Characterisation of and reflections on the synergy of bicycles and public transport

Kager, R.; Bertolini, L.; te Brömmelstroet, M.

DOI
10.1016/j.tra.2016.01.015
Publication date
2016
Document Version
Final published version
Published in
Transportation Research Part A - Policy and Practice

Citation for published version (APA):
Kager, R., Bertolini, L., & te Brömmelstroet, M. (2016). Characterisation of and reflections on the synergy of bicycles and public transport. *Transportation Research Part A - Policy and Practice*, *85*, 208-219. https://doi.org/10.1016/j.tra.2016.01.015

Transportation Research Part A 85 (2016) 208–219

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

Characterisation of and reflections on the synergy of bicycles and public transport

R. Kager [*], L. Bertolini, M. Te Brömmelstroet

University of Amsterdam, Centre for Urban Studies, Postbus 15629, 1001 NC Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 27 February 2015
Received in revised form 14 January 2016
Accepted 19 January 2016
Available online 10 February 2016

Keywords:
Integrated transport
Public transport
Cycling
Transport system analysis
Sustainable accessibility
Urban transport

ABSTRACT

The bicycle is often understood as a disjointed 'feeder' mode that provides access to public transport. We argue that combined use of the bicycle and public transport should be understood in a broader perspective, especially where bicycles link to higher speed and higher capacity public transport, such as the train. Cycling and public transport can have a symbiotic relationship forming a hybrid, distinct transport mode, which should be reflected in transport planning. The bicycle is as a way to soften the rigid nature of public transport and thus accommodate diverse individual travel needs and situations. Public transport can be seen as a means to dramatically extend cycling's speed and spatial reach. We combine a system perspective with conceptual analysis to explore how, why and when this reconsideration is important. We use the Netherlands as illustrative case because of the relative maturity of its bicycle–train connections. The case shows that the synergy between rather opposite yet highly complementary aspects, high speed of the train, high accessibility of the bicycle and flexibility in combining both sub-modes, are the fundamental characteristics to understand the functioning of this system in a wider spatial context. In our conclusion we propose a research agenda, to further explore the relevance of this system for land-use and transport planning and distil wider implications for the international debate.

1. Introduction

Urban mobility demand is becoming more differentiated in light of increasingly varied household and firm characteristics and activity patterns. At the same time, cities are increasingly under pressure to find ways to cope with the dilemma posed by mobility-dependent lifestyles and business models, and unsustainable urban mobility practices. These challenges need to be addressed urgently (Bertolini, 2012). One possible – and largely overlooked – response is the combined use of the bicycle and public transport. Together, they can serve a much greater variety of trip types compared to stand-alone use of either the bicycle or public transport, and they can better compete with unsustainable individual motorised modes.

This potential is clearly visible in the Netherlands. Of 1.2 million daily train users, around 47% come to their access stations by bicycle, compared to walking (16%) and feeder transit (28%). Also the bicycle accounts for 12% of travel from the egress stations (KiM, 2014, p. 22, p. 102, p. 117). The highest urban density areas in the Netherlands show a remarkable growth rate in the average number of daily trips per person of +15% for cycling trips and +25% for train trips, compared to stable or declining rates for all other public and private transport modes between 2011 and 2013 (CBS, 2014). At the national level, combined data sources indicate a consistent annual growth rate of around 5% in the number of bicycle–train

---

[*] Corresponding author.
E-mail addresses: r.m.kager@uva.nl (R. Kager), l.bertolini@uva.nl (L. Bertolini), m.c.g.tebrommelstroet@uva.nl (M. Te Brömmelstroet).

http://dx.doi.org/10.1016/j.tra.2016.01.015
0965-8564/

trips per person between 2000 and 2013, against the backdrop of a slight decline or only modest growth in the use of other modes (CBS, 2014; KiM, 2013, p. 34; Givoni and Rietveld, 2007, p. 361; Ministerie Verkeer en Waterstaat, 1994, p. 38; Ministerie Verkeer en Waterstaat, 2000, p. 30; Rietveld, 2000, p. 73; Keijer and Rietveld, 2000, p. 224; Fietsberaad, 2007, p. 18; OV-bureau Randstad, 2013, p. 11).

Many parts of the world are developing and promoting cycling and transit services, especially in urban centres (Pucher et al., 2011; Pucher and Buehler, 2012; Buehler and Pucher, 2012; Harms et al., 2014; Carstensen and Ebert, 2012; Curtis et al., 2009; Loo and Comtois, 2015). However, combined use of transit and bicycle is more a potential than a reality in most of these contexts. Therefore, understanding the rapidly developing combined use of these systems in the Netherlands is also relevant in an international context.

Previous work on combinations of cycling and transit either focused on the relative importance of the bicycle for trains (e.g., Rietveld, 2000; Keijer and Rietveld, 2000; Martens, 2004; Brons et al., 2009; Givoni and Rietveld, 2007; Heinen et al., 2010), on the effects this combined use has on replacing car-trips and on sustainable transport (e.g. Ministerie van Verkeer en Waterstaat, 1993; Martens, 2007; Tight et al., 2011), or on modelling their combined performance (e.g. Van Nes et al., 2014; La Paix and Geurs, 2015; Brands et al., 2014; Debrezion et al., 2009). In all these studies, however, there is no specification of the underlying, distinct mechanisms that explain how the inclusion of cycling makes for distinct travel behaviour. To address this knowledge gap and complement these state of the art views, in this article we map how the combined use of bicycle and train can be understood as a distinctive transport mode having intrinsically different characteristics than the sum of its parts. We acknowledge that treating the bicycle–transit combination as one integrated rather than two separate transport modes stretches the notion of what a transport mode is. However, we contend that such a perspective is needed in order to understand the specificities of this travel option. Such understanding is not only relevant from an academic standpoint, but also fills a key gap in planning practice, where both systems tend to be treated separately. In doing so, we propose the combined use of bicycle and train as an interesting case to further the concepts introduced in the research fields of integrated transport (Givoni and Banister, 2010) and its contribution to sustainable transport.

Although the rapid growth in combined use of bicycle and trains is recognised and desired, key actors in the field acknowledge that there is a clear lack of a common and holistic approach to understanding and managing the bicycle–train system. The paper aims to offer an initial exploration into developing such a holistic view, in support of future steps in planning practice and academia. We structure the paper along the following research sub-questions:

- What are the main components of a bicycle–train trip chain? (Section 2)
- What are the main distinct features of the bicycle–train system? (Section 3)
- How does this system function and perform in a real-world context? (Section 4)
- What are the implications for research and practice? (Section 5)

2. Combined use of bicycles and public transport from a system perspective

Within the tradition of system analysis, a system is defined as ‘a group of interdependent and interrelated components that form a complex and unified whole intended to serve some purpose through the performance of its interacting parts’ (Meyer and Miller, 2013, p. 3). By applying this view, the section examines the system that in such way permits the combined use of bicycles and public transport, identifying its supply components and system boundary. Section 2.1 first presents a generic joining of both transport sub-systems at the trip level. This generic system we refer to as the ‘bicycle–transit’ mode. Section 2.3 further specifies the mode, based on a subdivision in public transport services, to become the ‘bicycle–train’ mode. It is this narrowed down system that is considered to reflect *characteristic* combined use of bicycles and public transport more accurately, as it is the topic of subsequent sections.

