transport, especially in the cities of Den Haag and Rotterdam. While this is not positive for the bicycle access share, from the point of view of transit-oriented development this can be seen as a desirable situation. Strongly decreasing the frequencies of bus, tram and metro resulted in a 5% increase in the bicycle access share on average.

A problem at most train stations in the South Wing is the insufficient capacity for bicycle parking. Many stations have occupancy rates above hundred percent, meaning that there are a lot of bicycle parked outside the racks. A test with doubling the bicycle parking capacity at stations has a small effect on the bicycle access share (+2% on average), indicating that merely increasing parking capacity is not sufficient. An optimal road quality also contributes to an increase in the bicycle access share, averaging at 3%.

Main conclusion

The main research question of this thesis is:

What determines the bicycle accessibility of the train stations in the Randstad South Wing?

From reviewing the literature, performing the spatial and statistical analysis and relating the results of this in a case study, it became clear that bicycle accessibility of a train station is hard to quantify. The number of variables that are found significant in the choice of people to choose the bicycle to the station is extensive. However, even with the large number of variables, a large amount of the variation in the bicycle access mode choice remains unexplained. This indicates that there are important variables missing in the statistical analysis used in this research. From the literature, this is though to be mainly related to the individual preferences and attitudes towards bicycle use of travelers.

In short, the aspects that determine the bicycle accessibility of a train station are:

- The amount of bicycle parking space at the train station
- The quality of the bicycle access routes

- The catchment area of a station, determined by the connectivity of the road network, the presence of spatial barriers and the competition with other train stations
- The activity mix in the station environment with the presence of attractive facilities for cyclists
- The position of the train station in the network and the type of travelers it attracts

Then, in the way bicycle accessibility is represented, a combination has to be made of the bicycle access trip to the station and the train trip. Travelers base their choice on both these aspects. Therefore, improvement in bicycle accessibility of a station in order to attract more passengers only has effect if the station is already an attractive starting point for the train trip itself.

9.2. Scientific contribution

This research is, to the authors' knowledge, the first research that has explored the explanatory variables of bicycle use as access mode on a quantitative basis. Also, this research tried to incorporate all possible variable groups (built environment, connectivity, station and individual) that are thought to influence the access mode choice. While the results are not conclusive, the regression models give indications for what influences the choice to use the bicycle. More detailed data on the bicycle network is required to improve the quality of the variables related to the bicycle network, as a large percentage of roads still has unknown values for the quality aspects. Also, more customer survey data can help to improve the reliability of the results. Currently, the larger stations have enough cases to be able to make conclusions based on the statistics, but for some smaller stations the sample size is not sufficient.

Looking forward, the quality of the research on bicycle accessibility can be improved if a questionnaire with the individual preferences towards bicycle use is combined with the existing data sources. This is currently in development for the DBR program, in the form of a stated-preference survey. In this survey, subjects state their preferred choice in a situation. Recommendations for this survey would be to include competition between the bicycle and high quality public transport and the function mix at the access route and station environment.

9.3. Policy recommendations for StedenbaanPlus

The chain mobility program of StedenbaanPlus is currently developing a method to identify bottlenecks in the accessibility of train stations. These bottlenecks can relate to park and ride facilities, bicycle parking capacity and infrastructure and pedestrian facilities. With help of the explanatory variables, stations that perform low on bicycle accessibility can be analyzed. The explanatory variables can help to explain on which aspect the attractiveness of the station can be improved. For this purpose, maps and tables of the stations have been produced which are used in the publications of StedenbaanPlus. Besides general recommendations, attention needs to be given to improvements tailored to the specific issues at each station.

An aspect to keep in mind when optimizing bicycle accessibility of the station is the overall goal of the StedenbaanPlus program: increasing the number of train travelers in order to make higher train frequencies on the network possible. Also, the strong competition effect between the bicycle and urban public transport is relevant in how much improvement is possible.

Recommendation for bicycle accessibility improvements that incorporate these aspects include:

- Strongly increase bicycle parking capacity, as the current demand is much higher than the capacity. It can be expected that there is a latent demand, meaning that creating more parking capacity attracts more cyclists. From a cost perspective, investing in bicycle parking is attractive compared to investments in park and ride or urban public transport.
- Measuring the required bicycle parking capacity at the morning rush hour. In this research was found that most cyclists are rush hour travelers with a home-work or home-school motive, so the design capacity should accompany this demand.
- Increasing the catchment area of a station by eliminating spatial barriers. Spatial barriers can be identified by using the maps of the bicycle network accessibility measure. In urbanized areas, the competition of tram and metro is strong. This underlines the importance of direct, fast access routes.
- Investments in the station environment, on lighting, commercial activities or safety, are not only relevant for the cyclist, but also for the other traveler groups. While not specifically target at the cyclists, investments in the station environment help to attract more train travelers.

