Performance of municipal cycling policies in medium-sized cities in the Netherlands since 2000

Harms, L.; Bertolini, L.; te Brömmelstroet, M.

DOI
10.1080/01441647.2015.1059380

Publication date
2016

Document Version
Final published version

Published in
Transport Reviews

Transport Reviews, 2016
Vol. 36, No. 1, 134–162, http://dx.doi.org/10.1080/01441647.2015.1059380

Performance of Municipal Cycling Policies in Medium-Sized Cities in the Netherlands since 2000

LUCAS HARMS, LUCA BERTOLINI[§] AND
MARCO TE BRÖMMELSTROET

Department of Geography, Planning and International Development Studies, University of Amsterdam, Nieuwe Achtergracht 166, 1018 WV Amsterdam, The Netherlands

(*Received 30 October 2014; revised 27 May 2015; accepted 29 May 2015*)

ABSTRACT *With its high cycling mode share, the Netherlands is often seen as a best practice for cycling policies. However, there is little insight into the drivers behind this phenomenon, specifically which policy interventions increased cycling rates and which did not. The knowledge gap on the effectiveness of cycling policies seriously limits the potential for learning from the Dutch experience. This paper will address this gap, by exploring the performance of Dutch cycling policies in 22 medium-sized cities since 2000. First, the existing ideas regarding the effectiveness of cycling policy are reviewed. These insights structure the exploration of data from Statistics Netherlands and the Dutch Cyclists' Union, complemented with a survey of local policy-makers by means of an explorative data-mining methodology called rough set analysis. Our findings support the following hypotheses regarding the performance of cycling policy in Dutch cities: first of all, the way cycling policy is implemented seems important: setting measurable and verifiable goals, following through with most of the proposed policy interventions, allowing for experimental measures to be explored and showing strong leadership. Second, providing adequate cycling infrastructure and decreasing the attractiveness of car use (e.g. by increasing parking tariffs and increasing the area of paid on-street car parking) seem to be key drivers. Finally, we found that external circumstances, such as demographic trends, seem to influence cycling policy outcomes. Future research is needed to test these hypotheses.*

1. Introduction

The Netherlands is often seen as the gold standard for bicycle use and bicycle policies (e.g. Pucher & Buehler, 2008). Although cycling mode share is significantly higher than in other industrialized countries (and still increasing in urban areas), we know relatively little about the reasons behind this. Some useful knowledge on the general determinants of bike use is available (e.g. Harms, Bertolini, & Te Brommelstroet, 2014; Heinen, Van Wee, & Maat, 2010) but the key open question on the performance of different cycling policy interventions remains: Which strategies significantly contribute to increasing cycling rates and which do not (Handy, Van Wee, & Kroesen, 2014)? The answers can greatly enhance our

[§]Corresponding author. Email: l.bertolini@uva.nl

understanding of what constitutes effective cycling policies and how to develop them, both in the Netherlands and abroad.

In order to address this knowledge gap, this paper examines factors for the effectiveness of policies to improve conditions for cycling within the Dutch context of a mature cycling nation, by examining differences in cycling policies and policy performances between 22 medium-sized Dutch cities for the years since 2000. It is important to note that in the Netherlands much has already been accomplished prior to this period: especially between the early 1970s and 2000 (De La Bruheze & Veraart, 1999; Oldenziel & De La Bruheze, 2011). With the increase in car ownership and car use and the rise in the number of traffic fatalities, cycling safety became a serious issue in the early 1970s. In addition to safety, environmental, liveability and accessibility concerns resulted in many new cycling policy initiatives, as well as the foundation of the Dutch Cycling Union. In addition, Dutch national policy funded many initiatives to extend and improve urban and rural cycling conditions (De La Bruheze & Veraart, 1999). Although it is important to be aware of this historical context, this paper focuses on more recent policy performances in the years since 2000, in which policy efforts mostly aimed at further sustaining and strengthening cycling conditions.

First, we discuss the existing literature on the effectiveness of cycling policies, to identify knowledge gaps. Second, based on the literature review, we identify potential critical success factors. Third, these insights structure the exploration of data from Statistics Netherlands and the Dutch Cyclists' Union, complemented with a survey of local policy-makers and cycling advocates by means of an explorative data-mining methodology called rough set analysis (RSA). The paper closes with a discussion of the findings and methodology review, and an outline of implications for policy-making and further research.

2. Existing Meta-studies on the Performance of Cycling Policy

A review of literature in transport-related journals (in which we searched in academic as well as non-academic databases for evaluations of cycling interventions, successes of cycling policy, performances of cycling policies and effects of cycling policies) shows that academic research on the performance of cycling policy is limited. Furthermore, authors who explored this topic typically focus on evaluating a specific intervention in a specific setting, which makes generalization difficult. Pucher, Dill, and Handy (2010) and others have highlighted the need for a meta-level approach in studying the impacts of different sets of cycling policies in different contexts. Three types of such meta-level studies are commonly utilized:

- Evaluative meta-level studies provide an overview and assess the effectiveness of cycling policy interventions based on an analysis of ex post evaluation studies.
- Quantitative meta-studies associate variations in cycling levels between cities (or countries) with differences in cycling policy and other exogenous context variables, by examining heterogeneous, secondary data sources.
- Qualitative meta-studies provide insights in the performance of cycling policy based on in-depth analyses of case studies, which usually examine many factors.

One of the most comprehensive and most frequently cited evaluative meta-level study is Pucher et al. (2010). Based on 139 cases from both peer-reviewed and non-peer-reviewed research, they conclude that public policy has a crucial role in encouraging cycling, uncovering a positive association between specific interventions (e.g. providing separate cycle lanes or cycle parking facilities) and cycling levels. However, it has been observed that, in most of the underlying studies, the methodology used to evaluate effectiveness is inadequate or inconclusive (Handy et al., 2014). Only a few studies meet the rigorous criteria for ex post evaluation, evaluating behaviour before and after the policy implementation and comparing the outcomes with a control group (Pucher et al., 2010). This makes it almost impossible to determine the direction of causality, that is, whether the policy led to higher bicycle use or higher bicycle use prompted the implementation of the policy (Krizek, Handy, & Forsyth, 2009). Furthermore, in most cases other factors, which may have a greater effect than the explicitly pro-bicycle policy (e.g. social and spatial composition of the population in the city or region), are difficult to control for (Meyer & Miller, 2001, pp. 8–76). In an overview of 25 studies, Yang, Sahlqvist, McMinn, Griffin, and Ogilvie (2010) used more rigorous criteria including only controlled (rather than uncontrolled) comparisons (Yang et al., 2010). They concluded that community-wide promotional activities and improving infrastructure for cycling have the potential to increase cycling by modest amounts. However, the reliability and validity of the results are questionable because in most of the studies the method of adjustment for changes in the control group was not clarified. Another important shortcoming of meta-level evaluation studies is their focus on the effects of individual interventions, such as the provision of dedicated cycling paths or parking facilities. Based on our review of literature, we did not find evaluative studies that explicitly take into account the effects of combined interventions and contextual variables like social and spatial factors. To address these shortcomings, other types of meta-studies assess policy performance through quantitative or qualitative data analysis.

One of the most frequently cited examples of a quantitative meta-study is provided by Rietveld and Daniel (2004). Based on data from the Dutch Cyclists' Union, they apply a regression model to relate inter-municipality variations in bicycle use in the Netherlands to multiple variables, such as physical features (topography and meteorology), population and individual features (size of cities, density of human activity, levels of disposable income and share of immigrants) and bicycle-friendly policies (such as the quantity and quality of infrastructure). In the end, two types of policies come out as most effective: improving the attractiveness of cycling by providing infrastructure for cycling and making competing modes (car use) less attractive (e.g. by increasing parking tariffs). In addition, their findings highlight the importance of social and spatial variations as explanations for bicycle use. For example, cities with low bicycle use[1] have substantially larger than average populations, which can be partly explained by the better quality of public transport systems in larger cities (Harms et al., 2014). They also note that the proportion of immigrants in the population is far above the average in cities with low bicycle use. Although this study and other comparable efforts (see Klinger, Kenworthy, & Lanzendorf, 2013, on urban mobility cultures) do provide valuable insights, they often are snapshots of a particular moment in time. Furthermore, such studies make a correlation between certain attributes and bicycle use, but stop short of providing insight in the why of such a correlation. Due to the lack of comparable data for other periods, such static comparisons between cities or countries tend to view the peculiarities of the different locations as the success factors behind the performance of the policy under scrutiny.

The quantitative studies' predominant focus on a single moment in time can be compensated with qualitative, in-depth case studies that explicitly consider changes over time. One example is Buehler and Pucher's (2011) paper on the implementation and the effects of sustainable transportation policy in Freiburg, Germany. It outlines seven lessons for successful transport policies: controversial policies should be implemented in stages; policy should be flexible and adaptable over time; policies must include both incentives and disincentives; policies should integrate transport and land-use planning; policies should involve citizens; support from higher levels of government is crucial; and policies should focus on the long term and not strive for quick successes (Buehler & Pucher, 2011, pp. 61–62). An important advantage of these case studies is their ability to look at multiple, co-evolving factors affecting policy performance: *hardware* (e.g. provision of infrastructure), *software* (e.g. provision of education and information) and *orgware* (e.g. implementation of policies and the roles of various actors). A disadvantage of case studies is their focus on a particular city or country, which can limit the transferability of the outcomes to other cities or countries with different social, spatial or cultural contexts. Some researchers seek to overcome this limitation by comparing two or more cities or countries (e.g. Pucher et al., 2010).