2.1. Definition as a transport mode

We propose to analyse combined use of bicycles and public transport *at the level of a trip chain* from a given origin (O) to a given destination (D). In doing so, we in fact define it *a transport mode* that is a distinct system component within the general transport system and, at the same time, a distinct focus in the analysis of transport (Meyer and Miller, 2013, p. 3–4). According to mainstream debates about modal choice, the *combined* performance (rather than stand-alone performances) of the interacting components of a transport mode in terms of travel time, cost, comfort and general utility for an O–D relation determines its attractiveness and use compared to alternative transport modes (Ortúzar and Willumsen, 2011; Meyer and Miller, 2013) and its impacts on higher order systems like the urban land-use system, the environmental system, the socio-economic system or the socio-cultural system (Wegener and Fürst, 1999). Based on the trip chain level, Table 2.1 provides an overview of the supply side components of the combined use of bicycles and public transport as a transport mode, compared to stand-alone bicycle and stand-alone transit use as alternative transport modes.

2.2. Subdivision of transit: ‘train’ and feeder services

In our definition in Section 2.1, the bicycle–transit mode includes all supply elements that are part of either the stand-alone bicycle system or the stand-alone transit system. For a second, more specific definition of the combined use of bicycles

Table 2.1
Supply components of bicycle, transit and bicycle–transit transport mode.

Mode	Supply components (O = origin, D = destination; implicit walk trips at origin, destination and transfer locations)
Bicycle (stand-alone)	O → Bicycle parking → Bicycle infra[a] → Bicycle parking → D
Transit (stand-alone)	O → Access stop → Transit services, facilities and transfer locations → Egress stop → D
Bicycle–transit	O → (Bicycle parking → Bicycle infra → [**]Bicycle parking)[*] → Access stop → Transit services, facilities and transfer locations → Egress stop → ([**]Bicycle parking → Bicycle infra → Bicycle parking)[*] → D

[a] Compare Meyer and Miller (2013), p. 3–4 and p. 3–5 for their travel-oriented definition of 'infrastructure'.
[*] A bicycle–transit trip chain is defined to include a bicycle trip segment either before or after the transit trip segment, or on both sides.
[**] Bicycle parking at the access and egress stops is not used for a bicycle–transit trip in case the bicycle is taken on board.

and transit, we split the transit system and its components (services, facilities and transfer locations) into two conceptual subsystems: a 'train' (or 'train-like') transit system and a 'feeder' transit system.[1] For this subdivision, we conceptually define 'train' services as a proxy for higher speed and higher capacity transit services, generally also offering a range of other qualities that the bicycle mode does not offer. Examples of such qualities include enhanced action radius, travel comfort, productive use of time (compare Munafo et al., 2012), reliability and availability.[2]

Our conceptual understanding of a train in this respect is thus neither limited to real-world trains (metro or Bus Rapid Transport systems may for instance offer comparable characteristics, as well as bus services in sparsely populated areas that offer high effective speed in conjunction with high action radius) nor applicable to all real-world trains. In a somewhat looser interpretation, 'feeder' services conceptually represent the parts of the transit system that largely lack features that make them more attractive than cycling judged from the perspective of a traveller who considers use of the bicycle for that trip segment.

Our conceptual definition of the subdivision between 'train' services and 'feeder' services is thus based on whether or not a specific transit service is able to extend the qualities of the bicycle system at the trip level. As a consequence, real-world transit services might act both as a 'train' and as a 'feeder' service at the same time, depending on specific travel relations, contextual and personal circumstances.

2.3. Bicycle–train trip segments

For our final bicycle–train definition, we distinguish three trip segments within a bicycle–train trip: (1) 'access travel' between the origin (O) and the 'access station'; (2) 'main travel' between the access station and the egress station; (3) 'egress travel' between the egress station and the final destination (D). We define a trip to be made by the bicycle–train mode in case the following three conditions apply (as illustrated in Table 2.2):

(1) *The trip includes one or more 'train' trips that together constitute the 'main travel' segment of the trip chain*. This first condition excludes trips for which no train or train-like transit services are used. But also, the condition does not rule out the use of feeder services as part of a bicycle–train trip. For example, a feeder service may be used from the egress station of a train trip, while the bicycle is used in access transport or vice versa. Also, local feeder services may become part of the train trip as 'enchained' feeder services, for example if they offer a faster connection between separated rail stations than the trains themselves do.

(2) *The trip includes one or more bicycle trip segments, whereby at least one such cycling segment needs to be directly connected to a train segment at either the access or egress transit stop*. This second condition excludes trips where bicycles are used to get to or from a feeder transit service rather than a train service.

(3) *The trip consists only of the supply components included in* Table 2.2. This third condition excludes trips involving an access or egress mode other than walking, cycling or transit. Other access and/or egress modes (mostly car) can potentially introduce dynamics distinctive from the bicycle–train system as defined here.

In contrast, for a trip that includes a transit service as its 'main' travel component, but not satisfying all three conditions above, we will refer to as 'traditional transit'. Cycling trips without usage of transit services in the trip chain will be referred to as 'stand-alone cycling'.

---

[1] Compare Meyer and Miller (2013) who observe three major transit service types: 'high capacity' transit (HCT), 'frequent service' transit, and 'local service' transit (p. 3–10). The HCT subsystem focuses on carrying 'high volumes of passengers quickly and efficiently' (p. 3–10). On the other side of the spectrum, local service transit 'is focused more on accessibility and service coverage; speed is not the major concern' (p. 3–11).

[2] It is implied that these features apply (mostly or only) for prolonged distance. We therefore refer to competitive advantages of 'train-like' transit only for longer distances (at least 5 km), see also Section 5.2 (fourth bullet).

Table 2.2
Alternative configurations of a bicycle–train trip, defined above as requiring a bicycle segment at least at either the access or the egress side, but not necessarily on both sides.

	Supply components (O = origin, D = destination; implicit supply components for (local) walk trips at origin, destination and transfer locations)					
	Alternative configuration for access travel		Main travel		Alternative configuration for egress travel	
O→	Access stop → *Feeder* service(s), facilities and transfer locations → Stop at access station→ Bicycle park → Bicycle infra → Bicycle park→ Supply components of other access modes that are frequently used towards eligible access stations (e.g. walk, extended walk, P + R, K + R, individual or shared taxi)	Access station→	*Train* service(s), facilities and transfer locations (potentially using enchained *feeder* services)→	Egress station→	Stop at egress station → *Feeder* service(s), facilities and transfer locations → Egress stop→ Bicycle park → Bicycle infra → Bicycle park→ Supply components of other egress modes that are frequently used from eligible egress stations (e.g. walk, extended walk, K + R, individual or shared taxi, car-share)	D

