Scenarios for measuring station-based impedances in a national transport model

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Abstract

The measures of local and regional accessibility have been developed separately, resulting on a scarcely studied connection between these two. Accessibility evaluation of land-use and transport strategies can be much improved by linkages with more understandable, and local, accessibility measures for research and policy makers. This paper develops a multimodal model to analyse a set of scenarios of chain mobility , i.e. bicycle route quality, BTM frequency and bicycle parking cost . The results reflect the effects on accessibility levels in a national transport model. A detailed bicycle network is implemented and linked to the public transport network. The effect of access and egress *penalties* is verified by introducing station specific *penalties* by mode and station type (*mode-station constant*). The penalties are derived from time valuations (VOT) and willingness to pay (WTP) for transport improvements.

The study area covers 54 stations of the *Stedenbaan* corridor, within the Randstad south wing. Eight scenarios of transport measures are simulated for both 2012 and 2030. A potential job accessibility measure was calculated with the matrices of travel times generated from each scenario. On average the largest travel time reduction is by 15% between 2012 and 2030, when a scenario of better network and connectivity takes place. The results also show the increase in train passengers due to improved bicycle access. We identified that transport measures should be station based. The strongest effects occur in medium and small station types, i.e. 3, 4 and 5. Particularly, station types 3 and 4 are more sensitive to changes in bicycle network than the rest of stations. At the same time, labour force has a strong impact on reaching high job accessibility levels per region and station areas. The job accessibility increased up to 20%. As future research, the behavioural elements of the national transport models can be enriched to produce more user-oriented results.

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1 Introduction: on the development of multimodal models

Accessibility and multimodal modelling have been two separate topics in the current state-of- the-practice of multimodal modelling. However, facilitating smooth transfers between modes might reduce the trip duration, and by definition, the potential accessibility to destinations. For example, more places to reach within the same travel time budget. The extent to what accessibility can be improved by local measures is extremely important to define transport policies, e.g. both ridership and job accessibility can be improved at the time. At the same time, it has been previously stated that urban transportation accessibility should be extended towards a more holistic approach of transportation accessibility, by an integration of multi-modal transportation facilities (Chen *et al.*, 2014).

There is an urgency of applying multimodal modelling approaches in network design studies Modeling multimodality implies a set of requirements, such as the available choice sets, schedule, demand and supply interactions and adequate network. The choice sets should include all possible transport modes. For example, if P+R is available, car choice should be included as access mode. It should also be realistic, for example, the cost of using bicycle is different at home-side than at station-side. Arentze and Molin (2013) analysed a full range of choice options in multimodal network settings on a high level of detail concerning the trip stages. They found that valuations of costs are not homogeneous across travellers and modes, e.g. car users are less willing to use less convenient public transport and P+R facilities.

Additionally, considering that the disutility of a trip consists of three general components: time, costs and effort (Hoogendoorn-Lanser, 2005; Horowitz and Thompson, 1994; Van Hagen, 2011), a realistic generalised transport cost includes, for example, specific valuations of travel time savings (VTTS). These VTTS might vary either by access, egress or main modes. For example, VTTS by bicycle or by bus/tram/metro are perceived differently (La Paix and Geurs, forthcoming). It is also demonstrated that passengers dislike interchanges (e.g., see Balcombe *et al.* (2004)). Therefore, for a correct prediction, it is mandatory to assign specific *penalties* to each access/egress mode in a multimodal trip. Those *penalties* would represent any effort related to the mode use but cost and time, e.g. transfer disutility, or 'soft' elements such as smooth and convenience of the access/egress combinations. Station type might also have an impact on those penalties, passengers would be more prone to wait (Van Hagen, 2011), or even walk towards more attractive station (Cascetta and Cartenì, 2014). Also better connectivity by BTM (bus, tram, metro) would encourage the use of public transport to access the station(La Paix and Geurs, 2015).

A multimodal transport network should be able to predict the usage of the full range of modes and chains. van Eck *et al.* (2014) integrated a multimodal network of private and public transport modes in an integrated multi-modal network (*'super-network')* model. They found differences between the results from the *super-network* model and a *classical* model. Through the flexibility of the network representation, a priori choice set generation, and advanced choice models a multimodal model can better represent travel behaviour. Then, the key issue is the detailed modelization of travel demand through an accurately developed tool. This accuracy can be provided by either a more sophisticated transport network or a more robust choice model. In a traditional transport demand model, the incorporation of a choice model is done via the mode choice. Also, a priori choice set generation allows the incorporation of correlation between alternatives. The *Supernetwork* model has been extended to multiactivity and multimodal travel, and applied to develop policy scenarios, see for example (van Wee *et al.*, 2014) and (Liao *et al.*, 2010). The model was able to identify the shortest path, and as consequence the least generalized cost to complete a set of activities. As a result, positive synergies between land-use and transport scenarios were found. The combined effect of both scenarios exceeded the sum of the land-use and transport policies separately.

Station specific constants can be added to represent the attractiveness of boarding and alighting stops (van Eck *et al.*, 2014). Up to the current state-of-the practice, there is no study where these constants are both station-specific and mode-specific. The reason for adding station-mode specific constants is that the attractiveness of the trip can also depend on the composition of the trip, namely, the access, main and egress modes. Little attention has been paid to access and egress modes on predicting public transport ridership.

In this paper we approach both sides of this requirements. We implement a more detailed transport network, were access and egress modes (bicycle, bus/tram/metro and walking) are connected to the main modes (public transport and car). We integrate the results of a more robust choice model in the behavioural part via specific VTTS that varies by mode and station type (*mode-station constant*).

2 Implementing an accurate multimodal model on accessibility measures.

The impact of transport measures on transit ridership is typically predicted via data collection and mathematical modelling. Recent studies demonstrated that transit ridership depends to a statistically significant, and non-trivial extent, of the ability of the system to produce accessibility. For example, transit shares can be increased by 0.2–0.5% with an increase in accessibility of 10,000 jobs (Moniruzzaman and Páez, 2012). The current practice of accessibility evaluation of land-use and transport strategies can be much improved by operationalizing more advanced accessibility measures that are easy to interpret for research and policy makers, such as demand models (Geurs and Van Wee, 2004). At the same time, there is an already manifested lack of attention in the current generation of transport models and transport projections about the contribution of urban design and connectivity in the access to railway stations (Geurs *et al.*, 2012).