Existing meta-study findings suggest that the most successful cities employed a coordinated, comprehensive approach, including infrastructure provision, pro-bicycle programmes and car-use restrictions. However, most studies lack a means of systematically evaluating the effects of individual measures, which are usually part of a coordinated city-wide cycling policy, or taking into account the moderating effect of social and spatial context factors (Pucher et al., 2010).

In this paper, we address the limitations of existing meta-studies by jointly examining the changes in policy factors, policy performance and social and spatial context variables for 22 Dutch cities for the period 2000 till 2013. In the next section, we identify policy performance indicators and possible causal factors from academic literature.

3. Policy Inputs, Outputs and Outcomes

3.1. *Policy Outcomes*

As with most policies, the outcomes of cycling policy are difficult to measure. Short-term policy outcomes are often measured by the percentage of trips that are shifted from motorized modes to cycling, while long-term policy outcomes may include changes in automobile ownership or improved safety records. There are numerous other potential outcomes, for instance on health, the local economy and general liveability (Handy et al., 2014), but they are much harder to quantify (Krizek et al., 2009).

Pucher et al. (2010) find that the most widely applied definition of cycling policy outcome is absolute or relative change in the 'number of persons cycling' or 'an increase in bicycle mode share'. Bicycle mode share is also an outcome in many quantitative meta-studies (see Rietveld & Daniel, 2004). Another frequently used outcome indicator is the 'number of bicycle crashes' (often the exposition measure 'fatalities against distance travelled' is used[2]; see Thomas & DeRobertis, 2013). A more indirect outcome indicator gaining favour in recent studies is 'perception of cycling conditions'. Klinger et al. (2013) utilize it to assess mobility cultures, and Fernández-Heredia, Monzon, and Jara-Diaz (2014) use it as an outcome variable for psychosocial factors that shape attitudes towards cycling. Also, Castillo-Manzano and Sánchez-Braza (2013) used it to study effects of anti-car interventions in Seville.

In this paper, we use changes in bicycle mode share, (perceived) changes in bicycle safety and changes in the perception of cycling conditions as policy outcome indicators. The definitions and operationalizations can be consulted in Appendix 1.

3.2. *Policy Inputs and Outputs*

As defined by Methorst et al. (2010), policy outcomes are the results of policy inputs and policy outputs, as well as contextual factors (Figure 1). Policy inputs refer to the institutional conditions and framework in which cycling policy is created ('orgware'). Policy outputs refer to the material provision of infrastructure ('hardware') or immaterial measures such as education, communication and information ('software'). In addition to these policy inputs and outputs, there are a number of relevant socio-spatial context factors that can significantly influence the outcomes of cycling policies. All four categories are discussed in the following.

3.2.1. *Hardware: providing infrastructure*. Hardware are the physical interventions in the (cycling) infrastructure, which increases attractiveness and opportunities for cycling (see Graham-Rowe, Skippon, Gardner, & Abraham, 2011). This includes a wide variety of infrastructure investments, which makes cycling more attractive (the 'pull' factor), including the provision of cycle lanes (facilities with minimal separation between cycling and motor traffic in the form of a painted line or painted asphalt) and cycle paths (physically segregated facilities),

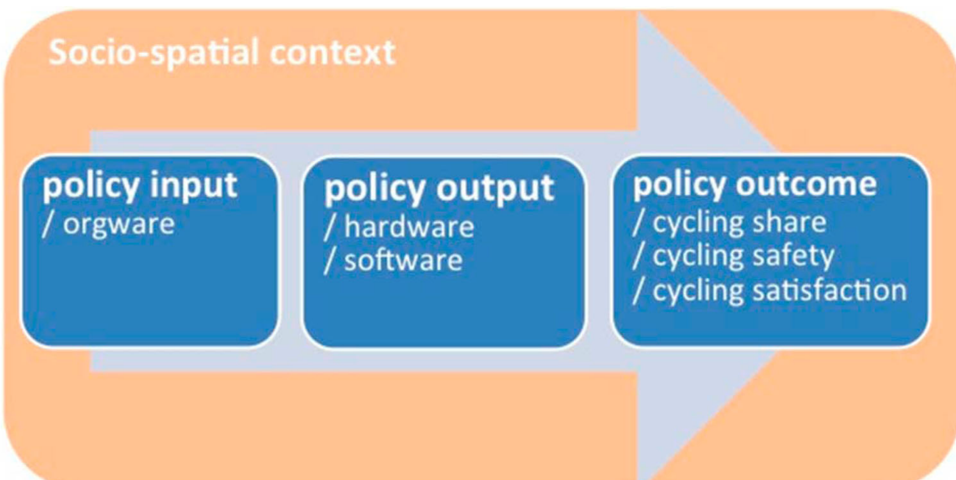

Figure 1. Policy input, policy output and policy outcomes.

alternative cycling routes, intersection improvements and bicycle parking facilities. Substantial evidence — from both aggregate, cross-sectional studies and disaggregate, individual studies — shows that improving both bike infrastructure quantity (e.g. network length) and quality (e.g. segregated cycle paths and new and faster routes) increases cycling levels (Buehler & Pucher, 2012; Forsyth & Krizek, 2010; Pucher et al., 2010; Vernez-Moudon, Lee, & Cheadle, 2005; Winters, Teschke, Davidson, & Kao, 2011). In addition, studies have found that the provision of adequate bike parking at train stations increases transit ridership (Hunt & Abraham, 2007; Noland & Kunreuther, 1995; Pucher et al., 2010; Wardman, Tight, & Page, 2007).

Provision of cycling infrastructure also influences cycling safety. Based on an international comparison of bicycle infrastructure and cycling safety records, Pucher and Dijkstra (2003) conclude that providing segregated facilities for bicyclists improves overall safety.

Other interventions aimed at improving hardware conditions focus on 'pushing' people to cycle by making the alternatives less attractive, for example, schemes that restrict traffic through city centres have shown to impact cycling levels (Furth, 2012; Rietveld & Daniel, 2004). Many European cities have seen the positive effects of limiting car access (narrowing streets, increasing curves and installing bollards) on cycling levels (Pucher et al., 2010; Topp & Pharoah, 1994). In addition, increasing car travel cost and reducing availability of car parking have a demonstrated positive influence on cycling levels (Forsyth & Krizek, 2010; Komanoff & Pucher, 2003; Rietveld & Daniel, 2004).

3.2.2. *Software: providing education, information and communication*. Software factors refer to interventions that are designed to change perceptions, beliefs and attitudes, thereby motivating voluntary change in transportation choices (Castillo-Manzano & Sánchez-Braza, 2013). Bicycle use is usually promoted through education, awareness-raising efforts and individual incentives. Such measures are designed to increase cycling rates through individual psychological changes or through social interactions and social learning (Krizek et al., 2009).

Many studies argue that early education (e.g. bike-to-school programmes) is a necessary condition for establishing cycling skills and habits that youngsters are likely to retain as adults (Pucher & Buehler 2012; Staunton, Hubsmith, & Kallins, 2003). Adult education matters as well, both for cyclists and for drivers. It has the potential to influence both road safety and societal perceptions towards cycling (although this seems to matter most in countries with low cycling levels). For motorists, building awareness of the cyclist's legal rights and responsibilities as well as establishing a firm sense of accountability for their actions towards cyclists is key (Komanoff & Pucher, 2003; Pucher et al., 2010; Schimek, 1996).

According to some studies, providing information and promotional campaigns also affect cycling rates. Brög (1998) shows that major life events like changing residences or jobs are important opportunities for triggering behavioural change with the help of individualized marketing programmes. Based on survey data in Portland, USA, Dill and Mohr (2010) conclude that individualized marketing programmes might be most effective in neighbourhoods with a physical environment more conducive to walking, bicycling and transit. In an overview of several studies, Yang et al. (2010) also found evidence for the effectiveness of individualized marketing to promote cycling.

Finally, there is some evidence for long-term increases in bicycle use following community-wide promotional activities (Yang et al., 2010) as well as large-scale bicycle-use promotions, such as Ciclovias (temporary restrictions of motorized traffic on main streets, in favour of bicyclists, pedestrians and skaters) or bike-to-work days (Rose & Marfurt, 2007; Sarmiento et al., 2010). In addition, some studies refer to the importance of mass media in influencing perception and attitudes towards cycling or health-related activity levels in general (Cavill & Bauman, 2007; Scheepers et al., 2014). European cities have employed various marketing campaigns to increase the number of cyclists, varying from photo contests in Munich to promoting cycling as a way of life in Copenhagen (e.g. 'Copenhagenize'). Unfortunately, these awareness-raising campaigns are rarely systematically evaluated (e.g. Hjuler & Krag, 2013).