2.4. Reflection

In reflection of the above system analysis, we note that

- The relationship between cycling and feeder transit services should not be seen as one of mere competition. While this is mostly true for individual *trip segments* (i.e. a train user who chooses bus or bicycle as access mode), on the level of the *trip chain* the two may strengthen each other. For example; selection of the bicycle–train mode because of good cycling supply components in access travel may lead to increased use of feeder transit services from the egress station. Vice versa, a high quality 'feeder' system for egress travel in one city might lead to increased use of bicycles for access travel elsewhere.
- Table 2.2 defines the bicycle–train mode to have 3 alternative configurations in access travel and 3 for egress travel, making for a total of five valid sub-configurations. Also each of the 7 cells in Table 2.2 may offer a degree of relevant choice on how the underlying supply components together generate attractive travel options for the related segment. This is an initial indication of the high complexity of the bicycle–train mode (both for its users as well as for its management and analysis). Sections 3 and 4 will conceptualise and illustrate how the bicycle–train mode *characteristically* involves evaluation of an increased number of access and/or egress stations, increasing this complexity further.
- The availability of the bicycle–train mode implies the option of traditional transit by definition (see Section 2.3). In Section 2.1 we argued that the bicycle–train mode will only be selected if it offers higher utility than a traditional transit alternative. This implies that in case we observe actual (high) use of the bicycle–train mode, by definition it implies that the transit system as a whole (traditional transit + bicycle–train) gains in relative utility compared to other transport modes, such as the car, as a direct consequence of the availability of the bicycle-train mode.

3. Characteristics of the bicycle–train mode

Building on the above system analysis and reflection, in this section we identify two key characteristics of the bicycle–train combination that we hypothesise make it worth conceptualising it as a distinctive transport mode. Section 4 will illustrate them in the Dutch context.

3.1. Synergy between heterogeneous but complementary components

In Fig. 3.1 the bicycle–train mode is mapped on the dimensions of *travel speed* and *accessibility*, relative to other transport modes (based on Meyer and Miller, 2013, p. 3–4). When the transfer is organised well, bicycles offer a substantial increase in door-to-door accessibility compared to train trips. The bicycle adds a fine-grained spatial distribution of origins and destinations that the train system alone can never achieve. Likewise, trains offer a substantial increase in speed and likewise to the spatial reach of the bicycle system. The resulting synergy of high speed (and thus spatial reach) of the train with the door-to-door accessibility of the bicycle give the system unique speed *and* accessibility characteristics, making it potentially competitive with the characteristics of personal motorised transport, as illustrated in Fig. 3.1. Whether this potential is also realised in practice will, of course, depend on the specificities of the context (e.g. road congestion levels, availability of car parking, speed and frequency of train services, quality of bicycle infrastructure).

Trains and bicycles also show contrasting tendencies on other dimensions of modal performance than speed and accessibility. This leads to further potential synergies as they could be visualised by drawing similar diagrams as Fig. 3.1 but replacing one or two of its axes by these other modal performance dimensions (compare also Bertolini and Le Clercq, 2003, p. 578):

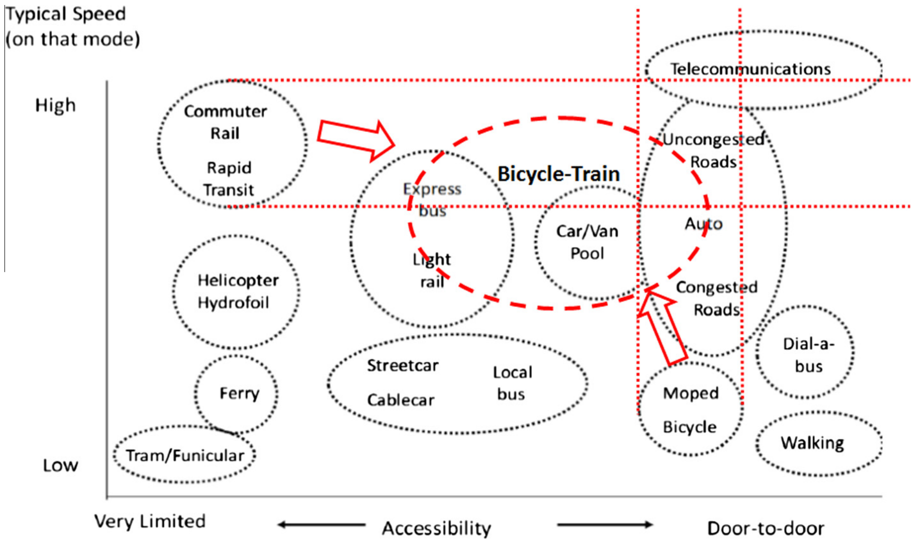

Fig. 3.1. Characterizing the bicycle–train mode according to speed and level of accessibility (indicative, adapted from Meyer and Miller (2013)).

- *Spatial reach.* The transport quality aspects for trains tend to increase with distance travelled, for example on effective speed, value for money (or effort), comfort, reliability, practical availability and potential for productive time use. For cycling, the opposite holds true; its qualities tend to decrease as distance increase.
- *Concentration of urban density at origin or destination.* Trains are better suited for concentrated densities of trip origins and destinations, whereas bicycles benefit from a more equal distribution of trip origins and destinations.
- *Flow intensity.* Bicycle infrastructure is relatively cheap to construct and maintain; it requires little space, enhances to -rather than detracts from- the quality of public spaces, and has a low environmental impact. For train systems all these cost components are significantly higher, especially in a dense, urban environment. The higher costs can only be justified for concentrated travel flows; alternative transport systems offer a better cost–benefit ratio for more dispersed flow intensities.
- *Individual adaptation.* The bicycle is a highly individualised transport mode, allowing freedom of departure time, route choice, ultimate destination or intermediate stop locations, choice in vehicle type or its adaptation, speed, a feeling to be 'in control' and choosing one's own way of travelling. Trains as a collective system score low on these aspects.
- *Activity.* Train travel allows carrying out other activities while travelling (e.g. working, conversing). Cycling does not, or much less. Conversely, cycling is an activity that fully engages body and mind, and as such can also have significant physical (exercise) and mental (relaxing) health benefits.

3.2. High degree of non-deterministic choice

Related to accessibility and radius, the bicycle–train system has specific effects on the catchment area of train stations. The catchment area of a train station is often based on walkable distance (often set at 10 min e.g. 1 km, either via a network or in a straight line (KiM, 2014, p. 102; Daniels and Mulley, 2013; PBL, 2014)). Reduced sensitivity to distance of the bicycle allows for larger but also complex catchment areas due to typical overlaps (more than one station to choose from) and variety between station characteristics and network topology. This aspect turns out to have far-reaching implications for travel choices, as already been noted by Brands et al. (2014) and La Paix and Geurs (2015). For distances over 1 km, walking generally cannot compete with feeder transit systems. In case no feeder transit is available, walking directly to a more distant station (perhaps offering a faster train service) typically does not result in a more attractive travel option than walking to the nearest train station, considering that distances between two alternative stations is usually more than 1 km. Therefore, each station can be assigned a rather fixed catchment area for access by foot. The higher potential speed of the bicycle, however, puts it in direct competition with feeder transit as well as creating complex overlaps of catchment areas serviced by multiple stations depending on, amongst others, final destination station, departure time, cycling speed, preference for the station or its surrounding amenities, the option of intermediate destinations, train characteristics or expectations of any of these aspects for the return trip.