The importance of regional versus local accessibility and travel behaviour research has been discussed in previous studies (Condeço-Melhorado *et al.*, 2011; Gutiérrez, 2001; Keeble *et al.*, 1981). The pattern of local accessibility is defined with respect to frequent and local journeys, short journeys (i.e. walking or cycling), whereas the pattern of regional accessibility is associated with long journeys (Handy, 1993). The measures of local and regional accessibility have been developed separately, resulting on a scarcely studied connection between these two components. A clear example is the measurement of public transport stops (local) accessibility by non-motorised modes. Cervero *et al.* (2004). In the Netherlands, especially the bicycle plays a large role with a share of 38% as an access mode and 10% as an egress mode (Givoni and Rietveld, 2007). But, only a few studies have examined non-motorised accessibility to public transport stops (see for an overview Iacono *et al.* (2010)). Furthermore, the access modes have received limited attention in the study of transport network effects (Liu and Zhu, 2004).

At the same time, t utility of e scenarios for assessing the effects of transport policies has been demonstrated in a few cases. For example, Chen *et al.* (2007) found that accessibility measures that are derived from combined travel demand models have the flexibility to reflect the effects of different travel choice dimensions on the network. Halden (2002) shown that quantitative accessibility analysis of the accessibility impacts of land use change has significant potential as a tool in development planning. Wang *et al.* (2015) evaluated the impact of transport policy scenarios on accessibility and welfare. However, there is indeed a need to analyse causal links between system and behavioural characteristics into transit use (Taylor *et al.*, 2009). Those behavioural elements are present in user's perceptions and needs, such as time valuations and assessment related to the trip, mode and station used.

The specification of both parameters and function in the measurement of accessibility levels, more precisely, job accessibility, is crucial. And, behavioural measures play a key role on the definition of transport cost, as basis of any accessibility measure. For example, the average cost per hour delay changes according to trip characteristics, i.e. it increases with journey delay (Jenelius *et al.*, 2011). Also, delays affect not only travel time but also the daily schedule. Furthermore, Levine *et al.* (2012) highlighted the importance of specific weighting factors by metropolitan areas when calculating accessibility levels. And, Geurs and Ritsema van Eck (2003) analysed the importance of incorporating job competition and the match between educational and job levels in the analysis of job accessibility.

Given the complexity of the abovementioned specifications, and among others, the impact of public transport measures on job accessibility has been scarcely developed, a far cry from implementations of job accessibility by car . For example, a GIS-based analyses of job or destination accessibility by transit (Mavoa *et al.*, 2012; Owen and Levinson, 2015); or accessibility based on the patronage from each zone, in-vehicle time, number of interchanges and interchange time, travel costs and parking costs (Chang and Lee, 2008), time of the day and destination of trip (Lei and Church, 2010). Nevertheless, neither scenarios effects nor the added information of transport demand models have been considered yet, such as timetables, access, egress modes, frequency of transit, routes and other penalties. The reason for this is the complex implementation of transport demand models in public transport accessibility measures. In the side of infrastructure, just a few studies have developed scenarios of accessibility, for example High Speed Rail, but based on travel time over the network (Martin *et al.*, 2004; Ortega *et al.*, 2014). But, Rietveld *et al.* (2001a) developed 19 variants to measure the impact on in-vehicle time during morning peak. They measured the improvement in generalised travel time and costs. As result, found that bicycle use as entrance and/or exit mode has the largest effect on improving travel time; which encourage the verification of additional scenarios related to access and egress modes to railway stations

This research reconciles three elements from the state of the practice: (1) to improve the behavioural part of transport demand models by integrating the results of a stated preference survey (2) to explore the effects of detailed local (access and egress) measures (e.g. bicycle related) on regional level of potential job accessibility levels. (3) develop scenarios of chain mobility measures, and its impacts on both train ridership and job accessibility. For this purpose, a set of 5 scenarios is simulated in the macroscopic traffic simulation model OmniTRANS. A job potential accessibility measure is calculated for the south-west of the Netherlands.

3 Improvements on the theoretical model

Public transport model

The public transport model consists of the train, bus, tram, metro and ferry network. The infrastructure with the transit stops is implemented in OmniTRANS for the complete Netherlands. Each transport service is associated with the infrastructure (train with rail infrastructure, bus with road infrastructure, etc. For each service the frequency, the stops and the travel time is implemented. Passengers travel from the zone to a stop with an access mode, from the stop to their destination with an egress mode. This access and egress mode is in the original NVM-modal always walking. The walking distance is calculated with the bicycle route planner. The speed changes with the distances; short distances have a speed of 5 km/h (is walking speed). For longer distances this speed increases to a maximum of 15 km/h (bicycle speed).

The waiting time for access at the stop (W_{TAS}) is based on the frequency of the public transport service. The formula for the waiting time is:

$$W_{TAS} = 0,2 * \frac{60}{F}, \quad (1)$$

Where F is the frequency of the public transport service

The same formula is used for calculating the waiting time for transfers between public transport services, but instead of 0,2 the value 0,5 is used. There is no waiting time for egress by foot.

The PT-model calculates the distance and travel time from each zone to each other zone with public transport. It starts with looking for the stops within a search distance around the original and the destination. Then the model searches for the possible travel connections between these access and egress stops. The model calculates the chance that a route will be used; routes with a chance lower that 1% will be rejected. The final travel time and distance from zone to zone is calculated with the sum of the chance a route is choices multiplied by the travel time of the route. The travel time and distance matrix can be subdivided in an access matrix, an in vehicle matrix and an egress matrix.

3.1 Simultaneous transport model

This model starts with the calculation of the number of trips between each zone. This number of trips is based on the social and economic data for each zone. The number of household, inhabitants, number and type of jobs, car ownership, workforce, age of inhabitants and educational places in each zone are the inputs for the calculation of the production from and attraction to each zone. The model distributes the trips and divides the trips over three modes: Car, public transport (PT) and bicycle. The multi-modal network is divided into PT (public transport) and Car, similar to Liao *et al.* (2010). The car network is available in the simultaneous model. This network is also used to estimate the bicycle distances and travel times. Park and ride facilities are available in the car model, while access and egress combinations are available in the PT model. Also, the PT travel times and distances are obtained from the PT-model. In the simultaneous model this three travel modes are compared with the generalised costs. The generalised costs for zone i to zone j are calculated by:

$$GC_{ij,m} = \beta_{ij}^{d} * d_{ij} + \beta_{ij}^{c} * t_{ij,m} \quad (2)$$

Distance costs (d_{ij}) and travel costs (t_{ij}) differ for each mode (m). The travel costs depend also on the purpose (work, business, shopping, education or other) of the trip. The simulation results in an OD-trip matrix for each mode separately. The matrix for PT can be applied to the PT model, to assign these trips to the PT-network. This model is called *supernetwork* model, since it considers multimodality and different networks for each mode.