9.4. Further research

This research is now performed for a selection of the train stations of the StedenbaanPlus network in the South Wing. The StedenbaanPlus program currently includes 56 train stations and 18 ‘plus’ stops, which are BTM stops with an important transfer function or P&R facilities. A request of StedenbaanPlus was to include the BTM stops in the research, but due to a lack of data on these stops this was not possible. In further research, more data could be collected for these stops, such as the modal splits, which was the main reason the stops were not included. With the collaboration of the tram and metro operators in the South Wing (HTM and RET), data from the OV-chipcard can be used to map detailed passenger flows. Looking further than bicycle use, this could also be interesting to do research on pedestrian activity or the combination of BTM and the train.

10 References

9292. (2012). 9292 Open Data, from http://9292opendata.org/

Aultman-Hall, L., Hall, F. L., & Baetz, B. B. (1997). Analysis of bicycle commuter routes using geographic information systems: implications for bicycle planning. *Transportation Research Record: Journal of the Transportation Research Board, 1578*(-1), 102-110.

Bertolini, L., le Clercq, F., & Kapoen, L. (2005). Sustainable accessibility: a conceptual framework to integrate transport and land use plan-making. Two test-applications in the Netherlands and a reflection on the way forward. *Transport policy, 12*(3), 207-220.

Broach, J., Gliebe, J. P., & Dill, J. (2011). *Bicycle Route Choice Model Developed from Revealed-Preference GPS Data.* Paper presented at the 90th annual meeting of the Transport Research Board, Washington, DC.

Bureau Spoorbouwmeester. (2012). De reiziger centraal: Bureau Spoorbouwmeester.

Centraal Bureau voor de Statistiek. (2010). *Wijk- en buurtkaart 2009*. Retrieved from: http://www.cbs.nl/nl-NL/menu/themas/dossiers/nederland-regionaal/publicaties/geografische-data/archief/2010/2010-wijk-en-buurtkaart-2009.htm

Cervero, R. (2004). *Transit-oriented development in the United States: Experiences, challenges, and prospects* (Vol. 102): Transportation Research Board.

Cervero, R., & Duncan, M. (2003). Walking, bicycling, and urban landscapes: evidence from the San Francisco Bay Area. *American journal of public health, 93*(9), 1478.

Cervero, R., Sarmiento, O. L., Jacoby, E., Gomez, L. F., & Neiman, A. (2009). Influences of built environments on walking and cycling: lessons from Bogotá. *International Journal of Sustainable Transportation, 3*(4), 203-226.

CROW. (2007). *Handboek sociale veiligheid in de verplaatsingsketen*. Ede: CROW.

Curtis, C., & Scheurer, J. (2010). Planning for sustainable accessibility: Developing tools to aid discussion and decision-making. *Progress in Planning, 74*(2), 53-106.

De Montis, A., Barthélemy, M., Chessa, A., & Vespignani, A. (2007). The structure of inter-urban traffic: A weighted network analysis. *Environment and planning: B, 34*, 905-924.

Fietsersbond. (2011). Snelheid 5 verschillende type fietsen vergeleken, from http://www.fietsersbond.nl/node/2066

Fietsersbond. (2012). Fietsersbond Routeplanner, from http://www.fietsersbond.nl/fietsrouteplanner/

Gemeente Den Haag. (2011). Gebiedsvisie Hollands Spoor en omgeving. Den Haag.

Geurs, K., Maat, K., Rietveld, P., & de Visser, G. (2012). *Transit Oriented Development in the Randstad South Wing: goals, issues and research*. Paper presented at the Building the Urban Future and Transit Oriented Development, April 16-17, 2012, Paris.

Geurs, K., & van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography, 12*(2), 127-140.

