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The Interplay between Land Use, Travel Behaviour and Attitudes: a Quest for Causality

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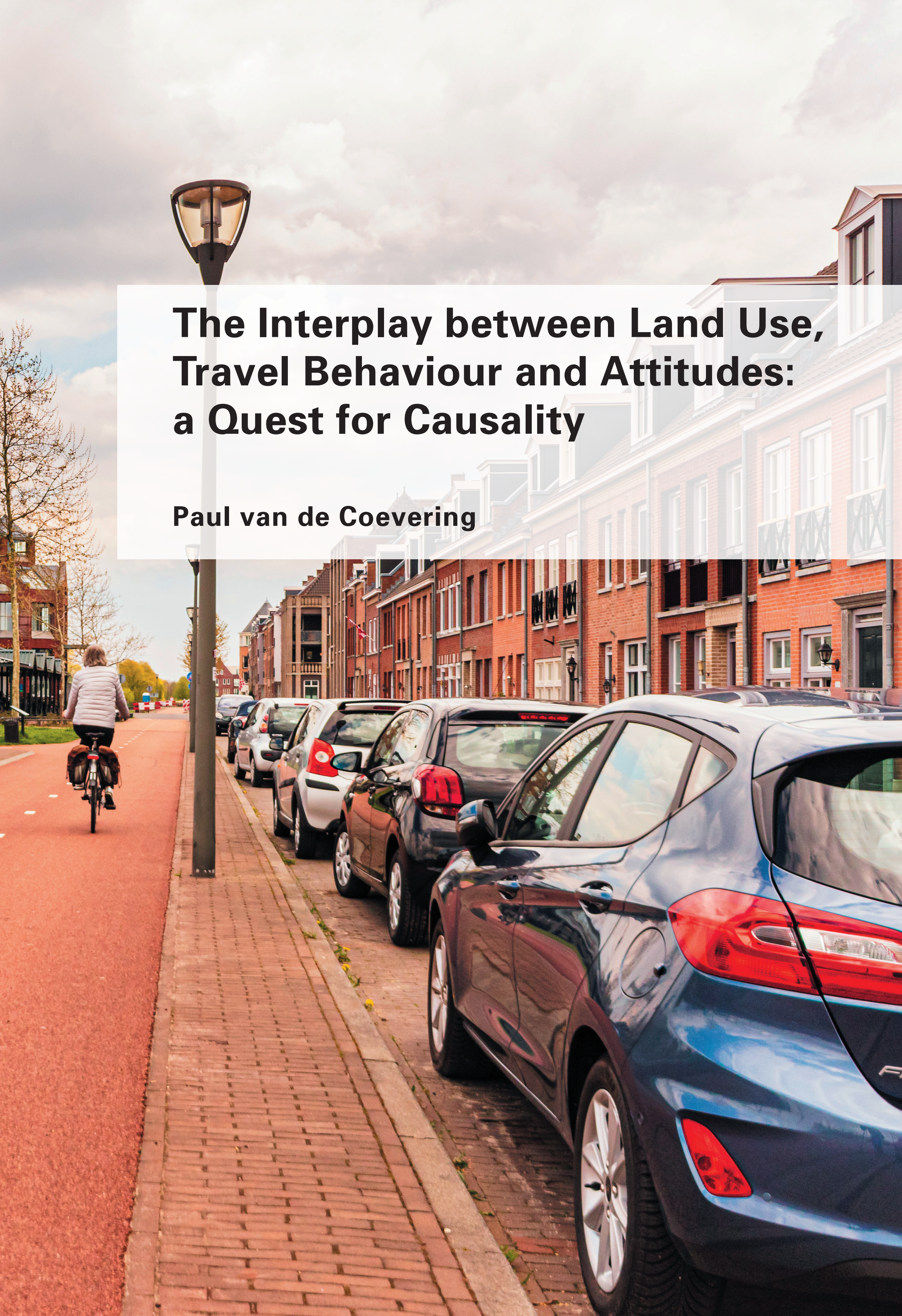

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Paul van de Coevering

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Dedicated to
Thomas, Wessel and Kik

Preface

The cover illustration gives an impression of Brandevoort, a suburb that was planned during the Vinex era (Fourth Memorandum on Spatial Planning Extra). These typical compact Dutch-style suburbs are a compromise between sustainable spatial planning goals and consumers' preferences for suburban and rural housing. Brandevoort was developed on former agricultural land. The same land where I used to work on a farm during my early teenage years. While working there I never imagined that my future profession would be related to spatial planning and travel behaviour. When it comes to people's everyday travel behaviour, the changes that I witnessed from my early childhood until today are impressive. My parents worked in close proximity to our home and they mostly used the bicycle for commuting. Like most families in our neighbourhood, we owned one car that was used for shopping, social visits, and leisure. As kids we used to play football, tennis, and other games in the streets of our residential area. Nowadays, people commute longer distances and dual-income, two-car households have become the new standard. The flexibility and speed of the car provided many additional opportunities for self-fulfilment, individual freedom, and personal development. But this also comes at a cost. The street where we used to play as children has become a place for mobility and in particular for parked cars. Opportunities to play outdoors are now restricted to dedicated playgrounds. This coincides with a lack of physical activity of children. Moreover, parking pressure has degraded the quality of the public realm. Over the years, the balance between the individual need for accessibility and the collective need for liveable and attractive living environments has become my key interest and expertise.

My interest in the interaction between land use and travel behaviour started long before my PhD. After I finished secondary school, I started studying traffic engineering at Breda University of Applied Sciences (BUas; NHTV at the time). Meanwhile, I always liked urban planning. Therefore, I continued studying Urban Geography at the University of Utrecht. The first time that I specifically focused on the interaction between land use and travel behaviour was during my master's thesis. It involved an aggregate analysis of land use and travel behaviour patterns in world cities based on the famous work *Cities and Automobile Dependency* by Kenworthy and Newman (1989). This also resulted in my first academic journal paper together with my supervisor Tim Schwanen who currently works at the University of Oxford.

During my master's thesis, I worked at a consultancy firm that focused on public transport. Shortly after finishing my master's studies at Utrecht University, I switched jobs and started working at the Netherlands Environmental Assessment Agency. Here I contributed to many studies at the interface of land use and transportation. In terms of subject matter content, this was very challenging, and I worked together with very talented researchers that enabled me to further develop my research and writing skills. As much as I liked conducting research, I also loved to share this knowledge with other people and organisations in the field. After a couple of years, I started giving guest lectures at BUas. It was only then that I realised how much I enjoyed teaching and coaching students. I never planned to go back to my roots, but only a couple of years later, I started as a lecturer and researcher at the place that I had left as a student many years earlier. The interaction between applied science, industry and lecturing has intrigued me ever since.
My plans for a PhD started to take shape at the end of 2011. I met Kees Maat during a conference on land use and transport and we talked about the current challenges in this field and opportunities for future research. Shortly after, I joined the OTB Research Institute for the Built Environment. Alongside, I continued working at BUas. Although challenging, the combination of the PhD research in Delft with applied science and lecturing in Breda created many interesting synergies. While my PhD involved the Dutch context, I also coordinated the minor in Urban Retrofitting that focused on reducing car dependency in the North American context. This enabled a smooth transfer of my newly acquired knowledge to education. Moreover, analysing the sprawled cities and related car dependency made it hard to believe for me that the built environment does not influence people's travel behaviour. During my time in Breda, there was also substantial growth in the volume and impact of applied research. This led to my appointment as a professor (*lector*) of Urban Intelligence. Together with my team and students, I connect academic knowledge to everyday challenges in the field of urban planning and transportation. My ambition is to further strengthen these links in the future and contribute to the development of liveable and sustainable cities with excellent multimodal accessibility.
Due to the long part-time nature of my PhD, many people contributed in some way to this thesis. First, many thanks go to my supervisors Kees Maat and Bert van Wee. The detailed and thorough feedback from Kees together with strategic and fundamental feedback from Bert has been an ideal combination. I enjoyed our meetings and learned a lot from our conversations. Thank you both for all your assistance and also for your patience in times when research progress was slow. Furthermore, I would like to thank all my former OTB colleagues and colleagues from TU Delft. In particular thanks to Wendy Bohte for sharing all her knowledge and data. In addition thanks to Maarten Kroesen (TU Delft) for his advice and assistance in statistical modelling and Filip Biljecki (NUS) for processing the GPS data. Also thanks to Dena Kasraian (TU/e) with whom I shared an office. Even though I was only present for one or two days a week, I really enjoyed our talks about our PhDs and the drinks in the coffee corner. Also thanks to the traffic engineers from the municipalities of Amersfoort, Veenendaal and Zeewolde and the field workers for their assistance with the questionnaires and the GPS surveys. In addition, I would also like to thank all my colleagues at BUas for their support during my PhD. In addition to my work environment, the support of my family and friends has been very important to me. Thanks to everyone for their support and patience during my long journey. In particular, I would like to thank my parents Cees and Leny van de Coevering. They always encouraged me to study and get the best out of myself. I could never have finished my PhD without you.

Paul van de Coevering

May 2021

Content

Chapter 1: Introduction

"Time, space, and causality are only metaphors of knowledge, with which we explain things to ourselves." (Friedrich Nietzsche)

1.1 Background

Hunger for accessibility

For centuries humanity has strived and succeeded to increase the speeds of travel and explore new horizons. New transportation modes such as the train, bicycle, the car and planes dramatically reduced travel resistance in terms of travel time and costs. This brought us freedom and flexibility which in turn resulted in a significant increase in personal mobility. Up until the 18th century, people's mobility was mostly restricted to their place of residence and rarely exceeded three kilometres a day (Harms, 2008). In 2017 people in the Netherlands on average travelled approximately 10,000 km, more than 29 km a day (CBS, 2019). In addition to physical movement, the last decades saw the rise of information and communication technologies (ICT). Nowadays high-speed internet is available almost everywhere and anytime for many people. Hence, our level of accessibility and the opportunities to engage in activities and interact with other people have never been higher before.

Yet, our need for more accessibility and mobility seems endless. Over the course of decades, road network congestion costs have risen and now for the EU alone, these costs reach a staggering 270.6 billion Euros (EC, 2019). To ease this congestion, there are constant calls for adding more road capacity or developing faster or more efficient systems such as self-driving cars or the hyperloop. The question is if this will help solve our accessibility problems or if it will fuel even higher demand for travel. According to the theory of constant travel time budgets (Zahavi and Ryan, 1980; Mokhtarian and Chen, 2004), people on average spend between 60 and 75 minutes of travel per day. If travel time budgets would be completely constant, road expansions and introducing faster modes of travel would only lead to travelling longer distances and not to saving travel time. Research shows that, despite individual differences in travel time budgets related to for instance sociodemographics, income and the built environment, the theory to a certain degree holds on an aggregate level (Mokhtarian and Chen, 2004; Van Wee, 2011). Research into induced demand, the phenomenon that contributes to increased traffic volumes after the expansion of road infrastructure also partially supports this notion (Cervero, 2002; Hymel, 2019). The famous slogan "you cannot build your way out of congestion" is associated with this phenomenon of induced demand (Ladd, 2019).

People's tendency to increase their travel distance when faster travel options are provided raises the question of whether more mobility is, in itself, a good thing. When do the additional costs exceed the additional benefits of travel? In conventional transport analysis, travel is considered as a derived demand for scheduling activities and as something to be minimised. In other words, "time is money" and therefore, congestion and other forms of delay are economically harmful (Banister, 2008). However, people do not just aim to minimise travel time. Instead, they trade off travel times against utilities derived at potential activity locations (Maat et al., 2005). Therefore, people not always choose the closest locations for activities. This may be because of a unique feature of the activity location that brings additional utility, or out of curiosity and the desire to explore new locations for shopping or leisure for instance. In addition to the utility derived at activity locations, people also derive utility during the travel itself. On the one hand, this can be related to performing additional activities while travelling such as making phone calls, reading, listening to music and increasingly also connecting to other people and businesses via the internet. In other words, travel time is transitioning more and more from 'wasted time' to potentially 'productive time'. In addition, people can intrinsically enjoy the act of travelling which can be a moment to relax and be on your own or to enjoy the environment. For instance, people tend to prefer a short commute over completely eliminating commute time (Mokhtarian and Salomon, 2001).

In addition to the question of whether more mobility is in itself a good thing, mobility also has important externalities. In 2017, the transport sector produced 27% of the total greenhouse emissions in the EU-28 and the total emission level was 28% higher compared to 1990 levels (EEA, 2020a). In addition, the transport sector is the most important contributor to noise pollution and an important contributor to air pollution. This is despite the fact that vehicle air pollution per kilometre has decreased significantly during the last decades (EEA, 2020b). Transport infrastructure also consumes a significant amount of space. In highly motorised North American cities, roads account for up to 30% of the total surface. In Western European cities, space consumption for roads varies between 15% and 20% (Rodrigue, 2020). Often large roads and railways result in visual blight which significantly reduces the perceived quality of the surrounding public realm. They can also act as a physical or psychological barrier that limits interaction between people and divides communities, also known as community severance. The reduced quality of the public realm and community severance can, in turn, lead to social exclusion if it limits interaction on the street or limits people to walk or use the bicycle to visit facilities or acquaintances (Anciaes and Jones, 2020). There is also an important link with health as excessive car use is associated with sedentary lifestyles and the lack of physical activity. Research shows that a shift from car use to active forms of mobility could deliver considerable health benefits due to the increase in physical activity (Rabl and de Nazelle, 2012; Mueller et al., 2015).

While the increase in mobility options brings us freedom and flexibility, it also leads to increasingly complex travel and activity patterns. People's daily and weekly urban systems are not restricted to their own core city anymore. Instead, there is a tendency from local interaction towards interaction in personalised networks at increasingly longer distances (Bertolini, 2009; Sheller and Urry, 2005). This transition makes us more dependent on systems that facilitate physical and virtual connectivity. To combine work with household maintenance activities (e.g. shopping and visits to services), and discretionary activities (leisure, sport) flexibility and speed are key and the car has been able to meet these demands best. The reliance on the car to schedule our complex activity patterns also made us more dependent on the car (Jeekel, 2013). This car dependency is strengthened by the interaction between transportation and land use.

The cyclical interaction between transportation and land use

The fact that transportation and land use are interrelated seems to make sense intuitively as the spatial distribution of activity locations for work, shopping, education, sport, leisure etc. influences the type and amount of transportation necessary for people to meet their daily needs. Vice versa, the accessibility provided by the transportation system determines the geographical area within which persons can undertake activities, also referred to as action space (Dijst, 1999). Moreover, to a certain extent accessibility also affects the location of new urban developments (Kasraian, 2017). Wegener and Fürst (1999) integrated these mechanisms and the role of other determinants in the 'land use transport feedback cycle' (Figure 1.1). The cyclical process highlights the two-way interaction between land use and transportation. At the top of the cycle, an expansion of the infrastructure network is considered. This increases capacity on the network and improves accessibility. Locations that profit from increases in accessibility become more interesting for developers and attract new land use developments. As people's action spaces expand, they consider more distant locations, either existing or newly developed, to engage in activities. These changes in the distribution of destination location choices affect travel behaviour patterns which results in the need for additional infrastructure investments.

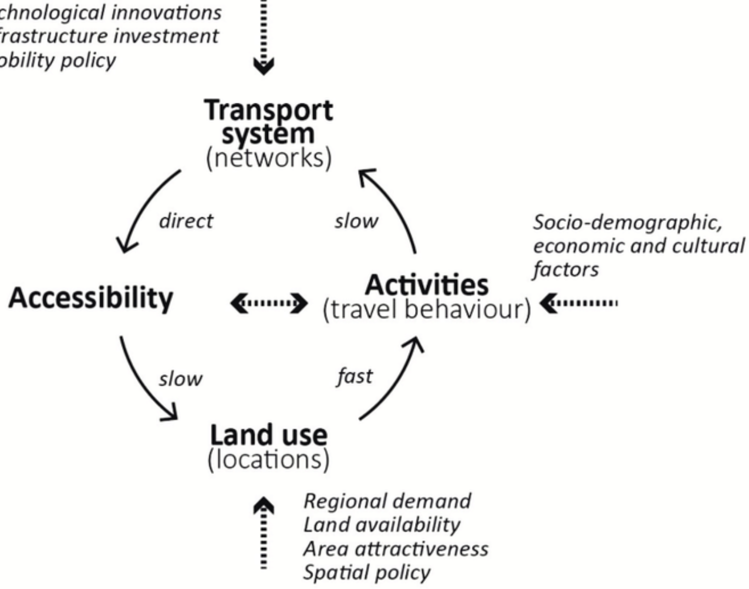

Figure1.1. Transport land use feedback cycle (Wegener & Fürst, 1999; adapted by Bertolini, 2012).

Land use policies to influence travel behaviour

So, in this car era, the cyclical two-way interaction between land use and transportation seems to weaken the position of sustainable travel modes. But what happens when we intervene in this process by restricting the suburban sprawl and promoting more compact and dense environments? So instead of promoting speed and consequently a further detachment between people's activity spaces, proximity is improved which enables people to visit activity spaces closer to their residential location. In combination with good facilities for walking, cycling and public transport this could promote sustainable travel behaviour and reduce the need for car use. This has been the motivation for many land use policies and concepts that aimed to influence travel behaviour. In Europe, these policies were introduced primarily at the level of city regions, in the form of compact city policies with, among other things, growth boundaries, specific targets for infill projects and compact and mixed-use developments. In Northern America, there was a stronger focus on the neighbourhood level in the form of the New Urbanism and Smart Growth. In both Europe and Northern America new developments have been concentrated around public transport nodes (Transit Oriented Development).

Although many regional and local governments embrace the integration between transportation and land use in their policies, the practical implementation proved to be not an easy task. In many cases, these policies turned out to be paper tigers having little effect on suburban sprawl and car dependency. Nevertheless, several cities have successfully integrated land use and transportation policies. Famous examples are Copenhagen (the 'finger plan'), Stockholm, Curitiba and Zurich (Kennedy et al., 2005; Knowles, 2012). The Netherlands has a rich and unique planning tradition where the central government used to have a strong influence on regional and local land use planning. A key element of these policies was the regional focus on the level of urban regions. Over the years different concepts have been applied including 'Concentrated Deconcentration', 'Growth Centres' and 'Compact City' policies (Maat, 2009). Although these policies differ, they all aimed to develop mixed-use, compact developments that are conducive to public transport, cycling and walking. Dutch land use policies also included dedicated location policies for business and retail. These policies aimed to develop labour-intensive businesses in proximity to public transportation stations and to restrict the development of peripheral retail locations. Although these policies have decentralised during the last decades, these policies have been influencing the Dutch urban development patterns for decades.

Land use and transportation interaction: the quest for causality

In the light of this consensus regarding the influence of land use on transportation in policies, it is somewhat surprising that the evidence for the effectiveness of these policies is mixed at best. Early aggregate studies in this field found strong correlations between the density of city regions and car dependency (e.g. Newman and Kenworthy, 1989). In addition to density, the impact of other land use characteristics has been studied. These have been popularly coined as the 5 Ds, density, diversity, design, destination accessibility and distance to public transport (Cervero and Kockelman, 1997; Ewing & Cervero, 2001). Academic studies support the notion that land use characteristics are associated with travel behaviour: building mixed-use dense environments, with good facilities for walking and cycling, tends to decrease trip distances and to increase the share of walking, cycling and public transport trips. However, disaggregate studies that took the influence of other variables such as demographics and socioeconomics into account only found limited effects (Handy et al., 2005; Ewing and Cervero, 2010; Transportation Research Board, 2009; Gim, 2013).

Moreover, the extent to which these associations represent a causal influence of the built environment on travel behaviour is a significant point of contention. For a causal link, it is crucial that the effects of confounding variables are controlled for. The majority of disaggregate studies that have been conducted during the last decades controlled for sociodemographics and increasingly attitudes. So, it seems fair to say that studies to date have met this criterion to a certain extent. However, to identify causality it is also crucial to identify the order of events. In other words: the cause (change in the built environment) should precede the effect (change in travel behaviour). In addition, there should be a logical causal mechanism that explains the cause-effect relationship (Singleton & Straits, 2009). Qualitative studies can explore these mechanisms by revealing people's reasoning and decision-making processes regarding residential location and travel behaviour choices. As most studies in this field relied on quantitative cross-sectional studies, evidence for a causal link between the built environment and travel behaviour remains rather thin on the ground. Longitudinal and qualitative studies are prerequisites for uncovering cause-effect relationships and underlying mechanisms and hence for providing stronger evidence for causality (Handy et al., 2005; Næss, 2015).

The limited number of longitudinal studies becomes more urgent as hypotheses occurred that provide alternative explanations for the observed associations between the built environment and travel behaviour (for a detailed discussion we refer to Mokhtarian & Cao, 2008; Cao et al., 2009; Heinen et al., 2018). The residential self-selection hypothesis posits that these associations are the result of people selecting themselves in neighbourhoods based on their travel-related attitudes, preferences, needs and abilities (Mokhtarian & Cao, 2008; Cao et al., 2009, Van Wee, 2009). For example, a positive association between higher densities and the use of public transport may be the result of people with a positive attitude towards public transport selecting themselves in compact neighbourhoods which makes it easier for them to use their preferred travel mode. In this case the attitude is the prevailing causal factor that explains higher public transport use and the built environment merely facilitates people with these attitudes. Therefore, the impact of densification is limited to the share of people in the population that currently have supporting attitudes. In the last two decades many studies have been conducted on this issue. Overall, most of the evidence regarding residential self-selection indicates that the effects of the built environment on travel behaviour are attenuated when self-selection is accounted for (Cao et al., 2009; Ewing & Cervero, 2010, Gim, 2013). However, results are mixed. For instance, Chatman (2009) found that self-selection may not only lead to overestimations but also to underestimations of the influence of the built environment, depending on the extent to which people are able to self-select themselves in conducive neighbourhoods and their responsiveness to the characteristics of the built environment.

During the debate revolving around residential self-selection, an alternative causal hypothesis has emerged implying a reverse causal influence from the built environment on attitudes (Bagley and Mokhtarian, 2002; Chatman, 2009; Maat & Van Wee et al., 2019). This reverse causal influence, also called residential determinism (Wang and Lin, 2009; Ewing et al, 2016), implies that the built environment shapes attitudes because people align their travel-related attitudes to the characteristics of their built environment. For instance, people with a preference for car use may adjust their attitudes after living in a dense neighbourhood and start appreciating public transport or bicycling over time. So, in this case, the built environment not only has a direct influence on travel behaviour but also an indirect influence that runs via travel-related attitudes. If this causal direction would be dominant, a common practice to control for self-selection by including attitudes in statistical analysis would lead to inflated results as the attitudes are not exogenous but endogenous to the characteristics of the built environment.

The significance and impact of the residential self-selection and reverse causality hypotheses depends on the extent to which people are inclined to match their travel-related attitudes with their residential environment. Even though people take travel-related attitudes and preferences into account during their residential location choice, they are only one of the many factors in the overall process. Furthermore, people experience changes in their household circumstances over time. Therefore, mismatches can occur between people's attitudes and preferences and the characteristics of the current residential environment. Studies by Schwanen and Mokhtarian (2005) and De Vos et al. (2012) show indeed that a significant share of people experiences mismatches which in turn affects their ability to carry out their desired travel behaviour.

Taken together, there is abundant evidence that land use and travel behaviour are associated and that travel-related attitudes and preferences play an important role in the debate revolving around the causal nature of this link. However, determining the order of events is requisite to acquire a better understanding of the role of attitudes and the causal mechanisms related to residential self-selection and reverse causality. To what extent do people select themselves in neighbourhoods based on their travel-related attitudes? To what extent do characteristics of the built environment exert an influence encouraging people to modify their attitudes over time? And to what extent is this dependent on the initial level of mismatch that people experience? Answers to these questions are important for the academic field but also for policy practices. If residential self-selection was the dominant causal mechanism, the impact of densification policies that governments have been implementing for decades would be limited to the share of people that already have favourable attitudes and preferences towards higher-density living and the use of more sustainable travel modes. In other words, land use policies would merely facilitate people's desired travel behaviour. If reverse causality was dominant, land use policies would not only have a direct influence on travel behaviour, but also an indirect influence due to their influence on travel-related attitudes. So, in this case, land use policies modify people's travel behaviour and related attitudes and their impact on achieving sustainable travel behaviour would be much larger. Even though an increasing number of longitudinal studies have been emerging in recent years (e.g Abou-Zeid et al., 2012; Van De Coevering et al., 2016; Wang and Lin, 2019), the quest for causality on the link between land use and transportation has only just started.

1.2 Research Aim and Research Questions

This dissertation aims to add to the integration of land use and transport policies by advancing the quest for causality on the link between the built environment, travel-related attitudes and travel behaviour. It builds on the current knowledge by adopting a two-wave longitudinal study design that includes measurements of all determinants and specifically travel-related attitudes at both moments in time. To construct the two-wave longitudinal database, this study builds on the previous work of Wendy Bohte (2010). She studied the role of attitudes on the interactions between land use and travel behaviour in 2005. Participants from her research in 2005 were contacted again and asked to participate in the second research wave in 2012, yielding a two-wave longitudinal dataset (2005-2012). The central research question is: *how and to what extent do households match their travel behaviour with the characteristics of their residential neighbourhood and how is this influenced by bidirectional relationships with travel-related attitudes?*

The following sub-questions guide this study:

1. How can multi-period designs be applied to uncover causal relationships on the BE-TB link?

This dissertation starts with an extensive literature review of multi-period designs. It describes the range of available study designs, their ability to infer causality, advantages and disadvantages related to data collection, and the practical application in research on the link between the built environment and travel behaviour. Empirical studies from the transportation field and adjacent fields of expertise such as environmental psychology will be used to illustrate opportunities for their application.

2. To what extent do characteristics of the built environment influence car mode share over time and how is this affected by their relationships with travel-related attitudes?

The first empirical article in this dissertation focuses on the overall interdependencies between the built environment, travel-related attitudes, and travel behaviour. It uses the car mode share derived from an online questionnaire as a general indicator of travel behaviour. A two-wave cross-lagged panel model is used to assess the dominant directions of causality and the remaining influence of the built environment on travel behaviour.

3. What is the dominant direction of influence between travel-related attitudes and the built environment in cross-sectional and longitudinal data and what is the remaining influence of the built environment on car kilometres driven over time?

The third article builds on the knowledge from the second article. First, it explicitly compares results from a longitudinal cross-lagged panel model with the results from cross-sectional analysis. The rationale behind this is that most evidence in this field is based upon cross-sectional designs. Therefore, it is important to investigate whether possible differences in outcomes originate from the longitudinal approach in this study, or from the characteristics of the research sample itself. Furthermore, the article includes a more detailed indicator of travel behaviour; the number of car kilometres travelled, derived from an extensive longitudinal GPS tracking scheme. GPS travel data was collected for one week during both research waves. This creates a better overall impression of people's travel behaviour compared to traditional one-day questionnaires (Bohte, 2010).

4. To what extent do people adjust their travel-related attitudes, neighbourhood preferences and their residential location over time and how does this depend on people's initial dissonance?

The third and last empirical article focuses on the mismatches between travel-related attitudes, neighbourhood preferences and neighbourhood characteristics and how they evolve over time. The article applies latent class transition modelling to segment the study sample into consonant and dissonant classes and to reveal differences in their adjustment process over time. An advantage of latent class transition modelling, compared to the a priori classification of dissonance used in most studies to date, is that it inductively derives consonant and dissonant groups from the data which provides a better base for evaluating adjustment processes over time.

1.3 Study Area, Scope and Data

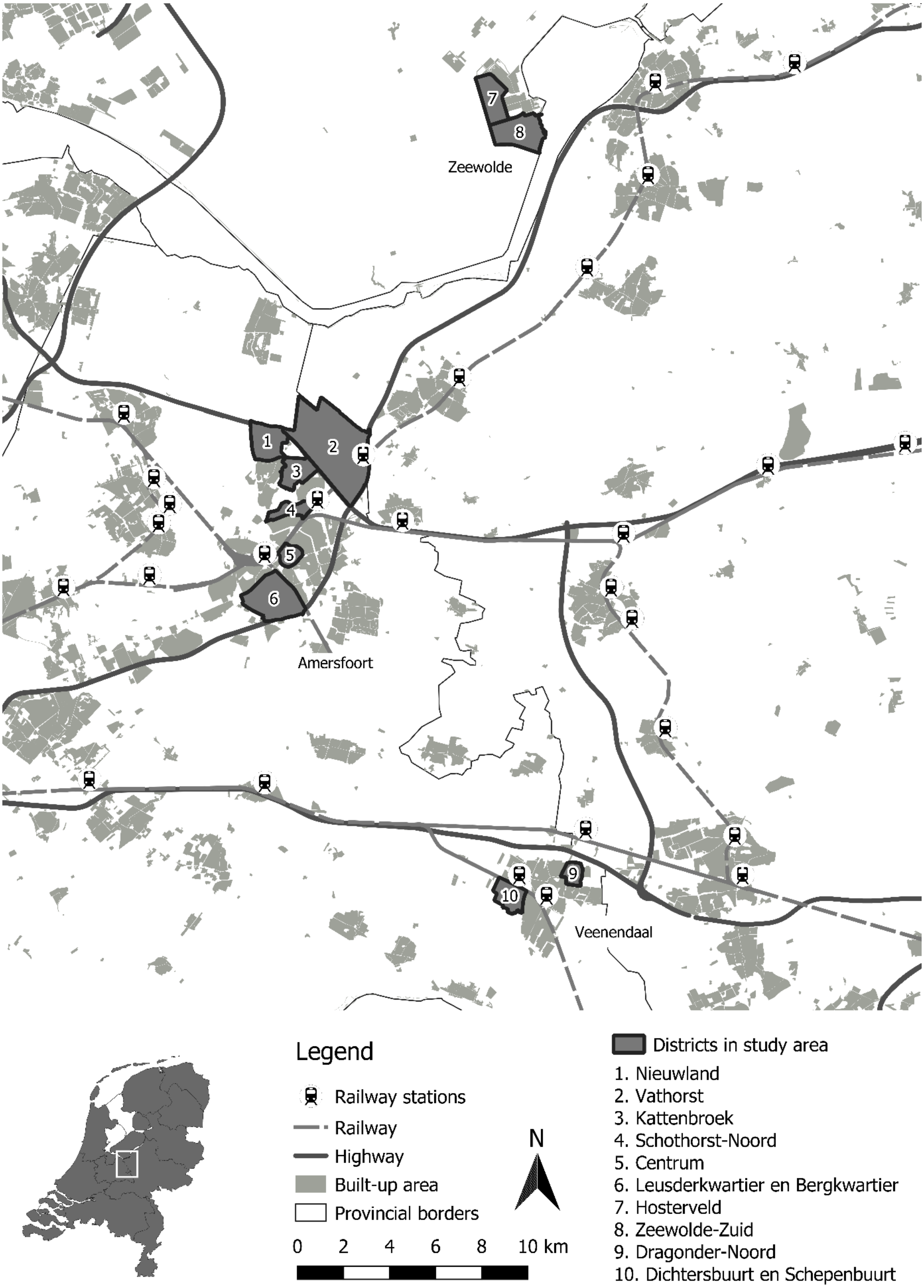

Figure 1.2. Study area.