3.2 Changes to the original National Transport (NVM) model

The availability of different access and egress modes for the PT-trips is an important characteristic of this model. In this research, the following access and egress options are available: walk-transit-walk, walk-transit-bicycle, bicycle-transit-walk, bicycle-transit-bicycle and car-transit-walk. With the new settings the public transport model calculates for these five combinations the generalised costs for travelling from each zone to each zone. A choice model is used to calculate the chance for each access-egress pair to be chosen for a zone to zone trip. With the chances, the average PT-travel time and distance matrix is calculated which is used in the simultaneous model. After the simulation, with the simultaneous model the PT-matrix will be split up in five matrixes with the use of the results of the choice model. As a result, a trip matrix for every access-egress combination is obtained. For the implementation of these access and egress options, the following changes take place in the model:

- A detailed bicycle network is implemented. The bicycle network is obtained from the Fietsersbond data (Fietsersbond, 2011). On this network cyclist in the model travel with a speed of 15 km/h to and from the transit stops. Also characteristics of the links for cyclists (road quality, lighting and nuisance) are added. The pedestrians use the same infrastructure and travel 5 km/h on this network.
- The basic car network is added to the transit network for the Netherlands. This network is connected with the centroids of all zones in the Netherlands and the railway stations in the Randstad south wing. This makes it possible to model park and ride in the Randstad south wing.
- For the added access/egress modes the search radius has to be set. The search radius defines the maximum search distances around a centroid for PT stops. PT-stops further away are considered as not feasible for access/egress. This distance is set to 3 km and 5 km for walking and cycling respectively. There is no distance specified for car access.
- A logit choice model is added to calculate the fractions for each access/egress combination.

3.3 Model calibration

3.4 Potential accessibility measure

For each scenario an accessibility measure is calculated based on the traditional formulation of potential accessibility measures:

$$A_i^{Sk} = \sum_{i=1} J_j * f\left(t_{ij}\right) \qquad \textit{Eq. 1}$$

Where A_i^{Sk} is the accessibility in transport zone i, J_j is the number of jobs in a number of zones j reachable from zone i in 180 minutes. t_{ij} is the travel time by public transport between i and j (modelled with Omnitrans). f(t) is the distance decay function of travel time, based on data from the Dutch National Travel Survey or *Mobiliteitsonderzoek Nederland* (*MON*) (Rijkswaterstaat, 2010). The travel survey contains almost 140 000 trips, with variables such as trip length, travel time, purpose and travel mode. The formulation for the decay function was log-logistic decay, as it was found to have the best fit with the observed data:

$$F\left(t_{ij}\right) = \frac{1}{1+\exp(a+b\ln t_{ij})} \qquad \textit{Eq. 2}$$

Where t_{ij} is the travel time between i and j, and a and b are parameters to be estimated. The parameters for log-logistic distance decay function were estimated for different modes.

Table 1 Parameters distance decay function

	National level		South-west area
Parameter	**Public transport**	**Car**	**Public transport**
a	-11.156	-6.15	-11.467
b	2.838	2.13	3.007

Then, the improvement in accessibility in zone i (A_i^{Δ}) is represented as follows:

$$A_i^{\Delta} = \frac{A_i^{Sk} - A_i^b}{A_i^b} \cdot 100 \qquad \textit{Eq. 3}$$

Where $A_i^{s_k}$ is the accessibility measure in zone i during the scenario S_k, where k takes K values depending on the scenarios conditions.

3.5 Economic scenario 2030

According to the levels of globalization and market orientation, there are four scenarios in a national transport model: *Regional Communities* (RC), *Global Economy* (GE), *Transatlantic Market* and *Strong Europe*. By definition, *RC* scenario is accompanied by higher unemployment rates and lower participation, as compared to the scenarios in which private initiatives are given more leeway (i.e. *Global Economy*). Labour productivity growth is the weakest in the *RC* situation, where at the same time, growth in world exports is negligible, and the share of intra-EU trade remains relatively high. Real interest rates still decrease in RC. On the other hand, in *Global Economy* as in Transatlantic Market, increasing investment demand causes a higher real interest rate. In *Global Economy* and *Transatlantic Market* the role of the public sector is limited. There is more room for private initiatives in these scenarios. For this analysis, we selected *Regional Communities* (RC) and *Global Economy* (GE) as scenarios of measures implementation in 2030, because these are the most extreme situations.

Specific transport characteristics of scenarios 2020 and 2030 in this project:

- the fuel prices will increase with 1% per year for scenarios after 2020 (SEO and Significance, 2008)
- The costs for public transport use will not increase in all scenarios after 2020(Janssen *et al.*, 2006). Therefore, the same values used for 2020GE are used for 2030GE, for 2030RC the values of 2020RC are used.
- Increase in freight transport by road: With information from the same study as is used for the estimation of 2020RC (Janssen *et al.*, 2006), interpolation between 2020GE and 2040GE is possible and results in a value for 2030GE.
- the number of jobs (subdivided by retail, industry and 'other') is also retrieved form the *Network References and Modelling* (NRM).

4 Case study and station types

The case study of this paper is composed by 54 train stations in the south wing of *Randstad* area. It comprises 3 million residents and is one the most urbanised areas in the Netherlands. This area is known as Randstad South in Dutch policy and planning documents. 6 different station types were considered, according to the classification of NS (Progammabureau Stedenbaan, 2012). The station type categories are defined as follows: (1) Very large station in city centre – 50.000 passengers per day or more, (2) Large station in medium-sized city – up to 50,000 passengers per day, (3) Suburban station with hub function – up to 16.000 passengers per day, (4) Medium-size station in centre of small town or village – up to 10.000 passengers per day, (5) Suburban station without node function – up to 5.000 passengers per day, (6) Station in rural small town or village – less than 5.000 passengers per day.