Givoni, M., & Rietveld, P. (2007). The access journey to the railway station and its role in passengers' satisfaction with rail travel. *Transport policy, 14*(5), 357-365.
Google. (2012). Google Maps - Bicycle route planner, from http://maps.google.nl/?ll=52.359825,4.884281&spn=0.03449,0.062656&dirflg=b&f=d&z=14&lci=bike
Hadas, Y., & Ranjitkar, P. (2012). Modeling public-transit connectivity with spatial quality-of-transfer measurements. *Journal of Transport Geography, 22*(0), 137-147. doi: 10.1016/j.jtrangeo.2011.12.003
Handy, S. L., & Clifton, K. (2000). Evaluating neighborhood accessibility: Issues and methods using Geographic Information Systems: Southwest Region University Transportation Center, Center for Transportation Research, University of Texas.
Handy, S. L., & Niemeier, D. A. (1997). Measuring accessibility: an exploration of issues and alternatives. *Environment and planning A, 29*, 1175-1194.
Heinen, E., van Wee, B., & Maat, K. (2010). Commuting by bicycle: an overview of the literature. *Transport Reviews, 30*(1), 59-96.
Kadaster. (2012). TOP10NL, from http://www.kadaster.nl/web/artikel/productartikel/TOP10NL.htm
Krizek, K. J., & Stonebraker, E. W. (2011). Assessing Options to Enhance Bicycle and Transit Integration. *Transportation Research Record: Journal of the Transportation Research Board, 2217*(-1), 162-167.
Kwan, M. P. (1998). Space‐time and integral measures of individual accessibility: a comparative analysis using a point‐based framework. *Geographical Analysis, 30*(3), 191-216.
L'Hostis, A., Wulfhorst, G., Morkisz, S., Pretsch, H., Stransky, V., & Leysens, T. (2010). *An Urbanism oriented towards rail in Germany and France: selected findings of the Bahn. Ville project.* Paper presented at the World Conference on Transport Research.
Martens, K. (2004). The bicycle as a feedering mode: experiences from three European countries. *Transportation Research Part D: Transport and Environment, 9*(4), 281-294.
Martens, K. (2007). Promoting bike-and-ride: The Dutch experience. *Transportation Research Part A: Policy and Practice, 41*(4), 326-338.
Mestrum, D., Tutert, S. I. A., & Thomas, T. (2011). *De competitiviteit van modatliteiten: een Quick Scan methodiek om de modal split van personenvervoer te bepalen*. Paper presented at the Colloquium vervoersplanologisch speurwerk 2011: Ruimte voor Excellentie, Antwerpen.
NS. (2013). NS API, from http://www.ns.nl/api
OpenStreetMap. (2013). OpenStreetMap Retrieved March 26, 2013, from http://www.openstreetmap.org/
Programmabureau StedenbaanPlus. (2012a). Factsheets stations, from http://www.stedenbaanplus.nl/content/stations
Programmabureau StedenbaanPlus. (2012b). StedenbaanPlusmonitor 2012. Den Haag: Programmabureau StedenbaanPlus.
Renne, J. L. (2009). From transit-adjacent to transit-oriented development. *Local Environment, 14*(1), 1-15.

Research voor Beleid. (2006). Verklaringsmodel voor fietsgebruik gemeenten - Eindrapport. Leiden.
Rietveld, P. (2000). The accessibility of railway stations: the role of the bicycle in The Netherlands. *Transportation Research Part D: Transport and Environment, 5*(1), 71-75.
Rietveld, P., & Daniel, V. (2004). Determinants of bicycle use: do municipal policies matter? *Transportation Research Part A: Policy and Practice, 38*(7), 531-550.
RTV Rijnmond. (2012). Meetfiets test snelfietsroute F16, from http://www.youtube.com/watch?v=dwmvGiJw40Q
Scheltema, N. (2012). *ReCycle City - Strengthening the bikeability from home to the Dutch railway station, Master thesis.* Delft University of Technology, Delft.
Zuidvleugelbureau. (2011). Agenda van de Zuidvleugel. Den Haag: Zuidvleugelbureau.