The inclusion of the bicycle in the train system in particular leads to increased choice when travelling to or from urbanised areas. This is because train systems distribute their stop locations over space in relation to urban density and the availability of connections with other transit systems. Also, they tend to branch out from urban centres. Both lead to a positive correlation of the level of urbanisation with the number of stations and the variety of services. Accessing this increased choice in stations by walk or transit is typically severely restricted by distance, timetables and feeder routes. Access by bicycle softens or eliminates these restrictions. Also we observe how both train and transit feeder systems generally offer slower effective travel speeds within urban areas, while bicycle speed is not, or much less affected,[3] amplifying effective station choice further. This combination of increased variety of transit options and decreased difference in speed between cycling and transit creates a complex, interrelated landscape of possible bicycle routes, access and egress stations and transit services, which can be adapted to fit, amongst others, individual user preferences and incidental circumstances (weather, disruptions, travel company, expectations for return journey).

4. Illustrations

This section presents illustrations of the distinct characteristics of the bicycle–train mode as they were hypothesised in previous sections. Data from the Netherlands is used to illustrate how the bicycle–train mode significantly enlarges the catchment area of rail stations (Section 4.1) and shapes the choice of departure and arrival stations (Section 4.2). Third, a closer scrutiny of the Amsterdam region illustrates how the bicycle–train mode allows higher overall travel speed and more station choices, relative to traditional transit (Section 4.3). While discussion in previous sections include the possibility of taking bicycles on board, the case of the Netherlands provides an example where a bicycle–train system operates at a high level but where taking a bicycle on board is a marginal practice. Both capacity of trains to carry bicycles and hours of the day when it is allowed are constrained, hence the option is ignored in this illustration.

4.1. Catchment areas of railway stations in the Netherlands

Table 4.1 shows the percentage of the Dutch population that resides within the catchment area of all 388 Dutch rail stations (excluding metro and light rail), differentiated per station type and distance category, resembling commonly accepted walking distance (1 km), bicycle distance (5 km) and potential bicycle distance (7.5 km) respectively (e.g. KiM, 2014, p. 102). The table illustrates how the bicycle–train system connects a much larger share of the Dutch population to the Dutch train system. Whereas just 19% of the Dutch population lives within 1 km walking distance of these 388 stations, this share rises to 69% and 81% for 5 km and 7.5 km of cycling distance, respectively.

A second observation from this illustration is that this ratio clearly favours stations of higher (network) importance. Only 1.1% of the Dutch population lives within a 1 km radius of the 17 main intercity stations, compared to 16–24% within cycling distance. Cycling thus connects around 15 time as much people to main intercity stations compared to walking. For local stations, this ratio is considerably lower: cycling connects around 4 times more people to stations compared to walking (36.3%/9.4%). From the perspective of network hierarchy, this is a useful characteristic; cycling significantly increases the catchment area of any station, but increasingly so for stations of higher hierarchy. In particular, note how stations of all hierarchy levels on average have a comparable 0.04–0.08% of Dutch population within walking distance *without correlation to hierarchy level*. In contrast, there *is* a clear trend when looking at cycleable distances. Basic local stations connect to just 0.17% of Dutch population at 5 km cycling distance, where large IC stations on average connect to 0.93% of Dutch population on the same distance.

Table 4.1
Percentage of Dutch population per distance category per railway station type, in brackets percentage per station. *Source*: CBS, 2013.

Station hierarchy[a]	*N*	<1 km	<5 km	<7.5 km
IC station – many services	17	1.1% (0.06%)	15.8% (0.93%)	23.8% (1.40%)
IC station – basic	27	1.8% (0.07%)	20.6% (0.76%)	28.5% (1.06%)
IC station – few services	22	1.5% (0.07%)	10.5% (0.48%)	17.0% (0.73%)
Hybrid station	16	1.2% (0.08%)	7.6% (0.48%)	12.3% (0.77%)
Local station – many services	86	4.6% (0.05%)	28.8% (0.33%)	42.3% (0.49%)
Local station – basic or few services	216	9.4% (0.04%)	36.3% (0.17%)	53.6% (0.25%)
All stations	388	19.2% (0.05%)	69.1% (0.18%)	81.2% (0.21%)

[a] For this hierarchy, we counted the number of train services departing per hour and weighted on service type and operating hours. We weighted intercity services, hybrid services and local services as 5:3:1 for peak-hour only services and as 10:5:2 for services running all day. Intercity services were defined as skipping at least 4 stations of the subsequent 6 stations, hybrid services needed to skip at least 2 stations on the subsequent 4 stations. We excluded light rail and services requiring reservation or supplement. Basic local stations were selected on aggregated service weights of 1–9, extended local stations 10–19, hybrid stations 20–29, small IC stations 30–49, basic IC stations 50–99 and large IC stations 100 or more. The stations of Stavoren and Hoek van Holland Strand shared the lowest aggregated service weight of 2, Utrecht Central Station had the highest weight at 292.

---

[3] Effective train speeds near urban centres may be affected by a higher stop density and sometimes longer stops, speed restrictions related to safety (curves, switches, mixed use) or noise considerations, or more indirect route layout (more kilometres).

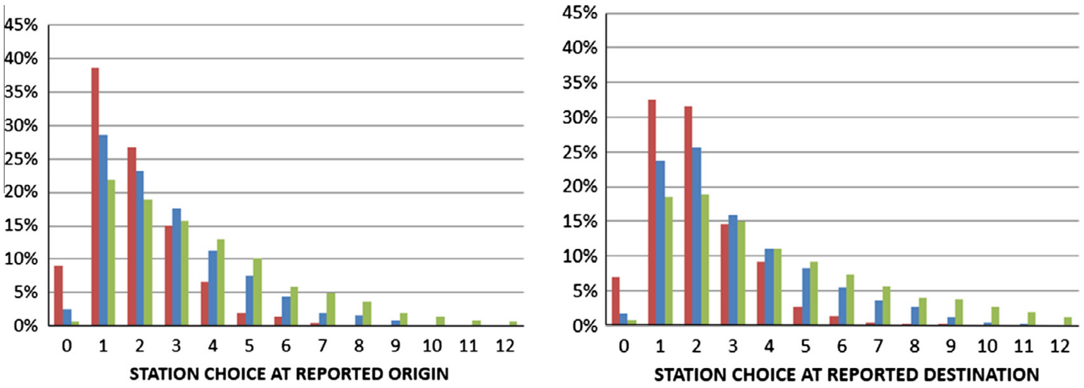

Fig. 4.2. Relative frequency of *n*-choice in departure and arrival station for all trips starting from 'home' location with train as main travel mode. Left bar (red) = 5 km, middle bar (blue) = 7.5 km, right bar (green) = 10 km. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.) *Source*: CBS, 2010–2012, National Travel Survey, $N = 2975$.