3.2.3. *Orgware: organization and implementation of policy.* These factors relate to the institutional and organizational aspects of cycling policy. They describe the roles of the primary actors in cycling policy and the degree of mutual collaboration and coordination. Elements include the involvement of citizens and advocacy groups, the financial means and organizational structure of bicycle policies, the consistency of policy goals and implementation over time, and the role of leadership and powerful actors. These factors have received the least attention in the literature. One of the rare exceptions is a case study focusing on the implementation of sustainable transport policy in Freiburg, Germany (Buehler & Pucher, 2011). Another study is the Pucher, Buehler, and Seinen (2011) meta-evaluation of several North American cities. One of the findings is that comprehensive, long-term planning is crucial for guiding overall strategies to increase cycling (e.g. Freiburg' sustainable transport policy was adopted almost 40 years ago). Flexibility and adaptability are important as well (Buehler & Pucher, 2011). An often debated issue is the involvement of multiple stakeholders, including citizens. On the one hand, there are various historic examples of effective citizen participation in cycling policy, sometimes it is even considered as a driving factor, as was the case in the Netherlands in the 1970s (Jordan, 2013). Pucher et al. (2011) state that cycling advocacy organizations were key — sometimes even more important than the city department of transportation — for promoting cycling in North American cities (see also Schneider, 2005). On the other hand, according to some decision-making studies, citizen participation can also have detrimental effects: for example, according to some sources it can result in added costs, inefficient implementation or even counterproductive decisions (Irvin & Stansbury, 2004). Regardless of the actors involved, cooperation and coordination seem important. Based on a review of planning policy efforts, Stead (2003) concludes that teams working together on varying aspects of urban planning (e.g. transport and land use) are generally considered more effective. Finally, strong leadership by charismatic and/or powerful individuals can also be crucial for the implementation of pro-bike policies and programmes (Portland and London are often mentioned as examples; see also Birk, 2010; Buehler & Pucher, 2011; Mapes, 2009; Wray, 2008). On the other hand, this can make implementation vulnerable for a political change of government (though this is much less a concern within the Dutch context where cycling policies over time have become less political).

3.2.4. *Socio-spatial contextual factors.* The effectiveness of the three categories of policy factors also depends on exogenous factors, like the socio-demographic composition of the population and the spatial structure of the cities and neighbourhoods, like density and diversity of urban functions and topography and meteorology.

Looking at socio-demographics, multiple studies report diverging trends in mode use within countries, notably between the largest cities and rural regions (Goodwin & Van Dender, 2013). Some researchers relate these different dynamics of mode choice in urban and rural areas to the growing numbers of people living in urban areas and the declining share of people living in rural areas (opposite developments in population density) (Harms et al., 2014; Headicar, 2013). The relative composition of the population also seems to be important, for example, the share of students, elderly 'baby-boomers', single-person households and immigrant groups, which have different impacts on cycling rates (Harms et al., 2014; Haustein et al., 2013; Pucher et al., 2011; Rietveld & Daniel, 2004).

Regarding spatial factors, several authors suggest that decreases in distance between destinations, increases in density of the built environment and increases in diversity of urban functions are associated with increases in cycling use (see Heinen et al., 2010; Nielsen, Olafsson, Carstensen, & Skov-Petersen, 2013; Pucher & Buehler, 2012; Rietveld & Daniel, 2004). In addition, there is some evidence of an association between an increase in the attractiveness of the built environment along cycling routes and an increase in cycling levels (Gatersleben & Uzzell, 2007; Jones, 2012; Southworth, 2005).

Other factors mentioned in the literature are topography and meteorology. In their literature review, Heinen et al. (2010) refer to various studies that report that more slopes and hills correspond with lower cycling levels. According to a literature review by Böcker, Dijst, and Prillwitz (2013), most studies find that cycling decreases in the presence of rain (comparing same locations with and without rain), although effects seem not to be linear and equal in all situations.

4. Method and Data

4.1. *Method*

To gather insights into the effectiveness of cycling policy programmes and the factors for success (e.g. hardware, software, orgware and socio-spatial context), we used a meta-study technique called RSA based on data for 22 Dutch cities. This effort builds on an earlier application to detect factors for success of transit-oriented development implementation (Thomas & Bertolini, 2014, in press). RSA is one of many cross-case techniques (Miles & Huberman, 1994) whose aim is to identify patterns and derive common elements from a set of case studies. Cases can then be compared, evaluated and ranked on the basis of well-defined criteria or performance measures (e.g. increase in cycling share), and the critical success factors behind the different results across similar studies can be identified (e.g. differences in cycling infrastructure provisions).

RSA addresses two key difficulties in comparing case studies: cases often contain nominal or categorical values (e.g. differences in the implementation of cycling policies), and a case comparison typically focuses only on a few cases, which makes the use of many statistical methods problematic. In their comparison of completed planning projects, Nijkamp, Van der Burch, and Vindigni (2002, p. 1867) wrote that 'the small sample size and the qualitative (often nominal or non-numerical) information on the performance of such projects' influenced their choice of RSA as a methodological approach. RSA's strength lies in the identification of deterministic rules supported by categorically classified data. Rules take the form of 'when ... then ... ' statements ('decision rules') and reveal under which conditions a certain statement is valid: '*when* these factors (e.g. hardware) are present *then* this performance (e.g. cycling share) is measured'. Although the generation of rules might imply some sort of causality, it is important to note that RSA is first and foremost an inductive research method. It aims at deriving hypotheses for discussion that can be used as a stepping stone for further research that test these hypotheses.

We used ROSE2 software to find a 'satisfactory' set of rules from the codified data matrix (see also Stefanowski, 1998; Walter & Scholz, 2007). We defined the so-called rule strength at 50% (i.e. to be considered the rules should be applicable to at least half of the cases) and the 'rule length' at three (each performance factor — e.g. cycling share — should at most be associated with three factors — e.g. cycling infrastructure provision, children education and political leadership) (see also Thomas & Bertolini, in press).

4.2. *Data*

We used data from various sources to compose a meta-matrix with information on changes in hardware, software, orgware and socio-spatial context factors and performance measures for all Dutch cities with more than 100 000 inhabitants. We excluded the four largest cities from our analyses (Amsterdam, Rotterdam, The Hague and Utrecht) because they are considerably larger and socially and spatially more complex and in many respects less comparable to other Dutch cities.[3]

We collected data for changes in both policy performance (cycling share, perceived cycling safety and cycling perception) and hardware, software, orgware and socio-spatial factors (policy inputs) in all cities from 2000 to 2013.

Our primary source of information was a web-based survey of municipal civil servants responsible for coordinating cycling policy. In addition to policy representatives, we asked local volunteers from the Dutch Cycling Union to participate as well (we aimed to have at least one policy-maker and one Cycling Union representative per city). We recruited respondents directly via email, and phoned them in case they had not responded within two weeks time. The survey consisted of 50 questions about hardware, software and orgware conditions, about performance measures, and about changes in these conditions and measures since 2000. For most of the questions, a five-point Likert scale was used, with response options defined as neutrally and objectively as possible (see Appendix 1). The web survey was accessible online for several weeks in February and March 2014. In only one city, we did not receive a response from a policy-maker. In five cities, we had no replies from local volunteers (78% response rate). Finally, 22 cities met the conditions for data reliability and validity (consistency across comparable variables and data sources).

The information from the web survey was supplemented with three additional sources of data: first, we retrieved mobility-related statistics from the Dutch National Travel Survey (NTS), an extensive and specialized survey on the mobility behaviour of the Dutch population (for a more detailed description, see Harms et al., 2014). Second, demographic and spatial data were collected through Statistics Netherlands (CBS) to derive insights in changes in the social and spatial context of the selected case cities since 2000 (see statline.cbs.nl). Third, we used data collected by the Dutch Cyclists' Union (Fietsersbond), which has been monitoring cycling conditions in most large cities since 2000 in the so-called Cycle Balance. Especially, hardware conditions such as the length and comfort of cycling infrastructure and parking conditions have been monitored. However, not for all cities and not for the whole period of time data are available. For this reason, when available and applicable, the data from the Dutch Cyclists' Union have been primarily used to validate the data from our web survey.

4.3. *Variables*

Regarding the outcome variables, we looked at changes in cycling levels, perceived changes in cycling safety and changes in cycling perception for the period between 2000 and 2013. We defined changes in cycling levels as increases or decreases in the modal share of cycling in total trips. We based this on the answers from the web survey in which respondents had to indicate whether the cycling share had increased or decreased since the year 2000 (based on a five-point Likert scale varying from increased with 5% or more to decreased with 5% or more). To validate reliability of the answers, we checked consistency with trends from the NTS and with answers regarding changes in the absolute amount of cyclists (referring to traffic counts, where and when available). In addition, we differentiated between cities with above-average and increasing cycling shares and cities with below-average and increasing cycling share, based on the data from the NTS (average values for 2010–2013). The average modal share of the 22 cities was 35%.[4]

Regarding changes in cycling safety we distinguished between cities where cyclists face a low and decreasing risk of being killed or severely injured in a crash and cities where traffic safety risks for cyclists are high and not decreasing. For this we used answers from our web survey in which respondents indicated whether cycling traffic safety levels improved or worsened since 2000. They could choose on a five-point Likert scale varying from strongly improved to strongly worsened (referring to the number of crashes relative to distances travelled). Where possible and available we validated answers with data from the Cycle Balance studies from the Dutch Cyclists' Union (which provides changes in levels of cycling safety for most of the cities for the period between 2000/2004 and 2006/2010). We defined changes in cycling traffic safety (as perceived by policy-makers and cycling advocates) as increases or decreases in the probability for cyclists being severely or fatally injured in traffic, defined as the number of fatalities per 100 million kilometres travelled.