To assess causality on the links between the built environment, travel-related attitudes and travel behaviour, it is important that the study area incorporates a wide variety of participants living in different types of built environments and with different lifestyles. Therefore, the study area includes the municipalities of Amersfoort, Veenendaal and Zeewolde (see Figure 1.2). Amersfoort is a typical medium-sized city in the Netherlands and has approximately 150,000 inhabitants in 2012. Veenendaal has a population of 63,000 inhabitants. It is known for its good bicycle facilities. Zeewolde is a small town with 22,000 inhabitants which is built on reclaimed land in the province of Flevoland (CBS, 2020). Because of its location, separated from the mainland by a lake, it is somewhat isolated. In these municipalities, central and more suburban neighbourhoods are selected resulting in a sample with bicycle and public transport friendly areas and also car-oriented areas.

The study only involves homeowners because in general renters have much more limited choice options in the Netherlands which would limit our ability to assess residential self-selection processes (Bohte, 2010). A random sample of households was drawn in the selected neighbourhoods and both partners in the households were asked to participate. The first wave involved an online questionnaire which was conducted in 2005. It included questions about travel-related attitudes, housing, travel behaviour and sociodemographics. To get a more detailed picture of people’s travel behaviour this was followed by a GPS survey in early 2007 where participants were asked to carry a GPS logger for one week to record their trips. After this first wave, several postcards were sent to the participants to keep in contact. This enabled us to contact the respondents for the second online questionnaire in 2012 and a subsequent GPS survey in 2013. This yielded a two-wave longitudinal dataset with detailed indicators for sociodemographics, attitudes and travel behaviour. In addition, GIS analyses were conducted to obtain data on the spatial characteristics of the participants’ residential neighbourhoods.

1.4 Thesis Lay-out

This thesis comprises one theoretical article and three empirical articles. All papers have been published or submitted to a peer-reviewed journal. The organisation of the paper follows the order of the research questions described in section 1.2. Chapter 2 describes a review of multi-period designs, their ability to infer causality, and advantages and disadvantages related to the practical implementation in research on the link between land use and transportation. This article was published in Transport Reviews in 2015. Chapter 3 involves the first empirical paper. It uses data from the online questionnaire and the GIS analysis to assess dominant directions of influence between attitudes, land use, and a general indicator of travel behaviour. This article was published in the European Journal of Transport and Infrastructure Research in 2016. Chapter 4 includes data from the GPS survey which enables a more detailed assessment of the travel behaviour indicator, albeit with a smaller research sample as not all people from the online survey also participated in the GPS survey. This article was published in the Journal of Transport Geography in 2021. Chapter 5 presents the last empirical article which focuses on the way in which residential matches and mismatches induced by travel-related attitudes and neighbourhood preferences evolve over time. This article was published in Transportation Research part A in 2018. Finally, Chapter 6 discusses the answers to the research questions and provides recommendations for further research and policy practice.

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Chapter 2: Multi-period Research Designs for Identifying Causal Effects of Built Environment Characteristics on Travel Behaviour

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Abstract

To date, most empirical studies have applied cross-sectional designs to investigate the relationship between the built environment (BE) and travel behaviour (TB). Since these studies cannot identify causal influence, the use of designs that provide data on multiple moments in time seems necessary. This article classifies these designs and describes how they can be applied to identify causality in this relationship. We recommend the use of natural experiments to assess the impact of changes in land use/infrastructure and prospective longitudinal designs to assess the impact of residential or job moves. In addition, the role of the BE can be explored by assessing the impact of (1) deliberate TB change experiments and (2) changes in household circumstances across different spatial contexts over time. The use of randomised experimental designs is recommended for the former and prospective longitudinal designs for the latter. The article concludes with an outlook on future research.

Keywords: multi-period research designs, longitudinal, causality, attitudes, travel behaviour, built environment.

2.1 Introduction

Background

For decades, researchers have recognised the impact of the built environment (BE) on travel behaviour (TB) (Maat & Timmermans, 2009; van Wee, 2011). Policy measures, such as densification and the improvement of cycle routes, have been undertaken to provide viable alternatives to car use and to alleviate problems such as air pollution and road congestion. Often, these measures involve high costs and/or have long-lasting implications. Reliable evidence on the causal effects of these BE changes on TB is therefore important. On the relationship between the BE and TB, the causality issue and specifically the role of residential self-selection (RSS) have become the subject of debate. The question is to what extent observed associations reflect a causal impact from the BE on TB and to what extent they can be attributed to people self-selecting residential areas that are conducive to their preferred TB.

To date, the vast majority of empirical studies on the BE– TB link applied cross-sectional designs that provide a snapshot of the variables at a single moment in time. Although these studies provide valuable insights, they cannot identify causal relationships because they (Kitamura, 1990; Mokhtarian & Cao, 2008):

1. do not assess the impact of BE changes on TB over time;
2. are vulnerable to third (confounding) variable influences;
3. neglect the dynamics involving behavioural change.

To overcome the limitations of cross-sectional studies, the use of research designs that provide data for two or more moments in time (hereafter referred to as 'multi-period designs') is increasingly being advocated in the literature (see Mokhtarian & Cao, 2008). While cross-sectional research addresses differences in TB between locations with different BE characteristics at one moment in time, these multi-period designs provide the opportunity to assess the change in TB that results from a change in BE characteristics over time. To date, few studies have been based on these designs because the practical application of these multi-period designs is generally considered more complex, expensive, and time-consuming (Transportation Research Board, 2009).

Knowledge Gaps and Aim

Experimental designs are often touted as the 'gold' standard for establishing causality (Shadish, Cook, & Campbell, 2002). However, the practical application of these designs in social science research is difficult because researchers often have limited control over the allocation of the experimental conditions (i.e. who receives the intervention and who does not) and in field experiment conditions cannot be completely controlled. Depending on the research aims and available resources, other less rigorous (quasi-)longitudinal and repeated cross-sectional designs may be reasonable alternatives (Behrens & Del Mistro, 2010; Shadish, 2011). To date, there is no comprehensive overview that describes how multi- period designs can be applied to the BE– TB link. Likewise, the advantages and disadvantages that arise from applying these designs remain unclear. This article aims to give an overview of how multi-period designs can be applied in research on the BE– TB link. It therefore provides a classification of research designs and discusses methodological advantages and disadvantages with regard to causality and data collection.

Scope

In the process of designing research, three main levels of interrelated decisions can be distinguished (Creswell, 2013): (1) decisions regarding the research approach: quantitative, qualitative, and mixed research; (2) decisions regarding the research design/strategy; and (3) decisions regarding specific methods of data collection and analysis. This article focuses on the second step. Thereby, we focus on quantitative multi-period designs where comparable data are gathered at regular or irregular intervals (e.g. once or twice a year for a certain number of years) and retrospective designs in which people are asked to recall their situation at previous moments in time. These designs enable to identify causal descriptions and assess the magnitude of effects, that is: what is the influence of a change in the BE on TB?

They do less well in explaining the mechanisms through which these effects come about, that is, provide a causal explanation (Shadish et al., 2002). Qualitative approaches are better suited for this purpose. However, a detailed discussion of qualitative approaches is beyond the scope of this article. This also applies to decisions related to the third level regarding specific methods of data collection, instrument development, sampling, data analysis, and so on. We refer to Clifton and Handy (2003), Creswell (2013), and Mokhtarian and Cao (2008) for further reading. Lastly, as some designs are not yet applied to the BE– TB link, we illustrate them by using examples of empirical studies from neighbouring fields.

Article Outline

The section 'The Conceptual Framework and Limitations of Cross-sectional Designs' describes a conceptual model and the causality debate that surrounds the BE– TB link. The section 'Advantages and Disadvantages of Multi-period Research Designs' provides a classification of multi-period research designs and describes the methodological advantages and disadvantages of each when it comes to identifying causality and analysing and collecting data. The section 'Applying Multi-period Designs on the BE– TB Link' describes how these designs can be applied to the BE– TB link. The last section synthesises the findings and defines implications for future research.

2.2 The Conceptual Framework and Limitations of Cross-sectional Designs

Figure 2.1 conceptualises the relationships between BE– TB and third variables: individual and household characteristics and attitudes.

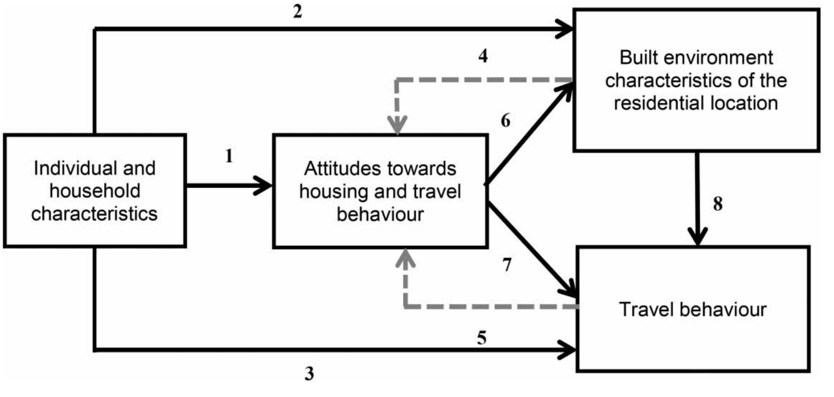

Figure 2.1. Conceptual model of relationships between BE– TB and third variables. Adapted from Bohte (2010).

Earlier studies have suggested a direct relationship between the BE characteristics of residential locations and TB. For example, living near a railway station would encourage travelling by train (link 8). Later studies accounted for the influence of objective socio-economic and demographic variables (link 3) and latterly for subjective variables such as attitudes to TB (link 7). Attitudes are considered to be the product of individual and household characteristics, including the phase in the life cycle and lifestyle preferences (link 1). As household members share resources, such as cars, coordinate activities, and take joint decisions, for example, on the residential location, the household is theoretically the preferable unit of analysis and is also the most common sampling unit in transport surveys (Yanez, Mansilla, & Ortúzar , 2010). More recently, the RSS hypothesis was introduced. It suggests that household location choices are based on travel-related attitudes and socio-economic and demographic characteristics (links 2, 6, and 8) (Cao, Mokhtarian, & Handy, 2009). For instance, someone who prefers to walk may settle in a neighbourhood that is conducive to walking. In this case, it is not the BE alone that causes someone to walk, but rather the combination of a person's pre-existing positive attitude towards walking and the BE that provides opportunities to do so, that causes that person to choose a walkable BE, which makes more walking possible. Then, the impact of the BE on TB may be limited to people who already favour walking and effects on people who are, for instance, car-oriented may be limited. Two-way causation is suggested between attitudes, residential location choice, and TB (links 4 and 5) because the influences may also work in the other direction. Attitudes may change gradually over time with exposure to changes in the BE or changes in the household composition. For example, after living in a residential location close to a railway station for some time, individuals may come to appreciate public transport and start using it. Alternatively, it is argued that attitudes may partially be the result of cognitive dissonance reduction (Festinger, 1957). People may adjust their attitudes to justify major choices such as their residential choice (Chatman, 2009).

To date, most studies have found significant but small associations, ceteris paribus: residents of higher density, mixed-use developments with good facilities for public transport, cycling and pedestrians and with short distances to destinations tend to drive less and make more use of alternative transportation modes. It was found that the BE influences TB at different levels of aggregation ranging from regional accessibility to local street design. The appropriate unit of aggregation is dependent on the specific TB under study (Krizek, 2003a). Destination accessibility, the ease of access to trip attractions, is most strongly associated with TB (Ewing & Cervero, 2010). Research concerning the effects of RSS remains equivocal. Cao et al. (2009) have concluded that controlling for RSS attenuates the effect of the BE on TB. Ewing and Cervero (2010) have found no (or even enhanced) effects. Næss (2009) argues that the fact that BE enables people to self-select into areas that match their travel-related attitudes in itself demonstrates the importance of the BE. Studies of Schwanen and Mokhtarian (2005) and De Vos, Derudder, Van Acker, and Witlox (2012) indicate that this match is by no means self-evident. Often, mismatches occur, for example, people with a preference for car use end up in a high-density environment. The impact of these mismatches on TB depends on the balance between the influence of travel-related attitudes and the constraints imposed by the residential environment.

Four conditions should be met to identify causal relationships (Singleton & Straits, 2009):

1. association;
2. non-spuriousness;
3. time precedence and
4. plausibility.

Association means that there is a significant statistical relationship between two variables. However, as the old adage goes: 'association does not prove causation' (Shadish et al., 2002). The fact that the BE and TB are bivariately related does not necessarily imply a meaningful association, even less a causal effect. The association may be the effect of a confounding variable or of sampling and measurement errors.

Non-spuriousness means that the relationship between two variables cannot be attributed to another confounding variable. Spurious relationships occur when an association between two variables is due to both variables being correlated with another (third) variable. Conversely, the absence of a significant bivariate relationship by itself does not rule out causality as this may be caused by a suppressing effect of confounding variables (Kline, 2010). Cross-sectional studies are highly vulnerable to third variable effects. The RSS issue, where travel-related attitudes influence TB as well as the BE through residential choice, is a clear example (Mokhtarian & Cao, 2008).

Time precedence implies that a cause should precede the effect in time. More specifically, a change in BE characteristics should precede a change in TB to provide evidence for a cause-effect relationship. Obviously, using observations at one particular point in time does not allow us to determine the sequence of events.

Plausibility implies that there should be a logical causal mechanism for the cause-and-effect relationship. van Wee (2011) offers an explanation based on the theory of utilitarian travel demand: the BE and the quality of the transport system affect travel distance, time, cost, and quality, which influence the competitive position of transport modes and the consumption of travel. However, as depicted in the conceptual model, the association may also (partially) be the effect of RSS. It is difficult to determine the direction of causality based on cross-sectional data. Moreover, if we were to predict the impact of future changes in the BE on TB with cross-sections, we would use differences in TB across different individuals at one point in time to predict changes in TB of the same individuals in time. The plausibility of this prediction is questionable since it implies that travel is contemporaneous — that is, the TB of the average person matches the expected TB based on the defining variables in the conceptual model (Figure 2.1) at any given point in time. In everyday life, (temporal) mismatches occur because households do not change their TB immediately as changes in the context occur. Response lags can occur because behavioural changes involve psychological or financial costs, for instance, or because households do not immediately find out about the change (Chen & Chen, 2009; Kitamura, 1990). Qualitative designs are particularly useful to get a more detailed understanding of the mechanisms by which people adapt their TB to the opportunities and restrictions provided by various types of BE characteristics.

Hence, although cross-sectional studies provide ample evidence for the associations, they fail to meet the other three conditions for causal influence. Multi-period designs offer advantages because they allow the temporal order of cause and effect to be determined. Particularly, designs that include repeated observations of the same respondents offer considerable advantages because (Handy, Cao, & Mokhtarian, 2005; Kitamura, 1990):

- they enable us to model the change in a dependent variable which means that unobserved variables that do not change over time are well controlled for; and
- they provide a more plausible behavioural foundation and provide the opportunity to investigate the dynamics and time lags.

2.3 Advantages and Disadvantages of Multi-period Research Designs

Table 2.1 classifies the main research designs according to their ability to support the criteria for causal influence. The classification will be used as a framework for the discussion on applying these designs in the next section. We will first turn to the general advantages and disadvantages of multi-period research designs for identifying causality as depicted on the left side of the table. We will then discuss issues related to data collection and analysis.

Causality

Experimental designs. In experimental studies, researchers have administrative control over the interventions that occur. They divide participants into groups

— an 'experimental group' and one or multiple 'control group(s)' and they plan an intervention in the experimental group while the control groups receive an alternative intervention or no intervention at all.

The randomised experiment (the classic before– after random-assignment control group design) is often considered the 'gold standard' for identifying causal effects. This design meets all the criteria and maximises the ability to identify causality. Because participants are randomly allocated to experimental and control groups, unobserved variables that may influence the outcome of the study will be evenly distributed between the groups. This minimises the threat of third variable bias (Shadish et al., 2002). Ideally, the allocation to groups is double-blinded to minimise the effects of expectations of both participants (placebo effects) and researchers on the study outcomes. More than one follow-up measurement is preferable in order to differentiate between short-term and long-term effects (Chen & Chen, 2009). These designs have been applied in TB research, for instance, to assess the effects of the introduction of a free public transport ticket on transit ridership (Thøgersen, 2009).

Quasi-experimental designs are often used in situations where full randomisation is not possible, for instance, due to the context of the study and/or ethical or political considerations. They share many characteristics with randomised experiments with the difference that the treatment is exogenously assigned or randomly assigned at a higher level of grouping (e.g. to schools, departments, neighbourhoods, etc.). For example, McKee, Mutrie, Crawford, and Green (2007) assessed the impact of a school-based active travel project by assigning an intervention to an experimental school and comparing the TB behaviour outcomes with a comparison school. This design scores lower on the third variables due to the risk of endogenous assignments. For instance, when participants can self-select themselves into research groups, their choice may partly be determined by third variables that will also influence the outcome variable, leading to biased estimates (Remler & Van Ryzin, 2010).

Observational designs. If the assignment of an intervention is beyond the control of the researchers, they can adopt observational designs that rely on naturally occurring (unplanned) events.

In *natural experiments*, the experimental condition happens naturally or at least in a way that is not related (exogenous) to the research results. Ideally, they use a before-and-after design with comparison groups. Natural experiments have been applied to examine the effects of infrastructure improvements on TB (Goodman, Sahlqvist, & Ogilvie, 2013). Because researchers do not have control over the assignment, they are often not considered 'real' experiments, but rather a sophisticated form of observational design (Shadish et al., 2002). With regard to causality, natural experiments can be comparable in power to quasi-experiments. However, the lack of control over the timing and allocation of the events poses challenges when it comes to identifying causal relationships.

With *prospective longitudinal designs*, researchers look ahead and observe what happens to each of the participants and analyse the effects of these events on the output variable over time. These run for longer periods of time and may have multiple points of measurement. General transportation panels such as the Dutch Mobility Panel and the German Mobility Panel are typical examples (Ortu´ zar, Armoogum, Madre, & Potier, 2011). Other examples include the assessment of the impact of residential moves on TB (Krizek, 2003b). One important disadvantage is that the majority of the events are not exogenous because people self-select

Table 2.1. Classification of research designs.

			Causality				Data collection and analysis						
	Number of waves	Design	Association	Time precedence	Causal mechanism	Third variable	Practical issues	Required Sample size	Initial non-response	Drop-out	Decline of accuracy	Periodic effects	Regression to the mean
Experimental design	≥ 2	Randomised experiment	++	++	++	++	--	++	-	Yes	Yes	Yes	Yes
	≥ 2	Quasi experiment	++	++	++	+	-	+	-	Yes	Yes	Yes	Yes
Observational design s	≥ 2	Natural experiment	++	++	++	+	-	+	-	Yes	Yes	Yes	Yes
	≥ 2	Prospective longitudinal studies	++	++	++	0	0	+	-	Yes	Yes	Yes	Yes
	1	Retrospective (quasi-) longitudinal studies	++	0	0	0	+	0	0	No	No	Yes	Yes
Independent cross-sectional samples	≥ 2	Repeated cross-sections / pseudo panel	++	+	-	-	+	--	++	No	No	Yes	No
	1	Single cross-section	++	--	--	--	++	--	++	No	No	No	No

Notes:

- The signs (++, -, 0, -, --) indicate a (very) strong, neutral or (very) weak score on the criterion. Note that scores are relative and based on qualitative judgment. Important differences in scores are explained in the text. Yes/No means that this is (not) an issue for the research design concerned.
- More detailed classifications in research designs are possible (e.g. based on the number of measurements or the presence of comparison groups) but this is not the aim of this section.

After: Remler and Van Ryzin (2010), Shadish *et al.* (2002); and Ortúzar *et al.* (2011).

themselves to the experimental condition (e.g. a residential move) (Remler & Van Ryzin, 2010). This leaves room for spurious effects which results in a lower score on the third variables criterion. However, like the previous designs, prospective studies enable the researchers to focus on changes in the dependent and independent variables over time, thereby meeting the criteria for time precedence and the logical causal mechanism and controlling for the influence of time-invariant confounding variables.

The *retrospective (quasi-)longitudinal designs* involve one-off surveys of individuals that ask respondents to recall information about events, activities, or other phenomena that happened to them in the past (Behrens & Del Mistro, 2010). However, partial or inaccurate responses are likely to be due to memory errors and other variables, notably attitudes, cannot be recollected reliably in retrospect (Verhoeven, 2010). This reduces the ability to meet the third variable and time-precedence criteria and to disentangle causal mechanisms for these variables. However, retrospective surveys allow for observations over longer time spans than would be feasible with panel surveys, data can be attained more quickly and research suggests that respondents are able to recall major life cycle events and report some of their key attributes. This allows for the assessment of these general changes over longer time spans, whereas panel data are able to cover more and yields more detailed information.

Independent cross-sectional samples. This technique involves taking independent random samples from the same target populations over time. They can be conducted before and after contextual changes take place or at fixed points in time to assess the changes in the average population parameters (trends), thereby meeting the time-precedence criterion. Continuous national travel surveys in Germany (KONTIV) and the Netherlands (NTS) are typical examples. However, continuous travel surveys have not been conducted in the large majority of countries (Ortúzar et al., 2011). A major advantage of independent cross-sectional samples is that they can be undertaken over longer periods of time because the independent samples are not affected by dropout. A major disadvantage is that they do not measure the same respondents across time, making it impossible to identify or explain intra-personal change or to resolve issues of causal sequence. However, existing repeated cross-section samples can be used to construct pseudo panels where individuals or households are grouped into cohorts based on time-invariant characteristics such as date of birth or residential location. The averages for the cohorts are treated as individual observations which are then tracked over time. This enables the analysis of dynamics in TB. Empirical applications show that pseudo-panel data can be treated as genuine panel data in panel-based models and in structural equations modelling (Dargay, 2002; Weis & Axhausen, 2009). Still, pseudo panels require large and high-quality repeated cross-sectional data as the number of cohorts has to be sufficiently large for statistical efficiency and for each cohort, a minimum number of individual records is required to reduce estimation bias. See Tsai, Mulley, and Clifton (2014) for further reading.

Data Collection and Analysis

While multiple observations of the same participants over time provide opportunities to identify causality, they are also the main point of concern when it comes to practical applicability. In the following section, the issues described in the right column of Table 2.1 will be elaborated in more detail.

Practical issues are related to the time and effort needed to collect data and produce research results. It goes without saying that designs that require two or more measurements take more time and effort than a single cross-section or retrospective design. Consequently, the initial financial investment will often be higher and longer-term motivation and financial support is required (Ortúzar et al., 2011). Furthermore, experimental designs require the design and controlled assignment of a deliberate intervention which takes additional effort while randomised assignment is often impossible. For natural experiments, the timing of a baseline measurement can pose challenges as researchers cannot control the timing of these events and are not always aware that they will occur in advance. It can also be difficult to select an appropriate comparison group that is not affected by the natural experiment (Ogilvie et al., 2011). Prospective longitudinal designs take less effort because they do not require a specific intervention. However, keeping contact with the respondents between the measurement points takes also effort and needs coordination over time. This is not required in the multiple cross-sectional and quasi-experimental studies, but the first still involves multiple measurement points and the second has challenges related to the complexity of the questionnaire design.

Required sample sizes for observational and experimental designs are generally smaller compared to repeated cross-sections because the same respondents are surveyed over time. The assessment of changes at the level of the individual reduces sampling errors and enables a more precise measurement of change (Duncan, Juster, & Morgan, 1987; Mokhtarian & Cao, 2008). Moreover, the selection costs per respondent can be lower than repeated cross-sections because the same respondents participate on two or more occasions, reducing the costs for each successive wave (Duncan et al., 1987).

Initial non-response is generally larger for observational and experimental designs that involve two or more measurement moments because they place a higher burden on the respondents (Behrens & Del Mistro, 2010; Kitamura, 1990; Shadish et al., 2002). To a lesser extent, the same is true of retrospective designs since these surveys are often more complex (Verhoeven, 2010).

Dropout refers to increases in non-response in subsequent research waves of (natural) experimental and prospective longitudinal studies as respondents drop out for various reasons — because they move, die or are simply not willing to participate anymore. This poses a threat to the internal validity of the study, because non-equivalent groups would be compared at different moments. This is a particular problem when the dropout is selective and related to the outcome variable of the study (Trochim, 2000).

A *decline in accuracy* for follow-up measurements of (natural) experimental studies and prospective longitudinal studies may occur first because participants are influenced by participating in the study itself. This includes test effects, in which people could become more aware of the issues related to the study and begin to behave differently, and fatigue, in which they get bored with answering the same questions repeatedly. Secondly, over time, natural changes occur in a research sample. This may result in stagnation effects where people in the sample become older and are no longer representative of the population and maturation effects where people develop their skills and understanding over time. These naturally occurring changes over time should not be confused with intervention effects (Meurs, 1991). Finally, alternations in the research instruments can lead to perceived intervention effects. This occurs when, for instance, a questionnaire is modified, or when technical improvements are made to observation tools (Trochim, 2000).

Periodic effects occur due to changes in the context between the measurement points, such as weather conditions and changes in the economic situation, which could influence the outcomes of multi-period studies (Shadish et al., 2002), for example, the drop in car use around 2008 is often attributed to the economic downturn after the financial crisis.

Regression to the mean refers to the fact that, given random variation over time, a high initial value is more likely followed by a lower value than by an even higher value (and vice versa for low values). This change can be confused with an intervention effect and applies to all experimental and observational designs. This phenomenon occurs when the selection of respondents for the research is biased and the characteristics of the sample differ significantly from the characteristics of the population. This sample selection bias occurs either accidentally, due to self-selection of respondents, or deliberately because studies deliberately concentrate on groups with certain behaviour (Seethaler & Rose, 2009).

From the advantages and disadvantages of multi-period research designs that have been set out in this section, it appears that the higher the ability for identifying causality, the lower the practical applicability of research designs. This gradual relationship is shown in Figure 2.2.

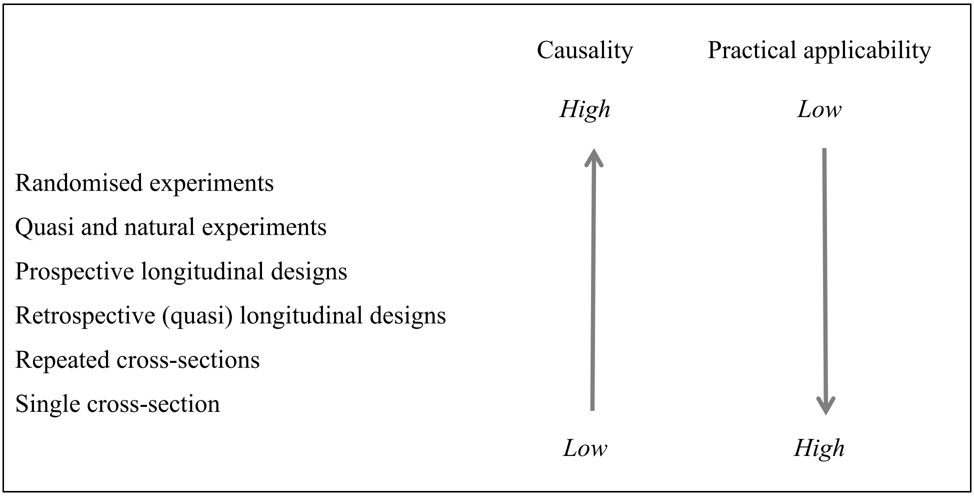

Figure 2.2. Gradual relationship of causality and practical applicability.

2.5 Applying Multi-period Designs on the BE– TB Link

This section discusses how multi-period designs can be applied on the BE– TB link according to the classification in Table 2.1. For each design, the opportunities and issues that arise in practical applications on the BE– TB link are described. Empirical studies are used to illustrate these applications. The exemplary empirical studies are selected on the basis of a systematic literature search. The vast majority of these studies used statistical controls for confounding variables. As few multi-period studies are available on the BE– TB link, we broadened our scope to studies from adjacent research fields of transportation, social and environmental psychology and physical activity. We only included peer-reviewed studies that incorporate determinants of the BE and TB. This paragraph ends with a discussion on two overarching issues in multi-period studies: the appropriate time frames and dropout.

Experimental Designs

Applying an experimental design directly to the BE– TB link would mean that researchers would randomly assign residents to different residential areas, or subject them randomly to changes in the BE. Aside from the financial costs, it would be impractical and unethical to move households, just for the sake of a study (Mokhtarian & Cao, 2008). Furthermore, meeting the requirements of double-blinded research would be impossible. Although experimental designs do not allow for a direct assessment, interaction effects between TB change experiments (e.g. awareness and promotional campaigns) and (changes in) BE characteristics can be determined.

Firstly, changes in the BE characteristics — due to land use and infrastructural changes or residential moves — provide a unique context for these interventions because they motivate people to reconsider their TB and make them more receptive to the intervention (Bamberg, 2006; Graham-Rowe, Skippon, Gardner, & Abraham, 2011). An experiment around land use or infrastructural changes was not found in the literature. Merom, Bauman, Vita, and Close (2003) come close with a before-and-after study on the impact of a general (non-experimental) pro- motional campaign involving walking and cycling around a newly constructed multi-use trail. They selected a random sample of households within an 'inner' (within 1.5 km) and within an outer area, 1.5 – 5 km from the Trail and concluded that the campaign slightly improved the awareness of the trail and increased cycling among those in close proximity to the trail. Bamberg (2006) used a residential move to Stuttgart as the context for an experiment with a baseline and one follow-up measurement. He allocated movers to an experimental group — that received an intervention in the form of a free public transport ticket and specially tailored information — and a control group that received no intervention. He concluded that only in the experimental group did the move actually provoke a change in TB, indicating that the intervention was necessary as 'a last push'. Ideally, these experimental studies should include an additional comparison group of people who are not affected by the BE change. This would have provided more detailed insight into the role of the BE changes and the interaction with the experiment.