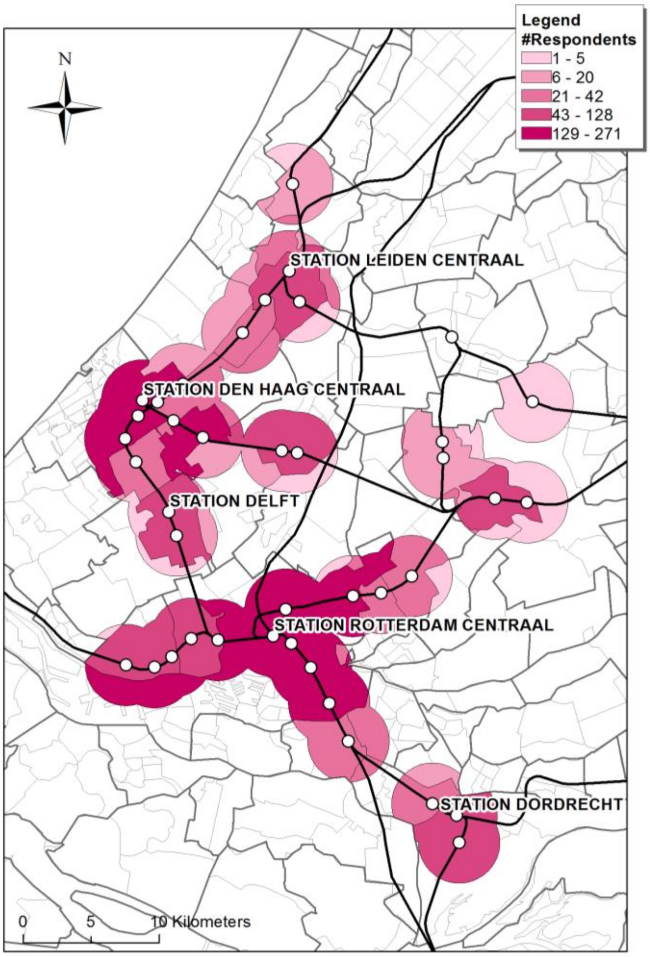


Figure 1 Map of stations in the case study

4.1 Survey and stated choice experiment for access and egress modes to train stations

A survey was conducted among 1524 respondents, who live in the catchment area of the 38 stations. The survey was composed by both revealed preference and stated choice experiment. The revealed preference part included the assessment of both departure and arrival stations. The assessment included three parts: station, pedestrian route and cyclist route to access or egress the station.

The stated choice experiment was composed by 12 choice situations, 6 of which were for access and 6 for egress mode choice. We estimated mixed logit models of access mode choice, as follows: station type 1 and 2, station type 2, station type 3 and 4, station type 5 and 6, Rotterdam and The Hague. The number of respondents varies from 163 (*The Hague*) up to 763 (grouped stations type 1 and 2). The model was used to estimate access mode choice using a number of factors, including travel time, costs and quality (La Paix and Geurs, forthcoming). From the models, the value of time (VOT) for access and egress modes was obtained. These VOTs were used as inputs for the scenarios in the National Transport Model.

The OmniTRANS software is used for the modelling of the effects of changes in the (transport) infrastructure or land use. OmniTRANS is a macroscopic modelling package which makes it possible to implement transport networks and zones with social economic information. Based on the network and the zone information OmniTRANS can model the trip generation and the distribution of these trips over the modes and the network. For this research the *National Transport Model* is used (NVM), which is applied in OmniTRANS. The NVM consist of two parts; the public transport model and a simultaneous model.

5 Developing scenarios in the national transport model

Table 3 shows a summary of the implementation scope. As we can observe, the scenarios are implemented over different station numbers according to the scenario design. All the scenarios are applied over 38 stations at least, given the design by station type. Except the scenario 4 which implemented over the complete network, then 54 stations are equally affected. The following subsections describe the scenario design in details.

5.1 Scenario Improved route quality

The aim of this scenario is to verify the influence of the improvements in both connectivity and station facilities on access time. An ordered logit model was estimated, where the dependent variable was the access time by bicycle. The independent variables were the assessment of 'connectivity' and 'station facilities', which are obtained from the revealed preference survey. The elasticity is used to translate the improvement for the stations into a decrease of the access time by bicycle. The decrease in access time is implemented in the waiting time formula in OmniTRANS. This results in the following formula:

$$w_{ls}^{k} = (1 + \Delta t_s) * 0,3 * \frac{60}{F_{ls}} \qquad Eq.\ 4$$

Where w_{ls}^{k} is the waiting time at access stop s by the access mode *k*, in this case bicycle; Δt is the access time reduction, $F_{ls}$is the frequency of the train line *l* at station *s*.

5.2 Scenario Free bicycle parking

This scenario intends to represent the plans of Netherlands Railways (NS) to offer free guarded bike parking facilities in the future. The effects of this policy are examined with this scenario for access by bicycle to stations. The fixed price of bicycle parking at Dutch stations is 1.25€. Then, based on the VOT by bicycle, the reduction in travel time for cycling can be calculated. The VOTs by stations type are retrieved from the survey. The travel time can be used in *OmniTRANS* to reduce the bicycle time and consequently improving its attractiveness.

For the implementation in OmniTRANS of this scenario is the average waiting time calculated for each station. This average waiting time is calculated with use of the number of cyclists who access a specific train station and choose a transit line with a specific frequency. The reduction in waiting time by station type, as described above, is subtracted of the average waiting time. Therefore, the waiting w_{ls}^{k} time is implemented in OmniTRANS as follows:

$$w_{ls}^{k} = \left(0,3 * \frac{60}{F_{ls}}\right) - \Delta t \qquad Eq.\ 5$$

w_{ls}^{k} is the waiting time at access stop s by the access mode *k*, in this case bicycle; Δt is the access time reduction, $F_{ls}$is the frequency of the train line *l* at station *s*.

5.3 Scenario Proximity of bicycle parking to train platform)

This scenario represents the effects of an improvement of the availability of bicycle places within 2 minutes walking form the platform. This reduces the parking time for cyclists. The time saving in minutes for access by bicycle is calculated with the values of time and the willingness to pay from the La Paix and Geurs (2014) and are presented in the table below. This scenario is implemented in the same way in OmniTRANS is as described for Scenario 3.

5.4 Scenario No delays on cycle routes

This scenario represents the situation where cyclist can be sure that there are no delays on the route to the station. This reduces the travel time, because they can leave later from their home place. The travel time savings are calculated with the willingness to pay retrieved from La Paix and Geurs (forthcoming) . The travel time savings per station type are indicated in the table below. This scenario is implemented as the aforementioned Scenario 3.