Finally, to examine changes in the perception of cycling conditions, we looked at whether media coverage on local cycling conditions became more positive or negative together with changes in the number of citizen's complaints. Both these variables were based on the answers from the web survey in which we asked the respondents to indicate changes based on a five-point Likert scale. A more positive media coverage about cycling and less complaints from citizens is assumed to correspond with a more positive perception towards cycling (see also Scheepers et al., 2014 and Section 3).

For an overview of all input and output variables, their operationalization and sources, see Appendix 1. For an overview of scores of factors and performance measures (i.e. policy outcomes) in the 22 case studies, see Appendix 2.

5. RSA Results

In the following, we present the main RSA outcomes for each of the three individual performance measures and the overall outcome measure (the average of the three individual performance measures), as they relate to different success factors. In the presentation and discussion of the results, we focus on the presence or absence of success factors, the frequency of the factors (often/seldom) and the occurrence of the combination of various factors (Thomas & Bertolini, in press). Due to the small number of cities with stagnating or decreasing cycling rates, we focused our analysis primarily on examining factors explaining improvements in performance.

5.1. *Change in Cycling Share*

Taking changes in cycling share as a performance measure, we differentiated between cities with high and increasing cycling shares and cities with low or medium and increasing cycling share (see also Section 4.3). The analysis resulted in 15 rules (Table 1), which are presented in vertical order in accordance with the RSA outcomes. For every rule, the associated factors are presented horizontally, segregated according to hardware, software, orgware and socio-spatial factors (an empty cell means this type of factor is not applicable to this particular rule). The first rule shows that cities with above-average and increasing cycling shares are characterized by improvements in the hardware factor 'network speed' (travel times of cycling when compared to the car has become much shorter) and progress in the orgware factors 'implementation' (most or all policy measures have been implemented) and 'citizen participation' (often participation or always participation).

The remainder of the rules relate to cities with below-average but increasing cycling shares (Table 1). Within this subset of rules, improvements in *hardware* factors that 'pull' people to cycle are most prevalent. Examples are more cycle lanes (+2.5 km or more), more separation of traffic flows (+2.5 km or more) and an increase in the number of crossings where cyclists have priority over other forms of traffic (6 or more extra crossings). These factors all correlate with an increase in cycling shares. In addition, and often in combination with the abovementioned measures, changes in *hardware* factors that 'push' people away from car use are also important, such as shorter travel times of cycling when compared to the car for local trips, higher parking tariffs (by 10% or more) and extending mandatory parking zones (by 10% or more). Changes related to *orgware* factors are also mentioned often in the generated rules and most of them appear in combination with *hardware* factors. The most prevalent *orgware* improvements that correlate with increasing cycling shares are a coherent and integrated organization of local cycling policy, high levels of flexibility and adaptability of cycling policy, and involvement of actors other than the policy-makers. *Software* factors seem to be less important as only one factor was noted: to implement at least some marketing campaigns aimed at increasing cycling shares. Finally, in many of the rules exogenous context factors are also prevalent; demographic changes in particular

Table 1. Rules[a] for performance measure 'cycling share'

Rule #	Hardware factors	Software factors	Orgware factors	Socio-spatial context factors
1[b]	Network speed => 4		Implementation => 4 & citizen participation => 4	
2			Institutional arrangement => 4	Destinations within 3 km (practitioners) = 1
3	Network facilities (inner urban areas) => 4		Involvement of actors = 3	
4	Network safety = > 4			Share of one-person households = 5
5				Share of one-person households = 5 & Share of non-western immigrants = 4
6	Network safety => 4		Policy consistency <= 2	Number of households = 4
7	Network quantity => 4 OR Network safety => 4 OR Network facilities (train stations) => 4 & Car parking tariffs => 4		Involvement of actors = 3	
8	Network quantity => 4 & Network safety => 4 OR Network facilities (train stations) => 4		Involvement of actors = 3	
9	Network safety => 4 & Network facilities (train stations) => 4		Involvement of actors = 3	
10	Network facilities (train stations) => 4 & Network speed => 4 OR Area size with parking regulation => 4	Marketing campaigns =< 2		
11	Network safety => 4 & Network quality (alternative cycling routes) => 4 & Car parking tariffs => 4			Population size = 4
12	Car parking tariffs => 4			Number of households = 4 & Share of one-person households = 5
13	Network safety => 4 & Network facilities (inner urban areas OR train stations) => 4 & Area size with parking regulation => 4			Population size = 4
14	Network safety => 4			Population size = 4 & Number of households = 4

(*Continued*)

Table 1. Continued

Rule #	Hardware factors	Software factors	Orgware factors	Socio-spatial context factors
15	Network facilities (train stations) => 4			Number of households = 4 & Share of one-person households = 5

[a]The RSA rules were generated by the ROSE2 software on the basis of the meta-matrix for 22 Dutch case study cities with 'cycling share' as performance indicator. The subsequent rules are presented in vertical order in accordance with the RSA outcomes. For every rule the associated factors are presented horizontally, segregated according to hardware, software, orgware and socio-spatial factors (e.g. an empty cell means this type of factor is not applicable to this particular rule). The first rule, for example, should be interpreted as follows: *when* improvements are present in the hardware factor 'network speed' (Network speed => 4, meaning travel times of cycling when compared to the car has become much shorter) and *when* progress is present in the orgware factors 'implementation' (Implementation => 4, meaning most or all policy measures have been implemented) and 'citizen participation' (Citizen participation => 4, meaning often participation or always participation) *then* increases in cycling shares are measured. For an elaborate description of presented factors and their values, see Appendix 1.
[b]This the only rule applicable to cities with above-average (+35%) and increasing cycling shares. The remainder of rules are applicable to cities with below-average (<35%) but increasing cycling shares.

are associated with higher cycling levels, such as increases in the number of inhabitants (+5%), households (+10%) and one-person households (+3%).

5.2. *Change in Cycling Safety (as Perceived by Policy-Makers and Cycling Advocates)*

We make a distinction between cities where cyclists face a low and decreasing risk of being killed in a crash (as perceived by policy-makers and cycling advocated) and cities were traffic safety risks for cyclists are neither low nor decreasing (as perceived by policy-makers and cycling advocates; see also Section 4.3). Based on this definition of perceived changes in cycling safety, the RSA generated 14 rules (Table 2). In all the generated rules, improvements in *hardware* factors that either 'pull' or 'push' people towards cycling are important, possibly implying an indirect effect on cycling safety (as perceived by policy-makers and cycling advocates) via an overall increase in the number of cyclists. This refers to the so-called safety in numbers phenomenon, in which more cyclists are associated with falling fatality rates (Jacobsen, 2003; Pucher & Buehler, 2008). Most frequently associated with increasing safety levels (as perceived by policy-makers and cycling advocates) are extensions of regulated on-street car parking zones (by 10% or more) and/or an increase in on-street car parking rates (by 10% or more). Other frequently mentioned factors are an increase in the number of crossings where cyclists have priority over other forms of traffic (6 or more extra crossings), more kilometres of paved cycling lanes (+2.5 km or more) and an increase in the separation of traffic flows (+2.5 km or more). Improvements in *orgware* factors that are associated with increasing safety levels (as perceived by policy-makers and cycling advocates) include successful implementation of most or all of the proposed policy interventions, a high degree of policy adaptability and strong leadership. Noted *software* factors are the local authorities' significant

Table 2. Rules[a] for performance measure 'perceived cycling safety'

Rule #	Hardware factors	Software factors	Orgware factors	Socio-spatial context factors
Cities with perceived increases in levels of cycling safety are characterized by:				
1	Network quantity (alternative cycling routes) => 4			Share of one-person households = 5
2	Network quality (paved) => 4			Share of students = 4
3	Network safety => 4			Share of one-person households = 5
4				Share of one-person households = 5 & Share of students = 4
5	Network facilities (train stations) => 4 & Car parking tariffs => 4	Educating children => 4	Implementation => 4	Share of one-person households = 5
6	Area size with parking regulation => 4 & Car parking tariffs => 4 OR Network safety => 4 OR Network facilities (train stations) => 4		Policyconsistency <= 2	
7	Car parking tariffs => 4 & Area size with parking regulation => 4		Leadership => 4	Share of one-person households = 5
8	Network quality (paved) => 4 & Area size with parking regulation => 4 OR Network facilities (train stations) => 4		Leadership => 4	
9	Network safety => 4 & Area size with parking regulation => 4	Marketing campaigns =< 2		
10	Network facilities (inner urban areas) => 4 OR Network facilities (train stations) => 4	Marketing campaigns =< 2		Share of one-person households = 5
11	Area size with parking regulation => 4 & Network safety => 4 OR Network facilities (inner urban areas) => 4	Educating children => 4		
12	Area size with parking regulation => 4 OR Network quantity => 4 OR Network facilities (inner urban areas) => 4	Educating children => 4		Share of one-person households = 5
13	Car parking tariffs => 4 & Network facilities (inner urban areas) => 4			Share of one-person households = 5

(*Continued*)