Secondly, the effectiveness of experiments can be assessed between neighbourhoods with different BE characteristics. Riley, Marka, Kristjansson, Sawadad and Reid (2013) analysed how neighbourhood walkability influenced the effect of a randomised intervention aimed at increasing moderate and vigorous physical activity. They compared the results of the intervention in neighbourhoods with high and low levels of walkability but found no significant interaction effects between walkability and the intervention. In this context, a couple of issues commonly arise in practical applications. Firstly, the effects of the interventions may increase, diminish or remain stable over time. Preferably, two or more follow-up measurements will be taken to determine the short-term and longer-term effects (Bradley, 1997; Graham-Rowe et al., 2011). Secondly, participants' TB can be affected by participating in the experiment itself. These 'test effects' can be minimised by preventing people from associating the evaluation methodology (e.g. questionnaires) with the experiment. Bamberg (2006), for example, presented his study as a general project to analyse daily mobility patterns and the promotional materials were sent to the participants by another company that did not make any reference to the research project.

Thirdly, experiments in TB change generally have a highly localised nature and suffer from small (unrepresentative) sample sizes and dropout rates (Graham- Rowe et al., 2011). In these cases, caution should be given to regression to the mean threats. Furthermore, the ability to generalise the study outcomes to the intended population is reduced. The oversampling of specific groups, testing for statistically significant differences between research groups at baseline and non-response analysis at follow-up measurements can reduce related risks. If studies focus on explaining relationships with other variables and do not intend to make generalisations, this is less of a problem (Babbie, 1998). Furthermore, even with a representative sample, a broader generalisation to another spatiotemporal context will require researchers to use inductive reasoning to determine the comparability of other contexts or repeat a comparable study in another context (Cook, 2013).

Observational Designs

Natural experiments involve comparing TB before and after the occurrence of significant changes in the BE (e.g. urban densification or the improvement of cycling facilities). Axiomatically, including a comparison group with comparable participants from an area that has not been affected by the change concerned will augment internal validity. It has been recognised that some developments may partially be the effect, rather than the cause of TB changes (for instance, due to community lobbying for new bicycle infrastructure). However, most of them can reasonably be considered as exogenous events (Krizek, Barnes, & Thompson,

2009). To date, only a handful of studies applied this design to the BE– TB link. An explicit assessment of spatial interventions was not found in the current literature. Available studies mainly assessed the effects of changes in the provision of public transportation (Arentze, Borgers, Ponjeacute, Starns, & Timmermans, 2001; Chatterjee, 2011; Yanez et al., 2010). Chatterjee (2011) assessed changes in TB after the introduction of a new bus rapid transit service using one baseline measurement and three follow-up measurements. Results showed that people gradually adapted to the new services, which resulted in an increase in bus use over time.
In recent years, the application of this design has progressed on the link between physical activity and the BE (Evenson, Herring, & Huston, 2005; Goodman et al., 2013; Ogilvie et al., 2010). Goodman et al. (2013) conducted baseline, one-year and two-year surveys to examine the TB effects of a new walking and cycling route and found that the infrastructure catered mainly for existing walkers and cyclists. An important issue for practical application is that researchers have limited control over the intervention and contextual influences. Studies by Yanez et al. (2010) and Evenson et al. (2005) were seriously affected by the chaotic and delayed introduction of new transport facilities. To address these issues and maximise opportunities to apply these natural experiments, collaboration between transport and land use planners and researchers is important (Boarnet, 2011; Ogilvie et al., 2011). Furthermore, the selection of proper treatment and comparison groups is far from straightforward: all the aforementioned studies lacked a comparison group or area. It appears to be difficult to determine the boundaries of the (intervention) areas that are exposed to infrastructure (re)developments; and comparable neighbourhoods and participants are often difficult to find (Ogilvie et al., 2011; Stopher, Clifford, Swann, & Zhang, 2009). Suggested alternative approaches to the inclusion of comparison groups are:

- data and information from alternative sources to control for unknown influences; Ben-Elia and Ettema (2011) used traffic count data from a trajectory being studied to test for disruptions or unexpected changes in the traffic flow and Merom et al. (2003) used longitudinal bike count data to corroborate their survey results;
- a ‘dose-response’ assessment (Ogilvie, Mitchell, Mutrie, Petticrew, & Platt, 2006); the distance to newly developed infrastructure (or access points like a public transport stop or on-ramp) can be used as a proxy for exposure and incorporated in the effect analysis;
- including multiple baseline and follow-up measurement points to identify a break in TB trends (Graham-Rowe et al., 2011; Merom et al., 2003); however, this increases the risk of dropout as it requires more commitment from the respondents.

Prospective studies enable us to assess the impact of the BE on TB in the occurrence of endogenous (self-selected) changes in household circumstances. There are two approaches. The first involves the environmental context explicitly and assesses the impact of, for instance, residential moves or job location changes. Krizek (2003b) examined changes in BE characteristics and household TB between two consecutive years and subdivided a research sample from a general-purpose travel panel survey into a ‘treatment’ group with people who had moved house and a comparison group of people who had not. He found that households changed their TB after relocation. Higher neighbourhood accessibilities in particular reduced the number of miles travelled by car. Meurs and Haaijer (2001) came to comparable results using a two-wave longitudinal data set based on the Dutch Time Use Study. In recent years, this design has increasingly been applied in research on the link between physical activity and the BE (Beenackers et al., 2012; Coogan et al., 2009; Gebel, Bauman, Sugiyama, & Owen, 2011). Under the second approach, the impact of life-course events on people’s TB over a longer period of time is assessed. The role of the BE is used as an explanatory factor for the impact of life-course events on TB. Bohnet and Gertz (2010) analysed data from a German multipurpose household panel survey and found that higher density housing increases the probability that residents will postpone the purchase of a car and the acquisition of a driver's license, and later in life, it increases the probability that they will sell their car. Clarke, Ailshire, and Lantz (2009) found that living in more pedestrian-friendly neighbourhoods was associated with a reduced probability of mobility disability in older age.

One of the major concerns of prospective research designs is the endogenous nature of life-course events (including residential relocation). To ensure that the observed relationships on the BE– TB link are not spurious, it is required to include confounding (third) variables in the analysis. This notwithstanding that control variables are also recommended for more rigorous designs as the influence of third variables cannot be completely eliminated through research design on the BE– TB link. Another issue is dropout, especially for those people who moved house. Methodologies such as providing incentives and maintaining contact proved effective in reducing these dropout rates (see Ortúzar et al., 2011; Yanez et al., 2010). Furthermore, these studies often lack a comparison group which reduces their internal validity. Possible alternatives are discussed in the previous paragraph. A problem with the second approach is that major life-course events and subsequent changes in TB do not take place regularly. This means that large time spans are needed to yield significant results, and this can be difficult to achieve with prospective designs (Woldeamanuel, Cyganski, Schulz, & Justen, 2009).

Retrospective designs. Similar to prospective designs, retrospective designs are applied in two different ways. The first approach assesses the TB effects of specific endogenous (e.g. residential moves) or exogenous (e.g. infrastructural or spatial interventions) changes in the BE. Handy et al. (2005) and Cao, Mokhtarian, and Handy (2007) assessed the impact of residential moves retrospectively in a US context, and Aditjandra, Cao, and Mulley (2012) used a comparable approach in the British context. They classified respondents into movers — those who moved house within the last year — and non-movers. Current travel-related attitudes were accounted for to reduce the risk of spurious results. All studies found significant longitudinal associations between the BE and TB. However, the latter two studies did not include the control group of non-movers in the analysis. Boarnet, Anderson, Day, McMillan, and Alfonzo (2005) conducted a retrospective assessment of the effects of an exogenous change in the form of improved walking and cycling routes on children's' active travel to school. They asked parents retrospectively about changes in their children's walking and cycling frequency after infrastructure improvements were made. Counter to expectations, children who used these improved routes showed a decrease in walking and cycling. However, this was against a backdrop of an overall decline in walking and cycling rates and the researchers eventually concluded that the children who used the improved facilities were more likely to increase their walking or cycling to school than their counterparts who did not use these facilities.

The second retrospective approach enables researchers to assess the influence of the BE during life-course events over a longer period of time. Using this design, Beige and Axhausen (2012) examined the impact of life-course events on TB. The retrospective design allowed them to cover a period of 20 years. They used the ownership of cars and public transport tickets and general TB indicators like the 'most used mode of transport' for commuting trips to assess changes in TB. They concluded that life-course events including changes in residential moves and changes in occupation create important opportunities for changes in TB.

It should be noted that, as suggested by Kitamura, Yamamoto, and Fujii (2003), retrospective recall questions can also be included in research waves of prospective longitudinal designs to collect richer data sets.

A disadvantage of the practical application of this design is that the retrospective questioning of attitudes and specific daily TB is not reliable. Handy et al. (2005) therefore used a relatively short time frame and asked the respondents to indicate changes in their TB retrospectively on a 5-point Likert scale. They only asked about current attitudes and considered these to be stable over the relatively short time period. As the authors acknowledge, this limits the ability to disentangle the causal chain on the BE– TB link. Another issue is that these studies do not always include a comparison group of non-movers or another form of comparison. The aforementioned study of Boarnet et al. (2005) illustrates its importance. It is clear that the authors' conclusion — namely that the improvement of facilities has a positive effect on walking and cycling — would have been different if no comparison group had been included in the research.

Independent Cross-sectional Samples

Even though repeated cross-sections do not identify intra-personal change over time, which limits their ability to answer questions regarding causality, they can still provide valuable insights. Firstly, they are used in studies to estimate aggregate changes before and after specific BE changes. Lovejoy, Sciara, Salon, Handy, and Mokhtarian (2013) surveyed two samples of respondents, one the year before and the other the year after the opening of a large retail store. They asked them to recall the characteristics of their most recent shopping trip and their general shopping behaviour in the last year. The study reveals that trips to the new retail store had largely displaced vehicle trips to other more distant retail facilities resulting in an overall reduction in the number of vehicle miles travelled for shopping. One important issue is that the two independent samples should have a comparable level of exposure to the BE changes. The distance to the location of the intervention can be used as a (dose-response) proxy for the level of exposure (Ogilvie et al., 2006).

Secondly, repeated cross-sections from national household transportation surveys or census statistics are used to detect TB trends in the population across different spatial contexts (see Ortúzar et al., 2011 for an extensive review of continuous transportation surveys). Scheiner (2010) used the national travel survey in Germany to examine TB trends between 1976 and 2002, thereby differentiating between city size categories. They found that the gap in motorisation rates between cities and suburban/rural areas has become wider, an indication that the BE affects car use.

Thirdly, pseudo panels are constructed with spatial indicators. Tsai and Mulley (2014) use the pseudo-panel approach to estimate demand elasticities of public transport. They explicitly take into account the role of the BE with cohorts based on birth year and distances of the residential neighbourhood to the central business district. Results indicate that land use variables are important determinants of public transport demand in Sydney.

Even though valuable information about trends can be deduced, identifying causality with cross-sectional designs on the BE– TB is limited. To increase validity, multiple measurements can be conducted before and after the interventions. If a consistent break in the trend of TB occurs after the intervention, a causal effect is more likely. Furthermore, confounding variables can be controlled for to a certain extent by incorporating them in the research. Pseudo panels are often based on existing travel surveys in which typically no attitudinal data are collected. Therefore, it can be difficult to discern the impact of the BE from a confounding RSS effect (Weis & Axhausen, 2009).

Time Frames and Dropout

The application of multi-period designs comes with two overarching issues. First, it is often difficult to assess in advance which TB effects (or other effects, such as residential relocation and attitude changes) can be expected over what time span. An explicit study into the length of response lags (Chen & Chen, 2009) indicates that changes in the BE could trigger a behavioural change (by itself) quite promptly. However, depending on temporal constrains and family/social obligations, response lags of, on average, 1.5 – 3 years occur. Results of the natural experiment by Goodman et al. (2013) indicate that the majority of TB effects occur in the first year after introduction of new bicycle infrastructure. Only a slight increase in total effects occurred in the second year. Therefore, time frames of approximately one year, commonly used in natural experiments and observational studies in this field, seem appropriate. However, the appropriate length of time frames strongly depends on the type of TB determinants and interventions. For instance, causal lags in experimental studies with temporary promotional campaigns are shorter. Consequently, these studies have used shorter time frames of approximately three to six months. Car ownership changes involve longer causal lags. A three-year time span of a prospective longitudinal study appeared too short to assess these changes (Woldeamanuel et al., 2009). Quasi-longitudinal designs provide an alternative to assess general TB changes over longer time frames, although at the cost of reduced measurement precision. Research indicates that people are able to recall general changes in the amount of car driving up to eight years from present (Aditjandra et al., 2012). The recollection of long-term mobility decisions such as car ownership and public transport season tickets is even possible up to time spans of 20 years (Beige & Axhausen, 2012).

Second, observational and experimental designs place a higher burden on the respondents. Yet, survey response rates in the empirical studies did not seem significantly affected. It is noted that response rates for household travel surveys have been declining over time. The more recent studies with data collections from the late 2000s show response rates between 16% and 33% which fall within the typical 10 – 40% range of response rates for a general population survey (Sommer & Sommer, 1997). The dropout between research waves was a more prominent issue. It ranges between 6% and 46% at the second wave and steadily increases in follow-up waves. Providing financial and material incentives, emails and phone calls to remind respondents and especially establishing long-term contact between surveyor and respondent proved to be effective in reducing dropout rates (see Ortúzar et al., 2011; Van Wissen & Meurs, 1989; Yanez et al., 2010). More information on sampling requirements for measuring TB changes in before-and-after studies is available in Stopher and Greaves (2007).

2.6 Synthesis

This article provides a classification of multi-period designs and discusses the advantages and disadvantages with regard to the identification of causality and data collection. This section synthesises the main findings and provides recommendations for future multi-period research on the BE– TB link. A first and overarching conclusion is that future research should focus more on examining the impact of BE changes on TB. Second, even the most rigorous multi-period designs applicable to the BE– TB link do not eliminate the possibility of third variable bias. Therefore, it is required to perform multivariate analysis to identify third variable influences (see Figure 2.1) and the underlying causal links in all cases (see Cao et al., 2009). The selection of the most appropriate research design depends on the trade-off between higher ability to identify causality and lower practical applicability of research designs, hence, taken into account should be:

1. the research aim: a causal or associative study;
2. the required accuracy and precision levels of the data;
3. practical constraints and opportunities, including time, money, and existing data sets.

Below, we discuss the opportunities for causal and associative research that are available to study the relationships on the BE– TB link over time.

Causal Research

To identify causality on the BE– TB link, research designs should include at least two (preferably more) measurements over time. Only these designs enable to measure attitudinal changes and rigorously control for the confounding influence of RSS. Additionally, they enable an accurate and precise measurement of TB and its determinants and an estimation of the specific magnitude of effects. Two approaches can be used to assess the causal impact of BE changes directly:

1. natural experimental designs with comparison groups/areas that involve an explicit assessment of the impact of BE changes (e.g. new retail facilities, traffic calming schemes);
2. prospective longitudinal designs with comparison groups that involve the assessment of changes such as residential moves or job changes. Natural experiments provide the strongest case for causality because of the exogenous nature of the BE changes. For prospective longitudinal designs, care must be taken for the endogenous (self-selected) nature of the changes.

Two alternative approaches consider the BE characteristics as contextual factors and allow for the estimation of interaction effects with other determinants of TB:

1. randomised TB change experiments (e.g. promotional campaigns) that assess to what extent (changes in) BE characteristics contribute to the success of these experiments in terms of TB change;
2. prospective designs with comparison groups where the impact of life-course events (e.g. the arrival of a new baby, reaching old age) on TB is assessed across different spatial contexts over time. Again, for the prospective designs, caution should be given to the endogenous nature of these changes.

While designs with multiple observations of the same participants over time provide opportunities to identify causality, they generally take more time, require long-term motivation/support and are more complex. This complexity involves (1) increase in non-response in subsequent research waves (dropout), (2) the inability to select a proper comparison group/area, and (3) the timing of baseline and follow-up measurements. These issues and possible solutions are discussed in this article.

Alternative Multi-period Designs

A research question does not always require identifying causality - the desired time span may be too large and/or practical constraints may prevent the use of rigorous designs. In these cases, retrospective and repeated cross-sectional designs provide reasonable alternatives that still allow the study of changes over time. Retrospective studies are appropriate when (1) a study aims to assess general changes at the level of individuals or households, (2) results need to be obtained in a relatively short time period, or (3) the BE changes being researched have already occurred. However, applying retrospective designs to assess attitudinal changes is probably less reliable and the measurement precision of TB changes is compromised. The final fallback option is a repeated cross-sectional design, in case (1) the study aims to assess aggregate population changes or trends and/or (2) only data from a continuous travel survey are available.

The classification of the research designs presented in this article will aid to select appropriate designs in future research on the BE– TB link. It is important to bear in mind that the scope of this article was limited to quantitative approaches. This does not, however, diminish the merits of qualitative and mixed approaches which are well suited to investigate the underlying causal mechanisms and choice processes of the causal relationships on the BE– TB link. Additionally, this article did not explore in depth the methods and instruments of data collection. The emergence of new data collection technologies in this area, such as automated data collection (‘big data’), GPS-based methods and online questionnaires, offers opportunities to further reduce data collection burdens and for a broader implementation of multi-period designs.

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Chapter 3: Causal Effects of Built Environment Characteristics on Travel Behaviour: a Longitudinal Approach

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Abstract

The influence of the built environment on travel behaviour and the role of intervening variables such as sociodemographics and travel-related attitudes have long been debated in the literature. To date, most empirical studies have applied cross-sectional designs to investigate their bidirectional relationships. However, these designs provide limited evidence for causality. This study represents one of the first attempts to employ a longitudinal design on these relationships. We applied cross-lagged panel structural equation models to a two-wave longitudinal dataset to assess the directions and strengths of the relationships between the built environment, travel behaviour and travel-related attitudes. Results show that the residential built environment has a small but significant influence on car use and travel attitudes. In addition, the built environment influenced travel-related attitudes indicating that people tend to adjust their attitudes to their built environment. This provides some support for land use policies that aim to influence travel behaviour.

Keywords: attitudes, built environment, causality, longitudinal, residential self-selection, travel behaviour.

3.1 Introduction

Today, cities are facing challenges in terms of accessibility, including car congestion and retail-service accessibility, and in terms of sustainability, such as air pollution and carbon dioxide emissions, decreasing the overall quality of life. One approach to sustainable transportation is shaping the built environment to influence travel behaviour (Krizek, 2003a; Van Wee, 2011). Planning concepts have been developed to prevent or at least reduce urban sprawl, by preserving cohesive urban regions, aiming for compact cities (Europe) and promoting transit and pedestrian-oriented, mixed neighbourhoods in the US referred to as New Urbanism, Smart Growth and Transit-Oriented Development. The hypothesis underlying this approach seems rather intuitive: if low-density, single-use development patterns are associated with car dependency, promoting compact mixed environments that create proximity to destinations may encourage people to drive less. The question, however, is whether the processes of car dependency and urban sprawl can be so easily reversed (Banister, 2008).

To date, study outcomes generally provide some support for the hypothesis that policies that shape the built environment can be used to influence travel behaviour. Meta-analyses reveal that built environment characteristics, in particular the accessibility of destinations, exert an independent but small influence on travel behaviour (Ewing and Cervero, 2010; Gim, 2013). However, discussions about the influence of the built environment on travel behaviour remain. They mainly revolve around issues of causality, research design and methodology. Within the causality debate, the discussion has specifically focused on the role of travel-related attitudes and residential preferences. Two additional hypotheses have been formed that provide an alternative explanation for the associations on the link between the built environment and travel behaviour (hereafter referred to as the BE-TB link).

The first is the residential self-selection hypothesis that entails that households choose their residential neighbourhood based on their travel attitudes. If the majority of people would succeed in finding a neighbourhood that is congruent with these attitudes, these attitudes and the built environment characteristics would be highly correlated. Consequently, if these attitudes are not controlled for in the analysis, they would confound the estimation of the built environment effects which could lead to biased estimations of the impact of the built environment on travel behaviour (Handy et al., 2005; Chatman, 2009). For example, are associations between people's proximity to a railway station and their frequency of public transport use the result of a causal influence of the built environment on travel behaviour? Or do residents with positive attitudes towards using public transport self-select themselves into neighbourhoods in proximity to the railway station and therefore use these modes more often? The existence of self-selection doesn't mean that the built environment is irrelevant as the built environment enables people to self-select into areas that match their travel-related attitudes (Næss, 2009). However, the impact of the built environment on travel behaviour may be limited to people who already have a positive attitude towards public transport (Cao et al., 2009).

The second is the 'reverse causality' hypothesis where the built environment influences travel-related attitudes over time which in turn affect travel behaviour (Bagley and Mokhtarian, 2002; Chatman, 2009). Reverse causality may occur because people adjust their travel-related attitudes to their previous residential choices or because people come to appreciate the convenience of alternative travel modes after living in an area that is supportive to these modes for some time. For example, areas in close proximity to the railway station generally have a good transport provision and less favourable conditions for car use. This may influence people's perceptions of these mobility options and encourage more positive attitudes towards the use of public transport which in turn may encourage the actual use of public transport. Hence, the positive attitudes towards public transport in areas in closer proximity to the railway station may not be (solely) the result of residential self-selection. Instead, the built environment may influence travel behaviour as well as travel-related attitudes which amplifies (rather than weakens) its importance to bring about changes in travel behaviour. These issues will be elaborated on in the next section.

Consequently, the question here is what is the cause and what is the effect, and to what extent? Does the built environment influence travel behaviour directly or is there an indirect influence via attitudes? And if so, do travel-related attitudes primarily influence the built environment as a result of residential self-selection or does the built environment primarily influence travel-related attitudes? This distinction between cause and effect can only be achieved by means of a longitudinal study design. However, to date, most studies assess individual behaviour by applying cross-sectional designs and controlling for intervening variables such as sociodemographics and, increasingly, travel-related attitudes and residential preferences (Bohte, 2010). Although these studies provide valuable insights, they cannot identify causal relationships because they (i) do not assess the impact of the built environment on travel behaviour over time (ii) are vulnerable to third (confounding) variable influences and (iii) neglect the dynamics involving behavioural change (Handy et al., 2005; Kitamura, 1990; see for an overview Van de Coevering et al., 2015). In the last decade, some progress has been made on this issue by the introduction of (quasi-)longitudinal designs that incorporated travel-related attitudes and residential preferences to control for residential self-selection (e.g. Handy et al., 2005; Cao et al., 2009). However, to the best of our knowledge, no previous study has included measurements of travel-related attitudes at two or more moments in time. This precludes the assessment of directions of causality between travel-related attitudes, the built environment and travel behaviour.

To overcome the limitations of previous studies, we conducted a longitudinal study where travel behaviour and its determinants, including attitudes, are measured at two separate moments in time. This study aims to unravel the complex directions of causality between the built environment, travel behaviour and travel-related attitudes. We specifically aim to address the following research questions: (1) To what extent are (changes in) built environment characteristics associated with changes in travel behaviour, after controlling for sociodemographics and the bidirectional relationships with travel-related attitudes? (2) What is the dominant direction of influence between travel-related attitudes and the built environment; does attitude based residential self-selection primarily influence the built environment or does the built environment primarily influence travel-related attitudes over time? (3) How do travel-related attitudes and travel behaviour influence each other over time?

The dataset used in this study builds on previous work of Bohte (2010). Respondents who fully completed the survey in 2005 have been re-invited to participate in the second survey in 2012. To our knowledge, this is the first longitudinal dataset containing all information on travel behaviour, travel-related attitudes and the built environment. A cross-lagged panel structural equation model is applied to this dataset to test the bidirectional relationships over time. Such cross-lagged models make use of the time-ordered nature of panel data to empirically determine which variable is the cause and which variable is the effect. Because the method meets the criterion of time-precedence, it provides a stronger basis for making causal inferences. The modelling approach will be elaborated on in Section 4.

The organization of this paper is as follows: the next section provides an overview of current literature and specifically the role of attitudes in research on the BE-TB link; the third section describes the data collection and the key variables followed by section four that describes the modelling approach; the fifth section describes and discusses the modelling results, and the last section summarizes the main findings and discusses policy implications.

3.2 Literature and conceptual framework

The influence of the built environment on travel behaviour is one of the most researched topics in urban planning and has been discussed in many reviews (see: Van Wee and Maat, 2003; Boarnet, 2011, Ewing and Cervero, 2010, Gim, 2013). A couple of reviews have focused specifically on the role of travel-related attitudes and the issue of residential self-selection (e.g. Cao et al., 2009; Mokhtarian & Cao, 2008; Bohte et al., 2009). The aim of this section is to further elaborate on the relationships between travel-related attitudes, the built environment and travel behaviour and on the need for applying longitudinal designs to determine causality in these relationships.

Attitudes and behaviour

Attitude-based research in transportation studies is often based on attitude theories derived from social psychology such as the Theory of Planned Behaviour (TPB) (Ajzen, 1991) and Swartz's Norm Activation Model (Schwartz, 1977). It is beyond the scope of this article to discuss these theories in depth; however, in the context of the current article two notions are of paramount importance.

First, various definitions of attitude exist. In general terms, an attitude is a favourable or unfavourable elevation of an attitude object (e.g. place, situation or behaviour) based on a person's beliefs about that object (Ajzen & Fishbein, 1977). Attitudes are typically considered to be relatively enduring dispositions which exert a pervasive influence on behaviour (Ajzen, 1987). Attitudes in this article are based on the multidimensional definition of attitudes by Eagley and Chaiken (1993) which recognizes three components: (i) the affective component; the degree that people enjoy or like a particular behaviour (e.g. I enjoy travelling by bike) (ii) the cognitive component; the perceived likelihood that performance of a behaviour will lead to a particular outcome (driving a car is environmental unfriendly) and (iii) the conative component; the actual actions of people related to the behaviour in question (I would use the bike for commuting).

Second, it is acknowledged that there are other psychological determinants of behaviour besides attitudes. Although attitudes are believed to be important determinants of behaviour, the actual correspondence between attitudes and behaviour is sometimes reported to be low, leading to the expression of attitude-behaviour inconsistency (Gärling et al., 1998). The TPB provides two explanations for this inconsistency. First, attitudes do not influence behaviour directly but indirectly through their influence on intentions, which represent a person's motivation to actually enact the behaviour. Second, attitudes are not the only determinants of importance. The TPB identifies two additional determinants: subjective norms (perceived social pressure) and perceived behavioural control (perceived ability to perform the behaviour) (Arjzen, 1991). This study does not incorporate these additional psychological determinants. However, past behaviour is taken into account as human behaviour is (at least partly) habitual and as past behaviour is sometimes considered the best predictor for current behaviour, especially if circumstances remain relatively stable (Thøgersen, 2006; Bamberg et al., 2003).

Attitudes in research on the BE-TB link

Figure 3.1 conceptualises the relationships between the built environment, travel behaviour and third variables: individual and household characteristics, travel-related attitudes (TA) and preferences. At the start of the causality debate, most studies hypothesized the direct relationship between the built environment and travel behaviour (link 8). The studies done by Newman and Kenworthy (1988, 1999), which assessed the influence of urban densities on per capita energy use in a large range of world cities, are famous examples. During the 1990s more cross-sectional studies appeared on the BE-TB link, most of them controlling for the influence of sociodemographics (link 3) and latterly attitudes (link 7) on travel behaviour. Cervero and Kockelman (1997) provided additional evidence for the influence of built environment on travel behaviour and coined the idea of the 3Ds, density, diversity and design, later extended to include destination accessibility and distance to public transport (Ewing & Cervero, 2001; Ewing and Cervero, 2010).

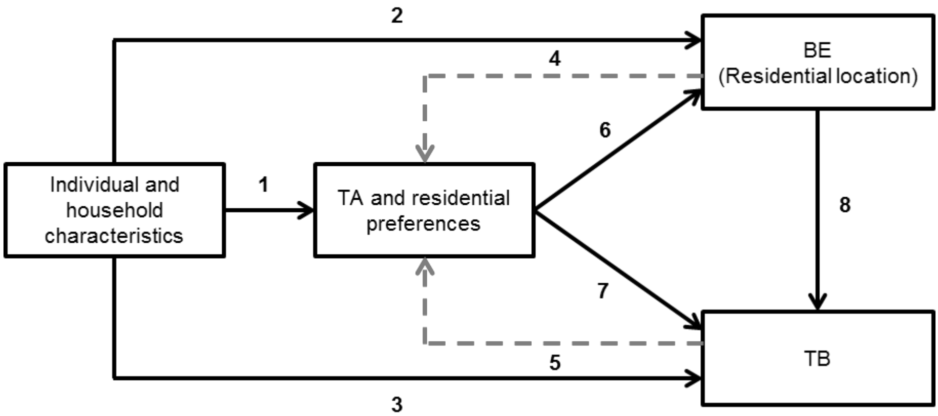

Figure 3.1. Conceptual model of relationships between BE-TB and intervening variables. Adjusted from Bohte (2010).

Policy concepts like New Urbanism, Smart Growth, Transit-Oriented Development and Compact City policies include these principles and aim at reducing car use and travel distances while simultaneously enhancing accessibility. The underlying hypothesis is that compact mixed-use environments provide proximity between destinations which enhances opportunities of slow modes such as walking and biking. In addition, these more compact mixed developments spatially concentrate travel demand making the provision of public transport easier and more profitable which in turn enables a higher level of service. Furthermore, the number of vehicle kilometres driven may decline because the distances that need to be covered between destinations are smaller (Van Wee, 2011). Most studies have provided support for this hypothesis, ceteris paribus: residents of higher density, mixed-use developments with good facilities for public transport, cycling and pedestrians and with short distances to destinations tend to drive less and make more use of alternative transportation modes. The built environment seems to have small but significant associations with travel behaviour at different levels of aggregation ranging from regional accessibility to local street designs (Krizek, 2003b). Destination accessibility, the ease of access to trip attractions, appears to be most strongly associated with travel behaviour (Ewing and Cervero, 2010; Gim, 2013).

Since the end of the 1990s, the residential self-selection hypothesis has become one of the prime topics in the discussion about causality. The general definition of residential self-selection is "the tendency of people to choose locations based on their travel abilities, needs and preferences" (Litman, 2005: p6). Residential self-selection generally results from two sources: individual and household characteristics (e.g. sociodemographics) and attitudes (link 2 and 6).

In the last decade, the importance of attitude-induced residential self-selection has increasingly been recognized. An example of attitude induced self-selection occurs when someone who prefers to walk settles in a neighbourhood that is conducive to walking and consequently walks more. In this case, it is not the built environment alone that causes someone to walk. Rather it is the combination of a person's pre-existing positive attitude and the selection of a neighbourhood conducive to walking that makes more walking possible. Then, the impact of the built environment on travel behaviour may be limited to people who already favour walking and effects on people who are for instance car-oriented may be limited.