5.5 Scenario Reduced 5 minutes of bicycle access to stations

This scenario represents the reduction of the travel time for access by bicycle with 5 minutes, due to less interruption on the route and priority at traffic lights and other intersections. The WTP for reducing 5minutes along the bicycle route is calculated from the SP experiment in La Paix and Geurs (2014); La Paix and Geurs (forthcoming). The WTP is converted to waiting time at the train stations and implemented in OmniTRANS.

5.6 Scenario : Sprinter frequencies

With this scenario the effects of an increase of the frequency of trains is simulated. In the *Stedenbaanmonitor* (Progammabureau Stedenbaan, 2012) is stated that the frequency of the sprinter (local train) will be increased from 4 to 6 per hour per direction on the corridor Leiden - The Hague Central station – Rotterdam Central station – Dordrecht. This extension of the frequency will be implemented when the expected number of passengers will be enough to cover the costs. The simulation of this scenario gives information about the extra passengers which will be attracted with the increase of the train frequency. In OmniTRANS a sprinter train is increased from 4 to 6 per hour in both directions in 19 stations on the corridor Leiden – Dordrecht .

Table 2 Willingness to pay and Time saving (minutes)

Scenario	Station type	Type 1: Rotterdam	Type 1: The Hague	Type 2	Type 3	Type 4	Type 5	Type 6	Avg. WTR	# stations
	VOT €/hr	€27,42	€ 17,61	€17,69	€16,48	€16,48	€22,77	€22,77		
1	*Improved route quality*								*-1.11*	*35*
3	*Free bicycle parking*								*-3.88*	*38*
	ETS (min)	2,74	4,26	4,24	4,55	4,55	3,29	3,29		
5	*Proximity to platform*								*-5.22*	*38*
	WTP	-1.49€	-1.49€	-1.49€	-1.63€	-1.63€	-1.97€	-1.97€		
	ETS (min)	3.26	5.08	5.05	5.94	5.94	5.19	5.19		
6	*No delays on cycle routes*								*-2.58*	*38*
	WTP	-0.65€	-0.65€	-0.65€	-0.95€	-0.95€	-0.89€	-0.89€		
	ETS (min)	1.42	2.21	2.20	3.46	3.46	2.34	2.34		
8	*Reduced 5 minutes of bicycle time to stations*								*-5.97*	*38*
	WTP	-1.46€	-1.46€	-1.46€	-1.89€	-1.89€	-2.55€	-2.55€		
	ETS (min)	3.19	4.97	4.95	6.88	6.88	6.72	6.72		
9	*Increased Sprinter frequencies*									*19*

WTR: Waiting time reduction

ETS: Equivalent time saving

6 Results of National Transport Model

This section presents the results of the simulations, in 2012 and 2030, for the 8 scenarios.

6.1 Change in number of train passengers

Table 3 shows the changes by station type, as can be observed in the table; the strongest effects occur in station types 3 and 4, while the station type 1 reduces the number of access passengers. This occurs because the scenario 1 upgrades the assessment of quality infrastructure to 8 in all stations. Therefore, smaller stations become more attractive, while the bigger stations remain with the same quality level. However, the *super network* model provides more room to manifest the impacts by access mode, such as the implemented scenarios 3 to 9, excluding 1.

Additionally, the overall effect over small stations, i.e. *Delft Zuid*, *Vlaardingen Oost* and *Barendrecht,* can be associated to the frequency of transit lines. It means that, a reduced waiting time highly significant for small stations, because the frequency is very low and better connections can be reached with a reduced waiting time. Scenario 3 shows that the implementation of ‘free bicycle parking’ over 38 stations increases the number of passengers by 9%. Scenario 8 shows the results of the reducing 5 minutes travel time of cyclist route to the station by bicycle (the equivalent of WTP for 5 minutes in the cycle journey to the station). The strongest effect is allocated to the station type 6, which is, at the same time, the smallest type of station with the highest bicycle access share in the recent years (NS, 2014).

Scenario 9 shows the results of increasing the Sprinter frequency from 4 to 6 trains per hour in the corridor Leiden-Dordrecht. The strongest effect occurs in the station type 5, which at the same time belongs to the stations with currently the poorest BTM services.. The stations that less benefits the scenario are the station type 1, which are *The Hague* and *Rotterdam*. This indicates that the implementation of such policy measure should be focused on the medium and small station. This result is reasonable because the BTM frequency is already good enough in the baseline scenario for large stations. Table 4 also shows the net increase in Randstad area (*net increase SW*), the net increase at national level (*net increase NL*) and the adjusted percentage of ridership change (*Adjusted total %*). The adjusted percentage considers only the new passengers in Randstad area. As can be seen, the increase in ridership is mostly composed by new passengers, since the difference between ‘total ‘ percentage and ‘adjusted total %’ is very small.