Table 2. Continued

Rule #	Hardware factors	Software factors	Orgware factors	Socio-spatial context factors
14	Network safety => 4 & Area size with parking regulation => 4 & Network quality (alternative cycling routes) => 4 OR Network quality (paved) => 4 OR Network facilities (inner urban areas) => 4 OR Network facilities (train stations) => 4			Population size = 4

[a]The RSA rules were generated by the ROSE2 software on the basis of the meta-matrix for 22 Dutch case study cities with 'perceived cycling safety' as performance indicator. The subsequent rules are presented in vertical order (rule number 1–14) in accordance with the RSA outcomes. For every rule the associated factors are presented horizontally, segregated according to hardware, software, orgware and socio-spatial factors (e.g. an empty cell means this type of factor is not applicable to this particular rule). The first rule, for example, should be interpreted as follows: *when* improvements are present in the hardware factor 'network quantity' (alternative cycling routes => 4, meaning more than 2.5 km of alternative cycling routes being added) and *when* change is present in the socio-spatial context factor 'share of one-person households' (=5, meaning increased with 3% or more) *then* perceived improvements in cycling safety are measured. For an elaborate description of presented factors and their values, see Appendix 1.

role in organizing cycling education for children and their (albeit small) role in general awareness-raising campaigns to stimulate cycling use. Finally, regarding the *context*, some demographic factors seem to be associated with an increase in safety levels (as perceived by policy-makers and cycling advocates) as well, especially the growing number of one-person households (+3%), inhabitants (+5%) and also an increase in the number of students (+1%). These three socio-demographic factors all corresponds with more cyclists (e.g. Harms et al., 2014), which again relates to the existing evidence that more cyclists are associated with falling fatality rates (Jacobsen, 2003).

If we consider the combination of factors, it is interesting to note that changes in *orgware* and *software* factors are often associated with changes in *hardware* factors. Also, changes in *hardware* factors (both 'push' and 'pull') in combination with *context* (i.e. demographic) changes have notable effects. In other words, the RSA indicates that in many cases *hardware* is a prerequisite for increased cycling safety (as perceived by policy-makers and cycling advocates). However, it should be noted that hardware by itself was not a sufficient factor for increasing safety (as perceived by policy-makers and cycling advocates) — it had a positive effect only in combination with other factors.

5.3. *Change in Cycling Perception*

To examine changes in the perception of cycling conditions, we looked at whether the media coverage on local cycling conditions has become more positive or more negative and we looked at changes in the number of complaints from citizens (see also Section 4.3). Based on this definition of changes in cycling perception, the RSA generated six rules (Table 3). The most prevalent outcomes are improvements in

Table 3. Rules[a] for performance measure 'cycling perception'

Rule #	Hardware factors	Software factors	Orgware factors	Socio-spatial contextfactors
Cities with improving levels of cycling perception are characterized by:				
1			Citizen participation => 4	Share of non-western immigrants = 4
2	Network quality (alternative cycling routes) => 4	Educating adults <= 2		
3	Area size with parking regulation => 4 OR Network facilities (train stations) => 4		Implementation => 4 & Citizen participation => 4	
4	Area size with parking regulation => 4		Allowing scope for experiments => 4 & Citizen participation => 4	Share of non-western immigrants = 4
5	Area size with parking regulation => 4		Leadership => 4 & Citizen participation => 4	
6	Area size with parking regulation => 4 & Network quality (alternative cycling routes) => 4 & Network facilities (train stations) => 4	Educating adults <= 2		Share of non-western immigrants = 4

[a]The RSA rules were generated by the ROSE2 software on the basis of the meta-matrix for 22 Dutch case study cities with 'cycling perception' as performance indicator. The subsequent rules are presented in vertical order (rule number 1–6) in accordance with the RSA outcomes. For every rule the associated factors are presented horizontally, segregated according to hardware, software, orgware and socio-spatial factors (e.g. an empty cell means this type of factor is not applicable to this particular rule). The first rule, for example, should be interpreted as follows: *when* improvements are present in the orgware factor 'citizen participation' (=>4, meaning often or always participation of civilians in policy formulation and implementation) and *when* change is present in the socio-spatial context factor 'share of non-western immigrants' (=4, meaning increased with 1% or more) *then* improvements in cycling perception are measured. For an elaborate description of presented factors and their values, see Appendix 1.

hardware (both 'pull' and 'push') or *orgware* factors. Most frequently associated with the improvement of cycling perception is the extension of paid on-street car parking areas (by 10% or more). Other *hardware* factors include the increase in the supply of bicycle parking facilities at station areas (by 10% or more) and in the kilometres of cycling routes being separated from motorized traffic (by 2.5 km or more). *Orgware* factors associated with improved cycling perceptions are high levels of citizen participation, a successful implementation of most or all of the proposed interventions, strong leadership and more opportunities for experimental interventions (such as temporary closures of main streets to motorized traffic). From all *software* factors only one is related to the improvement of the perception of cycling conditions, namely the role of the local government in educating adult motorists and cyclists. The contribution of social and spatial context factors seems to be limited as well. The one noteworthy exception is a growth in the number of non-western migrants (+1%), but the exact meaning of this finding is difficult to interpret.

6. Conclusions and Discussion

This study analysed the performance of cycling policy in a mature cycling country by identifying critical success factors. Based on existing research, we first developed a framework on the effectiveness of cycling policy. Subsequently we used an RSA to identify potential causal success factors that explain systematic differences in cycling policy performance in 22 medium-sized Dutch cities for the period between 2000 and 2013.

6.1. *Effectiveness of Bicycle Policy Programmes*

Based on our analyses, we arrived at the following hypotheses regarding the effectiveness of cycling policy in medium-sized Dutch cities:

(1) Improving quantity and quality of cycling infrastructure *while at the same time* decreasing attractiveness of car use (e.g. by increasing parking tariffs and extending the area of paid on-street car parking) seem to be critical success factors for increasing cycling shares, improving cycling safety (as perceived by policy-makers and cycling advocates) and improving the perception of cycling. The importance of both 'push' and 'pull' factors is in accordance with findings from Pucher et al. (2010), Forsyth and Krizek (2010) and Rietveld and Daniel (2004).
(2) Improving the organization and implementation of cycling policies seems to positively impact the effectiveness of cycling policy, specifically: formulating and implementing interventions that can be measured and monitored, a high degree of adaptability of policy, allowing opportunities for experimental measures, high levels of citizen participation and the presence of strong leaders (like mayors or other public figures). Although with a different focus on transport policy (e.g. transit-oriented development), the importance of 'orgware' factors have recently been stressed as well by Thomas and Bertolini (in press).
(3) There seems not to be overwhelming evidence for a positive impact of education and information dissemination tools on the effectiveness of cycling policy. The one exception is education for children, which is associated with improvements in perceived cycling safety (which has been noted in other studies as well, including Pucher & Buehler, 2012). It is important to note that the lack of evidence on the part of software factors might be attributed partly to low frequency. In other words, since 2000 only a few Dutch cities have invested in software measures, and therefore, these factors are virtually absent in the RSA outcomes. It might also be an indication for the maturity of Dutch cycling culture: for example, education and information are less relevant because the majority of people already know how to cycle.
(4) External 'context' circumstances seem to impact the effectiveness of cycling policy as well, especially demographic changes such as increases in total population, number of households, proportion of one-person households and students. Most of these context factors have been noted by other studies as well, including Harms et al. (2014).

6.2. *Discussion and Future Research Needs*

For cycling policy-makers in the Netherlands and abroad and for those who are interested in learning how the Netherlands sustained and strengthened its high shares of cycling in the period since 2000, our findings offer important lessons. Consistent with findings of earlier meta-evaluations (mostly notably Pucher et al., 2010), our results underline that there is no 'silver bullet' for designing effective cycling policy and that policy effectiveness in the Netherlands depended on a combination of various factors. At the same time, and going beyond previous analyses, we have identified what the most crucial of these factors might be, and in which combinations they should be applied for maximum effect. Altogether the rules we identified amount to a set of well-defined hypotheses that can be further tested, both in the Netherlands and in other comparable contexts (such as some Danish and German cities).

The RSA technique allowed us to develop a better understanding of the performance of urban mobility policies in the context of different data sources with vast quality differences. RSA can work with such a variety of data, combining quantitative with qualitative input enabling us to go beyond the limitations of existing studies on effectiveness of cycling policies. It is a very useful addition to the toolbox of social scientists and as such we advise to use it in other studies. It also raises an important point for cycling policy-makers. There is need to develop a much more disciplined way to structurally collect data on a variety of bicycle-related indicators. There is a lot of room for improvement and it is crucial for our understanding of how to promote cycling that these improvements are made.

To further test the validity of our findings, future research could focus on improving some of the intrinsic limitations of our research design. Since the focus of this research was on generating insights and new hypotheses, it could work with secondary data and self-reporting for several variables (the best available data thus far). More rigorous tests of the found relations call for more structured data gathering on especially these variables.

This future research can broadly go into two distinct but complementary design directions. First, it can enhance our understanding of how the variables interact in reality, by increasing context sensitivity. Deeper case studies with longitudinal data collection and stated and revealed preferences of cyclists come to mind, as well as content analyses of policy documents. But also (international) large-*N* studies, given that there is enough valid data, can serve this purpose. Second, it can use our hypotheses to test the causality of these in a much more controlled environment. Although it seems impossible to test cycling policy intervention in a sterile laboratory set-up, a *living lab* approach (e.g. Liedtke, Welfens, Rohn, & Nordmann, 2012) can still try to identify more or less comparable contexts that allow for a control versus treatment test of policy interventions.