Kitamura et al. (1997) were one of the first to discuss the role of travel-related attitudes. They concluded that attitudes are more strongly associated with travel behaviour than are characteristics of the built environment and noted that lifestyle choices and attitudes are probably relevant to both the selection of a residential neighbourhood and travel behaviour. If the associations between attitudes and residential choice would indeed be dominant, the observed associations on the BE-TB link may be attributed to residential self-selection. After the study of Kitamura et al. (1997) more studies appeared which assessed the influence of residential self-selection. The research outcomes are mixed (Ewing & Cervero, 2010). Using the dataset of Kitamura et al. (1997), Bagley and Mokhtarian (2002) explicitly controlled for residential self-selection based on travel-related attitudes and the built environment. They found that attitudinal and lifestyle variables were most strongly associated with travel behaviour and that built environment characteristics had little influence. Lund (2003) came to comparable results in a study on the frequency of walking trips. Conversely, Schwanen and Mokhtarian (2005) found that even after controlling for attitudes and mismatches, the built environment still exerts a significant influence on travel behaviour. They assessed the role of attitudes by incorporating an attitudinal-based measure of dissonance between one's preferred and actual neighbourhood types. Bohte (2010) also found a significant influence of the built environment after controlling for attitudes. For a more extensive insight, we refer to reviews that focused on the role of attitudes and the issue of residential self-selection (e.g. Cao et al., 2009; Mokhtarian & Cao, 2008; Bohte et al., 2009).

The 'reverse causality' hypothesis, where the built environment influences travel-related attitudes [link 4], has received considerably less attention in studies on the BE-TB link. The same holds for reverse causal relationships between travel-related attitudes and travel behaviour (link 5). Reverse causality may occur for two reasons. First, according to the well-known theory of cognitive dissonance (Festinger, 1957) people may not only adjust their behaviour but also their attitudes if dissonance occurs between the two. In this case, people may adjust their travel-related attitudes to their previous residential choices. Second, according to Cullen's model (1978) people will have positive and negative experiences during their daily routines in their current social and spatial context (for instance a lack of public transport provision). Consequently, they will develop and adjust certain attitudes and preferences towards their daily routines (less favourable towards public transport use) but also towards longer-term life choice decisions (residential and job location choices).

The earlier mentioned study of Bagley and Mokhtarian (2002) was also one of the first to take into account the reverse influences of the built environment and travel behaviour on travel-related attitudes. This study found no reverse effects of the built environment on travel-related attitudes, but the number of vehicle miles driven had a small but significant influence on pro-driving attitudes. More recently, findings of Bohte (2009) did suggest reverse causal influences on these relationships: the distance to the railway station appeared to have a relatively strong negative effect on respondents' attitudes towards using public transport and the share of car trips negatively influenced attitudes towards cycling and positively influenced their attitude towards car use. A few transportation studies specifically explored reverse causality between travel-related attitudes and travel behaviour and provided support for this reverse causal hypothesis (Tardiff, 1977; Golob, 1979; Tertoolen (1998) Thøgersen (2006).

Recently, the question was raised whether it is possible to convincingly test the bidirectional causal effects between the built environment, travel behaviour and travel-related attitudes, using cross-sectional research designs (Krizek, 2003; Handy et al., 2005). To identify a causal relationship on the BE-TB link four conditions should be met (Singleton and Straits, 2009; Shadish et al., 2002): (1) association; the built environment and travel behaviour are statistically associated, (2) non-spuriousness; the relationship between the built environment and travel behaviour cannot be attributed to another confounding variable (3) time precedence; the influence of the built environment (the cause) precedes a change in travel behaviour (the effect) in time and (4) plausibility; there should be a logical causal mechanism for the cause and effect relationship. Previous cross-sectional studies have met the first condition but hardly the other three (Handy et al., 2005).

The application of more rigorous (quasi-)longitudinal approaches is still limited on the BE-TB link. A couple of studies used prospective longitudinal designs and found a significant influence of the built environment (Krizek, 2003a; Meurs and Hajer, 2001) but these did not include travel-related attitudes. Bamberg (2006) did incorporate attitudinal questions before and after a residential move but did not explicitly assess the impact of changes in the built environment on travel behaviour. The studies of Handy et al. (2005) and Cao et al. (2007) used a quasi-longitudinal research design based on retrospective questioning. However, as retrospective questioning on attitudes is generally considered unreliable, these studies only controlled for current attitudes. They concluded that residential self-selection influences the relationship between the built environment and travel behaviour but that the built environment still exerts an independent but small influence on travel behaviour.

To the authors' knowledge, there have been no studies on the BE-TB link that have applied a prospective longitudinal design and have included the measurement of travel-related attitudes on two or more moments in time. Furthermore, reverse causal effects from travel-related attitudes to behaviour have been scarcely studied. This article builds on the current literature and aims to reduce this gap by evaluating the bidirectional relationships between (changes in) the built environment, travel-related attitudes and travel behaviour over time.

3.3 Data and methods

Data collection

This study builds on previous work and the previous data collection of Bohte (2010) who also studied the role of attitudes in residential self-selection. For this purpose, data was collected in three municipalities in the Netherlands in 2005: Amersfoort, a medium-sized city, Veenendaal, a small town with good bicycle facilities and Zeewolde, a remote town. Within these municipalities, different types of residential areas were selected ranging from historical centres to suburban areas, and representing a wide variety of built environment characteristics, including car-friendly, bicycle-friendly and public transportation friendly areas (see Figure 3.2). GIS-software was used to obtain detailed data on land use, infrastructure and accessibility. From each of these areas, a random sample of households was drawn from the civil registries, limited to homeowners because renters have a very limited choice set which hinders self-

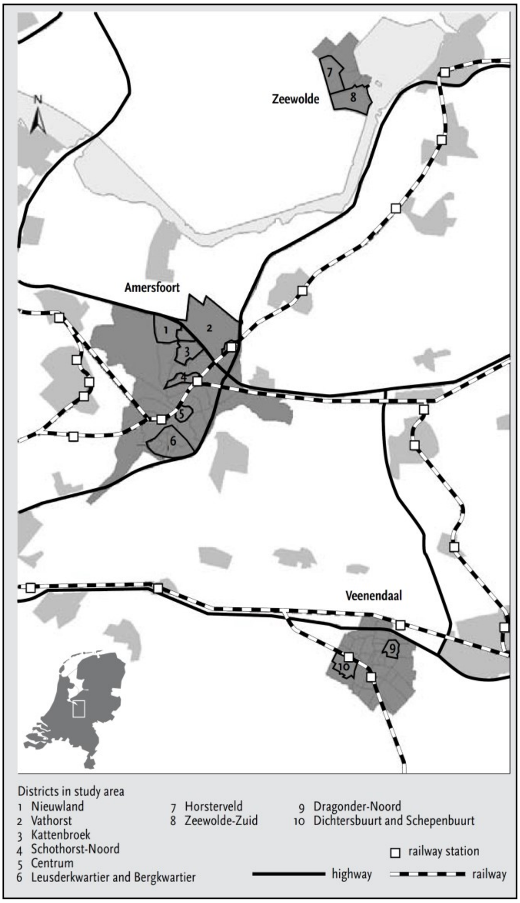

Figure 3.2. Study area. Source: Bohte, 2010.

selection on the Dutch housing market (Bohte, 2010). An internet questionnaire was conducted in 2005 with questions about demographic, socioeconomic, attitudinal and travel-related characteristics. Both partners in a household were asked to participate. From the 12.836 people who were approached, 3.979 completed the questionnaires – a baseline response rate of 31% (Bohte, 2010). After this initial data collection round, annual postcards and emails were sent to maintain contact with the respondents and respondents were invited to provide information regarding house moves and changes in contact details. We were able to contact approximately 3300 respondents (83%) again for a second-round questionnaire in 2012. The other respondents dropped out for a variety of reasons (e.g. house moves to an unknown destination, changed and unknown contact details, and some had passed away). From these 3300 respondents, 1788 participants from 1325 different households participated again in the second round, a response rate of 54%. Logistic regression was conducted to test whether a systematic drop-out had occurred between the research rounds. Results revealed that younger and less educated respondents, females and respondents from households with young children were more likely to drop out.

For this second wave, we only selected participants that had participated in both questionnaires. Due to the selection of homeowners at baseline, the ageing of our sample (also called stagnation effect), and the selective dropout, older people with a higher education level and higher incomes are overrepresented in our sample compared to population statistics of the neighbourhoods. The relatively high average age (57 years) in the second wave is apparent. Still, our panel encompasses 425 people aged between 33 and 51. To avoid any problems with dependency of observations in the analysis, we randomly selected one of the partners from the 463 households of which both partners participated. Furthermore, a couple of cases were removed because their data was incomplete on important variables. As a result, 1322 respondents were included in analyses for this article. In addition, new GIS analyses were conducted to obtain data on the spatial characteristics in 2012 and 2005 and changes that occurred over this time period.

Variables

Table 3.1 provides an overview of the key variables and their descriptive statistics in the first (2005) and second wave (2012). Travel behaviour was assessed with the question: "How often do you use the car compared to other modes such as public transport, bicycling and walking". Responses were provided on a 7-level Likert scale ranging from 1: "Almost never with the car and almost always with alternatives” to 7 “Almost always with the car and never with alternatives”. On average, respondents used their cars quite often. A single question is not a very precise measure to assess the various (sub)dimensions of an individual’s travel behaviour such as distances or travel times travelled and split by mode. However, deriving the mode split by asking people for their travel distances or travel times per mode, may offer pseudo-accuracy, while this simple measure directly reflects how people assess their mode split. Moreover, another benefit is that the full complexity of a person’s travel behaviour can be parsimoniously captured.

Attitudes towards car use, cycling and public transport use were measured by asking respondents to rate 9 statements on a 5-level Likert scale, ranging from –2 ‘strongly disagree’ to +2 ‘strongly agree’. These statements included affective (e.g. “driving a car is pleasurable”) as well as cognitive (e.g. “bicycling is environmentally friendly”) aspects. The 9 responses were then summed up to determine a person’s travel-related attitudes. An additional attitude variable was weighted by the importance, measured on a 5-level scale, to reflect that people do not always attach the same importance to each of these aspects, which can lead to an overvaluation of non-salient and unimportant beliefs. As the weighted and unweighted TA yielded highly similar results, we used the unweighted one. The mean values in Table 3.1 indicate that cycling attitudes are most positive, whereas public transport attitudes are negative.

The built environment was operationalized by measures of accessibility. Shortest routes between respondents’ homes to a variety of destinations were calculated along the network (source of road network: Dutch National Roads Database (NWB, 2013). Destinations included, amongst others, the municipal centre, the neighbourhood shopping centre, the nearest railway station and bus stops (with different levels of service) and highway ramps. Also, distances to services such as supermarkets, restaurants and pubs were measured. The coordinates of the destinations were derived from a retail database (Locatus, 2013) and the national employment database (LISA, 2013). Two types of accessibility measures were included in the analyses: (i) the distance to the nearest occurrence of each type and (ii) the number of locations of each type within 400, 3000 and 10.000m.

The average decline in the distance to the nearest railway station can be attributed to the opening of a new railway station in Amersfoort (Vathorst) which opened in May 2006. Sociodemographic variables included gender, age, household income, household composition, educational level and economic status. The majority of homeowners in our sample live together with a partner and have a relatively high education level and income. Most households own one or two cars (with an average of 1.5 cars per household). The table shows a couple of apparent changes in the panel; the number of partners without children has increased as children left the house and the number of people without a job increased due to people reaching pension age and due to job losses related to the economic crisis. However, the overall statistics cover the underlying dynamics in the sample. Almost 1 in 5 respondents moved house and 1 in 4 experienced changes in their job location. Also, considerable changes occurred in car ownership levels and travel behaviour.

Table 3.1 Key variables in 2005 and 2012 (N=1322).

Variables	Description	2005 Mean (st.dev)	2012 Mean (st.dev)
Travel behaviour variables			
Modal choice	Amount of car use compared to other modes	4.8 / (1.9)	4.7 (1.9)
Attitudinal variables			
Travel-related attitudes	Car attitude	2.8 (4.9)	3.5 (4.7)
	Public transport attitude	-4.8 (5.8)	-3.8 (6.1)
	Bicycle attitude	9.0 (4.9)	9.3 (5.1)
Built environment variables			
Residential location	Amersfoort	41.2%	39.7%
	Veenendaal	27.0%	26.8%
	Zeewolde	31.8%	28.7%
	Other	0%	4%
Average distances	To municipal centre	1949 (775) m	1955 (870) m
	To nearest shopping centre	1123 (778) m	1161 (819) m
	To nearest railway station	6150 (5458) m	5627 (5721) m
	To nearest bus stop	604 (566) m	495 (483) m
	To nearest highway ramp	5491 (5001) m	5255 (5048) m
Sociodemographics			
Age	Average	50.4 (10.6)	57.4 (10.6)
Gender	Female	42.7%	42.7%
	Male	57.3%	57.3%
Household composition	Single household:	7.1%	9.3%
	Single parent	1.7%	2.6%
	Partners without children	34.2%	44.3%
	Partners with children	56.4%	42.7%
	Other	0.6%	1.1%
Education	Low:	9.9%	9.6%
	Medium	37.6%	36.5%
	High	52.5%	53.9%
Net personal income (monthly)	Low (< € 1.000)	19.0%	12.2%
	Middle (>=€1.000,-< €2000,-)	39.4%	33.1%
	High (>€2000,-)	42.6%	54.7%
Paid work	No job	20.3%	31.3%
	Part-time job (< 30 hours)	24.9%	21.3%
	Fulltime job (>= 30 hours)	54.8%	47.4%
Car ownership	No car	2.5%	3.0%
	One car	51.9%	52.3%
	Two cars	41.4%	40.9%
	More than two cars	4.2%	3.9%
Dynamics in panel		*Change*	
Residential location and work location	Number of movers in database	250 (19%)	
	Number of changes in job location	315 (24%)	
Car ownership	Decrease	14.1%	
	No change	72.7%	
	Increase	13.2%	
Modal choice (car use compared to other modes)	Decrease	31.8%	
	No change	39.0%	
	Increase	29.0%	

3.4 Modelling approach and specification

Modelling approach
As mentioned in the introduction, in this paper we apply the Cross-Lagged Panel Model (CLPM) within a framework of structural equation modelling (SEM). The CLPM is well suited to assess the causal dominance among the variables of interest. In this model, each variable is regressed on its own values and on the values of other variable(s) of interest at a previous point in time. The autoregressive effect from each variable on itself at a later time reflects its stability. A small effect indicates that a substantial change has occurred over time whereas a large effect reflects high stability and little change over time. The remaining variance, after controlling for the autoregressive effects, can be ascribed to changes in the period between the measurement occasions. This variance may be (partially) explained by the cross-lagged effects from other variables at a previous point in time. If another variable has a significant cross-lagged effect, while accounting for the initial overlap between the variables at the first point in time, this variable can effectively predict 'change' in the first variable from the first point in time to the next (Selig & Little, 2012). Hence, in contrast to cross-sectional analyses, CLPMs are able to satisfy the criterion of time-precedence empirically (Finkel, 1995). It thus provides a stronger basis for making causal inferences.

Specification
Figure 3.3 shows the specification of the relationships between the built environment, travel behaviour, travel-related attitudes and household characteristics (as depicted in Figure 3.1) in the CLPM. The built environment is reflected by the built environment characteristics of the residential location, respondents' travel behaviour is reflected by mode use and travel-related attitudes are reflected by mode attitudes. In addition, baseline values, as well as changes in sociodemographics, are included.

In this model, correlations C1, C2 and C3 account for the initial overlap between the variables (due to previous causal influences vice-versa or possible shared causes), S1, S2 and S3 represent the stability coefficients, and L1 – L6 represent the over-time (cross-)lagged influences between mode use, travel-related attitudes and the built environment. In addition, D1 – D3 represent the influences of sociodemographic variables (and changes in these variables) that were included as control variables. It is assumed that the baseline values of the sociodemographic characteristics may influence travel behaviour and travel-related attitudes both at the first point in time (reflecting cross-sectional relationships) and at the second point in time (reflecting longitudinal relationships). The changes in the sociodemographics are only assumed to affect mode use and travel-related attitudes at the second point in time. Hence, it is assumed that travellers only respond to changes in these variables (lagged effects) and do not change their mode use or attitudes in anticipation of these changes (lead effects). Correlations C4, C5 and C6 account for the association that remains after accounting for the stability (S1, S2 and S3) and cross-lagged effects (L1-L6) and the included covariates (D1-D3). The significance and strength of the parameters L1-L6 indicate the primary direction of causality and allows us to answer the questions: does this relationship primarily run from travel-related attitudes to travel behaviour; is the reverse influence of travel behaviour on attitudes stronger or do effects run in both directions?

Synchronous effects, e.g. from travel-related attitudes to mode use at the second point in time and/or vice versa, are not modelled. A synchronous effect should be understood as a change in one variable at the second occasion resulting from a change in the other variable at some time after the first occasion. While it is certainly theoretically justifiable to include such synchronous effects in the present application (because of the long-time interval between measurement occasions), the inclusion of these effects will lead to problems with endogeneity (explanatory variables will be correlated with error terms) and possibly also identification problems (when it is not possible to uniquely estimate all of the model's parameters (see Kline, 2010)). We therefore decided not to include these effects in the model. It should be noted, however, that while the model is not able to provide direct evidence in favour of synchronous effects, the strength and significance of the C4-C6 correlations will inform us whether synchronous effects are likely present or not.

Finally, measurement errors of attitudes have been accounted for in the analyses. This feature is especially relevant with respect to the travel-related attitudes, as they (unlike the other variables in the model) can be conceptualized as latent constructs. To indicate that the travel-related attitudes are treated as such, they are represented as circles in the model.

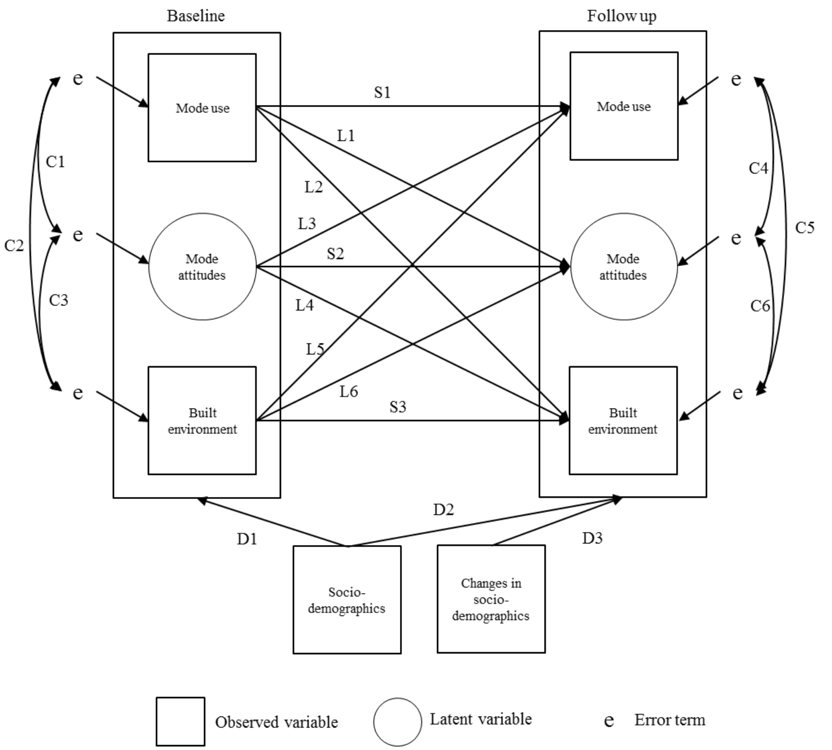

Figure 3.3. Specification of the cross-lagged panel model.

Specification issues

The maximum likelihood (ML) estimation, the most often used method in SEM, was applied. In ML, the multivariate normality is assumed for the distribution of the endogenous variables. In practice, many studies fail to meet this condition. Even though ML parameter estimates seem relatively accurate in large samples, the estimated standard errors tend to be too low which

results in type I errors (a 'false' significant effect). Statistical test of model fit also tend to be too high which results in a rejection of a 'correct' model (Kline, 2010).
Distances to destinations and car ownership were non-normally distributed (which is a common characteristic of these variables). Transformations to meet the normality assumption were considered but this did not result in a more normal distribution. To assess the impact of non-normality, a mean- and variance-adjusted weighted least square parameter estimator (WLSMV) was also applied on the same CLPM as an alternative estimator. WLSMV is a robust estimator which does not require normal distributions (Kline, 2010). Both estimation methods led to a comparable result which suggests that the non-normal distributions did not significantly affect the model outcomes. However, in some models the WLSMV estimator did not converge, which may be due to the fact that this estimator typically requires a larger sample size than the ML estimator. Therefore, in the next section, only the results of the ML estimation are discussed.
In addition, it is argued that the impact of non-normality is reduced in larger samples. Following Cao et al. (2007), the ratio between sample size and the number of observed variables and the power for hypotheses testing in our sample was assessed. The ratio between our sample size and the number of observed variables is relatively large (1322/24=55) compared to the suggested minimum ratio of 15 (Stevens, 1996). In addition, with 59 degrees of freedom, the power for hypotheses testing is 0,99 for sample sizes larger than 500 (MacCallum et al. 1996). Due to the large sample and high power, the impact of non-normal distributions in this research is reduced.
Previous studies on the BE-TB link have often resulted in mixed outcomes (see literature review). This can be attributed to a variety of reasons including different estimation methods and the type of control variables that are included in the analyses. To enrich the understanding regarding the impact of control variables on the research outcomes, multiple SEM models were built and differences in outcomes were assessed. The outcomes of the two models will be described in detail in the following section. In the first model, effects were estimated for the endogenous variables, namely mode use, mode attitudes and built environment characteristics. In the second model, we first added sociodemographic control variables (considered exogenous) and then car ownership (considered endogenous). The influence of car ownership has been estimated separately because most of the households in our sample own one or two cars. Consequently, its distribution is non-normal which does not comply with the data distribution requirements of endogenous variables in SEM. By including car ownership in a separate model, we have been able to assess its impact on the relationships between other variables in the model. This impact proved to be very limited. Therefore, it was decided to include the effects of car ownership in the description of the outcomes of the second model. Nevertheless, the results with regard to car ownership should be interpreted with considerable caution.

3.5 Results

Tables 3.2 and 3.3 present the unstandardized and standardised estimates of the two models; Model 1 includes only endogenous variables, while in Model 2 also sociodemographic variables (considered exogenous) and car-ownership (considered endogenous) were added. The relationships between the baseline sociodemographics and the built environment, mode use and mode attitudes in 2005 (link D1 in figure 3.3) are included in the continued part of Table 3.3. The results will be discussed according to our research questions and a number between brackets (#) will be used to refer to the links in the model conceptualisation in Figure 3.3.

The final models were constructed through model trimming, that is, that all non-significant relationships were removed from the models. Variables that were left with no path were removed from the model. It is important to note that these included the dummies for job changes (yes/no) and residential relocation (yes/no) because they yielded no significant results. The overall fit statistics of the models are included in the tables. All models appear to have good fits. Chi-square statistics indicate that the models could not be rejected at the 1 per cent probability level ($p<0.01$). RMSEA (values of less than 0.05 indicate good fit); TLI and CFI (closer to one indicate better fit) also indicate a good fit. This is not surprising since we removed non-significant results from a saturated model.

The influence of the built environment on travel behaviour

The results of the Model 1 indicate one significant effect of the built environment on travel behaviour: those living further away from the railway station in 2005 have a higher share of car use in 2012 [L5]. Hence, 'continued exposure' to low PT access induces higher car use over time. This outcome corroborates earlier findings of Bohte (2010) based on the cross-sectional dataset of 2005 and provides stronger evidence for causality in this relationship as the influence of built environment characteristics precede the change in car use in time, thereby meeting the time precedence criterion for causality. Surprisingly, this lagged influence of the built environment is relatively strong; the standardized effect is stronger than the standardized effects of the individual travel-related attitudes, sociodemographics and car ownership. Other determinants of the built environment (such as distances to local shopping areas and other destinations and the proximity to activity places) do not seem to exert a significant influence on the share of car use.

Model 2 shows that the inclusion of the sociodemographic control variables only marginally affects the influence of the distance to the railway station on travel behaviour. Interestingly, there are no significant lagged effects of baseline sociodemographics or 'change' variables such as residential moves, job changes or changes in household composition on travel behaviour in 2012 [D2-D3]. Nevertheless, the baseline sociodemographic variables significantly add to the explanation of the initial travel behaviour in 2005 [D1]. This confirms the adage, "association does not prove causation". Apparently, a large portion of the influence of the baseline sociodemographic variables on travel behaviour in 2012 is captured by the stability effect of travel behaviour from 2005 [S1] and changes in sociodemographics cannot explain the changes in travel behaviour in 2012. Compared to travel behaviour, the distance to the railway station is clearly more stable over time [S3]. Nevertheless, sociodemographic variables exert small but significant influences on this variable [D2]. Older respondents and those living together in households with children (compared to single-person households) in 2005 tend to increase their distance from the railway station in 2012 while the opposite applies to respondents that worked fulltime in 2005.

Car ownership is significantly influenced by the built environment over time: people living further away from the railway station in 2005 not only have a higher share of car use but also higher car ownership rates in 2012. In turn, car ownership significantly influences travel behaviour: people who own more cars in 2005 have a higher share of car use in 2012. In addition, car ownership not only influences travel behaviour but the reverse is also true: higher car use in 2005 has a positive effect on car ownership in 2012. Hence, these findings support earlier findings that car ownership (partly) mediates the link between the built environment and travel behaviour (Handy et al., 2005; Cao et al., 2007).

Influences between attitudes and the built environment

Model 1 does not reveal any significant influences of the lagged travel-related attitudes (2005) on the distance to the railway station in 2012 (or any other built environment determinant). Note that this may partially be related to the high stability of this variable over time [S3]. Conversely, significant longitudinal effects are found in the opposite direction: people living further away from the railway station not only increase their car use over time but also develop a more favourable attitude towards the car and a less favourable attitude towards PT [L6]. Hence, the 'continued exposure' to low PT access not only induces car use but also affects attitudes providing support for the reverse causality hypotheses on this link as suggested by Handy et al. (2005), Bohte (2010) and Chatman (2009).

The inclusion of the sociodemographics and car ownership in Model 2 (Table 3.3) only slightly affects the reverse influence of the built environment on travel-related attitudes which supports the robustness of these parameter estimates. Without discussing the effects of the sociodemographic characteristics in too much detail, it can be observed that, overall, the signs of the baseline effects in 2005 and lagged effects are in expected directions [D1-D2]. For example, men have a more favourable attitude towards the car (compared to women) and, over time, develop an even more favourable attitude towards the car. Highly educated people, on the other hand, have a more positive PT attitude (compared to people with a medium education level) and over time develop a more negative attitude towards the car. Another interesting finding is that people who are older at baseline tend to develop a more positive attitude towards PT over time. Car ownership is significantly related to the distance to the railway station and also effects travel-related attitudes: people with higher car ownership in 2005 tend to develop a more positive attitude towards the car and a more negative attitude towards public transport.

Influences between attitudes and travel behaviour

In model 1, car use in 2012 is positively influenced by the car attitude in 2005 and negatively by the cycling attitude in 2005 (Table 3.2). Hence, the baseline travel-related attitudes are able to predict changes in people's car use over time [L3]. It seems that the direction of influence primarily runs from attitudes to travel behaviour. However, reverse causality is also found on this link: higher car use in 2005 has a positive effect on car-related attitudes in 2012 [L1]. Furthermore, it is apparent that the autoregressive relationships are strong. The dictum, "past behaviour is the best predictor of future behaviour" seems to apply: higher car use in 2005 has a strong positive effect on car use in 2012 [S1]. The stability of travel-related attitudes is noticeably higher than the stability of travel behaviour; the car attitude is most stable [S2]. This is in line with expectations since behaviour is assumed to be more volatile than attitudes. Aside from the autoregressive effects, a more positive PT attitude in 2005 has a small but significant negative influence on the bicycle attitude in 2012. This is also the only significant interaction between attitudes which implies that attitudes towards a certain transport mode generally do not influence the attitudes towards the other modes over time.

The inclusion of sociodemographics and car ownership (Model 2) results in an important finding: the reverse influence from car use (2005) on car-related attitudes in 2012 is no longer significant while the influence of car attitudes (2005) on car use (2012) is strengthened. This suggests that the reverse causality from car use on car-related attitudes in the previous model was a spurious result related to the omission of the sociodemographic control variables.

Table 3.2 Model 1 with endogenous variables only (N=1322).

Endogenous variables 2012	Travel behaviour		Attitudes towards transport modes						Built environment	
Variables 2005	Car use 2012		Att. car 2012		Att. PT 2012		Att. bicycle 2012		Distance to railway station 2012	
	b	β	b	β	b	β	b	β	b	β
Travel behaviour										
Car use 2005	0.490**	0.490	0.164**	0.077						
Attitudes										
Att. car 2005	0.056**	0.125	0.707**	0.745						
Att. PT 2005					0.739**	0.696	-0.058**	-0.066		
Att. bicycle 2005	-0.054**	-0.121					0.693**	0.648		
Built environment characteristics										
Distance railway station 2005 (km)	0.048**	0.135	0.047**	0.063	-0.157**	-0.153			0.975**	0.931
	R^2= 0.44		R^2= 0.76		R^2= 0.85		R^2= 0.81		R^2= 0.87	

Chi-square: 14.140, 13 df, p: 0.3640, RMSEA: 0.008 , Prob. RMSEA <= .05: 1.000, TLI: 1,000, CFI: 0.999

Table 3.3 Model 2 with car ownership and controls for sociodemographics (N=1322).

Endogenous variables Exogenous variables	Travel behaviour Car use 2012		Attitudes towards transport modes Att. car 2012		Att. PT 2012		Att. bicycle 2012		Built environment Distance to railway station 2012		Car ownership # cars in hh. 2012	
	b	β	b	β	b	β	b	β	b	β	b	β
Travel behaviour												
Car use 2005	0.468**	0.468									0.025*	0.071
Attitudes												
Att. car 2005	0.055**	0.123	0.711**	0.748							0.014**	0.090
Att. PT 2005					0.723**	0.679	-0.059*	-0.067				
Att. bicycle 2005	-0.054**	-0.121					0.708**	0.660				
Built environment												
Distance railway station 2005	0.046**	0.132	0.051*	0.068	-0.138**	-0.135			0.981**	0.936	0.011**	0.093
Car ownership												
# cars in HH 2005	0.141*	0.047	0.405*	0.064	-0.454*	-0.052					0.462**	0.442
Sociodemographics												
Gender (ref=female) 2005			0.590**	0.071								
Age 2005					0.026*	0.049			0.020**	0.037	-0.010**	-0.160
High education level (ref=middle) 2005			-0.513*	-0.063							0.071*	0.052
Low income (ref=middle) 2005											0.150**	0.073
Work_fulltime_2005							1.012**	0.109	-0.328**	-0.029		
Family with children (ref= single-person hh) 2005									0.333**	0.029		
	R^2= 0.44		R^2= 0.76		R^2= 0.85		R^2= 0.81		R^2= 0.87		R^2= 0.35	

Table 3.3 Model 2 with car ownership and controls for sociodemographics (N=1322) (continued).