4.2. Station choice for train trips in the Netherlands

As a second illustration of the distinct characteristics of bicycle–train, we look at station choice for average travellers. For walk access, in nearly all cases, the choice of railway stations is effectively limited to 1 station only, because the typical railway station spacing is at least 3 km while typical walk distances are more in the order of 1 km. Also for feeder transport, station choice is often much constrained by the feeder routing and timetables. In contrast, Fig. 4.2 shows the choice potential of railway stations on cycleable distances of 5 km and more for *reported* origin and destination locations of actual train trips in the Dutch National Travel Survey[4] (CBS, 2010–2012, excluding home-bound trips). It shows the number of stations at varying distances from the trip origin (left) and trip destination locations (right) respectively. A majority of travellers could choose between two or more train stations within 5 km of their origin location, and an even higher share around their destination location. The latter can be explained by the observation that destination activities visited by train are more concentrated in larger cities than origin destinations (predominantly the home location), and that there are generally more stations per square kilometre in larger cities.

The high degree of choice in departure and arrival station is a relevant and complex aspect of bicycle–train trip chains. Fig. 4.2 illustrates that a significant number of reported trips show such choice: over 55% of reported trips have 2 or more stations to choose from within 5 km of both the origin and the destination location (with 2 choices on both sides resulting in 4 optional origin–destination pairs), while 10% of access trips and 15% of egress trips even have 4 or more stations within 5 km, and the relative frequencies of the latter roughly doubles when extending the catchment area to 7.5 km. The Amsterdam example below will further qualify this defining characteristic of the bicycle–train system by illustrating to which degree such station choice actually leads to attractive travel options.

4.3. Illustrative example of Amsterdam

To illustrate the specific door-to-door travel speed advantage that the bicycle–train system offers, we describe a detailed analysis of the city of Amsterdam and three adjoining municipalities: Amstelveen, Diemen and Ouder-Amstel. In 2012, the area had 880,500 inhabitants and 13 train stations with access to the national train system.

To analyse the bicycle–train system in Amsterdam we joined two open datasets on transport, combining them with a general zoning database for the area. First, OpenStreetMap provides highly detailed data on road networks (generally down to the level of minor foot paths). For each segment, it includes a range of properties like road classification, road layout and priority regimes. This network was used to calculate representative cycling times (and routes) between zone centroids and main entries of train stations. The main variables that were used are based on the OpenFietsModel as developed by Bram Fokke in 2013 (unpublished) as summarised in Table 4.2. The model was calibrated for the Netherlands using a variety of heterogeneous and randomly sampled cycling routes.

This data was complemented with detailed transit timetable data using the OpenOV database, the Dutch implementation of the General Transit Feed Specification (GTFS). For the example of Amsterdam, the 'train' system was selected as all train stations and any train service in this dataset, including all metro services as far as they operate between these train stations (an example of 'enchained' feeder services in Table 2.2) but excluding trains requiring reservation or supplement. The feeder transit system is made up of all remaining transit services (tram, regional fast buses, local buses and other metro services).

To link transit services and bicycle routes to origins and destinations, the National Statistics zoning scheme for neighbourhoods was used ('CBS-buurt'), subdividing the area into 148 zones, with approximately 6000 inhabitants per zone. Each zone was reduced to a centroid of minimal average distance towards each of its constituent residential addresses (using a National

---

[4] The data is based on all reported trips leaving the 'home' location with train as the main travel mode for 2010, 2011, and 2012. In total, 2,845 trips were reported by around 90,000 respondents.

Table 4.2
Main variables used to calculate bicycle travel times.

Parameter	Value
Maximum cycling speed ('free-flow')	– 19 km/h[a]
Cycling speed correction factor	– Exclusive cycling track: 1.00 $*$ max. cycling speed – Cycling lane ('fietsstrook'): 0.98 $*$ max. cycling speed – Footpath: 0.40 $*$ max. cycling speed – All other: 0.95 $*$ max. cycling speed
Time penalties for crossings	– Traffic lights: 23 s (Glas, 2012) – Unregulated crossing of primary road: 6 s – Unregulated crossing of secondary road: 4 s – Unregulated crossing of tertiary road: 2 s – Unregulated crossing of unclassified road: 1 s
Time penalties for curves	– Angles < 20 degrees: 0 s – Larger angles: 0.033 s per additional degree (e.g. 2.3 s for 90 degrees)

[a] A 'free-flow' cycling speed of around 19 km/h has been found for urban conditions and non-recreational purposes for the Netherlands as an outcome of the bicycle-tracking project 'BikePRINT' (van de Coevering et al., 2014).

Statistics database of all address locations). For analysis of transit services, we selected any transit stop within 500 m of the centroid,[5] opting for the transit stop that offered the most transit services during workday morning peak hour, weighing metro services by factor 6, tram services by factor 3 and bus services by factor 2 in order to resemble typical speed, comfort level and carrying capacity per mode. In a handful of cases without a transit stop within 500 m, the selection circle was increased to 1 km from the centroid.

To illustrate the performance of the bicycle–train system, we measured (a) effective total travel speed and (b) effective access station choice from any of the above 148 possible origin zones (weighted by their population) towards a representative set of 28 destination stations outside of Amsterdam, differentiated per access mode (walk, feeder transit, bicycle). The destination stations have been rather randomly selected as a proxy for typical train travel. Defining typical train travel as between 10 km and 80 km, we selected 28 out of around 200 stations in this distance range from Amsterdam, taking care to include stations in all (rail) directions around Amsterdam by the weight of the population in their catchment area, including stations of all hierarchies. Often, but not exclusively, stations in larger cities were favoured, because more densely urbanised areas are known to generate and attract more train passengers.[6]

4.3.1. Travel time scenarios

Finally, scenarios were defined on how travel times by bicycle and train are evaluated in detail. Considering the many aspects of travelling by both bicycle and transit, and comparing the resulting combination with alternative access/egress travel involving walk and/or feeder transit services, scenario development is a research theme in itself (see for example the work by Van Hagen, 2011).

For our illustrative, simplified case, we worked with a minimal set of rules to derive average travel times per origin–destination pair and per access or egress mode. Table 4.3 shows two scenarios used for the preparation of such total travel times. Scenario I is a simple joining of composite travel times according to detailed timetables: it represents ideal travel time without any evaluation of delays, frequencies, transfers, walking distances or subjective time evaluation, in recognition of the highly urban context and the aim of the exercise which is to test for sensitivity on such rules at an aggregate level. Scenario II introduces (rather conservative) penalties for (a) transfers, (b) the use of a bicycle or feeder transit service compared to walking and (c) low frequencies. While we fully acknowledge this set of penalties is both incomplete and their values too low for many travel contexts, we stress again that the aim is not to realistically model subjective travel times, but to compare the *sensitivity* to such (type of) penalties of bicycle–train relative to other modalities.

4.3.2. Travel speed of bicycle–train trips

Table 4.4 shows the resulting travel speeds for different access modes used in a train trip chain. The table illustrates that in Scenario I the bicycle–train combination results in slightly higher effective travel speeds compared to the use of feeder transit services, and much higher effective speed when compared to walking. The total time gain when using a feeder transit service compared to walking is 23 min on average. This average is influenced by very high walking distances to the nearest railway station (3–5 km) for parts of the region and also by favourable evaluation of feeder use under this scenario. Bicycle–

---

[5] In order to limit complexity, we did not choose to connect zones to transit stops in multiple directions. In light of the small average zone size of around 0.5 km^2 we derive a maximum theoretic error of 4 min for transit times per zone when travelling towards a specific rail station. For this error we do not expect a systematic bias when aggregating over all zones and all possible connections to surrounding rail stations.