Table 3 Changes in ridership by station type and scenarios

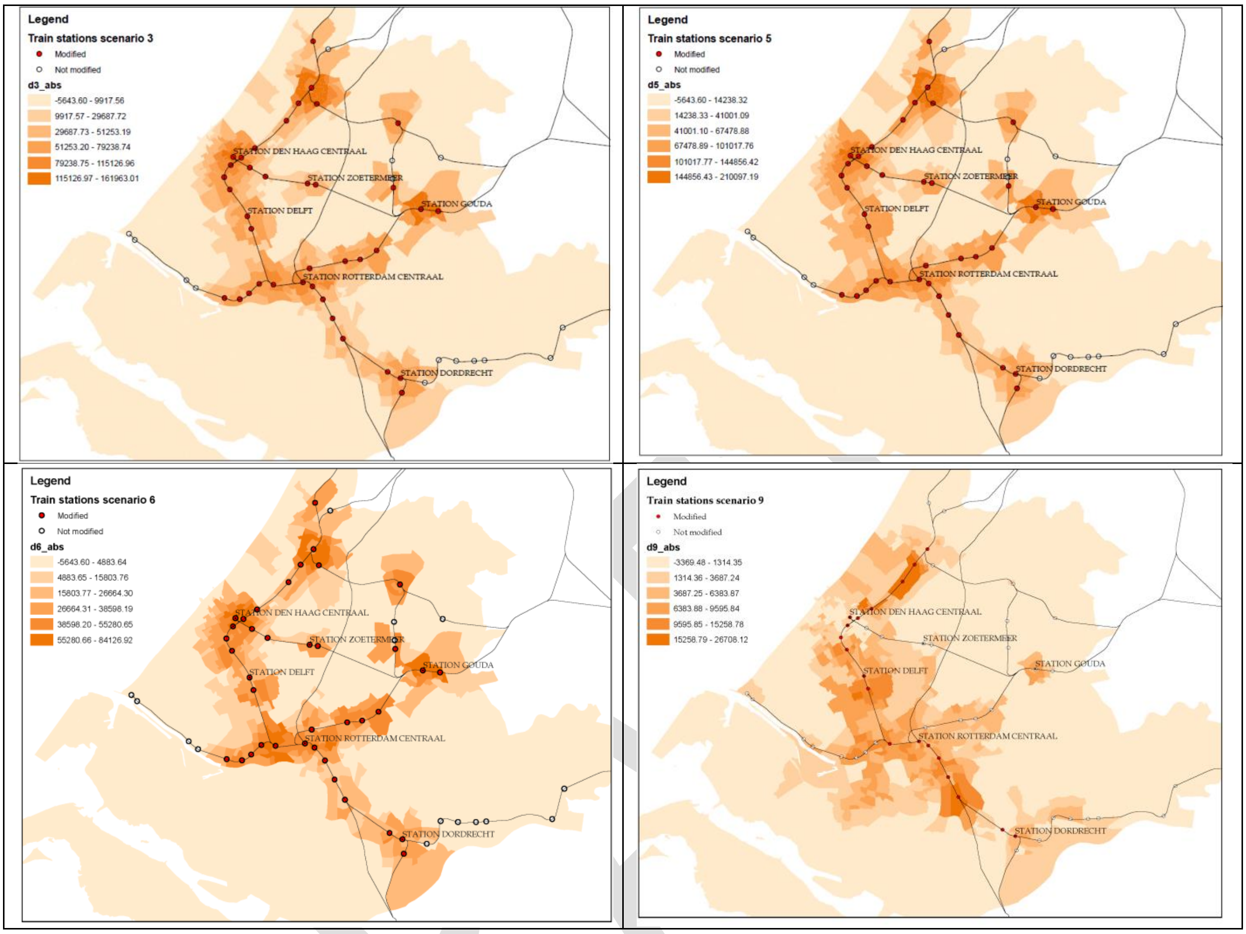
Station Type	**Improved route quality (Sc1)**	**Free bicycle parking (Sc3)**	**Proximity to platform (Sc5)**	**No delays on cycle routes (Sc6)**	**Improvement of 5' cycle time to station (Sc8)**	**Increased Sprinter frequencies (Sc9)**
NS-1	-1%	6%	13%	5%	8%	1%
NS-2	1%	14%	16%	6%	18%	1%
NS-3	2%	11%	**20**%	9%	18%	15%
NS-4	**7%**	**18%**	**31%**	**14**%	**28**%	14%
NS-5	**7%**	12%	17%	1%	23%	**21**%
NS-6	5%	16%	21%	5%	30%	12%
Total	2%	11%	14%	5%	16%	3%
Net increase SW	1102	5058	6728	2256	7764	1726

Station Type	Improved route quality (Sc1)	Free bicycle parking (Sc3)	Proximity to platform (Sc5)	No delays on cycle routes (Sc6)	Improvement of 5' cycle time to station (Sc8)	Increased Sprinter frequencies (Sc9)
Net increase NL	873	5845	6538	955	9030	827
Adjusted total %	**2%**	**9%**	**14%**	**2%**	**14%**	**2%**

6.2 Job accessibility improvements

Figure 2 shows the spatial distribution of accessibility impacts for scenarios 3, and 5 . As can be seen in the figure, the catchment area is demarcated by the effects, e.g. see scenarios 3, 5 and 6. There is a substantially higher effect of the access (bicycle) policies in the proximities of the station area. By contrast, scenario 9 shows more expanded results, as expected, due to the implementation of higher frequencies of BTM. As can be seen, the largest effects, in magnitude, belongs to scenario 5 (proximity bicycle parking to train platform). It means that one of the most important attributes of bicycle access to the station is the location of bicycle parking, and users are highly willing to pay for improvement of these facilities.

Figure 2 Scenarios and spatial distribution of impacts



Scenario 6 shows that cyclists are sensitive to small but strategic improvements, such as the improvements in bicycle routes. However, other scenarios are more attractive, also the public transport network is more sensitive to changes at the train station (scenario 5) than along the bicycle network (scenario 6). As we can observe, the measures related to bicycle infrastructure are the most powerful (Sc.8 and Sc. 5) to substantially improve job accessibility, consistent with (Rietveld *et al.*, 2001a); Rietveld *et al.* (2001b). Secondly, other transport measures more expensive, such as Sc. 9 are less effective.

Even though a bicycle trip to the station is longer than a BTM trip, bicycle related measures are more efficient. This means that reducing the impedances in bicycle trips reduces more the waiting times than reducing the impedances of BTM. In despite of the importance of frequency of BTM for the reliability perspective, bicycle is more reliable because is continuously available, so there is no risk that a connection is missed (Rietveld *et al.*, 2001a).

The results show a maximum improvement of 5.5 minutes by the scenario 5 (proximity – of bicycle parking- to train platform) and maximum improvement by 26% in potential job accessibility. This strong effect can be associated with the average travel time by train within the Randstad area, which is 30 minutes. For example, a reduction by 5 minutes (average) means a reduction by 20% of the in-vehicle travel time, which is a substantial amount of time to reach farther job positions.

As can be observed in table 4, the strongest effects occur in scenarios 5 and 8, within 60 minutes of travel time. These two scenarios include the highest WTP; therefore substantial improvements in travel time are expected. Additionally, the reduction in travel time is with *scenario 8* larger than other scenarios, also because the travel time saving can be applied for the access and egress side.

Scenario 3 (*free bicycle parking*) has the second largest impact on travel times. Consistent with the SP experiment conducted in La Paix and Geurs (2015), bicycle travel time and cost are the most important elements on access and egress mod choice.