Endogenous variables	Travel behaviour		Attitudes towards transport modes						Built environment		Car ownership	
Exogenous variables	Car use 2005		Att. car 2005		Att. PT 2005		Att. bicycle 2005		Distance to railway station 2005		# cars in hh. 2005	
	b	β	b	β	b	β	b	β	b	β	b	β
Sociodemographics												
Gender (ref=female) 2005	0.850**	0.219	2.226**	0.256			-0.926**	-0.106	0.673	0.061		
Age 2005	-0.025**	-0.139	-0.046**	-0.113	0.064**	0.129			-0.132**	-0.257	-0.004*	-0.066
High education level (ref=middle) 2005	-0.179	-0.047	-0.590*	-0.068	0.914**	0.087			-0.942**	-0.086		
Low income (ref=middle) 2005	-0.548**	-0.094	-0.951*	-0.072								
Work_fulltime_2005									-0.920*	-0.084		
Family with children (ref= single-person hh.) 2005	-0.564**	-0.146	-0.706*	-0.081	-0.578	-0.054	0.824**	0.095			0.210**	0.162
	R^2= 0.090		R^2= 0.089		R^2= 0.029		R^2= 0.021		R^2= 0.058		R^2= 0.038	

Chi-square: 52.748, 59 df, p: 0.7038, , RMSEA: 0.000 , Prob. RMSEA <= .05: 1.000, TLI: 1,00, CFI: 1,00

Correlations between error terms

The results of the three models above show that the autoregressive effects [S1-S3] are (very) strong, but that the cross-lagged relationships between the endogenous variables [L1-L6] are rather weak. Two possible explanations can be offered. One is that the relationships between the endogenous variables are simply not that strong. The other explanation is that the time-lag (7 years) is probably rather long compared to the true lags with which the endogenous variables influence each other. In attitude theory, influences between attitudes and behaviour are assumed to be rather direct. However, the influence of positive and negative daily experiences on attitudes as described in Cullen's (1978) model, evolve more slowly (Thøgersen, 2006). Research of Chen and Chen (2009) indicates that behavioural effects of built environment changes could take up to 3 years to materialize. The long time-lag in the panel increases the likelihood that additional changes occur in one of the endogenous variables or in other (unobserved) variables after the first measurement point in 2005 that affect the values in 2012. The correlations between the error terms of the travel-related attitudes and car use (C1-C3 in 2005 and C3-C6 in 2012) indicate that this could indeed be the case here (see Table 3.4).

Table 3.4 Correlations between error terms of endogenous variables in 2005 and 2012.

	Car use	Car attitude	PT attitude	Bicycle attitude	Distance railway station
Car use	-	0.199**	-0.138**	-0.127**	0.096**
Car attitude	0.425**	-	-0.109*	0.155**	0.037
PT attitude	-0.296**	-0.379**	-	0.150**	-0.019
Bicycle attitude	-0.344**	-0.241**	0.344**	-	0.073*
Distance railway station	0.306*	0.150**	-0.175**	-0.049	-

*p<0.05, **p<0.01

The correlations in the lower left triangle represent the initial overlap between the travel-related attitudes, car use and the built environment in 2005. It can be observed that significant and moderately strong correlations exist and that the signs are all in the expected directions. The correlations in the upper left triangle represent the correlations between the endogenous variables that remain in 2012 (after accounting for the stability, autoregressive and the covariate effects). These are generally lower (as expected). The correlations between travel-related attitudes and car use all remain significant. This indicates that either synchronous effects between travel-related attitudes and car use exist *or* that 'third variables' (not included in the model) have both influenced travel-related attitudes and car use in the period between the two measurements (see paragraph 4.2). An example of the first is an increase in car use after the baseline measurement in 2005 after which people started appreciating the flexibility of the car, leading to a more positive attitude. An example of the latter is a decline in oil prices after the baseline measurement in 2005 which makes car use cheaper, positively influencing car attitudes as well as car use. Given the relatively strong initial correlations (in 2005), it seems likely that these correlations can (at least partly) be ascribed to synchronous effects. Interestingly, the remaining correlations between the error terms of the distance to the railway station and the other variables are considerably smaller. Correlations with attitudes towards the car and public transport are no longer significant. This indicates that synchronous or 'third variable' effects do not play a major role here and that the estimates of the lagged effect of the distance to the railway system on the attitudes towards the car and public transport reflect its long-term influence.

Multi-group analyses

In the previous models, all respondents have been incorporated. As described in Table 3.1, our total sample is relatively old. This may have led to relatively higher stability (autoregressive effects) over time as older people become set in their ways. Furthermore, 81% of the households have not moved during the seven years between the research rounds. This may have attributed to the absence of a significant residential self-selection effect. To explore the effects of the sample composition we conducted two additional multiple group analyses on the sample: 1) a group analysis between people aged 30-51 and people aged 51+ in 2005 and (2) a multi-group analysis between movers and non-movers.

The analysis with different age groups revealed that the stability of both groups with regard to their attitudes, travel behaviour and built environment are rather comparable. The older age group appears to be even more dynamic as their attitude towards bicycling is less stable (standardized autoregressive effects are 0.588 versus 0.767; >0.01). This might be related to health issues of older people that affect their opportunities for bicycling. The small difference between the age groups may be related to the fact that most dynamics with regard to changes in residence, employment and travel behaviour take place early in life. After reaching the age of 30 years, the propensity for change drops rapidly, only to slightly rise again when people reach pension and/or old age (Beige and Axhausen, 2012). The second multi-group analysis, between movers and non-movers, did not reveal any significant residential self-selection effects within the group of movers. This may be related to the fact that most households moved locally, within a short distance from their old residence. Therefore, changes in distances to the railway station do occur but remain small. This is supported by the autoregressive effects for both groups (0.705 for movers versus 1.00 for non-movers; >0.01). Furthermore, the year of move may have influenced the effects of the built environment on travel behaviour as these effects can take years to materialize (Coevering et al., 2015). To control for the different time lags, the variable 'year of move' was included in the analysis for the movers. However, this variable did not have a significant effect on travel behaviour indicating that differences in the amount of time that movers were 'exposed' to their new residential environment did not significantly affect their travel behaviour above and beyond the effect of the new environment itself.

3.6 Conclusions and discussion

Building on cross-sectional studies about the impacts of the built environment on travel behaviour, this study departed from the assumption that longitudinal studies can provide stronger evidence for causal relationships. A cross-lagged panel structural equation model was developed based on a two-wave longitudinal dataset to analyse the impact of the built environment on travel behaviour and the directions of causality on the links between the built environment, travel behaviour and travel-related attitudes. The variables in 2012 were regressed on their 2005 counterparts and cross-lagged effects between all variables of interest were included.

Our results suggest that there is a causal influence from the built environment on travel behaviour: the distance to railway stations in 2005 has a significant and (compared to the other determinants) relatively strong influence on the share of car use in 2012. Presumably, people living in areas in closer proximity to the railway station, which generally provides better conditions for alternative transport modes, are more inclined to start using these alternatives. However, other determinants of the built environment (such as distances to local shopping areas and other destinations and the proximity to activity places) do not seem to exert a significant influence on the share of car us. The question is why this particular dimension of the built environment stands out. In this case, it might be related to the large variety in the distances to railway station in the sample, which is in Veenendaal 1,5 km on average, in Amersfoort 3,1 km and Zeewolde 13,9 kilometres. In contrast, differences in distances to the nearest shopping centres and municipality centres are relatively small which is partly due to the strong land use and retail planning traditions in the Netherlands (Van Wee & Maat, 2003). Hence, it seems that differences in built environment characteristics have to be quite large to exert a significant influence on travel behaviour.

In contrast to earlier studies in this field, we found no effects from travel-related attitudes on the built environment, indicating that attitude-induced residential self-selection did not significantly affect residential location choices. Importantly, we did find significant effects in the other direction, i.e., after living closer to a railway station people tend to adjust their attitudes in favour of public transport. These results are in line with Bamberg's findings (2006) who reported more positive attitudes towards alternative transportation modes after moving to areas with better public transport provision.
In line with attitude theory, it appears that travel-related attitudes affect travel behaviour, rather than the other way around. From a methodological point of view, it is important that reverse causality was found in the model that only included the endogenous variables (built environment, travel behaviour and attitudes). However, after controlling for sociodemographics this influence was no longer significant. This might indicate that this relationship was spurious in the model that included the endogenous variables only.
A remarkable finding was the high temporal stability of attitudes. We were surprised that even after 7 years, people's attitudes hardly changed. In addition, the attitude's interrelationships were weak meaning that even if people did change their attitude towards for instance car use, it does not imply that they have necessarily developed more positive (or negative) ones towards other transport modes.
Finally, the findings point to a significant and intermediate role of car ownership on the link between the built environment and travel behaviour, as suggested in literature. However, as the car ownership variable does not fully comply with the normality assumption of the ML estimation method, these results should be interpreted with considerable caution.

Even though the longitudinal modelling approach in this study provides additional opportunities for causal research on the BE-TB link, some remarks should be made. First of all, the time lag of 7 years between the research rounds is relatively long. During this period, unobserved changes may have taken place in the endogenous variables and in exogenous variables that affect the variables in 2012. One or more intermediate measurements points would have given better insights. The correlations between the error terms of the endogenous variables in 2012 indicate that the effects of unobserved changes are most profound on the bidirectional relations between attitudes and travel behaviour. The relations between attitudes and the distance to the railway station do not seem to be affected. This makes sense as changes in the built environment do not occur very often and as it may take relatively long before people adapt to changes in their environment. Second, a more precise measurement of travel behaviour than the share of car use, measured using a Likert scale would be preferable to assess the links between the transport modes and their related attitudes. Including more detailed indicators derived from travel dairies or GPS based research such as distances travelled, or travel times will provide a more comprehensive picture of the way in which the built environment affects different dimensions of travel behaviour.

Taken together, findings from this study provide some support for land use policies that aim to influence travel behaviour. The significant influences of the distance to the railway station on travel behaviour and travel-related attitudes are promising. It implies that urban planning concepts such as the compact city, New Urbanism and Transit-Oriented Development, may not only provide opportunities for segments of the population who already favour living in more compact transit-accessible environments with alternatives to car use. In addition, these concepts may encourage other segments of the population to start appreciating such an environment and increase their use of car alternatives after living there for a while. Even though the net effect of the built environment is by itself not sufficient for realizing large changes, the built environment may play an important role in comprehensive packages of policies and programs (e.g. pricing policies, promotional campaigns) which aim to bring about substantial changes in travel-related attitudes and travel behaviour.

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Chapter 4: Causes and Effects Between the Built Environment, Car Kilometres and Attitudes: a Longitudinal Analysis

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Abstract

Travel-related attitudes are believed to affect the connections between the built environment and travel behaviour. Previous studies found supporting evidence for the residential self-selection hypothesis which suggests that the impact of the built environment on travel behaviour could be overestimated when attitudes are not accounted for. However, this hypothesis is under scrutiny as the reverse causality hypothesis, which implies a reverse direction of influence from the built environment towards attitudes, is receiving increased attention in recent research. This study tests both directions of influence by means of cross-sectional and longitudinal structural equation models. GPS tracking is used to assess changes in travel behaviour in terms of car kilometres travelled. The outcomes show stronger reverse causality effects than residential self-selection effects and that land-use policies significantly reduce car kilometres travelled. Moreover, the longitudinal models show that the built environment characteristics provide a better explanation for changes in car kilometres travelled than the travel-related attitudes. This contradicts the cross-sectional analysis where associations between car kilometres travelled and travel-related attitudes were stronger. This highlights the need for more longitudinal studies in this field.

Keywords: travel behaviour, built environment, attitudes, residential self-selection, reverse causality, longitudinal approach

4.1 Introduction

Land use policies and concepts aiming at compact cities have been developed to curtail urban sprawl, reduce car dependency, and promote active and multi-modal travel behaviour. An important assumption behind these policies and concepts is that people will shift to more sustainable travel behaviour when sufficient opportunities are provided by the built environment and the transportation system. In general, study outcomes provide some support for these assumptions. Ceteris paribus, people in dense, mixed-use environments with good facilities for sustainable transport modes tend to use the car less and sustainable alternatives such as walking, biking and public transport more often (Krizek, 2003; Ewing and Cervero, 2010; Gim, 2013, Chatman, 2014; Næss, 2014; Cao et al.,2019).

However, the built environment is only one of the many factors that influence travel behaviour. Many studies have shown that socioeconomic and demographic characteristics are at least as important. Over the last two decades, the role of attitudes has received increased attention. Where socioeconomic and demographic characteristics can be incorporated as control variables in statistical analyses, the role of attitudes is more complex. Previous studies suggested reciprocal and indirect relationships with residential choices and travel behaviour. This direction of influence is of great importance as it may lead to under-or overestimations of the extent that travel behaviour is affected by land use policies (Cao and Chatman, 2016; Bohte, 2010). Therefore, this article applies a longitudinal design and structural equations modelling, unravelling the role of attitudes and their dominant direction of influence.

One direction of influence is related to the well-known ‘residential self-selection hypothesis’. According to this hypothesis, people locate themselves in neighbourhoods with conducive circumstances for their preferred travel modes. If studies would not control for this role of attitudes, the extent to which travel behaviour is influenced by the built environment may be overestimated or underestimated, depending on the extent to which people can self-select themselves (Cao et al., 2009; Bohte et al., 2009; Lin et al., 2017; Næss, 2009). For instance, the influence of high-density urbanisation on public transport use appears to be strong, but this may be partly because people with strong public transport attitudes opt for high-density neighbourhoods. Studies evaluating the role of attitudes arrive at different conclusions. Bagley and Mokhtarian (2002) found that miles travelled for car, public transport and active modes were strongly associated with attitudes and lifestyle variables and that the influence of the built environment characteristics was limited. Lund (2003) found comparable results for the frequency of walking trips. Conversely, Schwanen and Mokhtarian (2005), Bohte (2010), Næss (2009), Ewing at al. (2016) and Van Herick and Mokhtarian (2020), did find significant influences of the built environment on car use when attitudes and mismatches were controlled for. For more extensive insight, we refer to Mokhtarian and Cao (2008), Bohte et al. (2009), Gim, (2013) and Heinen et al. (2018).

The ‘reverse causality hypothesis’ (Bohte et al., 2009; Chatman, 2009; Van Wee et al., 2019), also called ‘residential environment determinism’ (Ewing et al., 2016), assumes an opposite direction of influence where the residential environment influences attitudes. Reverse causality occurs when people adapt travel-related attitudes to align them with their previously selected residential environment. First, this adjustment process may be related to the cognitive dissonance theory. This theory suggests that people tend to harmonise their attitudes and behaviour and reduce dissonance (Festinger, 1957; Golob et al., 1979). For example, people that favour car use may experience cognitive dissonance when they start living in a compact neighbourhood. Aligning their attitudes towards this new, compact environment would cause them to develop a less positive car attitude and a more positive attitude towards alternative transport modes such as biking and public transport. Secondly, reverse causality may occur due to new experiences and resulting positive or negative emotions during people's daily routines in their social and spatial environment (Cullen, 1978; Van Wee et al., 2019). For instance, people living near the railway station experience that car use is less convenient and conditions are more favourable for public transport, cycling or walking. This may influence people's perceptions and encourage more positive attitudes towards public transport, cycling and walking over time. Although many scholars have acknowledged the possibility of this reverse causal direction (Næss, 2009; Næss, 2014; Cao et al., 2009; Chatman, 2009), few empirical studies have been conducted to date. To the best of our knowledge, Bagley and Mokhtarian (2002) were the first to explicitly analyse reverse causal influences. They found no significant reverse influences. Bohte (2010) did find reverse causal influences: living further from the nearest railway station had a negative impact on people's public transport attitudes. Some recent studies also found evidence for reverse causality (Van Acker et al., 2014; de Abreu e Silva, 2014; Ewing et al., 2016; Van De Coevering et al., 2016; Lin et al., 2017; De Vos et al., 2018).

There are four conditions for identifying causal relationships (Singleton and Straits, 2009; Shadish et al., 2002): (1) association, (2) non-spuriousness, (3) time precedence and (4) plausibility. Previous studies mostly applied quantitative cross-sectional research designs and found significant associations after controlling for confounding factors. However, the time precedence and plausibility criterion received less attention (Handy et al., 2005). To determine the direction of influence and disentangle the cause and effect, a longitudinal research design and controlling for confounding variables is necessary. In a cross-sectional study, all variables are measured at one moment in time. This enables the identification of associations between variables, e.g. people living in denser environments use the car less often. In a longitudinal study, variables are measured at two or more moments in time. This enables the identification of intra-personal change over time, e.g. people use the car less often after a move to a denser environment. This provides more evidence for a causal relationship (Van De Coevering et al., 2015). To date, few longitudinal studies include attitudes at multiple moments in time which is remarkable since the direction of influence is very important (Cao et al., 2009; Gim 2013). Sometimes attitudes were simply not part of the research focus (e.g. Krizek, 2003; Meurs and Haaijer, 2001) and in other studies retrospective longitudinal designs were used (Handy et al., 2005; Cao et al., 2007). As retrospective questioning is considered unreliable to assess changes in attitudes, retrospective studies often include current attitudes only (e.g. Handy et al., 2005). The studies by De Vos et al. (2018) and De Vos et al. (2020) are exceptions. They conducted retrospective questioning on attitudes after relocation and found reciprocal influences that revealed self-selection effects during the move and gradual changes in attitudes after the relocation. We only found two studies that applied longitudinal designs that incorporated attitudes on two occasions (Van De Coevering et al., 2016; Wang and Lin, 2019). Interestingly, these studies indicated reverse causality, but no evidence was found for residential self-selection.

Taken together, there is some evidence for both directions of influence, but it is still inconclusive. In other words, we do see that different people in different residential environments have different attitudes. However, to what extent are people's attitudes the cause of this, due to people choosing a neighbourhood with characteristics that are aligned with their preferred travel behaviour? And to what extent are they the effect of people adjusting their attitudes to their residential environment? The answers to these questions are vital for the effectiveness of land use policies. If residential self-selection is dominant, the effectivities of land use policies and concepts in achieving more sustainable travel behaviour would be limited.

The key role would be to enable people that already have a positive disposition towards sustainable travel behaviour to select a conducive neighbourhood and next travel in the desired way. If reverse causality would be dominant, the impact of the built environment is significantly larger. In addition to a direct effect on travel behaviour, the built environment would also have an indirect effect by its influence on people's attitudes.

This study aims to add to the academic debate and to assess the practical relevance of modifying the built environment to reduce the number of car kilometres driven. Therefore, we identify the dominant direction of influence between attitudes and the built environment and determine the resulting impact of the built environment on car kilometres driven. The inclusion of multiple directions of causality and the use of longitudinal designs are both at an early stage in this field. That is why it is interesting, from a methodological viewpoint, to assess whether potential differences in results between previous cross-sectional studies and our longitudinal study originate from the inclusion of multiple directions of causality or from the longitudinal design. Therefore, this study starts with cross-sectional analyses, testing rival assumptions regarding the directions of influence, which will show which hypothesis fits the data best. Subsequently, a longitudinal analysis will be conducted that will assess the direction of causality over time.

We specifically focus on the following research questions:

1. Which assumed direction of influence fits the cross-sectional data best, residential self-selection, or reverse causality?
2. To what extent are residential self-selection and reverse causality able to explain changes in residential location characteristics and travel-related attitudes over time?
3. What is the remaining influence of the built environment on car kilometres driven over time?

This study builds on previous work of (Van De Coevering et al., 2016). It is based on the same questionnaire which includes attitudes at two moments in time (2005-2012), however, partially with other variables. This study adds to the current knowledge by using data from GPS tracking to specifically determine the number of car kilometres driven. The GPS dataset includes car trips during one week, which provides a better overall picture of kilometres driven than if only one day would be included, without placing a burden on the respondents (Bohte, 2010). To the best of our knowledge, a longitudinal dataset with a time span of seven years incorporating detailed information about attitudes and travel behaviour is unique. Furthermore, the effects of two built environment indicators are compared: the distance to the nearest railway station and residential density. Lastly, this study includes cross-sectional and longitudinal SEMs, explicitly comparing their results. This will demonstrate to what extent the cross-sectional associations reflect causal influences over time.

Data are described in the next section. The modelling approach is described in the third section and the results in the fourth one. Finally, conclusions are drawn, and the scientific and societal implications discussed.

4.2 Data

Data collection, study area and sample

The data collection encompasses two research rounds both including an internet questionnaire and GPS tracking. The internet questionnaire will only be described briefly here. A more detailed description is available in Van De Coevering et al. (2016). The questionnaire was carried out in the Netherlands and included questions relating to demographics, socioeconomics, attitudes, and travel behaviour. A random sample was taken from homeowners and their partners living in three typical municipalities in the central part of the Netherlands, in the medium sized-city of Amersfoort (150,000 inhabitants), the smaller town of Veenendaal (62,500) and the remote town of Zeewolde (20,000). The research was limited to homeowners because renting in the Netherlands is regulated and does not provide many opportunities for residential self-selection. The sample represented people living in residential areas with diverse built environment characteristics. In the first round, 31% of the people in the sample participated, yielding a total response of 3,979 respondents (Bohte, 2010). In the second round, we were able to contact 3,300 (83%) of these respondents again and 1,788 of them participated in the survey, which equals a response rate of 54%. At the end of the questionnaires in 2005 and 2012, respondents were asked to participate in the subsequent GPS surveys. In the first round, 1,200 respondents took part in the GPS fieldwork that was conducted in early 2007. The participants logged their trips for one week with a handheld GPS device. Subsequently, the data was downloaded and analysed using various rule-based algorithms to derive travel behaviour determinants such as mode use, kilometres travelled and travel times (Bohte, 2010). Afterwards, participants were able to validate their trips via an online portal. This eventually resulted in 936 usable GPS surveys. For more details on this method see Biljecki et al. (2013). The GPS fieldwork in the second round involved 896 participants, but not all of them also took part in the first round. In total 595 people participated in both rounds. The same rule-based algorithms were used to analyse the new data. However, in 2013 we did not have an online portal available for the validation of the GPS trips. Therefore, we asked respondents to fill in a travel diary containing only the essential travel characteristics - departure time, trip purpose and travel mode - to validate the GPS trips in the second round. During data cleaning and validation, we removed respondents that did not validate their data online in 2007 or with the travel diary in 2013. Moreover, we only selected participants that recorded at least four days of travel or indicated that they stayed at home during one of these four days. This resulted in 479 longitudinal cases. Dependence on observations is prevented by a random selection of one partner per couple. This led to a dataset of 344 respondents for the present paper. Distances over the network towards important destinations, such as supermarkets, shopping centres and the railway station, were calculated using GIS software.

Variables

The variables are described in Table 4.1. Travel behaviour was operationalised by the average number of car kilometres driven per weekday. The average of 50 kilometres is high by Dutch standards, which may be due to the relatively high education and income levels and to the fact that a large share of the respondents has a paid job. The sample is evenly distributed among males and females. The average age in the sample is relatively high because of the selection of homeowners (Bohte, 2010). The majority of respondents live together with a partner and children, but this has significantly decreased while the share of partners living without children significantly increased between 2005 and 2012.

The travel-related attitudes were determined for three specific transport modes: car, public transport and bicycle. Respondents rated nine statements for each mode on a five-point Likert scale. The statements included cognitive (e.g. “public transport is timesaving”) and affective (e.g. “car driving is fun”) items and were rated on a range from -2 ‘completely disagree’ to +2 ‘strongly agree’. Subsequently, we summed up the individual items to determine a person’s overall attitude for each transport mode. The internal consistency of the scales proved to be satisfactory (Cronbach’s Alpha for all attitudes >0.75). Interestingly, the mean values of all mode-related attitudes became more positive towards that mode between 2005 and 2012.

The built environment was operationalised by two types of measures. The first one is a measure of accessibility that represents the shortest route between respondents' homes to different types of facilities along the road network (NWB, 2018). The second one is the surrounding address density, a density measure that was obtained from Statistics Netherlands (CBS). This measure represents the number of addresses per square kilometre. It is calculated per address by counting the number of addresses within a circular area with a radius of one kilometre, divided by the surface area. Subsequently, it is aggregated to the PC6 postal code level by averaging the scores of all addresses in the PC6 postal area (CBS, 2018). The small overall increase in density is probably due to new housing projects in and around the research areas.

Table 4.1. Variables (N=344).

Variables	Description	2005 Mean (st.dev) & shares (%)	2012 Mean (st.dev) & shares (%)
Behaviour			
Kilometres driven by car	Kilometres on an average weekday	54,498 / (39,068)	50,397 (44,126)
Residential move	No	n.a.	287 (83%)
between 2005 and 2012	Yes	n.a.	57 (17%)
Attitudes			
Travel-related attitudes	Car attitude	3.4 (4.6)	4.3 (4.3)
	Public transport attitude	–3.6 (5.8)	–2.8 (5.7)
	Bicycle attitude	9.8 (4.7)	10.3 (4.8)
Built environment			
Average distance	To municipal centre [m]	1,949 (775)	1,955 (870)
	To nearest shopping centre [m]	1,123 (778)	1,161 (819)
	To nearest railway station [m]	6,431 (5473)	5,868 (5814)
	To nearest bus stop [m]	604 (566)	495 (483)
	To nearest highway ramp [m]	5,491 (5001)	5,255 (5048)
Density	Surrounding addresses density	1,459 (732)	1,515 (736)
Sociodemographics			
Age	Average	46.7 (9.4)	53.7 (9.4)
Gender	Female	45.0%	45.0%
	Male	55.0%	55.0%
Household composition	Single household	5.6%	6.1%
	Single parent	1.4%	3.1%
	Partners without children	25.0%	38.1%
	Partners with children	67.2%	51.7%
	Other	0.8%	1.1%
Education	Low:	4.2%	4.2%
	Medium	30.6%	28.9%
	High	65.3%	66.9%
Net personal income	Low (< € 1,000)	18.9%	11.9%
(monthly)	Middle (≥€1,000< €2,000)	40.0%	33.6%
	High (≥€2,000)	41.1%	54.4%
Paid work	No job	14.2%	21.8%
	Part-time job (< 30 hours)	24.7%	22.7%
	Full-time job (≥ 30 hours)	61.0%	55.5%

4.3 Modelling approach and specification

Modelling approach

We applied Structural Equations Modelling (SEM) on cross-sectional and longitudinal data. SEM allows us to use multiple endogenous variables and identify and estimate directions of influence, while controlling for the confounding influence of exogenous variables such as sociodemographics. The cross-sectional analyses do not provide evidence for the causal direction, but they do enable us to compare the model fit indicators and the model parameters to determine which model fits the data best. The dominant direction of influence in the cross-sectional analysis was assessed by estimating separate models with different assumptions regarding the direction of causality. In addition, an attempt was made to develop a non-recursive model, including both directions of causality at the same time. However, this model posed challenges regarding identification, as the core of the model - represented by the links between the built environment indicator, car use and attitudes - was underidentified. With the inclusion of sociodemographic control variables, the model converged. However, all the coefficients between the variables of interest were insignificant and the overall modal fit was less favourable. Due to the lack of meaningful results, this approach was abandoned.

The longitudinal dataset enables us to analyse directions of influence over time, which provides stronger evidence for causality on these links (Mokhtarian and Cao, 2008). We applied a Cross-lagged Panel Model (CLPM) which determines to what extent values of variables at an earlier point in time can explain 'change' in other variables over time. In our case with two time points, the CLPM for instance shows to what extent changes in people's car attitudes between 2005 and 2015 can be explained by the characteristics of the residential location at baseline. To determine change, the baseline value of each endogenous variable is regressed on its value at the second point in time. This autoregressive effect reflects the stability of this variable over time and the remaining variance reflects the change of the variable over time. The higher the autoregressive effect, the higher the stability in the variable and the lower the change over time. The change is explained by what are called 'cross-lagged effects'. A significant effect indicates that the baseline values of that particular variable explain the change in the variable of interest over time (Selig and Little, 2012). Hence, the CLPM can meet the first criteria for identifying causal relationships, association, non-spuriousness and time precedence (Finkel, 1995). Assumptions regarding causal mechanisms were derived from literature and are explained in the specification of the models in the next paragraph.

Specification

Figure 4.1 shows the specification of the cross-sectional model including the built environment, mode-related attitudes, kilometres driven by car, and socio-demographics. To adjust for measurement errors in the composite scales of the mode attitudes, a latent variable was defined for each mode attitude. Each composite scale, measuring a mode attitude based on the nine items mentioned in Section 2, was then used as a single observed indicator for the associated latent construct. In line with published literature, the error variances were fixed to 1 minus the Cronbach's alpha of the composite scales, multiplied by the variances of these scales (Bollen, 2014), The mode-related attitudes in this model represent these latent constructs and are therefore visualised as circles.

The built environment variables are assumed to influence kilometres driven by car directly. Essential are the solid and dotted arrows between the built environment and the attitudes. The solid lines represent residential self-selection where attitudes influence kilometres driven by car via their influence on the built environment. The dotted arrows reflect reverse causality; the built environment influences attitudes (which are still assumed to affect kilometres driven by car). Similarly, both traditional and reverse influences are assumed between attitudes and kilometres driven by car. Socio-demographic characteristics are specified exogenously, influencing attitudes, built environment and kilometres travelled. To assess whether the residential self-selection or the reverse causality hypothesis fits the data best, we estimated three separate models. The first model reflects residential self-selection where attitudes are assumed to influence the built environment directly (solid lines). The second model reflects reverse causality, assuming an influence from the built environment towards the attitudes (dotted lines) but still the conventional influence of attitudes on kilometres driven by car. In addition to reverse causality from the built environment towards attitudes, the third model also assumes a reverse causal direction from car kilometres driven towards attitudes and not the converse.