11 Appendices

11.1. Distance contour calculation

Creating the distance contours from the origin node of the train station to all road notes within a maximum distance of 5km, using the pgRouting 'driving_distance' function:

```
CREATE TABLE station_name AS
SELECT * FROM nodes
JOIN (SELECT * FROM driving_distance(
     'SELECT gid     AS id,
      from_id::int4  AS origin,
      to_id::int4    AS destination, -- not used
      length::float8 AS cost -- use length as cost
      FROM links',
      1044333, -- origin node of the station
      5000,    -- maximum distance for destination nodes (5km)
      false,
      false))
AS route
ON CAST(nodes.ID AS int4) = route.vertex_id; -- combine route
                                                points with nodes
```

11.2. Postcode 4 to station routes calculation

Creating the routes table from all postcode-4 nodes (origin) to the station node (destination) using the pgRouting 'shortest_path' function:

```
CREATE TABLE routes_station_name AS
SELECT gid, id, shortest_path('
    SELECT gid AS id,
    from_id::int4 AS origin,
    to_id::int4 AS destination,
    length::float8 As cost,
    * FROM links',
    id::int4, -- origin nodes (all postcode-4 nodes)
    935560, -- destination node (the station)
    false, false) AS segment
FROM nodes;
```

11.2.1. Variable description

In Table 11.1, an overview of the variables used in the statistical analysis is displayed. Variables names in italics are only represented in the individual regression model.

Table 11.1: A description of the variables used in the statistical analysis

Built environment

Variable	Description
WP Hospitality	Percentage of people working in Hospitality, in a 1200m buffer around station
WP Education	Percentage of people working in Education, in a 1200m buffer
WP Governance	Percentage of people working in Governance, in a 1200m buffer
WP Retail	Percentage of people working in Retail, in a 1200m buffer
WP Healthcare	Percentage of people working in Healthcare, in a 1200m buffer
WP Agriculture	Percentage of people working in Agriculture, in a 1200m buffer
WP Construction	Percentage of people working in Construction, in a 1200m buffer
WP Consultancy	Percentage of people working in Consultancy, in a 1200m buffer
WP Culture	Percentage of people working in Culture, in a 1200m buffer
WP Water	Percentage of people working in Water, in a 1200m buffer
WP Extraterritorial	Percentage of people working in Extraterritorial, in a 1200m buffer
WP Financial	Percentage of people working in Financial, in a 1200m buffer
WP Industry	Percentage of people working in Industry, in a 1200m buffer
WP Information	Percentage of people working in Information, in a 1200m buffer
WP Mining	Percentage of people working in Mining, in a 1200m buffer
WP Other services	Percentage of people working in Other services, in a 1200m buffer
WP Utilities	Percentage of people working in Utilities, in a 1200m buffer
WP Property development	Percentage of people working in Property development, in a 1200m buffer
WP Professional services	Percentage of people working in Professional services, in a 1200m buffer
WP Transport	Percentage of people working in Transport, in a 1200m buffer
Population 2011	Number of inhabitants within 1200m of influence area in 2011
Jobs 2011	Number of jobs within 1200m of influence area in 2011
Dwellings 2011	Number of dwellings within 1200m of influence area in 2011

Station

Variable	Description
Sprinter dummy	Only Sprinter trains stop at the station, no Intercitiy trains. Dummy variable: 1 = yes, 0 = no
Train passengers	Number of train passengers
Bicycle network density	Number of kilometers of bicycle roads in a 3km contour area around station
Bicycle parking spaces	Number of bicycle parking places 2011
Bicycle parking share	Number of bicycle parking places per train passenger (2011)
BTM lines	Number of BTM lines serving the station

Contour area 3km	Area that can be reached from the station within 3km over the road network
Detour factor	Euclidian 3km area divided by the contour area 3km, as measure of indirectness / detour
Bicycle access share	Average share of the bicycle as access mode to the station over the years 2009-2011

Connectivity

Variable	Description
HST trains	Number of high-speed trains serving the station
IC trains	Number of Intercity trains serving the station
Sprinter trains	Number of Sprinter trains serving the station
Jobs per inhabitant	Number of jobs divided by the number of inhabitants in a 1200m influence area
Companies per inhab.	Number of companies divided by the number of inhabitants in a 1200m influence area

Individual

Population density	Average population density in the 3km contour area
% single households	Average percentage of single households in the 3km contour area
% immigrants	Average percentage of non-western immigrants in the 3km contour area
% non-active	Average percentage of people not active in the labor force in the 3km contour area
% age 14-25	Average percentage of people age 14-25 in the 3km contour area
Cars / household	Average number of cars per household in the 3km contour area
Income	Average income in thousands in the 3km contour area
No. supermarkets	Average number of supermarkets within 3km, in the 3km contour area around station
Length	Distance from origin postcode to station, in meters
Bicycle length per inhab.	Meter of bicycle roads divided by number of inhabitants, on neighborhood level
Bicycle length per area	Meter of bicycle roads divided by land area, on neighborhood level
Rail lines	Number of rail (tram/metro lines) serving the train station
Rail bonus dummy	Rail bonus dummy with value 1 if a tram or metro line is present at the train station
Student dummy	Student dummy with value 1 for students
Captive dummy	Captive dummy with value 1 for captive traveler (cannot use car for this train trip)
Frequency dummy	Frequency dummy with value 1 for 1-3 times a week or more