Acknowledgements

We would like to thank three anonymous reviewers, the journal Editor, our colleagues at the University of Amsterdam for their input and useful comments on earlier drafts, and Quinn Kelly, who contributed to the review of literature during his visit to Amsterdam as part of his Summer Internship from Cornell University. We are also grateful to all of the participants of our web survey who provided a rich insight into the effectiveness of cycling policy. Finally, we would like to thank the participants of our community of research and practice (the so-called Fietscommunity), which was facilitated by the CROW Fietsberaad and the VERDUS research funding programme, and which brought together the knowledge from practitioners and researchers in multiple sessions with approximately 70 participants.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was supported by The Netherlands Organisation for Scientific Research (NWO) as part of the Sustainable Accessibility of the Randstad programme.

Notes

1. Note that low bicycle use according to Dutch standards is still substantially higher than almost all other cities and towns in other parts of the world.
2. Although the exposition measure 'fatalities against distance travelled' is most used in the literature and in national statistics, the alternative measure 'fatalities against time spent in traffic' or 'fatalities against number of trips' is often more appropriate when comparing different modes of transport.
3. Note that in the international context even the largest Dutch cities are rather modest in size, but they are considerably larger and therefore not comparable to the Dutch cities in our sample, which are (in alphabetical order): Alkmaar, Almere, Amersfoort, Arnhem, Breda, Delft, Den Bosch, Deventer, Dordrecht, Eindhoven, Emmen, Enschede, Groningen, Haarlem, Leeuwarden, Leiden, Maastricht, Nijmegen, Tilburg, Venlo, Zaanstad and Zwolle.
4. Although this demarcation between below and above average is extremely high according to international standards (below-average values are still substantially higher than almost all other cities and towns in other parts of the world), 35% is the average value for the sample of Dutch cities and we only used it to further distinguish between cities with overall increasing cycling levels. Note that in our sample most cities with above-average cycling levels, the cycling share is 40% or higher, whereas the lowest cycling levels are around 20%.

References

Birk, M. (2010). *Joyride: Pedaling toward a healthier planet*. Portland, OR: Cadence Press.

Böcker, L., Dijst, M., & Prillwitz, J. (2013). Impact of everyday weather on individual daily travel behaviours in perspective: A literature review. *Transport Reviews*, *33*(1), 71–91.

Brög, W. (1998). Individualized marketing: Implications for transportation demand management. *Transportation Research Record*, *1618*, 116–121.

Buehler, R., & Pucher, J. (2011). Sustainable transport in Freiburg: Lessons from Germany's environmental capital. *International Journal of Sustainable Transportation*, *5*(1), 43–70.

Buehler, R., & Pucher, J. (2012). Cycling to work in 90 large American cities: New evidence on the role of bike paths and lanes. *Transportation*, *39*(2), 409–432.

Castillo-Manzano, J., & Sánchez-Braza, A. (2013). Can anyone hate the bicycle? The hunt for an optimal local transportation policy to encourage bicycle usage. *Environmental Politics*, *22*(6), 1010–1028.

Cavill, N., & Bauman, A. (2007). Changing the way people think about health-enhancing physical activity: Do mass media campaigns have a role? *Journal of Sports Sciences*, *22*(8), 771–790.

De La Bruheze, A., & Veraart, F. (1999). *Fietsverkeer in praktijk en beleid in de twintigste eeuw*. Ministerie van Verkeer en Waterstaat, Rijkswaterstaat.

Dill, J., & Mohr, C. (2010). *Long term evaluation of individualized marketing programs for travel demand management*. Portland, OR: Oregon Transportation Research and Education Consortium (OTREC-RR-10-08).

Fernández-Heredia, A., Monzon, A., & Jara-Diaz, S. (2014). Understanding cyclists' perceptions, keys for a successful bicycle promotion. *Transportation Research Part A: Policy and Practice*, *63*, 1–11.

Forsyth, A., & Krizek, K. (2010). Promoting walking and bicycling: Assessing the evidence to assist planners. *Built Environment*, *36*(4), 429–446.

Furth, P. (2012). Bicycling infrastructure for mass cycling: A transatlantic comparison. In J. Pucher & R. Buehler (Eds.), *City cycling* (pp. 105–139). Cambridge, MA: MIT Press.

Gatersleben, B., & Uzzell, D. (2007). Affective appraisals of the daily commute: Comparing perceptions of drivers, cyclist, walkers, and users of public transport. *Environment and Behaviour*, *39*(5), 416–431.

Goodwin, P., & Van Dender, K. (2013). 'Peak car' — themes and issues. *Transport Reviews: A Transnational Transdisciplinary Journal*, *33*(3), 243–254.

Graham-Rowe, E., Skippon, S., Gardner, B., & Abraham, C. (2011). Can we reduce car use and, if so, how? A review of available evidence. *Transportation Research Part A*, *45*, 401–418.

Handy, S., Van Wee, B., & Kroesen, M. (2014). Promoting cycling for transport: Research needs and challenges. *Transport Reviews: A Transnational Transdisciplinary Journal*, *34*(1), 4–24.

Harms, L., Bertolini, L., & Te Brommelstroet, M. (2014). Spatial and social variations in cycling patterns in a mature cycling country; exploring differences and trends. *Journal of Transport & Health*, *1*(4), 232–242.

Haustein, S., Siren, A., Framke, E., Bell, D., Pokriefke, E., Alauzet, A., . . . O'Neill, D. (2013). *Demographic change and transport*. CONSOL, European Commission — Directorate-General for Mobility and Transport.

Headicar, P. (2013). The changing spatial distribution of the population in England: Its nature and significance for 'Peak Car'. *Transport Reviews: A Transnational Transdisciplinary Journal*, *33*(3), 310–324.

Heinen, E., Van Wee, B., & Maat, K. (2010). Commuting by bicycle: An overview of the literature. *Transport Reviews*, *30*(1), 59–96.

Hjuler, S., & Krag, T. (2013). *Measuring the impact of bicycle marketing messages*. Proceedings from the annual transport conference at Aalborg University, Aalborg, DK.

Hunt, J., & Abraham, J. (2007). Influences on bicycle use. *Transportation*, *34*(2), 453–470.

Irvin, R., & Stansbury, J. (2004). Citizen participation in decision making: Is it worth the effort? *Public Administration Review*, *64*(1), 55–65.

Jacobsen, P. (2003). Safety in numbers: More walkers and bicyclists, safer walking and bicycling. *Injury Prevention*, *9*, 205–209.

Jones, T. (2012). Getting the British back on bicycles — the effects of urban traffic-free paths on everyday cycling. *Transport Policy*, *20*, 138–149.

Jordan, P. (2013). *In the city of bikes: The story of the Amsterdam cyclist*. New York, NY: HarperCollins.

Klinger, T., Kenworthy, J., & Lanzendorf, M. (2013). Dimensions of urban mobility cultures — a comparison of German cities. *Journal of Transport Geography*, *31*, 18–29.

Komanoff, C., & Pucher, J. (2003). Bicycle transport in the US: Recent trends and policies. In R. Tolley (Ed.), *Sustainable transport: Planning for walking and cycling in urban environments* (pp. 450–464). Cambridge: Woodhead Publishing.

Krizek, K., Handy, S., & Forsyth, A. (2009). Explaining changes in walking and bicycling behavior: Challenges for transportation research. *Environment and Planning B: Planning and Design*, *36*(4), 725–740.

Liedtke, C., Welfens, M. J., Rohn, H., & Nordmann, J. (2012). Living lab: User-driven innovation for sustainability. *International Journal of Sustainability in Higher Education*, *13*, 106–118.

Mapes, J. (2009). *Pedaling revolution: How cyclists are changing American cities*. Corvallis: Oregon State University Press.

Methorst, R., Monterde, I., Bort, H., Risser, R., Sauter, D., Tight, M., & Walker, J. (Eds.). (2010). *COST 358 pedestrians' quality needs, PQN final report* (European Cooperation in Science and Technology). Cheltenham: Walk21.

Meyer, M., & Miller, E. (2001). *Urban transportation planning: A decision-oriented approach* (2nd ed.). New York, NY: McGraw-Hill.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook*. Thousand Oaks, CA: Sage Publications.

Nielsen, T., Olafsson, A., Carstensen, T., & Skov-Petersen, H. (2013). Environmental correlates of cycling: Evaluating urban form and locations effects based on Danish micro-data. *Transportation Research Part D: Transport and Environment*, *22*, 40–44.

Nijkamp, P., Van der Burch, M., & Vindigni, G. (2002). A comparative institutional evaluation of public–private partnerships in Dutch urban land-use and revitalization projects. *Urban Studies*, *39*, 1865–1880.

Noland, R., & Kunreuther, H. (1995). Short-run and long-run policies for increasing bicycle transportation for daily commuter trips. *Transport Policy*, *2* (1), 67–79.

Oldenziel, R., & De La Bruheze, A. A. (2011). Contested spaces; bicycle lanes in urban Europe, 1900–1995. *Transfers*, *1*(2), 29–49.