[6] The selected destinations stations in alphabetic order Alkmaar, Almere Buiten, Almere Centrum, Amersfoort, Amersfoort Schothorst, Beverwijk, Den Haag Centraal, Deventer, Deventer Colmschate, Enkhuizen, Haarlem, Heerhugowaard, Hoorn, Houten, Koog Bloemwijk, Nieuwerkerk aan de IJssel, Rotterdam Alexander, Rotterdam Blaak, Rotterdam Centraal, Rotterdam Noord, Rotterdam Zuid, Schiphol, Utrecht Centraal, Utrecht Lunetten, Utrecht Overvecht, Utrecht Zuilen, Zaandam and Zandvoort aan Zee.

Table 4.3
Travel time scenarios for analysing total travel time from Amsterdam region using optimal access railway stations.

Scenario	Rules
Scenario I = Ideal travel time	– Zero walk time to feeder service stop – All transfers of 1 min or more always succeed – Travel times according to timetable for a regular workday, Thu May 15 2014 with departures between 7 am and 8 am – Walk time for walk access = 4 $\ast$ bicycle time on same relation (see Table 4.2) – Aggregation on alternative travel options between same origin and destination: average of travel times for any travel option: • That is at maximum 16 min slower than fastest travel option AND • That departs later and arrives earlier than an alternative (valid) travel option, both by 3 min or more
Scenario II = Ideal travel time + penalties The penalties simulate preference for (a) Reduced number of transfers, (b) Walk access mode (if comparable) and (c) Higher frequency	– All settings for Scenario I – Transfer penalty: 90 s per transfer – Fixed modal penalty: 3 min for feeder transit, 3 min for bicycle access and zero penalty for walk access[a] – Low frequency penalty: • 25% of time interval between 2 travel options exceeding 6 min PLUS • 25% of time interval between 2 travel options exceeding 18 min[b]

[a] For feeder services, this relates to walking time to the access stop (which is not counted otherwise) and waiting time. For cycling, it relates to parking the bicycle. Both are -like the other penalties-kept at a conservative value, as the aim of the scenario is primarily to model the sensitivity of bicycle–train as compared to other modalities.

[b] For example, the penalty for two subsequent travel options on the same travel relation for a 30-min interval: $25\% \ast (30-6) + 25\% \ast (30\text{–}18) = 9$ min. For a 15-min interval: $25\% \ast (15-6) = 2.25$ min. The penalty simulates how low frequencies can lead to waiting times at the destination due to ‘early arrivals’ which is simulated a progressive effect.

Table 4.4
Average effective total travel speed and travel time from doorstep to an average destination station per access mode for rush hour travel from Amsterdam region.[a]
Source: OpenStreetMap.nl, OpenOV.nl, CBS neighbourhood classification.

Total travel time scenario	Average distance (straight line) (km)	Walk (km/h|time)	Feeder transit (km/h|time)	Bicycle (km/h|time)
Scenario I	39.3	34.1|1′09″	51.6|0′46″	54.6|0′43″
Scenario II	39.3	33.3|1′11″	41.0|0′58″	49.2|0′48″

[a] While it would be of interest to compare these travel times with car travel times, this also adds methodological complexity on e.g. how to compare travel time spent in the car and in transit or how to define the destination of the trip. This is a relevant future research direction. Here the purpose is just to compare bicycle-inclusive transit to transit without bicycles.

train use is on average 26 min faster than walking, or 3 min faster than feeder transit, again, even under favourable conditions for feeder transit under this scenario.

When introducing (conservative) penalties that simulate real-life preferences (Scenario II), feeder transit is affected more than the bicycle–train combination. This appears mostly as a consequence of conditions where the rail system offers higher or incompatible frequencies than (part of the) feeder transit services, or where such higher frequencies are only available at stations not served (favourably) by the transit system from the trip origin. In Scenario II the original, average advantage of feeder transit over walking is almost halved, from 23 min to 13 min. On the other hand, the average time gain of cycling over walking decreases much less, from 26 min to 23 min. Cycling thus results in an average 3 and 10 min advantage over feeder transit services, respective to Scenario I and II, and per single journey (not including return journey) as summarised in Table 4.4.

For illustration of the kind of mechanisms that might explain the aggregated results, but without any implication of representativeness, Table 4.5 shows individual distances and travel times for four travel relations (2 random origin zones towards 2 random rail stations, out of $148 \ast 28 = 4.144$ travel relations aggregated by population weight in Table 4.4 and Table 4.6). For these four travel relations, we see that travel times for cycling are much less affected than travel times for feeder transit. This is because cycling for these travel relations connects to more departing trains that result in roughly equivalent total travel time at different departure/arrival times. This results in higher effective frequencies which lead to lower frequency-related penalties. Also, cycling involves at least one less transfer, and sometimes more, leading to a lower transfer penalty.

4.3.3. Station choice for bicycle–train trips

Further analysis focused on the second characteristic of the bicycle–transit system discussed in Section 3.2; the introduction of non-deterministic station choice. This analysis explores in more detail the general patterns identified in Section 4.2 above. For this purpose, we analysed the number of alternative access stations that could be selected next to the optimal access station (i.e. the station allowing the shortest *total* travel time) per access mode and per destination station. The Amsterdam area has 13 train stations in a 225 km^2 area. Per access mode, we counted the number of stations that could be selected as an alternative access station and add up to (only) 3 min of additional travel time in travelling towards a fixed

Table 4.5
Example travel times for two selected CBS neighbourhood zones to two destination rail stations for walk, transit and cycling access mode, underlying the aggregate results in Table 4.4 and Table 4.6.

Example travel times (in h′mm″) per access mode	Distance (straight) (km)	Walk (Scenario I vs. II)	Feeder transit (Scenario I vs. II)	Bicycle (Scenario I vs. II)
Weesperbuurt (BU3630008) → Alkmaar	32.8	1′24″|1′28″	0′47″|0′53″	0′50″|0′55″
Weesperbuurt → Den Haag CS	50.7	1′31″|1′34″	0′50″|1′00″	0′55″|1′00″
Museumkwartier (BU3630447) → Alkmaar	32.8	1′23″|1′27″	0′52″|1′06″	0′56″|1′01″
Museumkwartier → Den Haag CS	48.7	1′10″|1′12″	0′48″|1′01″	0′45″|0′49″

destination station. A similar exercise was performed for an ‘equivalent time interval’ of 5, 7 and 9 min of additional total travel time. Table 4.6 shows the average amount of station choice per such equivalent time interval, as it applies for Scenario I and II respectively. The table illustrates how the bicycle–train mode on average leads to a significantly augmented station choice compared to walking and feeder transit. This increased station choice without significant increases in travel time allows optimisation relative to other characteristics than travel time (e.g. station access route characteristics; facilities available along the route, at the station and/or on the train; type of train service; number of train transfers, expectations for return journey and others), thus adding multiple dimensions to the situational adaptability, and thus attractiveness, of the integrated system.