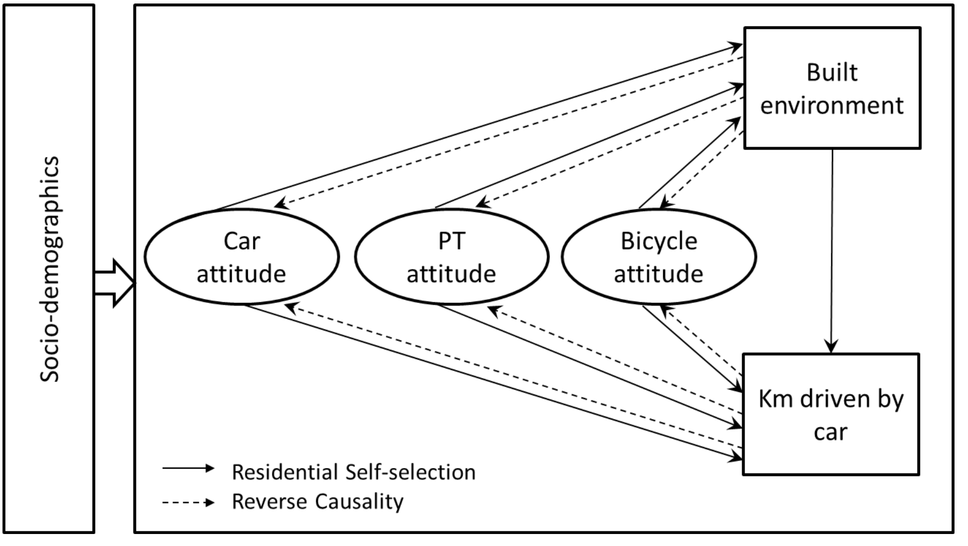

Figure 4.1. Specification of the cross-sectional model.

The longitudinal CLPM is specified in Figure 4.2. The model includes the values of the endogenous variables in 2012 and their counterparts in 2005. Sociodemographics are represented as exogenous variables and include the baseline values and their changes between 2005 and 2012.

The core of the model consists of the stability coefficients (S1-S3) of the built environment, attitudes and kilometres driven by car, and their related cross-lagged relationships (L1-L6) over time. In this model, the cross-lagged relationship from the baseline values of the mode attitudes towards the built environment characteristics in 2012 (L4) reflects residential self-selection. Reverse causality is represented by the cross-lagged relationship from the baseline values of the built environment characteristics towards mode attitudes in 2012 (L6). By testing the significance of these relationships and by comparing their strength we were able to determine the dominant direction of causality.

D1–D4 represent the influence of exogenous control variables. Sociodemographic characteristics are specified exogenously, influencing attitudes, built environment and kilometres travelled. The changes in sociodemographics also influence these variables, but only in 2012, as we only assume lagged effects in this model. For the sake of parsimony, lead effects (which involve people anticipating changes in their household circumstances by adjusting their current attitudes or choices regarding residential choice or car use) are not included. Finally, correlations are assumed between the error terms of the kilometres driven by car, mode-related attitudes and built environment characteristics These correlations represent the associations between these variables at baseline (C1-C3) and the remaining associations, after accounting for the lagged effects, the cross-lagged effects and the influence of the sociodemographics and their changes (C4 - C6). The sociodemographics and their changes are also assumed to be correlated themselves. Synchronous effects, for instance from the built environment indicators in 2012 to the attitudes in 2012, are not included in the model. Including them would lead to endogeneity issues as correlated error terms are assumed for variables at the same moment in time. What's more, including synchronous effects may cause challenges regarding identification, as this increases the number of parameters in the model. Even though we did not model synchronous effects, the associations between the error terms of these variables in 2005 and 2012 (C1-C6) indicate the presence of these effects.

We applied the commonly used maximum likelihood (ML) estimation, which assumes normally distributed endogenous variables, so we tested the distribution of the car kilometres per day and the built environment characteristics. As their distribution deviated from normality, we took the natural logarithm of these variables.

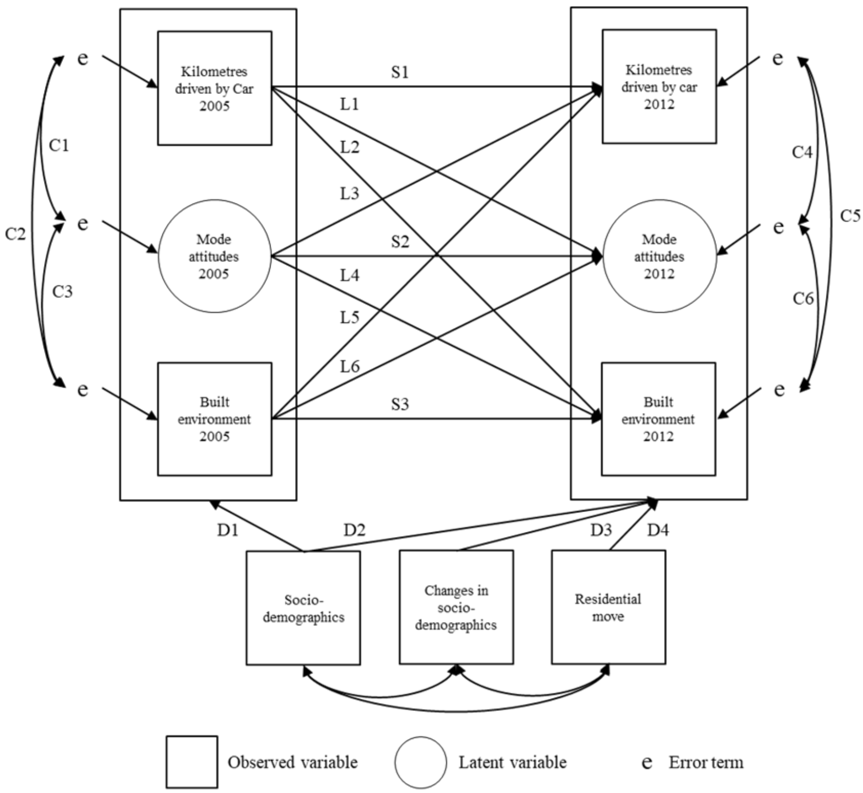

Figure 4.2. Specification of the of the CLPM.

4.4 Results

All models were constructed via the process of backward elimination, starting with the least significant relationship. All non-significant effects of the exogenous variables were removed, but the relationships between the endogenous variables were retained, as they concern the main research questions. During model development, all built environment indicators included in Table 4.1 were tested. As many show high levels of multicollinearity, it was infeasible to analyse all variables simultaneously. Therefore, we chose to take two strong indicators, the distance to the nearest railway station and residential density, and use them in all analyses. Both can be considered as a proxy reflecting among other things the quality of facilities for public transport and cycling, available parking space, function mix, accessibility of retail, etc. As they correlate strongly, they cannot both be included in one model. It was decided to estimate separate models for each determinant. By doing so we avoided limiting our analysis to just one determinant of the built environment, while enabling a comparison of their impact. For the sake of brevity, we only report the results of the main variables of interest here. For the interested reader, full model results are available in appendix 4.A.

Cross-sectional results

Figure 4.3 presents the standardised parameter estimates and model fit of six cross-sectional models for (I) residential self-selection, (II) reverse causality between attitudes and the built environment and (III) reverse causality between attitudes and the built environment and between attitudes and car kilometres driven. The models including the distance to the railway station as a determinant for the built environment are presented on the left and results for the residential density indicator on the right. Their outcomes are discussed together.

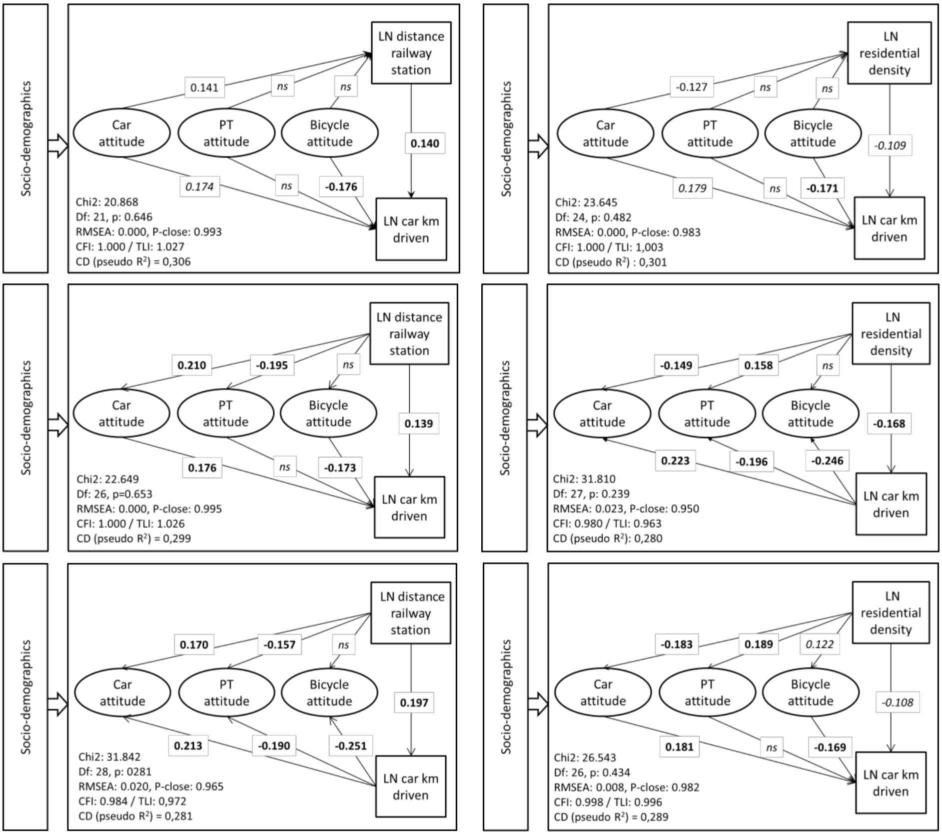

Figure 4.3. Cross-sectional results for car km driven based on the distance to the railway station (left) and residential density (right), and model 1 assuming residential self-selection (top), model 2 assuming reverse causality on the attitude-built environment link (middle) and model 3 assuming reverse causality on the attitude-built environment and the attitude-car km driven link (bottom). Significance: bold p<.01; italics p<.05; other p<.1.

Overall, the cross-sectional analyses revealed that models assuming reverse causality and models assuming residential self-selection fit the data equally well. The insignificant chi-square and RMSEA P-values and the CFI and TLI close to 1, indicate an acceptable to good model fit for all models (Bollen, 2014). The differences in the overall model fit between the models are small and may also stem from the different influence of the sociodemographic variables in the models. As the cross-sectional analyses are based on similar - but different - models, a direct comparison of the strengths of the coefficients is not justified. However, comparing the models does indicate the direction and magnitude of effects on the links between attitudes, built environment and travel behaviour. A comparison of the coefficients of the first two models shows that the assumed direction of influence from the built environment towards attitudes is stronger than vice versa. In other words, reverse causality effects seem stronger than residential self-selection effects. Self-selection effects are small and only indicated for the car attitude. People with a stronger car attitude tend to self-select into lower-density neighbourhoods and further away from a railway station. The reverse causality coefficients are significant for the car and public transport attitudes. They indicate that living further from the railway station positively affects car attitudes, while the opposite holds for public transport attitudes. For the density indicator, the signs are opposite. A higher density has a negative influence on car attitudes and a positive influence on attitudes for public transport and cycling (the latter marginally significant). In line with expectations, travel-related attitudes have a direct effect on car kilometres driven. Stronger car attitudes have a positive effect and stronger bicycle attitudes have a negative effect on car kilometres driven. The results for public transport attitudes are insignificant, which may be an effect of the limited amount of public transport use in the sample. This is related to the nature of the sample with medium and small-sized Dutch municipalities where people often combine car and bicycle use, and the share of public transport is limited.

Results of the third model reveal that the reverse causal effects from the built environment indicators on attitudes are somewhat attenuated when reverse causality is assumed on the link between attitudes and car kilometres driven. This indicates that the effect of the built environment on attitudes is partially indirect. For example, people use the car more often when they live further from the railway station and this, in turn, has a positive effect on people's car attitude. In all models, the direct influence of the distance to the railway station and of the residential density on car kilometres travelled is significant. Larger distances to the railway station and lower densities have a positive influence on car kilometres travelled. The impact of the built environment indicator is somewhat smaller than the influence of the attitudes. So how large is this effect? When both independent and dependent variables are log-transformed, as in our case, the unstandardised regression coefficients can be interpreted as elasticities for small changes in the independent variable. For the distance to the railway station, the unstandardised coefficients vary between b=0.15 (model 1 and 2) and b=0.21 (model 3) and for residential density between b=-0.20 (model 1 and 2) and b=-0.32 (model 3). So, a 1% increase in the distance to the railway station leads to an approximate 0.15-0.21% increase in car kilometres travelled. A 1% increase in residential density leads to a 0.2-0.32% decrease in car kilometres travelled. For reasons of parsimony, the effects of sociodemographics, which are primarily used as control variables, are not described here. Their role will be elaborated on in the longitudinal models.

Longitudinal results

The results of the two longitudinal models are shown in Figure 4.4 and will be described together. Note that non-significant links between the variables depicted in Figure 4.4 have been retained in the statistical model, but they are not visualised here for the sake of clarity. The same holds for correlations between the error terms of these variables. With insignificant chi-square and RMSEA values, and CFI and TLI values close to one the model fit appears to be good for both models (Newsom, 2015). We start with a description of the standardised effects on the relationships between the endogenous variables as shown in Figure 4.4. We describe the autoregressive effects (indicators of stability), the cross-lagged effects (including residential self-selection and reverse causality) and the impact of the distance to the railway station and residential density on car kilometres driven. Finally, we present the effects of the sociodemographic variables and their changes on the endogenous variables in 2005 and 2012, as shown in Table 4.2.

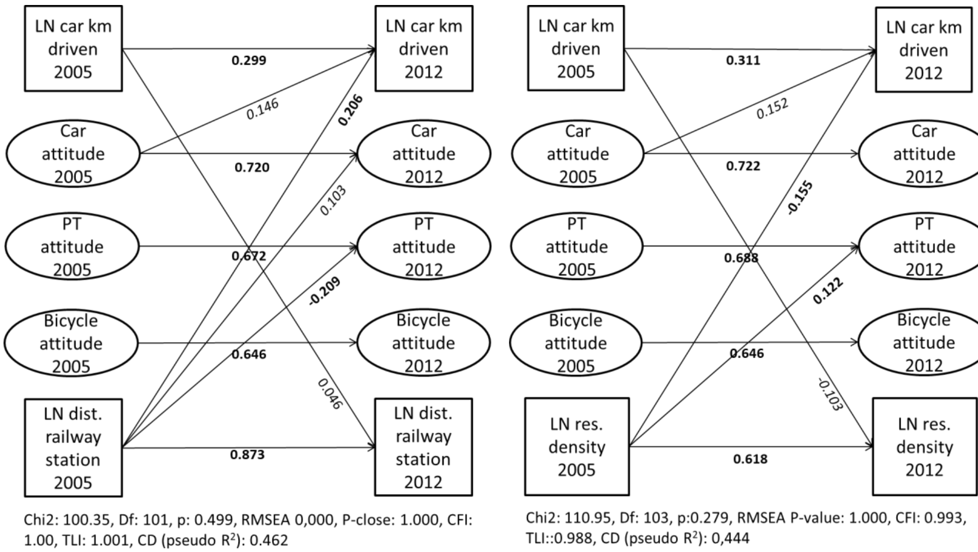

Figure 4.4. Standardised effects for the longitudinal models based on the distance to the railway station and residential density. Significance: bold p<.01; italics p<.05; other p<.1.

The results in Figure 4.4 show that autoregressive effects are strong in both models. In other words, the indicators in 2005 are a good predictor for their counterparts in 2012, which means that stability is rather high. The distance to the railway station shows high levels of stability. The stability of the residential density is lower but still rather high. The high stability of the built environment indicators reflects the fact that the characteristics did not change a lot between 2005 and 2012. The attitudes seem to be more stable over time than the car kilometres driven. This was expected, as attitudes are generally assumed to be more stable than (travel) behaviour.

The cross-lagged effects between attitudes and the indicators for the built environment show that reverse causality effects prevail over residential self-selection effects. This is in line with the cross-section results in Figure 4.3. This means that the built environment indicators do a better job at explaining the changes in attitudes between 2005 and 2012 than vice versa. In the first model, the distance to the railway station in 2005 influences attitudes towards public transport negatively and car attitudes positively in 2012. Thus, living further away from a railway station leads to weaker public transport attitudes and stronger car attitudes over time. In the second model, the residential density in 2005 significantly affects the public transport attitude. Thus, living in denser neighbourhoods leads to stronger public transport attitudes over time. In both models, the attitude-based residential self-selection effects are all insignificant. Thus, people's travel-related attitudes in 2005 do not explain the changes in the proximity towards the railway station or residential density between 2005 and 2012. This may be related to a rather small share of people in the sample (17%) moving house between 2005 and 2012, which reduces the statistical power to determine self-selection effects. Furthermore, travel-related attitudes are only one of the aspects of people's residential choices and arguably not the most important ones. So even if people take travel-related attitudes into account in their residential choice, they may need to trade them off against other aspects in their residential decision.

Interestingly, there is a significant lagged effect of car use on residential density and distance to the railway station in 2012 (the latter marginally significant). So instead of attitude-induced self-selection, this indicates self-selection based on previous behaviour where people who used the car more often in 2005 tend to end up in less dense areas and at larger distances from the railway station in 2012. Finally, it seems that the changes in car kilometres driven are relatively strongly affected by the built environment indicators compared to the other indicators. The positive impact of the distance to the railway station and the negative impact of residential density in 2005 on the change of car kilometres driven between 2005 and 2012 are stronger than the impact of the car attitude in 2005. Interestingly, this contradicts the findings of the cross-sectional analysis. This analysis found that the associations between attitudes and car kilometres driven were stronger than the associations between proximity to the railway station and residential density, and car kilometres driven. The unstandardised coefficients of the longitudinal models reveal that a 1% increase in the distance to the railway station leads to a 0.23% increase in car kilometres travelled. A 1% increase in residential density leads to a decrease of 0.3% in car kilometres travelled.

Due to the time lag of seven years, it is likely that unobserved events took place or that changes in the endogenous variables occurred after 2005. These may have affected the relationships between the variables in 2012. The correlations between the error terms of these variables (see C1-C6 in Figure 4.4) indicate the presence of these effects. Not surprisingly, most correlations between these error terms are strongly significant in 2005. For instance, the distance to the railway station is strongly associated with car and public transport attitudes. These correlations are considerably weaker in 2012. The correlations between the error terms of the built environment indicators and attitudes in particular are much lower in 2012 and often insignificant. This indicates that the model explains the changes in these variables quite well. For the relationships between car kilometres driven and built environment indicators, significant error term correlations remain in 2012. Apparently, unobserved events or synchronous effects influenced the relationship between these variables.

Table 4.2 presents the influence of the sociodemographics and their changes on the endogenous variables for the model including the proximity to the nearest railway station. For reasons of parsimony, we do not present a separate table for the model with residential density, as both models yielded almost identical results. Instead, the effects of the sociodemographics on residential density are included in a separate column in this table.

Table 4.2 Standardised effects of sociodemographics on endogenous variables (N=344).

Endogenous variables	Travel behaviour		Attitudes towards transport modes						Built Environment			
Exogenous variables	β Car use		β Att. car		β Att. PT		β Att. bicycle		β Distance to railway		β Density	
	2005	2012	2005	2012	2005	2012	2005	2012	2005	2012	2005	2012
Sociodemographics (2005)												
Gender (ref.=female)			**0.223**									
Age			-0.091						**-0.228**		**0.212**	
							-0.118					
Education												
Low education level												
High education level		**0.184**			0.109							
(Ref. = Middle education level)												
Income and work												
Low income	*-0.119*						*0.138*			*0.060*		
High income	**0.202**											
(Ref=Middle income)												
Employed			*-0.145*	**0.130**								
Work full-time			**0.216**		*-0.119*		-0.114					
(Ref=No Job)												
Household												
Single parent household				*0.099*								
Couple without children				*0.210*						*0.105*		*-0.168*
Family with children				0.163						0.093		-0.153
Other household types				0.080								
(Ref. = single person hh)												
Residential move between 2005 and 2012										**-0.128**		

Significance: bold p<.01; italics p<.05; other p<.1

As the sociodemographics are mainly included as control variables and do not concern the main research questions, we do not go into detail here. Overall, their effects on the baseline endogenous variables in 2005 seem plausible. For example, people with higher incomes and education levels drive more, whereas people with lower incomes drive less. People with a low education level express weaker bicycle attitudes, whereas people with a high education level have stronger public transport attitudes in 2005. Compared to not having a paid job, working full-time is related to more positive car attitudes and also to more negative public transport and cycling attitudes. A less intuitive outcome is that working part-time is negatively associated with the car attitude in 2005. Perhaps people in part-time jobs work closer to home and are less reliant on the car, which may affect their car attitude. Finally, higher age is associated with a weaker car attitude, living closer to the railway station, and living in higher density areas. This effect is probably related to the high average age (around 50 years old) in our sample. So, as people age, they tend to become less car-oriented and move more often to denser areas and areas nearer to the railway station.

Interestingly, the effects of the sociodemographics on changes in the endogenous variables over time are not aligned with the baseline results in 2005. In other words, the fact that exogenous variables are associated with endogenous variables in 2005, does not mean that these exogenous variables can also account for changes in the endogenous variables between 2005 and 2012. Results reveal that people with a higher education level are more inclined to drive more kilometres and people in larger households tend to develop a stronger car attitude. Surprisingly, people with a part-time job tend to develop a more positive car attitude between 2005 and 2012. This finding is at odds with the negative effect of working part-time on the car attitude in 2005. Furthermore, couples and families end up at larger distances from the railway station and in lower-density areas in 2012. The effect of a residential move has a negative sign for distance to the railway station as well as for residential density. This indicates that people who moved between 2005 and 2012 tend to end up in areas that are closer to the railway station but also in less dense residential environments. The fact that people moved between 2005 and 2012 did not have a significant effect on their car kilometres driven or their attitudes. So, it seems that moving house did not break current habits and mobility patterns. This may be because most households in our sample moved over small distances within the same municipality, reducing their necessity to re-evaluate their travel behaviour choices. Changes in sociodemographics and job changes also did not significantly affect changes in travel behaviour in 2012. This may be due to the limited number of changes and/or because the majority of the influence of these variables is already included in the stability effect of travel behaviour from 2005 to 2012.

Multi-group analysis

It is not an easy task to statistically prove residential self-selection as it requires respondents to:

1. move over time;
2. be able to select themselves in an area conducive to their travel attitudes and preferences;
3. experience significant changes in BE characteristics to an area more aligned with their travel attitudes and preferences.

In the previous models, movers and non-movers were included. The fact that only 57 out of the 344 people moved house may have affected the ability to find significant self-selection effects. To get a sharper understanding of the respondents who moved and took the opportunity to self-select, we conducted a multi-group analysis for both built environment indicators. We created two groups: (1) people that moved house and (2) people that did not move house between 2005 and 2012. The model with the railway station indicator yielded an interesting result. Within the movers' group, a more positive car attitude in 2005 resulted in a larger distance to the nearest station in 2012. This suggests self-selection of people with a positive car attitude that choose, for instance, a more suburban car-oriented residential environment after their move. No other significant self-selection effects were found in the model with the distance to the railway station or in the model with residential density. Furthermore, the results show that reverse causality effects are stronger, regardless of whether people moved house or not.

4.5 Conclusions and implications for policy and research

This study aimed to add to the academic debate regarding the residential self-selection and reverse causality hypotheses and to assess the practical relevance of modifying the built environment to reduce the number of car kilometres driven. Six cross-sectional SEMs were developed involving alternative directions of influence and two separate built environment indicators (distance to the railway station and residential density). Subsequently, two longitudinal Cross-Lagged Panel Models (2005-2012) were developed in SEM for both built environment indicators.

Overall, the models show that reverse causality effects are dominant. In other words, the impact of the built environment on attitudes is stronger than vice versa. This finding is in line with recent findings by Van De Coevering et al. (2016), Ewing et al. (2016) and Wang and Lin (2019). Furthermore, travel-related attitudes are more strongly influenced by the distance to the nearest railway station than they are by residential density. Living further from the railway station positively affects car attitudes while the opposite applies to public transport attitudes in the cross-sectional and longitudinal models. Attitudes towards the car, bicycle and public transport are significantly affected by higher densities in the cross-sectional analysis. However, in the longitudinal analysis, only the positive influence of higher densities on public transport attitudes is significant and, overall, standardised effects are lower. This may be since Dutch suburbs, even though they are dense, are still well-suited to car use. In general, older neighbourhoods nearby railway stations are less conducive for the car and more for public transport. Therefore, the proximity to the nearest railway station could be a stronger proxy for a neighbourhood’s conduciveness to mode use than residential density.

Even though reverse causality effects prevail over residential self-selection effects, it seems that the latter ones also occur. The cross-sectional models showed that stronger car attitudes were associated with living in lower-density neighbourhoods and at larger distances from the railway station. Although residential self-selection effects were not present in the overall longitudinal analysis, a group analysis revealed that people with stronger car attitudes who moved house tended to end up in residential areas further from the railway station. This indicates reciprocal influences between attitudes and the built environment. Somewhat surprisingly, the longitudinal analysis also revealed an influence of car kilometres driven on built environment indicators. As this car-use related self-selection does not originate from attitudes, it probably originates from constraints. In other words, it could be that people do not self-select themselves in more car-oriented areas because they want to, but because they feel they have to. This perceived car dependency may be a consequence of their long-term and medium-term choices regarding lifestyles, work, household structure, etc. (Van Acker et al., 2010).

In addition, the distance to the railway station and residential density have a significant and direct influence on car use when the influence of attitudes and sociodemographics is controlled for. The cross-sectional analysis shows that the direct influence of travel-related attitudes on car kilometres driven is stronger than the effects of the built environment. Somewhat surprisingly, in the longitudinal analysis, this is the other way around, the influence of the built environment indicators prevails over the impact of the attitudes. In other words, even though attitudes have a strong direct relationship with travel behaviour, changes in travel behaviour are more strongly affected by the opportunities and constraints provided by the built environment. This is at odds with findings of a recent longitudinal study by Wang and Lin (2019) who found that attitudes affect total travel time and the number of trips by different modes more strongly than built environment indicators. This may be due to the longer time span of seven years in our study, enabling us to estimate long-term effects that are generally higher compared to short-term effects. However, our results are in line with previous findings by Handy et al. (2005). They also found that the influence of the built environment prevailed over the influence of travel-related attitudes in their quasi-longitudinal analysis, while it was the opposite in their cross-sectional analysis.

This study took many methodological issues into account, such as the reliance on cross-sectional designs and the lack of travel-related attitudes in most previous studies in this field. Nevertheless, some limitations apply. First, due to model complexity it was not possible to estimate comprehensive models including all determinants and directions of causality. Instead, a more explorative approach was chosen using multiple simplified models with different underlying assumptions. Thus, research outcomes represent an accumulation of results based on separate models. Second, the sample is restricted to homeowners, as renters have fewer opportunities to self-select in the Netherlands. Third, the number of movers in the sample is limited. This may have reduced the statistical power to determine self-selection effects. The smaller numbers of participants in the GPS survey may also have reduced the overall representativeness of the study sample. However, the outcomes of a previous study based on a similar but larger dataset, but without the GPS data, support the outcomes of this study. This suggests that the smaller size of the sample did not affect the overall outcomes of this study. In addition, the longer time span of seven years enabled us to estimate long-term effects, but it also increased the opportunity that unobserved events affected the outcomes of this study. Finally, the GPS survey to determine the number of car kilometres driven was carried out approximately one year after the household survey. Changes in household circumstances and attitudes during that timeframe may have influenced the results.

The results of this study have major implications for researchers as well as practitioners. First, and in line with previous studies, this study shows the relevance of including attitudes in studies that study the connection between land use policies and travel behaviour. Secondly, the bi-directional nature of the relationship between attitudes and the built environment should be considered. Only controlling for residential self-selection will probably lead to an underestimation of the influence of the built environment, as the attitudes themselves are conditioned by people's residential environment. Furthermore, our results indicate that self-selection may not always be attitude induced, but may also originate from previous behaviour and constraints related to car dependence. So additionally, it is interesting to take reverse causality related to travel behaviour into account in future research. Finally, the differences between the cross-sectional and longitudinal models regarding the impact of built environment indicators and travel-related attitudes on car use show the importance of conducting more longitudinal studies in this field.

For practitioners, these findings provide support that spatial policies are important to reduce car kilometres driven. Densification and developing new dwellings within the catchment area of public transport stations significantly reduce car use. Even though the impact of built environment characteristics on travel behaviour changes is strong compared to other determinants, the elasticities show that their practical impact is fairly modest. In other words, major changes in the built environment would be necessary to achieve a shift towards sustainable travel behaviour. The impact of these policies can be enhanced by encouraging people with supportive attitudes to self-select in these areas. In addition, we found that the built environment affects people's attitudes, so the impact of these policies is not restricted to population segments with already favourable attitudes. This means that even in areas with people with less supportive attitudes, densification, TOD and other spatial policies could promote sustainable travel behaviour. What is important, is that - at least in the Dutch situation - the distance to the railway station has a stronger influence on car kilometres travelled than residential density alone. This implies that when compact developments are considered, locations closer to railway stations are preferable.

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Appendix 4.A Full model results

Table 1. Cross sectional model 1: residential self-selection, distance to railway station (N=344)

	Endogenous variables									
	Travel behaviour LN car km driven		Attitudes towards transport modes Att. car		Att. PT		Att. bicycle		Built environment LN Distance to railway station	
	b	β	b	β	b	β	b	β	B	β
Exogenous variables										
Built environment										
LN Distance to railway station	**0.151**	**0.140**								
Attitudes										
Att. car	*0.044*	*0.174*							0.033	0.141
Att. PT										
Att. bicycle	**-0.042**	**-0.176**								
Sociodemographics										
Gender (ref=female)			**1.887**	**0.234**						
Age			*-0.056*	*-0.129*	*0.063*	*0.109*			**-0.024**	**-0.237**
Low education level (ref=middle)							-2.169	-0.119		
High education level (ref=middle)					1.166	0.103				
Low income (ref=middle)							**1.71**	**0.159**		
High income (ref=middle)	**0.335**	**0.165**								
Employed	*0.163*	*0.113*	*-0.801*	*-0.141*						
Work fulltime			*1.225*	*0.154*					*-0.209*	*-0.112*
Chi2: 20.868, Df: 24, p: 0.646, RMSEA 0.000, P-close: 0.993, CFI: 1.00, TLI: 1.027, CD (pseudo R2) = 0.306										

Significance: bold p<.01; italics p<.05; other p<.1.