Pucher, J., & Buehler, R. (2008). Making cycling irresistible: Lessons from the Netherlands, Denmark and Germany. *Transport Reviews*, *28*(4), 495–528.

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

Pucher, J., Buehler, R., & Seinen, M. (2011). Bicycling renaissance in North America? An update and re-appraisal of cycling trends and policies. *Transportation Research Part A*, *45*, 451–475.

Pucher, J., & Dijkstra, L. (2003). Promoting safe walking and cycling to improve public health: Lessons from the Netherlands and Germany. *American Journal of Public Health*, *93*(9), 1509–1516.

Pucher, J., Dill, J., & Handy, S. (2010). Infrastructure, programs, and policies to increase bicycling: An international review. *Preventive Medicine*, *50*, S106–S125.

Rietveld, P., & Daniel, V. (2004). Determinants of bicycle use: Do municipal policies matter? *Transportation Research Part A: Policy and Practice*, *38*, 531–550.

Rose, G., & Marfurt, H. (2007). Travel behaviour change impacts of a major ride to work day event. *Transportation Research Part A*, *41*, 351–364.

Sarmiento, O., Torres, A., Jacoby, E., Pratt, M., Schmid, T., & Stierling, G. (2010). The Ciclovía-Recreativa: A mass recreational program with looming public health potential. *Journal Physical Activity & Health*, *7*, S163–S180.

Scheepers, C., Wendel-Vos, G., Den Broeder, J., Van Kempen, E., Van Wesemael, E., & Schuit, A. (2014). Shifting from car to active transport: A systematic review of the effectiveness of interventions. *Transportation Research Part A: Policy and Practice*, *70*, 264–280.

Schimek, P. (1996). *The dilemmas of bicycle planning*. Cambridge, MA: U.S. Department of Transportation: Volpe National Transportation Systems Center.

Schneider, R. (2005). *TCRP synthesis 62 integration of bicycles and transit*. Washington, DC: Transportation Research Board.

Southworth, M. (2005). Designing the walkable city. *Journal of Urban Planning and Development*, *131*(4), 246–257.

Staunton, C., Hubsmith, D., & Kallins, W. (2003). Promoting safe walking and biking to school: The Marin County success story. *American Journal of Public Health*, *93*, 1431–1434.

Stead, D. (2003, November 16–18). *Institutional arrangements: Experiences and lessons from Denmark, England and Germany.* Discussion paper presented at the WHO/UNECE workshop on sustainable and healthy urban transport and planning, Nicosia.

Stefanowski, J. (1998). On rough set based approaches to induction of decision rules. In A. Skowron & L. Polkowski (Eds.), *Rough sets in data mining and knowledge discovery* (Vol. 1, pp. 500–529). Heidelberg: Physica.

Thomas, B., & DeRobertis, M. (2013). The safety of urban cycle tracks: A review of the literature. *Accident Analysis & Prevention*, *52*, 219–227.

Thomas, R., & Bertolini, L. (2014). Beyond the case study dilemma in urban planning: Using a meta-matrix to distil critical success factors in transit oriented development. *Urban Policy and Research*, *32*(2), 219–237.

Thomas, R., & Bertolini, L. (in press). Defining critical success factors in TOD implementation using rough set analysis. *Journal of Transport and Land Use Planning*.

Topp, H., & Pharoah, T. (1994). Car-free city centers. *Transportation*, *21*, 231–247.

Vernez-Moudon, A., Lee, C., & Cheadle, A. (2005). Cycling and the built environment, a US perspective. *Transportation Research Part D: Transport and Environment*, *10*, 245–261.

Walter, A., & Scholz, R. (2007). Critical success conditions of collaborative methods: A comparative evaluation of transport planning projects. *Transportation*, *34*(2), 195–212.

Wardman, M., Tight, M., & Page, M. (2007). Factors influencing the propensity to cycle to work. *Transportation Research Part A*, *41*, 339–350.

Winters, M., Teschke, K., Davidson, G., & Kao, D. (2011). Motivators and deterrents of bicycling: Comparing influences on decisions to ride. *Transportation*, *38*(1), 153–168.

Wray, H. (2008). *Pedal power: The quiet rise of the bicycle in American public life*. Boulder, CO: Paradigm.

Yang, L., Sahlqvist, S., McMinn, A., Griffin, S., & Ogilvie, D. (2010). Interventions to promote cycling: Systematic review. *British Medical Journal*, *341*(7778), 870.

Appendix 1. Overview of variables used as input for the RSA

Table A1. Variables used in RSA

Name	Description	Classes	Source(s)
Performance measures			
Change in cycling share	Increase or decrease in the share of cycling (as % of all trips)	1 = cycling share declined with 2% or more; 2 = cycling share changed with ±2%; 3 = cycling share <35% and increased with 2% or more and 4 = cycling share ≥35% and increased with 2% or more	NTS, Dutch Cycling Union and web survey
Change in cycling safety (as perceived by policy-makers and cycling advocates)	Increase or decrease in the chance for cyclists to be injured (as perceived by policy-makers and cycling advocates)	1 = risk for cyclists to be severely of fatally injured per 100 million kilometres travelled has increased; 2 = no change in cycling safety levels and 3 = risk for cyclists to be severely or fatally injured per 100 million kilometres travelled has decreased	Dutch Cycling Union and web survey
Change in cycling perception	Framing of news about cycling conditions in the (local) media	1 = local media coverage has become more negative and number of complaints has increased; 2 = local media coverage varied and number of complaints stabilized or increased and 3 = local media coverage has become more positive and number of complaints has stabilized or decreased	Web survey
Hardware — pull conditions			
Change in network quantity	Added length of segregated cycling paths (in kms); added length of alternative cycling routes (in kms)	1 = 0 km; 2 = 0.1–1.0 km; 3 = 1.1–2.5 km; 4 = 2.6–5.0 km and 5 = 5 km or more	Dutch Cycling Union and web survey
Change in network quality	Improvements of existing cycling paths: added length being paved (in kms)	1 = 0 km; 2 = 0.1–1.0 km; 3 = 1.1–2.5 km; 4 = 2.6–5.0 km and 5 = 5 km or more	Dutch Cycling Union and web survey
Change in network safety	Added crossings where cyclists have right of way	1 = 0; 2 = 1 or 2; 3 = 3 till 5; 4 = 6 till 9 and 5 = 10 or more	Dutch Cycling Union and web survey

(*Continued*)

Table A1. Continued

Name	Description	Classes	Source(s)
Change in network facilities (parking)	Change in number of parking facilities at train stations and inner urban areas	1 = decreased; 2 = stayed the same; 3 = increased between 1% and 10%; 4 = increased between 11% and 25% and 5 = increased with 25% or more	Dutch Cycling Union and web survey
Hardware — push conditions			
Change in network speed	Travel times of cycling when compared to the car for local trips (ratio of travel times as a measure for competitiveness of cycling)	1 = has become much slower; 2 = has become slower; 3 = stayed the same; 4 = has become faster and 5 = has become much faster	Dutch Cycling Union and web survey
Change in car parking tariffs	Change in on-street car parking tariffs	1 = rates decreased; 2 = rates stayed the same; 3 = rates increased with 1–10%; 4 = rates increased by 10–25% and 5 = rates increased with more than 25%	Web survey
Change in area size with parking regulation	Change in area with on-street car parking tariffs	1 = area decreased; 2 = area stayed the same; 3 = area increased with 1–10%; 4 = area increased by 10–25% and 5 = area increased with more than 25%	Web survey
Software conditions			
Educating children	Role of local government in learning or improving cycling skills and habits, and awareness of traffic rules and logic	1 = no role; 2 = very small role; 3 = small role; 4 = large role and 5 = very large role	Web survey
Educating adults	Role of local government in educating motorists and cyclists	1 = no role; 2 = very small role; 3 = small role; 4 = large role and 5 = very large role	Web survey
Marketing campaigns with incentive	Frequency of campaigns aiming to stimulate cycling use with incentive	1 = no campaigns; 2 = one or few general campaigns; 3 = many general campaigns; 4 = one or a few targeted (or individualized) campaigns and 5 = many targeted (or individualized) campaigns	Web survey

(*Continued*)

Table A1. Continued

Name	Description	Classes	Source(s)
Marketing campaigns without incentive	Frequency of campaigns aiming to stimulate cycling use with incentive	1 = no campaigns; 2 = one or few general campaigns; 3 = many general campaigns; 4 = one or a few targeted (or individualized) campaigns and 5 = many targeted (or individualized) campaigns	Web survey
Orgware conditions			
Formulation of policy goals	Whether or not cycling policy goals have been formulated which are measurable and have been monitored	1 = no goals formulated; 2 = goals formulated; 3 = measurable goals formulated; 4 = measurable goals formulated which are monitored and 5 = measurable goals formulated which are monitored and which is acted upon	Web survey
Implementation of policy measures	Whether or not cycling policy has been implemented	1 = (almost) nothing has been implemented; 2 = few has been implemented; 3 = roughly half has been implemented; 4 = most have been implemented and 5 = all policy measures have been implemented	Web survey
Financial sources for cycling policy	Sources of budget for cycling policy: structural budgets, maintenance budgets, general infra budgets, neighbourhood budgets, national or regional budgets, free budgets, other	1 = not applicable; 2 = for a very small part; 3 = for a small part; 4 = for a large part and 5 = for a very large part	Web survey
Opportunities for experimental measures	Such as temporary closures of main streets to motorized traffic	1 = no opportunities for experimental measures; 2 = almost no opportunities for experimental measures; 3 = sometimes opportunities for experimental measures; 4 = often opportunities for experimental measures and 5 = always opportunities for experimental measures	Web survey