Table 4 Overall change in job accessibility improvement over the network 2012

Impedance	Minutes	Sc1.-Station Network and Connectivity	Sc3.-Free bicycle parking	Sc5.- Proximity to platform	Sc6.-No delays cyclist route	Sc8.- Improvement 5'cycle time	Sc9.- Sprinters 4 to 6 per hour
ZH	60	2.70%	16.70%	23.00%	9.20%	26.00%	6.50%
ZH	90	2.10%	12.50%	16.70%	7.20%	18.70%	4.20%
ZH	120	1.50%	8.80%	11.80%	5.10%	13.20%	3.00%
ZH	180	1.20%	7.20%	9.60%	4.20%	10.80%	2.50%
ZH	60	0.50%	3.00%	4.00%	1.30%	4.30%	5.30%
ZH	90	0.40%	2.90%	3.70%	1.50%	4.00%	3.00%
ZH	120	0.30%	1.80%	2.30%	0.90%	2.50%	2.10%
ZH	180	0.20%	1.40%	1.90%	0.80%	2.00%	1.80%

Table 7 shows the average improvements in travel times among the OD pairs in the network. This evaluation indicator is calculated using the same data as the job accessibility maps. The improvement in travel times for 2030 are slightly lower than for 2012. Scenario 9 is only performed for 2030 since it is a measure over the network of 2030.

Table 5 Average reduction in travel time over the network

Scenario	Improvement travel time 2012 (min.)	Improvement travel time 2030 (min.)	% of change 2012-2030
Sc1.-Station Network and Connectivity	1.30	1.10	15.4%
	-	-	
Sc3.-Free bicycle parking	4.40	4.10	6.8%
Sc5.- proximity – of bicycle parking- to train platform	5.50	5.10	7.3%
Sc6.-No delays cyclist route	2.90	2.60	10.3%
Sc8.-Improvement 5'cycle time	6.00	5.70	5.0%
Sc9.-Sprinters 4 to 6 per hour		2.30-	

6.3 *Regional differences and workforce weights*

After weighting the job accessbility by workforce, the scenarios range from 0. 6 to 0.8 jobs per worker, without considering the educational level. The best scenario is the scenario 8, which provides 0.17 more jobs per worker than the baseline.

The regional differences are illustrated in Figure 3, where the ordered job accessibility data in the southwest of the Netherlands is weighted by the distribution of worker population. The distance threshold is 60 minutes by public transport. The figure shows the baseline scenario, scenario 3 (free bicycle parking), 5 (proximity to platform) and 8 (reduced interruptions along bicycle route) . As can be seen 8 shows the highest impact, and actively urbanized areas (i.e. *Rotterdam* and *Deflt*) are heading the list, but also medium urbanized (i.e. *Gouda*) and suburban areas (i.e. *Voorhout*) are benefited, peripheral areas receive marginal effects (i.e. *Zoetemeer*). After 200 (weighted) jobs the scenarios impact barely differ. The strongest differences across scenarios and cities can be observed from 600 to 400 (weighted) jobs.

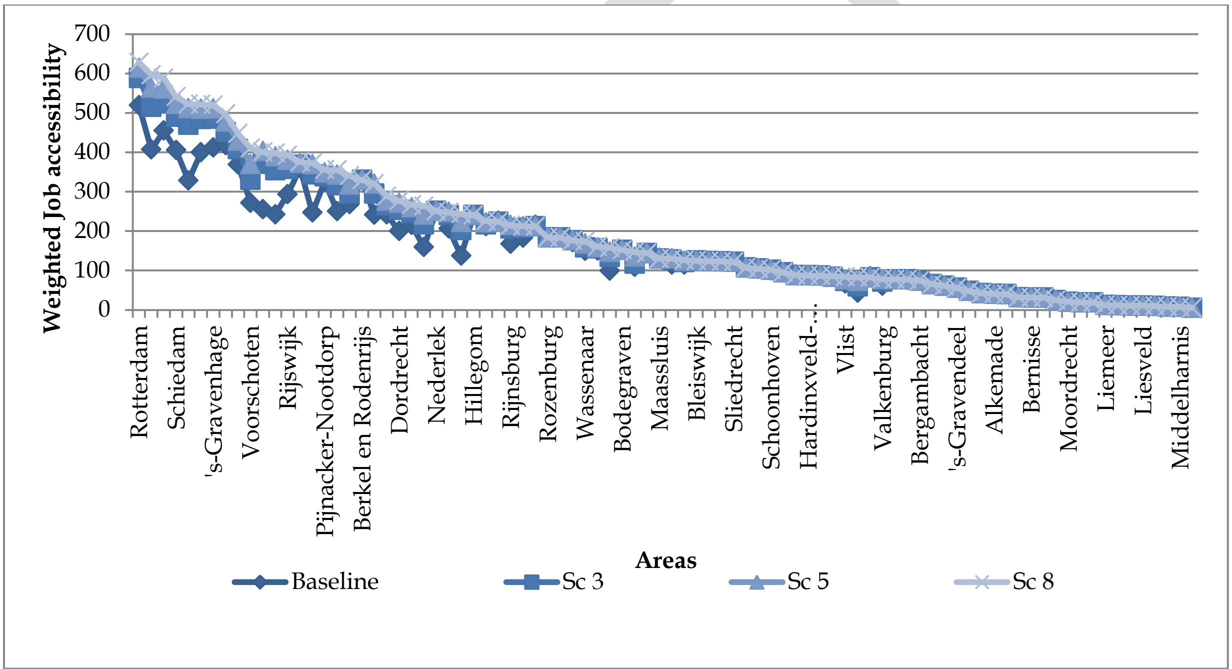


Figure 3Scenarios for Job accessibility by public transport per municipalities, weighted by worker population (2012). Baseline scenario – do nothing, Scenario 3 – Free bicycle parking, Scenario 5 – proximity of bicycle parking to train platform, Scenario 8 – Reduced 5 minutes bicycle access