Table 2. Cross sectional model 2: reverse causality (BE-ATT), distance to railway station (N=344)

	Endogenous variables									
	Travel behaviour LN car km driven		Attitudes towards transport modes Att. car		Att. PT		Att. bicycle		Built environment LN distance to railway station	
	b	β	b	β	b	β	b	β	b	β
Exogenous variables										
Built environment										
LN distance to railway station	**0.15**	**0.139**	**0.905**	**0.210**	**-1.114**	**-0.195**				
Attitudes										
Att. car	**0.044**	**0.176**								
Att. PT										
Att. bicycle	**-0.042**	**-0.173**								
Sociodemographics										
Gender (ref=female)			**1.777**	**0.218**						
Age									-0.025	-0.249
Low education level (ref=middle)							*-2.239*	*-0.122*		
High education level (ref=middle)					1.177	0.104				
Low income (ref=middle)							**1.852**	**0.171**		
High income (ref=middle)	**0.334**	**0.164**								
Employed	*0.163*	*0.112*	*-0.681*	*-0.118*						
Work fulltime			**1.631**	**0.203**	1.074	-0.101				
Chi2: 22.649, Df: 26, p: 0.653, RMSEA 0.000, P-close: 0.995, CFI: 1.00, TLI: 1.026, CD (pseudo R2) = 0.299										

Significance: bold p<.01; italics p<.05; other p<.1.

Table 3. Cross sectional model 3: reverse causality (BE-ATT and Car use-ATT), distance to railway station (N=344)

	Endogenous variables									
	Travel behaviour		Attitudes towards transport modes						Built environment	
	LN car km driven		Att. car		Att. PT		Att. bicycle		LN distance to railway station	
	b	β	b	β	b	β	b	β	b	β
Exogenous variables										
Travel behaviour										
LN car km driven			**0.846**	**0.213**	**-1.008**	**-0.19**	**-1.039**	**-0.251**		
Built environment										
LN Distance railway station	**0.213**	**0.197**	**0.729**	**0.17**	**-0.901**	**-0.157**				
Attitudes										
Att. car										
Att. PT										
Att. bicycle										
Socio demographics										
Gender (ref=female)			**1.572**	**0.193**						
Age									**-0.025**	**-0.249**
Low education level (ref=middle)							-2.063	-0.113		
High education level (ref=middle)					*1.277*	*0.113*				
Low income (ref=middle)	*-0.336*	*-0.129*					*1.51*	*0.14*		
High income (ref=middle)	**0.392**	**0.193**								
Employed			*-0.76*	*-0.133*						
Work fulltime			*1.279*	*0.16*						
Chi2: 31.842, Df: 28, p: 0.281, RMSEA 0.020, P-close: 0.965, CFI: 0.984, TLI: 0.972, CD (pseudo R2) = 0.281										

Significance: bold p<.01; italics p<.05; other p<.1

Table 4. Cross sectional model 4: residential self-selection, residential density (N=344)

	Endogenous variables									
	Travel behaviour		Attitudes towards transport modes						Built environment	
	LN car km driven		Att. car		Att. PT		Att. bicycle		LN Residential density	
	b	β	b	β	b	β	b	β	b	β
Exogenous variables										
Built environment										
LN residential density	*-0.203*	*-0.109*								
Attitudes										
Att. car	*0.045*	*0.179*							-0.017	-0.127
Att. PT										
Att. bicycle	**-0.041**	**-0.171**								
Socio demographics										
Gender (ref=female)			**1.893**	**0.234**						
Age			*-0.056*	*-0.13*	*0.063*	*0.109*			**0.013**	**0.222**
Low education level (ref=middle)							-2.163	-0.118		
High education level (ref=middle)					1.166	0.103				
Low income (ref=middle)							**1.708**	**0.158**		
High income (ref=middle)	**0.323**	**0.159**								
Employed	*0.175*	*0.122*	*-0.817*	*-0.144*						
Work fulltime			*1.228*	*0.154*					0.115	0.107
Chi2: 23.645, Df: 24, p: 0.482, RMSEA 0.000, P-close: 0.983, CFI: 1.00, TLI: 1.003, CD (pseudo R2) = 0.30										

Significance: bold p<.01; italics p<.05; other p<.1

Table 5. Cross sectional model 5: reverse causality (BE-ATT), residential density (N=344)

	Endogenous variables									
	Travel behaviour LN car km driven		Attitudes towards transport modes Att. car		Att. PT		Att. bicycle		Built environment LN residential density	
	b	β	b	β	b	β	b	β	b	β
Exogenous variables										
Built environment										
LN residential density	*-0.203*	*-0.108*	**-1.364**	**-0.183**	**1.873**	**0.189**	*0.949*	*0.122*		
Attitudes										
Att. car	**0.046**	**0.181**								
Att. PT										
Att. bicycle	**-0.041**	**-0.169**								
Socio demographics										
Gender (ref=female)			**1.74**	**0.213**						
Age									**0.013**	**0.23**
Low education level (ref=middle)							-2.176	-0.119		
High education level (ref=middle)					1.195	0.106				
Low income (ref=middle)							**1.885**	**0.174**		
High income (ref=middle)	**0.322**	**0.158**								
Employed	*0.174*	*0.121*	-0.624	-0.109						
Work fulltime			**1.612**	**0.201**	-1.064	-0.100				
Chi2: 26.543, Df: 26, p: 0.434, RMSEA 0.008, P-close: 0.982, CFI: 0.998, TLI: 0.996, CD (pseudo R2) = 0.289										

Significance: bold p<.01; italics p<.05; other p<.1

Table 6. Cross sectional model 6: reverse causality (BE-ATT and Car use-ATT), surrounding address density (N=344)

	Endogenous variables									
	Travel behaviour		Attitudes towards transport modes						Built environment	
	LN car km driven		Att. car		Att. PT		Att. bicycle		LN residential density	
	b	β	b	β	b	β	b	β	b	β
Exogenous variables										
Travel behaviour										
LN car km driven			**0.881**	**0.223**	**-1.038**	**-0.196**	**-1.02**	**-0.246**		
Built environment										
LN residential density	**-0.316**	**-0.168**	**-1.104**	**-0.149**	**1.574**	**0.158**				
Attitudes										
Att. car										
Att. PT										
Att. bicycle										
Socio demographics										
Gender (ref=female)			**1.533**	**0.189**						
Age									**0.013**	**0.23**
Low education level (ref=middle)							-2.041	-0.111		
High education level (ref=middle)					*1.294*	*0.114*				
Low income (ref=middle)	-0.276	-0.106					*1.545*	*0.143*		
High income (ref=middle)	**0.354**	**0.173**								
Employed	*0.16*	*0.11*	*-0.719*	*-0.126*						
Work fulltime			*1.259*	*0.157*						
Chi2: 31.81, Df: 27, p: 0.239, RMSEA 0.023, P-close: 0.950, CFI: 0.980, TLI: 0.963, CD (pseudo R2) = 0.280										

Significance: bold p<.01; italics p<.05; other p<.1

Table 7.1 Longitudinal model: distance to railway station (N=344).

	Endogenous variables									
	Travel behaviour		Attitudes towards transport modes						Built environment	
	LN car km driven 2012		Att. car 2012		Att. PT 2012		Att. bicycle 2012		LN distance to railway station 2012	
Exogenous variables	b	β	b	β	b	β	b	β	b	β
Travel behaviour										
LN car km driven 2005	**0.31**	**0.299**							0.047	0.046
Built environment										
LN distance railway station 2005	**0.233**	**0.206**	*0.418*	*0.103*	**-1.178**	**-0.209**			**0.971**	**0.873**
Attitudes										
Att. car 2005	*0.038*	*0.146*	**0.675**	**0.720**						
Att. PT 2005					**0.659**	**0.672**				
Att. bicycle 2005							**0.668**	**0.646**		
Socio demographics (2005)										
High education level (ref=middle)	**0.409**	**0.184**								
Low income (ref=middle)									*0.161*	*0.06*
Employed			**0.701**	**0.13**						
Single parent ((ref=single household)			*3.111*	*0.099*						
Partners without children (ref=single household)			*1.805*	*0.21*					*0.247*	*0.105*
Partners with children (ref=single household)			1.302	0.163					0.204	0.093
Other hh-composition			3.947	0.08						
Residential move between 2005 and 2012									**-0.356**	**-0.128**

Significance: bold $p<.01$; italics $p<.05$; other $p<.1$

Table 7.1 Longitudinal model: distance to railway station (N=344) (continued).

	Endogenous variables									
	Travel behaviour		Attitudes towards transport modes						Built environment	
	LN car km driven 2005		Att. car 2005		Att. PT 2005		Att. bicycle 2005		LN distance to railway station 2005	
Exogenous variables	b	β	b	β	b	β	b	β	b	β
Socio demographics (2005)										
Gender (ref=female)			**1.819**	**0.223**						
Age			-0.04	-0.091					**-0.023**	**-0.228**
Low education level (ref=middle)							*-2.147*	*-0.118*		
High education level (ref=middle)					1.231	0.109				
Low income (ref=middle)	*-0.313*	*-0.119*					*1.49*	*0.138*		
High income (ref=middle)	**0.413**	**0.202**								
Employed			*-0.832*	*-0.145*						
Work fulltime			**1.737**	**0.216**	*-1.271*	*-0.119*	-0.955	-0.114		

Chi2: 100.35, Df: 101, p: 0.499, RMSEA 0.000, P-close: 1.000, CFI: 1.00, TLI: 1.001, CD (pseudo R2) = 0.462

Significance: bold p<.01; italics p<.05; other p<.1

Table 7.2 Correlations between error terms in 2005 (lower left) and 2012 (upper right): distance to railway station (N=344).

	LN Car km driven	Car attitude	PT attitude	Bicycle attitude	LN distance railway station
LN Car km driven	-	*ns*	*ns*	**0.216**	*0.119*
Car attitude	**0.267**	-	*ns*	**0.302**	*ns*
PT attitude	**-0.225**	**-0.477**	-	*ns*	*ns*
Bicycle attitude	**-0.254**	**-0.318**	**0.414**	-	*ns*
LN distance railway station	**0.202**	**0.199**	**-0.178**	*ns*	-

Significance: bold p<.01; italics p<.05; other p<.1; *ns*=non-significant

Table 8.1 Longitudinal model: residential density (N=344).

	Endogenous variables									
	Travel behaviour LN Car km driven		Attitudes towards transport modes Att. car 2012		Att. PT 2012		Att. bicycle 2012		Built environment LN residential density 2012	
Exogenous variables	b	β	b	β	b	β	b	β	b	β
Travel behaviour										
LN Car km driven	**0.322**	**0.311**							*-0.067*	*-0.103*
Built environment										
LN residential density 2005	**-0.303**	**-0.155**			**1.189**	**0.122**			**0.764**	**0.618**
Attitudes										
Att. car 2005	*0.04*	*0.152*	**0.677**	**0.722**						
Att. PT 2005					**0.675**	**0.688**				
Att. bicycle 2005							**0.669**	**0.646**		
Socio demographics (2005)										
High education level (ref=middle)	**0.403**	**0.181**								
Low income (ref=middle)									*0.161*	*0.06*
Employed			**0.71**	**0.132**						
Single parent ((ref=single household)			3.084	0.098						
Partners without children (ref=single household)			*1.846*	*0.215*					*-0.254*	*-0.168*
Partners with children (ref=single household)			*1.316*	*0.165*					-0.215	-0.153
Other hh-composition			4.119	0.083						
Residential move between 2005 and 2012									**-0.406**	**-0.228**

Significance: bold p<.01; italics p<.05; other p<.1

Table 8.1 Longitudinal model: residential density (N=344) (continued).

	Endogenous variables									
	Travel behaviour		Attitudes towards transport modes						Built environment	
	Car use 2005		Att. car 2005		Att. PT 2005		Att. bicycle 2005		Residential density 2005	
Exogenous variables	b	β	b	β	b	β	b	β	b	β
Socio demographics (2005)										
Gender (ref=female)			**1.811**	**0.222**						
Age									**0.012**	**0.212**
Low education level (ref=middle)					2.261	0.097	-2.079	-0.114		
High education level (ref=middle)					*1.249*	*0.11*				
Low income (ref=middle)	*-0.324*	*-0.124*					*1.516*	*0.14*		
High income (ref=middle)	**0.406**	**0.198**								
Employed			*-0.799*	*-0.139*						
Work fulltime			**1.68**	**0.209**	*-1.215*	*-0.114*	-0.957	-0.115		
Chi2: 110.95, Df: 103, p: 0.279, RMSEA 0.015, P-close: 1.000, CFI: 0.993, TLI: 0.988, CD (pseudo R2) = 0.444										

Significance: bold p<.01; italics p<.05; other p<.1

Table 8.2 Correlations between error terms in 2005 (lower left) and 2012 (upper right): residential density (N=344).

	LN Car km driven	Car attitude	PT attitude	Bicycle attitude	LN residential density
LN Car km driven	-	0.16	*ns*	**0.213**	*-0.111*
Car attitude	**0.267**	-	-0.182	**0.297**	-0.14
PT attitude	**-0.226**	**-0.479**	-	*ns*	0.116
Bicycle attitude	**-0.255**	**-0.318**	**0.415**	-	*ns*
LN residential density	**-0.167**	**-0.168**	**0.173**	*0.127*	-

Significance: bold $p<.01$; italics $p<.05$; other $p<.1$; *ns*=non-significant.

Chapter 5: Residential Self-selection, Reverse Causality and Residential Dissonance. A Latent Class Transition Model of Interactions Between the Built Environment, Travel Attitudes and Travel Behaviour

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Abstract

Travel-related attitudes and dissonance between attitudes and the characteristics of the residential built environment are believed to play an important role in the effectiveness of land use policies that aim to influence travel behaviour. To date, research on the nature and directions of causality of the links between these variables has been hindered by the lack of longitudinal approaches. This paper takes such an approach by exploring how people across different population groups adjust their residential environments and attitudes over time. Two latent class transition models are used to segment a population into consonant and dissonant classes to reveal differences in their adjustment process. Interactions between (1) the distance to railway stations and travel-mode-related attitudes and (2) the distance to shopping centres and the importance of satisfaction with these distances are modelled. The models reveal mixed patterns in consonant and dissonant classes at different distances from these destinations. These patterns remain relatively stable over time. People in more dissonant classes generally do not have a higher probability of switching to more consonant classes. People adjust their built environments as well as their attitudes over time and these processes differ between classes. Implications for policies are discussed.

Keywords: travel behaviour, built environment, attitudes, residential self-selection, reverse causality, longitudinal approach

5.1 Introduction

Governments generally aim for more sustainable travel behaviour (Banister, 2008). One approach to this is to develop built environments that are conducive to the use of alternatives to the car (walking, cycling and public transport). In recent decades, policy measures such as densification and transit-oriented development have been applied for this purpose. While integrated spatial and transport planning is receiving increasing attention in policymaking, the causality and strength of the relationship between the built environment and travel behaviour (the BE-TB link) remains subject to academic debate. The research has been summarised in many reviews (see: Van Wee and Maat, 2003; Boarnet, 2011; Ewing and Cervero, 2010; Gim, 2013; Cao et al., 2009; Mokhtarian and Cao, 2008; Bohte et al., 2009; Chatman, 2014; Næss, 2014).

Direction of causality

The causality debate revolves around the residential self-selection hypothesis. It assumes that people self-select in neighbourhoods that are conducive to the use of their preferred travel modes based on their travel abilities, travel-related attitudes, needs, and preferences (Handy et al., 2005; Cao et al., 2009; Bohte et al., 2009; Litman, 2005). For example, people with a favourable attitude towards public transport may choose to live in close proximity to railway stations. Overall, the literature supports the residential self-selection hypothesis, but the outcomes are mixed (Ewing and Cervero, 2010). While some studies, such as Kitamura et al. (1997), Bagley and Mokhtarian (2002) and Lund (2003), concluded that attitudes are more dominant than built environment characteristics, others found a significant influence of the built environment on travel behaviour, even after controlling for residential self-selection (Schwanen and Mokhtarian, 2005; Bohte, 2010; Van de Coevering et al., 2016; De Abreu e Silva, 2014; Lin et al., 2017). For more extensive reviews on this subject, we refer to Cao et al. (2009), Bohte et al. (2009), Ewing and Cervero (2010) and Gim (2013).

People are not always able to fully self-select, as they may be constrained by their income, household circumstances, supply in the housing market or other conflicting residential preferences. Moreover, life course events such as having a child can influence the needs and preferences of households, which may result in the occurrence of residential dissonance over time (Schwanen and Mokhtarian, 2004; De Vos et al., 2012). In addition to moving house (residential self-selection), people can adjust their attitudes towards their current residential neighbourhood in order to reduce residential dissonance. This reverse causality may occur for two reasons. First, according to the theory of cognitive dissonance (Festinger, 1957) people do not only adjust their behaviour but also their attitudes if dissonance occurs. In this case, people may adjust their travel-related attitudes to their residential choices. Second, according to Cullen (1978), people will have positive and negative experiences during their daily routines in their current social and spatial context and consequently adapt their attitudes over time. For example, if they live close to a railway station, people may become more familiar with public transport, start to see it as a good alternative travel option and consequently adjust their attitudes and travel behaviour (Bagley and Mokhtarian, 2002; Bamberg, 2006; Chatman, 2009; Bohte et al., 2009; Van de Coevering et al., 2016).

This reverse direction of influence has received considerably less attention in literature. To the best of our knowledge, only the studies of Bagley and Mokhtarian (2002), Bohte et al. (2009), Van de Coevering et al. (2016) and Lin et al. (2017) explicitly modelled multiple directions of causality, arriving at different conclusions. Bagley and Mokhtarian (2002) found evidence of residential self-selection but not of reverse causality, while Bohte et al. (2009) found that initial residential self-selection effects diminished after controlling for reverse causal influences. Lin et al. (2017) found reciprocal influences and concluded that the direction of influence depends

on people's ability to self-select. Van de Coevering et al. (2016) found no evidence of residential self-selection but instead found reverse causality effects between the distance to the railway station and travel-related attitudes.
The dominant direction of causality between travel-related attitudes and the built environment is extremely important for integrated spatial and transport planning. If residential self-selection is dominant, measures such as densification and transit-oriented development environments would primarily benefit people who already have favourable attitudes towards sustainable travel behaviour. It is the combination of a person's attitude and the selection of a conducive neighbourhood that facilitates this behaviour.
This implies that the impact of the built environment on sustainable travel behaviour is influenced by the share of people who already have a positive attitude towards alternatives to the car and their ability to self-select conducive neighbourhoods. If the reverse causal direction is dominant, the built environment not only has a direct effect on travel behaviour but also an additional indirect effect, through its influence on travel-related attitudes. This would mean that controlling for residential self-selection by incorporating travel-related attitudes would lead to an underestimation of the impact of the built environment (Cao et al., 2009; Chatman, 2009; Handy et al., 2005; Næss, 2005; Næss, 2009).

Approaches to control for residential self-selection
To date, most evidence on residential self-selection is based on variable-centred models such as regression analyses and SEM modelling and most studies apply cross-sectional research designs (see: Mokhtarian and Cao, 2008 for a review). A simple way to control for residential self-selection is to include sociodemographics and travel-related attitudes that influence both travel behaviour and residential location directly in the models (Bhat and Guo, 2007). Kitamura et al. (1997) were the first to explicitly control for attitude induced self-selection in a cross-sectional design study. Since then, many other studies have controlled for the influence of residential self-selection in this way (Bagley and Mokhtarian, 2002; Bohte et al., 2009; Van de Coevering et al., 2016; Lin et al., 2017). A couple of studies use longitudinal or quasi-longitudinal data (Meurs and Haaijer, 2001; Krizek, 2003; Handy et al., 2005; Cao et al., 2007; Cao et al. 2007; Aditjandra et al., 2012; Van de Coevering et al., 2016; Klinger, 2017). To the best of our knowledge, Van de Coevering et al. (2016) were the first to collect attitudinal data at multiple moments in time. They applied linear cross-lagged panel analysis to assess longitudinal directions of influence. In addition to the inclusion of attitudes and sociodemographics, Schwanen and Mokhtarian (2005) introduced the concept of residential neighbourhood dissonance. They distinguished consonant and dissonant groups of urban/suburban residents and residents with a high/low preference for high-density living and compared their travel behaviour. They incorporated these measures of dissonance in their regression models and found that the impact of dissonance on travel behaviour differs between consonant and dissonant groups. Similar measures of dissonance were used by Frank et al. (2007), De Vos et al. (2012), Kamruzzaman et al. (2013) and Cho and Rodríguez (2014). For a more detailed overview, we refer to Cao (2015).
Another less popular approach is based on person-centred analyses, which identify key patterns of values across variables, where the person is the unit of analysis. These analyses – with cluster analysis as a typical example – result in the identification of a small set of segments from a sample by maximising homogeneity within these segments and heterogeneity between segments (Bauer and Shanahan, 2007). In transportation studies, to the best of our knowledge, Anable (2005) was the first to use cluster analysis to define clusters based on attitudinal variables. However, the applications in studies on the interaction between land use and transportation are few. Manaugh and El-Geneidy (2015) used cluster analysis to create segments based on various aspects of housing choice, including financial constraints and

preferences related to travel, neighbourhood and housing. Using regression analysis, they demonstrated that the influence of public transport quality on public transport use varies significantly between clusters. Liao et al. (2015) applied a discrete choice model in combination with a latent class analysis and found that preferences for compact walkable and transit-friendly developments are strongly associated with travel-related preferences and travel behaviour.

Research aim and approach

Previous research has primarily investigated whether attitudes are associated with residential location choice and travel behaviour by performing cross-section analyses. The purpose of this paper is to understand how people adjust their attitudes and their residential location over time, that is to say, in what circumstances do residential self-selection and reverse causal influences from residential choices on attitudes occur.

While determining the dominant direction of causality between these variables is important, it may oversimplify complex underlying adjustment processes. Therefore, we explore how the adjustment process differs across population groups, depending on people's residential dissonance. For example, it is assumed that people who prefer the train but live in suburbs that are not connected to a railway station (referred to as a dissonant situation) are more likely to move house or adapt their attitudes than those with the same preference who live in city centres close to a railway station (referred to as a consonant situation). We also analyse the role of sociodemographic characteristics. Households with children may, for example, have more difficulties finding a sufficiently large house in closer proximity to a railway station to reduce their travel-related dissonance.

In order to identify whether and how adjustment processes differ between various groups, we apply latent class transition modelling (LCTM) on a longitudinal dataset. LCTM does not analyse direct lagged relationships between variables over time as in cross-lagged panel models (e.g. Van de Coevering et al., 2016). Instead, it is a segmentation technique – like cluster analysis – that inductively reveals patterns of cases (Collins and Lanza, 2013). We use it to identify consonant and dissonant clusters of people based on their travel-related attitudes and residential built environments and estimating transition probabilities between cluster over time. In other words, LCTM allows us to explore the circumstances and processes through which adjustments in behaviour and attitudes occur over time (Kroesen, 2014).

We estimate two models. The first includes commonly used travel-mode attitudes (related to the use of cars, public transport and bicycles) and their interaction with the distance to the nearest railway station. Schwanen and Mokhtarian (2005) have shown that self-selection is not restricted to attitudes to these specific modes. Therefore, we include a second model concerned with the importance people attach to the distance to shops and services and the actual distance to the nearest neighbourhood shopping centre. The second model also includes people's satisfaction with the current neighbourhood characteristics. This allows us to analyse the extent to which larger objective mismatches between the importance that people attach to the distance and the actual distance are associated with lower levels of satisfaction (i.e. perceived mismatch). We refer to the method section for further details on the models used in this study.

Paper outline

The remainder of this paper is organised as follows. The following section describes the theoretical background and current knowledge on the relationship between travel-related attitudes, the built environment and travel behaviour. The method section describes the data collection and model specification. The results section describes the findings of the analyses, and the final section presents the conclusions and a discussion, including policy recommendations.

5.2 Method

Data collection

Data was collected in three municipalities in the Netherlands in 2005 and 2012: Amersfoort, a medium-sized city; Veenendaal, a small town with good bicycle facilities; and Zeewolde, a remote town. Within these municipalities, different types of residential areas were selected, ranging from historical centres to suburban areas, and representing a wide variety of built environment characteristics, including car-friendly, bicycle-friendly and public transportation-friendly areas. GIS software was used to obtain detailed data on land use, infrastructure and accessibility.

A random sample of households was drawn from the civil registries of each of these areas. It was limited to homeowners because renters in the Dutch housing market have a very limited choice set, which hinders self-selection (Bohte, 2010). An internet questionnaire was conducted in 2005, including questions about demographic, socioeconomic, attitudinal and travel-related characteristics. Both partners in a household were asked to participate. From the 12,836 people who were approached, 3979 completed the questionnaire – a response rate of 31% (Bohte, 2010).

After this initial data collection round, letters and emails were sent annually to maintain contact with the respondents, and they were invited to provide information regarding house moves and changes in contact details. We were able to contact approximately 3300 respondents (83%) again for a second-round questionnaire in 2012. The other respondents dropped out for a variety of reasons (e.g. moved to an unknown destination, changed or unknown contact details, and some had passed away). From these 3300 respondents, 1788 individuals from 1325 different households participated in the second round, a response rate of 54%. Logistic regression was conducted to test whether systematic drop out had occurred between the research rounds. Results revealed that younger and less educated respondents, females and respondents from households with young children were more likely to have dropped out.

For this second wave, we only selected participants that had completed both questionnaires. Due to the selection of homeowners in the first round, the ageing of our sample (also called the stagnation effect), and the selective dropout, older people with a higher education level and higher incomes are overrepresented in our sample compared to population statistics of the neighbourhoods. The relatively high average age (57 years) of the second wave is apparent. Nevertheless, of our panel, 425 people were aged between 33 and 51. To avoid any problems with dependence of observations in the analysis, we randomly selected one of the partners from the 463 households in which both partners participated. Furthermore, a couple of cases were removed because their data was incomplete on important variables. As a result, 1322 respondents were included in analyses for this paper. In addition, new GIS analyses were conducted to obtain data on spatial characteristics in 2005 and 2012 and changes that occurred over this time period.

Variables

Table 5.1 provides an overview of the key variables and their descriptive statistics in the first (2005) and second waves (2012). Sociodemographics include gender, the age of the respondents, the number of children in the household and income level. In line with the first wave (Bohte, 2010) we used personal income for the second wave to enable the longitudinal assessment of this indicator. As the personal income does not reflect all resources within the household, results should be interpreted with caution.

Table 5.1 Key variables in 2005 and 2012 (N = 1322).

Variables	Description	2005 %/Mean (st.dev)	2012 %/Mean (st.dev)
Sociodemographics			
Age	Average	50.4 (10.6)	57.4 (10.6)
Gender	Female	42.7%	42.7%
	Male	57.3%	57.3%
Children	Number of children in household	1.18	0.98
Net personal income (monthly)	Low (< €1000)	19.0%	12.2%
	Middle (> = €1000 - < €2000)	39.4%	33.1%
	High (> €2000)	42.6%	54.7%
Importance & satisfaction with distance			
Importance distance to shops and services		0 (0.26)	0 (0.27)
- Importance dist. to non-daily shops		3.12 (0.81)	3.30 (0.78)
- Importance dist. to restaurants, pubs, etc.		2.62 (0.87)	2.68 (0.88)
- Importance dist. to cultural and other services		2.78 (0.88)	2.93 (0.89)
Satisfaction with distance to shops and services		0 (0.40)	0 (0.28)
- satisfaction dist. to non-daily shops		0.98 (0.75)	1.13 (060)
- satisfaction dist. to restaurants, pubs, etc.		0.71 (0.72)	0.80 (0.64)
- satisfaction dist. to cultural and other services		0.70 (0.73)	0.74 (0.71)
Travel-mode-related attitudes			
Car attitude		0.57 (0.35)	0.54 (0.35)
- Travelling by car is comfortable (loading = 0.69)		1.30	1.31
- Travelling by car is flexible (loading = 0.90)		1.35	1.36
- Travelling by car is fun (loading = 0.73)		0.89	0.94
- Travelling by car is private (loading = 0.89)		1.16	1.13
Public transport attitude		-0.85 (0.41)	-0.81 (0.42)
- Travelling by PT is comfortable (loading = 0.69)		-0.21	-0.10
- Travelling by PT is flexible (loading = 0.90)		-1.10	-0.91
- Travelling by PT is fun (loading = 0.73)		-0.27	-0.13
- Travelling by PT is private (loading = 0.89)		-1.04	-0.98
Bicycle attitude		0.29 (0.41)	0.28 (0.40)
- Travelling by bicycle is comfortable (loading = 0.69)		0.39	0.43
- Travelling by bicycle is flexible (loading = 0.90)		1.00	1.06
- Travelling by bicycle is fun (loading = 0.73)		1.21	1.16
- Travelling by bicycle is private (loading = 0.89)		0.63	0.62
Built environment variables			
Average distances in meters	To neighbourhood shopping centre	1123 (778)	1161 (819)
	To nearest railway station	6150 (5458)	5627 (5721)

Table 5.1 (continued).

Travel behaviour variables			
Car share	Frequency of car use compared to other modes	4.8 / (1.9)	4.7 (1.9)
Car availability	% always access to a car	73%	73%
Car ownership	# of cars in household	1.48 (0.64)	1.47 (0.66)
Company cars	# of company cars in household	0.24 (0.44)	0.20 (0.42)
Public transport card	% of public transport card owners	23.1%	32.5%
Dynamics in panel		*Change*	
Residential relocation	Number of movers in database	250 (19%)	
Job changes	Number of job changes	238 (18%)	
Children	Arrival of new-borns/adopted children	100 (8%)	
Changes in Income	Decrease	180 (14%)	
	Stable	511 (48%)	
	Increase	631 (39%)	

Due to the selection of homeowners, the average age and income of the respondents are relatively high; low incomes are due to part-time workers. Travel-related attitudes were determined using confirmatory factor analysis. The importance of the distance to shopping and services is derived from indicator variables which are measured on a 5-point scale ranging from 1 (very unimportant) to 5 (very important). Satisfaction is based on the same indicators and was measured on a 5-point scale ranging from -2 (very un- satisfied) to +2 (very satisfied). Attitudes to car use, cycling and public transport use were measured by asking respondents to rate nine statements on a 5-point Likert scale, ranging from -2 'strongly disagree' to +2 'strongly agree'. These statements included affective (e.g. 'driving a car is pleasurable') as well as cognitive (e.g. 'bicycling is environmentally friendly') aspects.

In order to obtain the same factor structure for each transport mode, the responses for these modes were pooled and analysed together. In other words, the factor analysis was conducted on all nine statements, irrespective of mode. The advantage of this approach is that the mean of the latent factor for each mode can be compared to the mean of the other modes. If the factor scores had been conducted for each individual mode, the average for each mode would have been zero, since factor scores are standardised (see Molin et al., 2016).