5. Conclusion

5.1. Main findings

With this article, we aimed to explore the distinct characteristics of the bicycle–train combination. In Sections 2 and 3 we used the system analytical discourse to map its scope and some of its key characteristics, focusing on what distinguishes bicycle–train trips from stand-alone bicycle or traditional transit use. In Section 4 we illustrated how this conceptual distinctiveness materializes in a real-life context, using the case of the Netherlands and zooming in on the Amsterdam region.

A key observation on the bicycle–train combination is that many of the characteristics of its two subsystems provide for strong synergy when combined in a single trip chain. This synergy generates an integrated transport system that is both fast (because of the train) *and* flexible (because of the bicycle), for short and for long distances, with increased adaptability to individual demand, urban densities and regional conditions of trip origins and destination locations. Cycling performs better for short distances, while trains (used as proxy for high-speed, high-capacity transit) excel at longer distances, introducing a ‘wormhole’ capability to the cycling system in the connection between urban areas located further apart.

5.2. Research themes

By providing a conceptual framework for examining the combined use of bicycles and transit services as a distinct transport mode, the authors hope to both stimulate and facilitate case studies, data collection and knowledge development of this high-potential transport mode. The following topics have been identified as promising research themes:

- *Competition with personal motorised modes.* In this paper, we focused on the relative performance of the bicycle–train mode with stand-alone bicycle and traditional transit modes. In Section 3 we have argued how, conceptually, bicycle–train might be also competitive with individual motorised modes, at least in some contexts. Further illustration and exploration under which conditions this is the case, and how this competitiveness could be increased, is an obvious and urgent direction for future research, with evident implications for a transition to a more sustainable urban transport system.
- *Reciprocal effects to land-use, in particular urbanisation.* We have limited our system analysis of the bicycle–train system to the transport supply side. One external aspect is its reciprocal and positive relationship with urban density and urban proximity. The latter relationship is mainly because (1) bicycles have a rather limited spatial reach and speed but can outperform other modes in dense and diverse urban contexts; (2) high-speed, high-capacity transit is only viable for trans-

Table 4.6
Number of *alternative* access stations within equivalent time interval in excess of shortest possible total travel time (approx. 1 h) to an average destination station per access mode from Amsterdam region (first figure in range refers to Scenario I and the second to Scenario II). *Source*: OpenStreetMap.nl, OpenOV.nl, CBS neighbourhood classification.

Equivalent time interval (min)	Walk (0.25 cycling speed)	Feeder transit (workday, rush hour)	Bicycle (average speed)
⩽3	0.13–0.13	0.54–0.39	0.61–0.58
⩽5	0.21–0.22	0.85–0.65	1.08–1.02
⩽7	0.30–0.31	1.18–0.92	1.55–1.51
⩽9	0.39–0.39	1.42–1.15	2.08–1.95

port corridors offering enough ‘mass’, thus favouring corridors to and from urban areas; (3) bicycle–train offers highly selective accessibility to locations depending on the distance from a ‘train-like’ transit stop. These reciprocal relationships need to be further explored.

- *Applicability of bicycle–train in various spatial settings and/or transit configurations.* We expect considerable impact of spatial settings and public transport configurations on the degree in which synergetic effects (can) occur between the bicycle and the train system and hence applicability of bicycle–train as a concept. Further research can compare characteristics of spatial settings and transit systems in different parts of the world to research to what degree bicycle–train could be a useful concept under such divergent conditions. Framing the bicycle as an integral part of the public transport system, we feel such analysis could also bear further relevance in understanding the operation and optimisation of transit systems on a system level.
- *Design and operation of transit systems.* Sections 2 and 3 showed that the bicycle–train mode has a distinct and dynamic impact on the functioning of the two conceptual subsystems identified within the transit system; ‘trains’ and ‘feeders’. Further research could serve to clarify these relationships and illustrate how this knowledge can be used to optimise transit systems for users, operators and land-use planning under conditions of elevated levels of cycling or where these are strived for. This includes analysis of modal spilt between the traditional transit mode, the stand-alone bicycle mode and the bicycle–train mode with an eye on optimising investments in different types of train services and feeder options. This would also help understand which supply conditions might be needed to unleash the potential of bicycle–train in other, less mature contexts.
- *From the bicycle–train mode to bicycle–train-based mobility.* We discussed and illustrated how the bicycle and the train can constitute a synergetic transport system that provides enhanced, and distinct, travel options. In future research, the reasoning can be extended to how this bicycle–train mode together with its two subsystems (stand-alone bicycle and traditional transit use) allows for distinct bicycle–train-based *mobility practices*. In particular, we expect distinct sensitivity for distance; namely high sensitivity for short distances (bicycle) and reduced sensitivity for long distances (train) as compared to car-based mobility practices, a higher propensity to visit locations of higher ‘urbanity’ when travelling extended distances and implications on activity scheduling and activity chaining.
- *Societal impact.* Mobility has reciprocal relations with a wide and complex variety of other individual user and general societal characteristics (e.g. Van Acker et al., 2010; Allen, 1997). If we accept that the bicycle–train system is a distinctive travel option, we need to develop a better understanding of how it relates to these characteristics. In other words, we need to catch up with insights in the relationships between individual and societal characteristics and modal choice that have been researched for the other, ‘traditional’ transport modes. How do sociological and psychological insights in mobility choices influence the (non-) use of this travel option? What are both the positive and the negative effects of bicycle–train mobility on our societies, who wins and who loses, what are the impacts on our personal health and well-being? (Te Brömmelstroet, 2014)
- *Data availability, case studies and calibration.* To support the abovementioned research themes and in order to calibrate effects as they have been assumed in Section 4, better data availability is a prerequisite. In part, combinations of existing data sources can be used to bridge this gap, if enriched by (perhaps comparatively small) case studies. The illustrative case for Amsterdam region in Section 4 is an initial example of such an approach.

5.3. Final note

This paper illustrated conceptually and in practice how bicycles and (train or train-like) transit services together constitute a distinctive travel option, both fast *and* flexible, for short and for long distances, with increased adaptability to individual demand, urban densities and regional conditions of trip origins and destination locations. These characteristics combined with its relatively low financial, environmental and social cost make it an attractive alternative to other, less performing and less sustainable modes. The bicycle–train system should be considered as a distinct and important component of future metropolitan developments, and correspondingly, its specific dynamics, constraints and opportunities should be acknowledged and explored further. We hope the above conceptualisation in this respect fills a need for both planning practice and the academic community.

Acknowledgements

This research was supported by The Netherlands Organisation for Scientific Research (NWO) as part of the Sustainable Accessibility of the Randstad programme (Grant Number 434-11-012). We would like to thank Bram Fokke for his valuable support in combining the detailed databases used for Section 4, including his development of the OpenFietsModel, Nikola Stalevski for his edit on grammar and style, our colleagues at the University of Amsterdam and the reviewers for their valuable comments and suggestions.

References

Allen, P.M., 1997. Cities and Regions as Self-Organizing Systems: Models of Complexity. Gordon and Breach Science Publishers, Amsterdam.

Bertolini, L., 2012. Integrating mobility and urban development agendas: a manifesto. In disP – Plan. Rev. 188 (1), 16–26.