Age 50+ dummy	Age dummy with value 1 if age of person is 50 or higher
Work motive	Work motive dummy
Business motive	Business motive dummy
School dummy	School or study dummy

11.3. Descriptive statistics of the variables used in the statistical analysis

Table 11.2: Descriptive statistics of the variables used in the statistical analysis

Descriptive statistics

Variable	**Min.**	**Max.**	**Mean**	**Std. Dev.**
Temperature	-9	35	12.34	7.37
Route road quality	-0.07	1.00	0.35	0.21
Route traffic nuisance	-1.38	1.41	0.04	0.39
Route lighting	-0.78	1.00	0.87	0.22
Route length	193	4992	1889	1254
Percentage of people age 15-24	4	57	14.95	8.42
Population density	8	23265	8740	5851
Percentage single households	10	83	51.01	16.68
Percentage immigrants	0	85	21.62	16.63
Avergage income	14.30	78.80	33.05	10.06
Percentage non-active people	8	65	24.24	11.35
Cars per household	0.10	2.10	0.69	0.27
Supermarkets within 3km	0.00	47.50	22.12	12.80
WP Hospitality	0.00	0.08	0.05	0.02
WP Education	0.02	0.37	0.08	0.05
WP Public	0.00	0.45	0.15	0.15
WP Retail	0.06	0.35	0.14	0.05
WP Health	0.04	0.52	0.17	0.11
WP Agriculture	0.00	0.05	0.00	0.00
WP Construction	0.01	0.13	0.03	0.02
WP Consultancy	0.02	0.20	0.09	0.03
WP Culture	0.00	0.04	0.03	0.01
WP Water	0.00	0.04	0.00	0.01
WP Extraterritorial	0.00	0.05	0.00	0.00
WP Financial	0.00	0.18	0.07	0.07
WP industry	0.00	0.31	0.03	0.04
WP Information	0.00	0.33	0.04	0.03
WP Mining	0.00	0.03	0.00	0.00

WP Other business services	0.01	0.09	0.02	0.02
WP electricity	0.00	0.08	0.00	0.01
WP Real estate	0.00	0.07	0.01	0.01
WP movable goods	0.01	0.21	0.04	0.04
WP Transport	0.00	0.10	0.04	0.02
Population 2011	6000	58800	33975	14151
Jobs 2011	2000	55200	32940	17436
Dwellings 2011	2800	28000	17093	7444
Intercity dummy	0	1	0.78	0.41
Train passengers	1100	85500	47544	31123
Bicycle parking share	0.01	0.51	0.14	0.10
BTM lines	0	31	18.15	8.66
Detour factor	1.44	2.55	1.60	0.19
HST trains	0	3	0.75	1.22
IC trains	0	12	5.85	3.96
Sprinter trains	1	7	4.64	1.87
Jobs per inhabitant	0.12	3.47	1.19	1.08
Companies per inhabitant	0.02	0.27	0.10	0.08
Weather dummy for rain	0	1	0.23	0.42
Rush hour dummy based departure time	0	1	0.34	0.47
Bicycle network length per inhabitant	0.00	722.50	9.39	40.71
Bicycle network length per area	0.00	8.60	0.22	0.66
Rail lines (tram and metro)	0	11	4.19	4.09
Student OV-chipcard dummy	0.00	1.00	0.24	0.43
No car available for this trip	0.00	1.00	0.62	0.48
High frequency dummy	0.00	1.00	0.74	0.44
Age 50+ dummy	0.00	1.00	0.19	0.39
Work motive	0.00	1.00	0.34	0.48
Business motive	0.00	1.00	0.08	0.27
School motive	0.00	1.00	0.16	0.37
Bus lines	0.00	31.00	13.97	9.56
Train passengers in thousands	1.10	85.50	47.54	31.12
Dwellings in thousands	2.80	28.00	17.09	7.44
Average BTM headway	1.00	60.00	15.58	13.42
Sum of employees in origin area	.24	8.52	3.94	2.95
Route length over 3km dummy	0.00	1.00	0.21	0.41
Valid N (listwise)	10403			