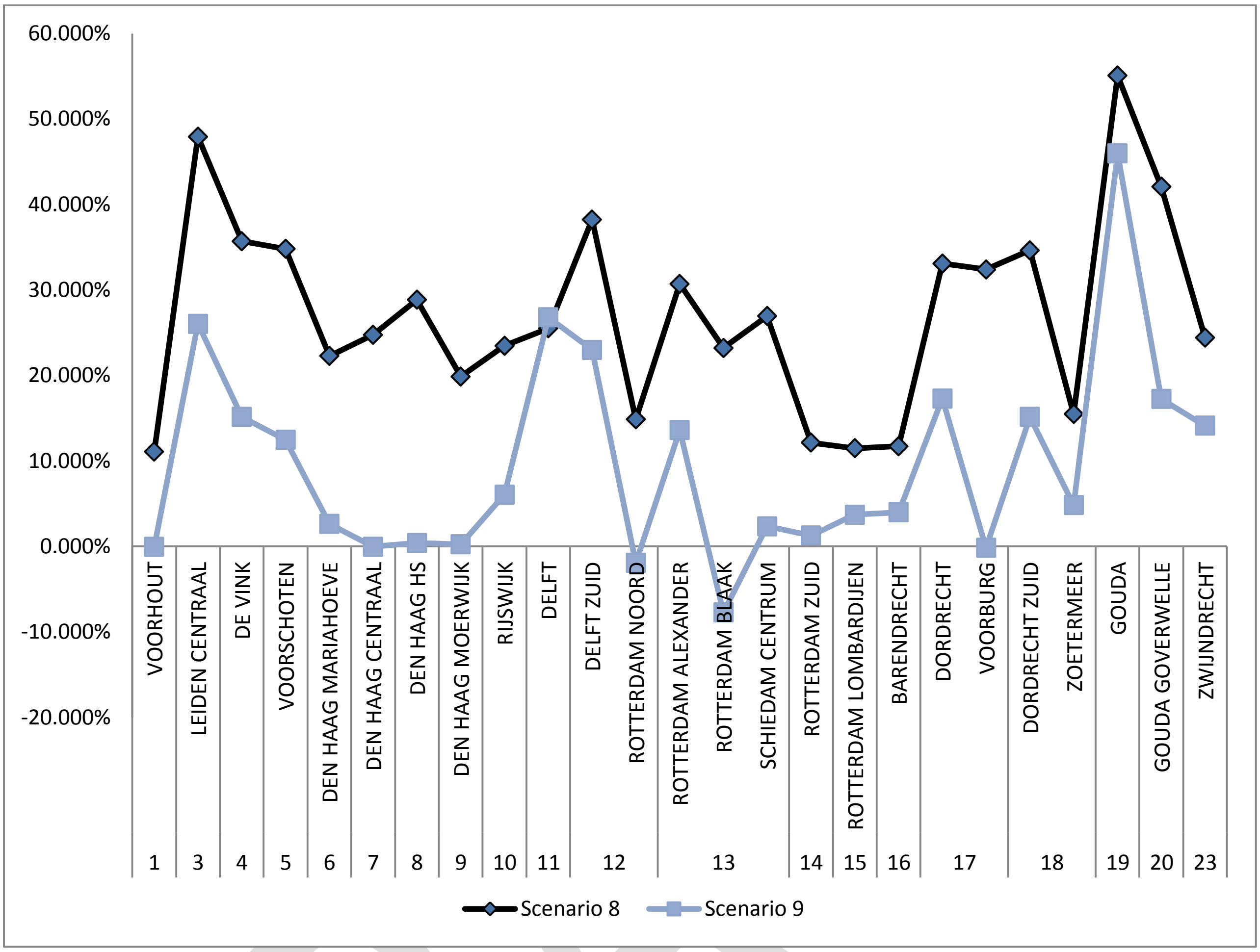


Figure 4 Change in job accessibility (weighted by workforce) by station area in the Stedenbaan corridor: scenario 8 – reduced 5 minutes of bicycle time; scenario 9 – sprinter frequencies

Figure 4 is a cross-section along the Stedenbaan corridor. It shows the weighted change in job accessibility in scenario 8, in respect to the baseline. As we can see, the improvement in job accessibility is substantial, from 10% to 50%. The accessibility reaches the highest in northern Randstad (i.e. *Leiden*), and gradually decreases towards the south-east, while reaching a peak in *Delft Zuid*. The strongest impacts belong to medium size stations, such as *Gouda*.

The biggest increase in job positions takes place in *Rotterdam* followed by *Zoetemeer*, with around 50% more job positions in 2030 than 2012. Two extreme cases are shown, but there is a clear connection between with the results of 2012, where Rotterdam area has the highest job accessibility in the sample. Comparing Table 4 (overall change) and Figure 3 (by station), a clearstronger spatial variation is shown in the latest one, a local perspective of transport scenarios effects.

7 Conclusions

Accessibility impacts of land-use and transport policies are often calculated over car network and infrastructure effects. This paper calculated a measure of potential job accessibility by public transport, with network effects for a set of scenarios. This study has important implications for the current practice of evaluating accessibility impacts of land-use and transport plans and projects.

Firstly, in line with previous studies (See for example Chen *et al.* (2007)) accessibility measures are used to quantify the consequences of individual's choice behaviour, via the SP experiment. In addition, from the SP experiment we deducted specific valuations of time for transport measures by station type. With this we incorporate the effect of station size, liveliness and connectivity over travel time perceptions. As a result, we can conclude that transport planners can define more specific transport measures, by station size and modes (*mode-station constant)*. For example: measures over bicycle network for small station; and, improvement on BTM network for medium stations, which are more sensitive to those changes.

Secondly, the current practice of accessibility impacts needs to overcome traditional infrastructure based accessibility measures (Geurs, 2006; Martin *et al.* (2004)) and focus more in a holistic approach (Chen *et al*., 2014). We contribute to fulfil this need by developing job accessibility scenarios, from a multimodal transport model that considers an explicit link between main modes and access/egress modes. We have seen that access and egress journeys are very sensitive on train trip. Additionally, the scenarios show the potential improvement on regional accessibility by implementing local measures.

Thirdly, since we consider more specific LOS variables (i.e. link with access and egress modes, scenarios for improvements over station quality), we observe that a more accurate generalised cost function in accessibility leads to a range of different impact levels. For example, spatially (by city, by type of urban area or station type) and temporally distributed (i.e. 2012 and 2030). The results show that transport system is very sensitive to a multimodal network. In this case, via the *supernetwork* methodology we measured the effects of multimodal strategies in accessibility and train ridership, which at the same time extended the findings from Liao *et al.* (2010); van Wee *et al.* (2014) to accessibility advances.

Finally, we have shown the advantages of a more detailed stratification of accessibility impacts. For example, by considering station type and transport modes for impedance calculations, but also work force for job competition effects. Consistent with Geurs and Ritsema (2001), the changes in the accessibility are better quantified with a proper impedance function and detailed inputs.

As future research, the following limitations of this work could be coped. In Omnitrans the detailed bicycle network belongs to the Randstad area, therefore the effects of bicycle improvements were only measured in this area. It is of special interest to extend this study to a national level. Additionally, there is still a gap in the research on the use of robust choice models to calculate demand, and therefore its implementation accessibility measures. Our model partially covered this limitation by applying VOTs and WTPs calculated from a behavioural mode. However, the generalised cost function, and mode choice model, in the national transport model does not admit further modifications in this respect.

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