(*Continued*)

Table A1. Continued

Name	Description	Classes	Source(s)
Policy consistency and adaptability	Frequency of adaptations in (goals/measures of) cycling policy	1 = very much adaptations; 2 = many adaptations; 3 = not much but also not few adaptations; 4 = few adaptations and 5 = no adaptations	Web survey
Institutional arrangement of cycling policy	Level of integration and collaboration with other policy domains	1 = all parts of cycling policy is spread over a variety of departments; 2 = most parts of cycling policy is spread over a variety of departments; 3 = a part of cycling policy is spread over a variety of departments; 4 = most parts of cycling policy are organized integrally and 5 = all parts of cycling policy is organized integrally	Web survey
Involvement of actors outside policy arena	Actors being involved with cycling policy: employees, schools and educational institutions; sport and recreational organizations; retailers; (public) transport organizations; cycling advocacy organizations; residents' groups, others	1 = not involved; 2 = little involved; 3 = not much but also no little involved; 4 = much involved and 5 = very much involved	Web survey
Relationship between actors inside and outside policy arena	Communication between actors, collaboration, clarity of roles and tasks	1 = none; 2 = hardly; 3 = average; 4 = good/clear and 5 = very good/clear	Web survey
Levels of citizen participation	Participation of civilians in policy formulation and implementation	1 = no participation; 2 = little participation; 3 = sometimes participation; 4 = often participation and 5 = always participation	Web survey
Strong leadership	Role of authoritative actors (like mayors)	1 = no role; 2 = almost no role; 3 = sometimes a role; 4 = often a role and 5 = always a role	Web survey
Socio-demographics			
Population size	Change in the number of inhabitants	1 = decline with −2% or more; 2 = between −2% and +2%; 3 = between +2% and +5%; 4 = between +5% and +10% and 5 = +10% or more	Statistics Netherlands (CBS)

(*Continued*)

Table A1. Continued

Name	Description	Classes	Source(s)
Number of households	Change in the number of households	1 = decline; 2 = between 0% and +5%; 3 = between +6% and +10%; 4 = between +11% and 15% and 5 = 16% or more	Statistics Netherlands (CBS)
Composition of households	Change in share of one-person households, non-western minorities and students	1 = decreased with −2% or more; 2 = decreased with −1%; 3 = no increase/decrease; 4 = increased with +1% and 5 = increased with +3% or more	Statistics Netherlands (CBS)
Spatial characteristics			
Number of destinations within 3 km	Change in the number of potential destinations within 3 km for practitioners, primary schools, supermarkets and restaurants	1 = decreased with −6% or more; 2 = decreased with −3% to −5%; 3 = increased/decreased between −2% and +2%; 4 = increased with +3% to +5% and 5 = increased with +6% or more	Statistics Netherlands (CBS)

Appendix 2. Overview of scores of factors and performance measures in the 22 case studies

Table A2. Variable scores per city

	Alkmaar	Almere	Amersfoort	Arnhem	Breda	Delft	Deventer	Dordrecht	Eindhoven	Emmen	Enschede	Groningen	Haarlem	Leeuwarden	Leiden	Maastricht	Nijmegen	Den Bosch	Tilburg	Venlo	Zaanstad	Zwolle
Indicators for success																						
Change in cycling share	4	3	4	3	3	4	2	2	3	1	1	4	4	2	4	3	3	3	2	3	3	4
Change in cycling safety (as perceived by policy-makers and cycling advocates)	1	3	3	2	2	3	2	3	3	3	1	1	3	2	1	2	3	3	2	2	3	1
Change in cycling perception	2	2	2	2	1	2	3	1	3	1	2	2	1	3	3	3	3	1	1	2	2	3
Hardware — pull conditions																						
Change in network quantity — segregated cycling paths	1	1	5	4	4	4	3	5	5	5	5	5	5	4	5		2	5	5	5	5	4
Change in network quantity — alternative cycling routes	1	5	3	3	4	4	3	1	3	4	4	3	5	4	3	3	5	5	1	4	5	5
Change in network quality — paved cycling paths	4	5	5	3	5	4	5	5	5	5	5	5	5	3	3		5	3	5	5	5	5
Change in network safety	4	5	5	5	5	4	3	3	5	3	1	5	5	5	3		4	5	3	4	4	5
Change in network facilities — parking at train stations	3	5	3	5	4	5	4	5	5	2	5	5	5	4	4	4	5	5		5	5	5
Change in network facilities — parking in inner urban areas	3	5	3	5	4	5	3	5	5	3	5	5	5	5	3	4	5	5	4	5	5	5
Hardware — push conditions																						
Change in network speed	4	4	2	4	4	4	3	3	4	3	4	4	3	3	4	3	5	5	3	4	3	4

(*Continued*)

Table A2. Continued

	Alkmaar	Almere	Amersfoort	Arnhem	Breda	Delft	Deventer	Dordrecht	Eindhoven	Emmen	Enschede	Groningen	Haarlem	Leeuwarden	Leiden	Maastricht	Nijmegen	Den Bosch	Tilburg	Venlo	Zaanstad	Zwolle
Change in car parking tariffs	5	4	4	5	4	5	5	5	4	3	5	4	3	3	3	3	4	4	3	4	4	4
Change in area size with parking regulation	4	4	4	4	3	5	5	4	4	2	4	3	3	3	4	4	5	5	4	3	4	4
Software conditions																						
Educating children	3	4	3	3	4	4	4	5	4	4	5	4	3	4	4	3	3	5	3	4	4	4
Educating adults	3	2	3	2	4	2	3	5	3	3	4	4	1	4	3	3	2	4	3	3	3	4
Marketing campaigns with incentive	2	1	1	2	3	2	2	1	2	4	1	1		1	1	4	1	1	2	4	4	3
Marketing campaigns without incentive	3	1	2	2	5	3	2	2	5	3	3	3		1	1	5	2	3	5	4	3	5
Orgware conditions																						
Formulation of policy goals	2	3	2	1	3	5	3	3	5	2	5	4	3	5	5	2	3	4	3	2	4	4
Implementation of policy measures	4	4	3	3	3	5	3	4	4	3	3	4	3	4	4	4	3	4	4	4	3	4
Financial sources for cycling policy	1	1	2	3	3	2	1	1	1	1	2	2	1	2	2	3	2	2	2	2	3	1
Allowing opportunities for experimental measures	3	2	3	3	4	4	3	1	4	3	4	4	2	3	3	4	4	4	3	2	3	4
Policy consistency and adaptability	4	3	4	3	2	2	3	3	2	3	2	2	3	2	3	3	2	2	2	3	2	4
Institutional arrangement of cycling policy	4	4	3	4	4	4	2	3	5	2	4	4	4	4	2	4	4	3	4	4	3	3
Involvement of actors outside policy arena	3	2	2	3	4	4	3	2	3	3	4	2	4	3	2	4	2	3	2	3	3	4

(*Continued*)

Table A2. Continued

	Alkmaar	Almere	Amersfoort	Arnhem	Breda	Delft	Deventer	Dordrecht	Eindhoven	Emmen	Enschede	Groningen	Haarlem	Leeuwarden	Leiden	Maastricht	Nijmegen	Den Bosch	Tilburg	Venlo	Zaanstad	Zwolle
Relationship between actors inside and outside policy arena	2	3	3	3	4	2	2	4	4	2	4	3	2	2	2	3	4	4	2	2	2	4
Levels of citizen participation	4	2	3	3	3	3	3	3	4	4	4	4	4	3	4	4	5	2	2	3	4	4
Strong leadership	3	3	3	4	4	4	3	5	4	3	3	4	4	3	4	4	4	3	5	3	4	3
Socio-demographics																						
Population size	2	5	5	4	4	4	5	2	4	3	4	4	2	4	2	2	4	4	4	3	4	5
Number of households	3	5	5	3	4	3	5	2	4	3	4	4	2	3	2	2	4	4	4	3	4	4
Composition of households — share of one-person households	5	5	4	5	5	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	4
Composition of households — share of non-western minorities	2	5	5	5	4	3	3	3	4	3	5	4	5	3	5	4	4	4	4	3	5	4
Composition of households — share of students	4	4	4	4	5	5	3	4	5	4	5	5	4	4	5	5	5	4	5	3	4	4
Spatial characteristics																						
Number of destinations within 3 km — practitioners	1	3	1	1	1	2	1	1	3	2	3	3	1	3	2	1	1	3	1	1	3	3
Number of destinations within 3 km — primary schools	4	1	4	3	3	2	5	1	3	2	3	3	2	1	3	1	3	2	2	1	4	2
Number of destinations within 3 km — supermarkets	5	5	5	4	5	5	3	3	4	5	3	5	5	5	3	5	4	4	5	5	5	5
Number of destinations within 3 km — restaurants	5	2	5	5	5	5	2	4	5	5	5	5	3	3	3	5	5	4	4	3	5	4