Bertolini, L., Le Clercq, F., 2003. Urban development without more mobility by car? Lessons from Amsterdam, a multimodal urban region. Environ. Plan. A 35, 575–589. http://dx.doi.org/10.1068/a3592.

Brands, T. et al, 2014. Modelling public transport route choice, with multiple access and egress modes. Transport. Res. Proc. 1, 12–23.

Buehler, R., Pucher, J., 2012. International overview: cycling trends in Western Europe, North America, and Australia. In: Pucher, J., Buehler, R. (Eds.), City Cycling. MIT Press, Cambridge, Mass., London, England, pp. 9–29.

Brons, M., Givoni, M., Rietveld, P., 2009. Access to railway stations and its potential in increasing rail use. Transp. Res. Part A 43, 136–149.

Carstensen, T.A., Ebert, A.-K., 2012. Cycling cultures in Northern Europe: from 'Golden Age' to 'Renaissance'. In: Parkin, J. (Ed.), Cycling and Sustainability, vol. 1. Emerald Group Publishing, Bingley, pp. 23–58.

CBS (2010, 2011, 2012, 2014), Onderzoek Verplaatsingsgedrag in Nederland (OViN), on: <http://statline.cbs.nl>.

CBS (2013), Kerncijfers Wijken en Buurten, on: <http://statline.cbs.nl>.

van de Coevering, P., Kruijf, J. de, Bussche, D., 2014. BikePRINT, presentation for Colloquium Vervoersplanologisch Speurwerk (CVS) 20/21 Nov 2014, on: <http://www.bikeprint.nl/download/bikeprint-cvs-2014-5.pptx> (p. 13) and <http://www.bikeprint.nl> (choose 'snelheid' in the top bar).

Curtis, C., Renne, J., Bertolini, L. (Eds.), 2009. Transit-Oriented Development: Making it Happen. Ashgate, Farnham.

Daniels, R., Mulley, C., 2013. Explaining walking distance to public transport: the dominance of public transport supply. J. Transport Land Use 6 (2), 5–20.

Debrezion, G., Pels, E., Rietveld, P., 2009. Modelling the joint access mode and railway station choice. Transp. Res. Part E 45, 270–283.

Fietsberaad, 2007. Fietsverkeer Nr.15, on: <http://www.fietsberaad.nl/library/fietsverkeer/fietsverkeer_15.pdf>.

Givoni, M., Rietveld, P., 2007. The access journey to the railway station and its role in passengers' satisfaction with rail travel. Transp. Policy 14, 357–365.

Givoni, M., Banister, D., 2010. Integrated Transport: From Policy to Practice. Routledge, London.

Glas, R., 2012. Verkeerslichten voor fietsers in Utrecht – Waar wachten we op, on: <http://www.fietsersbondutrecht.nl> (consulted Sep 2014).

Harms, L. et al, 2014. Spatial and social variations in cycling patterns in a mature cycling country exploring differences and trends. J. Transport Health 1 (4), 232–242.

Heinen, E., van Wee, B., Maat, K., 2010. Commuting by bicycle: an overview of the literature. Transport Rev.: Trans. Transdisciplinary J. 30 (1), 59–96.

Keijer, M.J.N., Rietveld, P., 2000. How do people get to the railway station? The Dutch experience. Transport. Plan. Technol. 23, 215–235.

KiM, 2013. Mobiliteitsbalans 2013, on: <http://www.kimnet.nl>.

KiM, 2014. Mobiliteitsbalans 2014, on: <http://www.kimnet.nl>.

La Paix, L., Geurs, K., 2015. Modelling observed and unobserved factors in cycling to railway stations: application to transit-oriented-developments in the Netherlands. Eur. J. Transport Infrastructure Res. 15 (1), 27–50.

Loo, B., Comtois, C., 2015. Sustainable Railway Futures. Issues and Challenges. Ashgate, Farnham.

Martens, K., 2004. The bicycle as a feedering mode. Transp. Res. Part D 9, 281–294.

Martens, K., 2007. Promoting bicycle and ride, the Dutch experience. Transp. Res. Part A 41, 326–338.

Meyer, M., Miller, E., 2013. Chapter 3: urban travel and transportation system characteristics: a system perspective. In: Urban Transportation Planning: a Decision-Oriented Approach. McGraw Hill, New York.

Ministerie van Verkeer en Waterstaat, 1993. Gecombineerd gebruik van fiets en openbaar vervoer, Verwachte effecten op de vervoerwijzekeuze van optimale fietsbeschikbaarheid in voor- en natransport, Delft.

Ministerie van Verkeer en Waterstaat, 1994. Feiten over het fietsen in Nederland.

Ministerie van Verkeer en Waterstaat, 2000. Feiten over het fietsen in Nederland.

Munafo, S., Christie, D., Vincent-Geslin, S., Kaufmann, V., 2012. Typologie et évolution des logiques de choix modal chez les actifs motorisés urbains, Genève, Lausanne, <http://www.unige.ch/ses/geo/oum/Choix%20modal%20-%20Rapport%20final.pdf>.

Ortúzar, J.de D., Willumsen, L.G., 2011. Modelling Transport. John Wiley and Sons, UK.

OV-bureau Randstad, 2013. Kiezen voor kwaliteit, Aanbevelingen voor beter OV in de Randstad.

PBL (Planbureau voor de Leefomgeving), 2014. Kiezen en Delen, Strategieën voor een betere afstemming tussen verstedelijking en infrastructuur, p. 224.

Pucher, J., Buehler, R., Seinen, M., 2011. Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies. Transp. Res. Part A 45, 451–475.

Pucher, J., Buehler, R., 2012. International overview: cycling trends in Western Europe, North America and Australia. In: Pucher, J., Buehler, R. (Eds.), City Cycling. MIT Press, Cambridge/London, pp. 9–30.

Rietveld, P., 2000. The accessibility of railway stations: the role of the bicycle in the Netherlands. Transp. Res. Part D 5, 71–75.

Te Brömmelstroet, M., 2014. Sometimes you want people to make the right choices for the right reasons: potential perversity and jeopardy of behavioural change campaigns in the mobility domain. J. Transp. Geogr. 39, 141–144.

Tight, M. et al, 2011. Visions for a walking and cycling focussed urban system. J. Transp. Geogr. 19, 1580–1589.

Van Acker, V., Van Wee, B., Witlox, F., 2010. When transport geography meets social psychology: toward a conceptual model of travel behaviour. Transport Rev. 30 (2), 219–240.

Van Hagen, M., 2011. Waiting Experience at Train Stations: Theory and Practice, PhD-thesis University of Twente, <http://doc.utwente.nl/80061/1/>.

Van Nes, R., Hansen, I., Winnips, C., 2014. Potentie multimodaal vervoer in stedelijke regio's, DBR-notitie Nr.10, on: <http://verdus.dbr.nl>.

Wegener, M., Fürst, F., 1999. Land-Use Transport Interaction: State of the Art. Berichte aus dem Institut für Raumplanung 46. Institut für Raumplanung, Universität Dortmund, Dortmund. <http://www.inro.tno.nl/transland/Deliverable%202a.pdf>.