In the confirmatory factor analysis, one factor labelled 'pleasant' was identified, on which the variables pleasant, comfortable, flexible and privacy loaded strongly in both 2005 and 2012. The other indicators did not lead to the identification of a strong second factor or to an acceptable model fit and were therefore discarded. To gain reliable and stable factor scores, only indicators with a loading of over 0.60 were included (see Kline, 2010, for further discussion). Furthermore, measurement invariance was assessed for all factors by constraining the factor loadings to be equal for both years. This constraint did not result in a significant decrease in model fit. The equal form and equal loadings invariance suggest that the indicators have a comparable influence on the factor in both years, which is a prerequisite for a longitudinal assessment of change in this factor (Newsom, 2015). The factor scores were saved and added to the database as mode-specific variables.

The built environment was operationalised by measures of accessibility. Shortest routes between respondents' homes to the neighbourhood shopping centre and the nearest railway station were calculated based on the network (source of road network: Dutch National Roads

Database, NWB, 2013). The coordinates of the destinations were derived from a retail database (Locatus, 2013) and the national employment database (LISA, 2013). Travel behaviour was assessed by the question: 'How often do you use the car compared to other modes such as public transport, bicycling and walking?'. Responses were provided on a 7-point Likert scale ranging from 1: '(Almost) never with the car and (almost) always with alternatives' to 7 '(Almost) always with the car and (almost) never with alternatives'. The dynamics in the panel show that approximately 1 in 5 respondents moved house and 1 in 4 experienced changes in their job location. A significant share of respondents (39%) experienced an increase in income category. The distribution of the continuous indicator variables, the travel-mode attitudes, importance and satisfaction and the distances to destinations deviated strongly from normality. Therefore, the attitudes were recoded into 5-point ordinal scales, which corresponded with the 5-point scales of the underlying indicators. The distances to destinations were recoded into 10-point ordinal scales. For each variable, thresholds were chosen that divided the sample into more or less even proportions.

Model specification

An important assumption in this paper is that differences in the nature and degree of dissonance will lead to different adjustment processes. To date, many studies used a priori classifications of dissonance and 'variable-centred' approaches such as regression modelling to identify the role of dissonance (see Cao, 2015 for an overview). An advantage of 'variable-centred' approaches is that they enable to estimate an easy to interpret the main effect for a dissonance variable in the model controlling for other variables. A disadvantage is that these main effects could mask differences in adaption processes between subgroups in the population and nonlinear effects and interactions effects have to be specifically controlled for. This paper presents a 'person-centred' approach, as an alternative by applying LCTM. It groups a set of respondents in subgroups by maximising homogeneity within groups and heterogeneity between groups. In LCTM, these groups are assumed to explain associations between the indicators including nonlinear effects and interaction effects. The advantage is that these groups are inductively derived from the data which enables a more thorough understanding of adjustments in behaviour and attitudes over time under different circumstances. A disadvantage of LCTM is that they require more parameters and may produce less accurate and stable results compared to 'variable-centred' methods when sample sizes are small and when nonlinear and interaction effects are not present (Bauer and Shanahan, 2007).

The major benefits of LCTM compared to k-means cluster analyses are that it involves a model-based clustering technique that probabilistically assigns individuals to a class (or cluster), which reduces misclassification biases, and these statistical criteria can be used to determine the optimal number of classes (Collins and Lanza, 2013; Vermunt and Magidson, 2013). Furthermore, it is a transition model, which means that it enables the identification of these classes at multiple moments in time and estimation of transition probabilities between these classes (Collins and Lanza, 2013).

Two models are estimated below. Model I clusters travel-mode attitudes and their interaction with the distance to the nearest railway station. Model II clusters the importance that people attach to the distance to shops and services and the actual distance to the nearest neighbourhood shopping centre. The model specifications are presented in Figures. 5.1 and 5.2. They show that LCTMs consist of a measurement, a structural and a longitudinal part. Below, the model conceptualisations and related assumptions of both models are described.

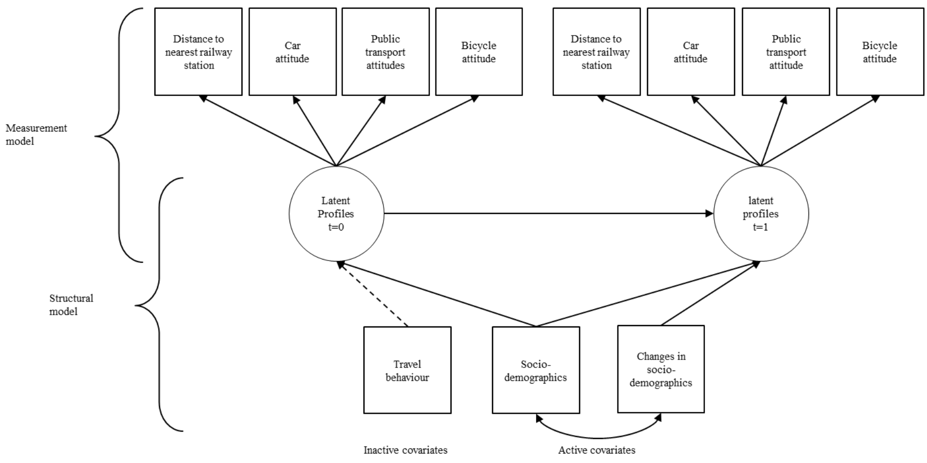

Figure 5.1. Model I: LCTM for travel-mode attitudes and distance to the railway station.

The measurement model in Model I is specified by four indicators: three travel-mode-related attitudes, for car, public transport and the bicycle, respectively, and one built environment characteristic, the distance to the railway station (Figure 5.1). In the measurement part, latent profiles (a set of latent classes) are assumed to explain associations between these indicators (Vermunt and Magidson, 2013). The latent classes represent different combinations of travel-related attitudes and distances to the nearest railway station. The assumption here is that, due to the processes of residential self-selection and reverse causality, the majority of people will have travel-mode attitudes which are aligned to the characteristics of their residential environment. Thus, people living in areas in closer proximity to railway stations will have more positive attitudes to alternatives to the car (public transport and cycling), while people who have positive attitudes to the car would live further away.

In the structural part of the model, the transition probabilities are conditional on exogenous covariates to control for differences in sociodemographic characteristics. Sociodemographic characteristics in 2005 (t = 0) are assumed to influence membership of the profiles in 2005. For example, males may have a higher probability of being assigned to classes with stronger car attitudes. The following covariates are considered: gender, age, the number of children in the household and personal income. Travel behaviour variables are included as inactive covariates. This means that they do not actively contribute to the model, but their average values are included for the respective classes. This enables us to describe the travel behaviour of the different classes and to also profile them. They are not specified as indicators, as this would lead to identifying attitude and travel behaviour patterns, while the focus of this study is on the interaction between travel-related attitudes and the built environment. Including them as active covariates would lead to endogeneity issues, as travel behaviour is generally considered to be affected by characteristics of the built environment and not the other way around.

In the longitudinal part of the model, the same latent profiles are estimated for two separate moments in time (2005 and 2012), which results in an LCTM. Change is represented by transitions between latent classes over time. These transitions are based on a model that estimates the probability of class membership in 2012 (t = 1), conditional on class membership in 2005. They can be translated into a matrix of transition probabilities. In accordance with the theory of cognitive dissonance (Festinger, 1957), we expect that the influence of residential self-selection and reverse causality will depend on the level of initial dissonance in 2005. For example, it is expected that car lovers living in close proximity to the railway station have a higher probability of moving house and self-select to a more conducive neighbourhood than their counterparts who already live in a suburban area. The above-mentioned covariates (sociodemographics) are assumed to influence class membership in 2012. For example, older people may have a higher probability of transitioning to classes with more positive attitudes to public transport. In addition, changes in sociodemographics and two dummy variables indicating whether a person moved house or changed jobs, respectively, in between the two waves, are assumed to influence class membership in 2012.

Model II is specified with three indicators: the distance to the nearest shopping centre, the importance which people attach to the distance to shopping facilities and satisfaction with the current distance (Figure 5.2). We expect people who attach more importance to the distance to shopping facilities will live in closer proximity to shopping centres. If they live further away from these facilities, we expect them to be less satisfied. In other words, we assume that a higher level of objective dissonance is reflected in lower satisfaction levels (perceived dissonance).

The structural and longitudinal parts are identical to the previous model. In accordance with the assumptions of the previous model, we expect that the influence of residential self-selection and reverse causality will depend on the initial level of dissonance in 2005. For example, people who consider proximity to shopping facilities to be important but currently live far from them will have a higher probability of moving house or will adjust the level of importance attributed to the distance to reduce cognitive dissonance.

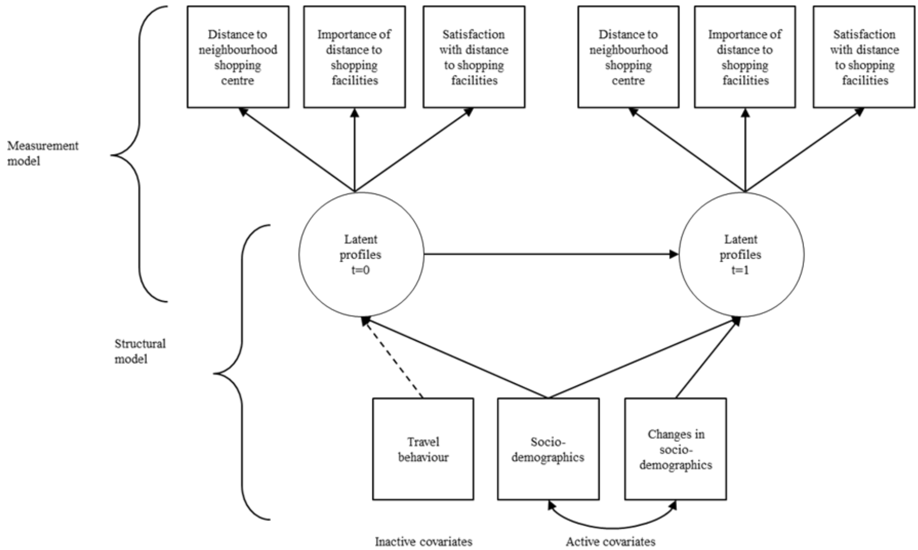

Figure 5.2. Model II: LCTM for importance, satisfaction and distance to shopping centre.

Model estimation

Since the indicators of the latent classes are ordinal variables in both models, ordinal logit models were used to estimate the relationships of the latent class variables to the indicators. The latent class variables are nominal variables. Therefore, the influence of background variables on the latent class variables as well as the probability of transitions over time were modelled using multinomial logistic regression models.

Multiple measurement models with one to seven classes that only included the indicators were estimated and compared to determine the optimal number of latent classes. Their ability to account for the associations between the indicators and their BIC values were compared to determine the best model. Subsequently, the best model was selected and the covariates added. The six class solutions showed the lowest BIC values and the chi-square of all bivariate residuals was below 3.84 for both models, indicating that there was no significant covariation between the indicators. These were selected and are described in the following section. The models in this study were estimated with Latent Gold 5.0 (Vermunt and Magidson, 2013), a dedicated software package for LCTMs.

5.3 Results

This section considers the results of both models, which are presented in two separate tables each. The first table presents the results of the measurement and structural part of a model. This includes the unconditional probability of belonging to a certain class and the conditional probability of having a certain response pattern dependent on class membership. In addition, it describes the influence of the covariates on these latent classes. For ease of interpretation, we translated these probabilities into the profile of class membership in 2005. This reveals people's level of dissonance and their average sociodemographic characteristics. The second table presents the results of the longitudinal part of a model, which includes transition probabilities and the effect of the covariates on these transition probabilities. This reveals how people adjusted their residential environment and attitudes between 2005 and 2012.

Travel-mode attitudes and distance to the railway station

Table 5.2 presents the profile of latent class membership in 2005 of the first model, which includes: (1) the class sizes based on unconditional class membership probabilities, (2) the Wald statistics and average values of the indicators and covariates conditional on class membership and (3) the inactive covariates and their average values.

Class size shows that people have a relatively high probability of being in first class, while the remainder is distributed quite evenly over the other classes. The Wald indices reveal that all indicators have a significant influence on the latent class variable. Thus, the indicators significantly discriminate between the clusters. With regard to the active covariates, age, the presence of children in the household and income have a significant influence on class membership in 2005. Gender is significant at the 10% level. Note that no coefficients were calculated for the inactive covariates since they are not part of the model. However, below they are used to characterise the classes.

The latent profiles uncover six classes at, on average, 2, 3 and 14 km from the railway station. For the ease of interpretation, we added labels to the classes. Please note that these labels do not cover the full heterogeneity within each class:

- Class 1: nearby discontented (N-D)
- Class 2: nearby PT/bike (N-PT/B)
- Class 3: remote multimodal (R-MM)
- Class 4: remote car (R-C)
- Class 5: suburban car (S-C)
- Class 6: suburban car /bike (S-C/B)

Table 5.2 Profile of class membership in 2005: mode attitude and distance to railway station N = 1322.

	Class	**1** **N-D**	**2** **N-PT/B**	**3** **R-MM**	**4** **R-C**	**5** **S-C**	**6** **S-C/B**	**Overall**
Indicators	Class size (%)	26	18	16	16	12	12	**100**
Distance to train station ((Wald = 95, p < 0.01)	Avg. [meters]	2282	2253	13918	14045	3248	2629	**6150**
Car attitude (Wald = 188, p < 0.01)	Factor score	.40	.34	.43	.82	.87	.79	**.57**
Public transport attitude (Wald = 307, p < 0.01)	Factor score	-.87	-.34	-.70	-1.21	-1.22	-.92	**-.85**
Bicycle attitude (Wald=223, p < 0.01)	Factor score	.17	.44	.30	.24	-.01	.69	**.29**
Active covariates								
Age (Wald = 52, p < 0.01)	Avg. [years]	49	50	45	44	46	48	**47**
Children in household (Wald = 15, p < 0.01)	% hh with children	53	49	62	70	49	66	**58**
Gender (Wald = 10, p < 0.1)	% males	48	58	47	63	82	58	**57**
Income (Wald = 12, p < 0.05)								
% < avg. income (< €20,000 net personal income)		43	34	48	30	12	37	**36**
% avg. income -2x average income (€20,000-30,000)		37	42	34	44	53	3	**41**
% > 2 x avg. income (> 30,000)		20	24	18	26	36	23	**24**
Inactive covariates								
Car availability	% car always access to car	69	54	80	83	88	72	**73**
Car share	1 = always alternatives, 7 = always car	4.48	3.56	5.30	5.83	5.83	4.23	**4.79**
Public transport card	% of PT card owners	23	53	12	10	14	21	**23**
# cars per household	% 0 cars	2	9	0	0	0	1	**2**
	% 1 car	57	72	38	37	47	54	**52**
	% 2 cars	38	18	57	56	44	42	**42**
	% 3 + cars	4	1	4	6	10	3	**4**
Company cars	% hh with company car	23	11	25	31	31	23	**23**

Differences in attitude profiles vary strongly between – and interestingly also within – these distance categories. Overall, the patterns of attitudes and distance to the railway station do not completely support our assumption that people living in closer proximity to the railway station have more favourable attitudes towards public transport and the bicycle. Two classes are aligned with this expectation and show consonant profiles:

- Class 2: nearby PT/bike (18%): people who live, on average, closest to the railway station and have favourable attitudes towards public transport and the bicycle and the least favourable attitude towards car use.
- Class 4: remote car (16%): people who live furthest from the railway station and have more favourable car use attitudes and less favourable attitudes towards the bicycle and, in particular, public transport.

Other classes show less consonant patterns.

- Class 1: nearby discontented (26%): people in this largest class live close to the railway station but do not show favourable attitudes towards public transport, the bicycle or, interestingly, car use.
- Class 3: remote multimodal (16%): people live far from the station but their car attitude is below average and their public transport and bicycle attitudes slightly above average.
- Class 5: suburban car (12%): people are clearly oriented towards car use and less towards the other modes, while the average distance from the railway station is not great.
- Class 6: suburban car/bike (12%): people with favourable bicycle attitudes close to the railway station (in line with our assumption) but also favourable car attitudes and somewhat less favourable attitudes towards public transport.

Somewhat surprisingly, it can also be observed that there are no distinct classes with more favourable attitudes towards the bicycle or public transport in closer proximity to the railway station. Instead, these more favourable attitudes appear in the nearby PT/bike and suburban car/bike classes at approximately 2.5 km from the station, on average. This suggests that people living in areas in closer proximity to stations do not have distinct attitude profiles and, consequently, there is no gradual relationship between this distance and attitudes.

The profile of the covariates shows that people in the nearby PT/bike class are, on average, a little older and clearly have low car availability and car use and there is a high share of public transport cardholders. This suggests that public transport is used in combination with the car to cope with the single car in many households. The nearby discontented class contains more females than males and income levels are lower than average. The lack of sufficient financial resources may be a cause of the less favourable attitudes towards all transport modes. The suburban car class has a very large share of males, a high-income level and high car availability and use. This suggests that males are more car-oriented and, in combination with sufficient financial opportunities, use the car very often, even if they live relatively close to the railway station.

Table 5.3 presents the transition probabilities between 2005 and 2012 and parameter estimates for the influence of the covariates on these probabilities. The rows represent initial cluster membership in 2005 and the columns represent cluster membership in 2012. The greatest probabilities are on the diagonal, which means that people have the highest probability of remaining in the same class over time. Contrary to our expectations, people in more dissonant classes (1, 3, 5 and 6) generally do not have a higher probability of switching to more consonant classes (2 and 4).

Table 5.3 Matrix of transition probabilities: mode attitude and distance to the railway station.

State [t = 1](%)	**1**	**2**	**3**	**4**	**5**	**6**
	N-D	**N-PT/B**	**R-MM**	**R-C**	**S-C**	**S-C/B**
State [t = 0] (%)(Wald = 43, P < 0.05)						
1 (N-D)	100	0	0	0	0	0
2 (N-PT/B)	1	99	0	0	0	0
3 (R-MM)	5	1	92	1	2	0
4 (R-C)	2	0	1	87	6	3
5 (S-C)	0	0	0	0	96	4
6 (S-C/B)	4	10	0	0	0	86
Covariates 2005						
Age (Wald = 11, P < 0.05)	-0.07	0.09	0.08	-0.09	0.05	-0.05
Gender, ref. = female (Wald = 13, P < 0.05)	**3.74**	-1.94	-2.92	2.02	**-2.88**	1.98
Income (Wald = 12, P < 0.05)	**-1.58**	**1.23**	-0.58	-0.32	0.20	**1.04**
Children in hh, ref = no. (Wald = 16, P < 0.01)	**3.61**	-1.63	**4.66**	-2.46	0.74	**-4.91**
Changes in covariates 2005-2012						
Arrival children (Wald = 11, P < 0.05)	**4.06**	-4.92	2.62	-2.47	0.39	0.32
Change in income (Wald = 12, P < 0.05)	**-1.72**	0.74	0.27	-0.23	0.37	0.57
House move (Wald = 15, P < 0.01)	**5.56**	0.17	**-6.77**	**-6.75**	2.62	**5.18**
Job change (Wald = 7, n.s.)	**2.03**	-0.82	1.69	-1.07	-1.97	0.13

*Estimates in bold are significant at $p < 0.05$.

People in the first two classes remained almost completely inert. For people in the consonant nearby PT/bike class, this was more or less expected. However, for people in the nearby discontented class, living in relatively close proximity to the railway station for seven years apparently did not result in more positive bicycle or public transport attitudes, nor did the dissonance increase the probability of moving house. As expected, the most important transitions indicate that the built environment and mode-related attitudes mutually influence each other over time and that the direction of influence differs across the classes. People in the suburban car/bike class showed the strongest tendency to move to the second nearby PT/bike class. This indicates that people's attitudes towards public transport use shifted upwards, which may be due to their relatively close proximity to the railway station. The transition of people from the remote car class to the suburban car class implies a move to a residential area closer to the railway station, without adjusting their car or public transport attitudes. This may be people moving from remote areas to suburban areas in cities that are still conducive to car use for reasons that we do not control for in this model. Interestingly, attitudes to the bicycle became less favourable after the move.

A similar unexpected negative influence of proximity on attitudes appeared in the transition from the remote multimodal to the nearby discontented class. This involved people who move from an area far from the railway station to a residential area in closer proximity, while their attitudes towards public transport and the bicycle become less favourable.

The parameters of the covariates show that, apart from job changes, all covariates significantly influence the transition probabilities. A higher income in 2005 increases the probability of being in the nearby PT/bike and the suburban car/bike classes in 2012, with favourable attitudes towards public transport and the bicycle, respectively. It also reduces the probability of being in the nearby discontented class in 2012, with less favourable attitudes towards all modes. An increase in income between 2005 and 2012 also reduces the probability of being in the nearby discontented class in 2012. Households with children find themselves more often in the nearby discontented and remote multimodal classes in 2012, with less favourable car attitudes, and less often in the suburban car/ bike class, which has a more favourable attitude towards the car and the bicycle. People who moved house had a higher probability of living in closer proximity to the railway station. In other words, there was an overall tendency to move to areas in closer proximity to railway stations.

Importance, satisfaction and distance to the shopping centre

Table 5.4 presents the profile of the latent class membership in 2005 for Model II. The class sizes reveal that people are distributed quite evenly over them, and the Wald indices reveal that all indicators are significant. With regard to the active covariates, age, presence of children in the household and gender have a significant influence on class membership in 2005. Income only just fails to be statistically significant at the 5% level ($p = 0.052$).

The profile roughly reveals three distance categories, within 450, 900 or 2200 m from the nearest neighbourhood shopping centre. We labelled them as follows:

- Class 1: nearby indifferent (N-I)
- Class 2: nearby caring (N-C)
- Class 3: remote indifferent (R-I)
- Class 4: closest indifferent (C-I)
- Class 5: closest caring (C-C)
- Class 6: remote caring (R-C)

In each of these classes, there are people who do and people who do not attach importance to this distance. Contrary to expectations, there is no clear-cut relationship between the importance that people attach to the distance to shopping facilities and the actual distance to the nearest neighbourhood shopping centre. In line with expectations, people who live closer to the neighbourhood shopping centre are more satisfied. This particularly applies to people who attach importance to this distance. For them, a higher level of dissonance due to larger distances to shopping facilities is related to lower satisfaction levels. These differences are smaller for classes of people who do not attach much importance to this distance. Nevertheless, people in the remote indifferent class, who live furthest away, are unsatisfied despite the fact that they do not attach much importance to this distance.

With regard to the covariates, people living in closer proximity to the nearest neighbourhood shopping centre are on average a little older. In particular, the closest caring class consists of older people with fewer children in the household and a stronger orientation to alternatives to the car. They appear to be satisfied with the current distance to shopping facilities. More generally, the distance classes seem to be related to people’s mobility profiles. People in the remote indifferent and remote caring classes are clearly more car-oriented. Furthermore, within each distance class, people who attach more importance to this distance are less car-oriented and use alternatives more often.

Table 5.4 Profile of class membership in 2005: Importance of and satisfaction with distance to shopping facilities.

	Class	1 N-I	2 N-C	3 R-I	4 C-I	5 C-C	6 R-C	**Overall**
Indicators	Class size (%)	21	19	16	16	14	14	**100**
Distance neighbourhood shopping centre (Wald = 360, p < 0.01)	Avg. distance [meters]	878	899	2126	414	432	2153	**1123**
Importance distance to shopping facilities (Wald = 242, p < 0.01)	Factor score distance	-.19	.20	-.19	-.17	.24	.19	**0.00**
Satisfaction distance to shopping facilities (Wald = 144, p < 0.01)	Factor score distance	.01	.10	-.13	.01	.21	-.22	**0.00**
Active covariates								
Age (Wald = 61, p < 0.01)	Avg.[years]	47	49	43	49	52	45	**47**
Children in household (Wald = 27, p < 0.01)	% HH with children	67	58	70	55	35	56	**58**
Gender (Wald = 32, p < 0.01)	% males	64	53	62	64	48	49	**57**
Income (Wald = 11, p < 0.1)								
% < avg. income (< €20,000 net personal income)		33	36	37	34	36	40	**36**
% avg. income -2x average income (€20,000-30,000)		43	40	41	44	39	35	**40**
% > 2 x avg. income (> 30,000)		24	24	22	21	26	25	**24**
Inactive covariates								
Car availability	% car always access to car	70	64	80	75	68	85	**73**
Car share	1 = always alternatives, 7 = always car	4.45	4.44	5.51	4.71	4.44	5.40	**4.79**
Public transport card	% of PT card owners	24	28	11	23	35	18	**23**
# cars per household	% 0 cars	2	4	1	2	4	1	**2**
	% 1 car	54	58	43	53	63	38	**52**
	% 2 cars	42	33	52	37	30	56	**41**
	% 3+ cars	3	5	4	8	2	4	**4**
Company cars	% hh with company car	20	26	30	21	17	26	**23**

Table 5.5 presents the probabilities of transitioning between classes between 2005 and 2012 and the parameter estimates for the influence of the covariates on these probabilities. It shows that people are most likely to remain in the same class over time. Contrary to expectations, dissonant groups, in general, do not appear to clearly have higher probabilities of transitioning

compared to consonant groups. However, dissonant individuals in the remote caring class, the least satisfied, do have the highest probability of transitioning to another class over time.
The largest share of people transitioned from the remote caring class to the nearby caring class. This indicates residential self-selection, where people who attach importance to and are currently unsatisfied with the distance to shopping facilities move to an area in closer proximity and become more satisfied. In other classes, higher levels of dissonance (or lower satisfaction) do not seem to be related to larger transition probabilities. A smaller group of people transitioned from the remote caring class to remote indifferent class. This may be due to cognitive dissonance reduction, where dissonant people reduce the importance that they attach to the distance and reduce their dissatisfaction level over time.
The other transitions show that most people remain more or less stable with regard to the importance that they attach to the distance to shopping facilities. Transitions from the closest caring class to the nearby caring class 2 the remote caring class show that consonant individuals living in close proximity to shopping facilities may transition to classes with larger distances and lower levels of satisfaction. Transitions between the closest caring class and the closest indifferent class, where people who live in close proximity to the neighbourhood shopping centre reduce their importance and satisfaction levels over time, seem counterintuitive. Perhaps changes in household circumstances that were not controlled for explain these changes.
The parameter estimates of the covariates show that people who moved house more often joined one of the first three classes in 2012. This is in line with the overall pattern in the transition matrix, where more people transitioned to these classes. People who experienced a rise in income had a higher probability of transitioning to classes that attach more importance to the distance to shopping facilities.

Table 5.5 Matrix of transition probabilities: Importance of and satisfaction with distance to shopping facilities.

State [t = 1] (%)	1 N-I	2 N-C	3 R-I	4 C-I	5 C-C	6 R-C
State [t = 0] (%) (Wald = 103, p < 0.01)						
1 (N-I)	92	4	4	0	0	0
2 (N-C)	0	98	1	0	0	1
3 (R-I)	9	0	91	0	0	0
4 (C-I)	8	0	4	86	1	0
5 (C-C)	1	4	0	5	87	4
6 (R-C)	0	12	7	0	0	80
Covariates 2005						
Age (Wald = 7, n.s.)	-0.04	0.04	-0.05	0.05	-0.09	*0.09*
Gender (Wald = 8, n.s.)	0.10	-1.00	-0.22	**3.52**	-2.54	0.14
Income (Wald = 20, P < 0,01.)	-0.55	-0.40	-0.31	**3.46**	-2.37	0.16
Children in hh, ref = no. (Wald= 9, n.s.)	**-1.00**	0.66	-0.41	**-1.59**	*1.08*	**1.27**
Changes in covariates 2005-2012						
Arrival children (Wald = 6, n.s.)	*2.25*	*2.45*	1.89	-1.32	**-8.26**	*2.99*
Change in income (Wald = 19, P < 0.01)	**-1.66**	*0.82*	**-1.19**	**-1.43**	**2.03**	**1.44**
House move (Wald = 37, p < 0.01)	**7.64**	**12.31**	**3.73**	**-7.65**	**-12.96**	**-3.07**
Job change (Wald = 4, n.s.)	-0.83	-1.00	-1.35	-0.66	*4.02*	-0.18

*Estimates in bold are significant at p < 0.05.

5.4 Conclusions

How are people's travel-related attitudes aligned with the characteristics of their residential built environment, and do people adjust one or the other over time to bring them more in line with each other? This paper aimed to enhance our understanding of interactions between the characteristics of the residential built environment, travel-related attitudes and travel behaviour. We identified consonant and dissonant subgroups based on travel-related attitudes and residential environment characteristics and we explored how people in these groups adjust their travel-related attitudes and residential environments over time. Two separate LCTMs were developed based on a two-wave longitudinal dataset from the Netherlands. Model I addressed the interaction between the distance to the train station and travel-mode attitudes. Model II addressed the distance to shopping facilities and the importance and satisfaction that people attach to this distance.

Contrary to our expectations, we did not find clear-cut relationships between travel-mode attitudes and characteristics of the built environment. The profile of latent class membership in 2005 showed no overall tendency for people to live closer to a railway station if they liked public transport or cycling. Nor was there an overall tendency for people who preferred close proximity to shops and services to live closer to shopping areas. Instead, people with supportive and non-supportive attitudes were distributed across the distance ranges, revealing consonant and dissonant population groups. For Model II, we analysed the impact of this residential dissonance on people's satisfaction. The results indicate that higher levels of dissonance negatively affect people's satisfaction with the distance to shopping facilities. This mainly applies to people who attach importance to the distance to shopping centres. Others do not seem to care much until the distances become very large.

The latent class profiles remained relatively stable over time in both models. Again, contrary to our expectations, people in more dissonant classes generally did not show a greater likelihood of switching to more consonant classes. In the first model, the public transport attitudes of the dissonant suburban car/bike class shifted upward after living in proximity to a railway station thereby reducing the dissonance. However, people the nearby discontented class remained almost inert, despite living relatively close to the railway station and having less favourable attitudes towards all travel modes. In Model II, only people who were very unsatisfied with the distance to shops showed higher transition probabilities. Thus, it appears that dissonance and dissatisfaction levels have to reach a certain threshold before people adjust their behaviour or their attitudes.

As expected, both models reveal adjustments in people's attitudes as well as adjustments in the residential environment, and both adjustments differ across population groups. This suggests that processes of residential self-selection and reverse causality both occur and depend on initial residential dissonance.

Furthermore, people's sociodemographics significantly influenced transition probabilities. One example is the role of income in the nearby discontented class from the first model. People with lower incomes are overrepresented in this group and also had a higher probability of being in this group in 2012. This suggests that at least for a share of people in this group, their lower income reduced the opportunity to lower their dissonance by moving to a more conducive environment. This result should be interpreted with caution as we were only able to include respondent's personal income while household income would provide a more complete picture of the resources in the household.

Some methodological remarks should be made. Despite the long time lapse of seven years, the number of changes in the dataset was limited. Although this is, in itself, an interesting research finding, it limits the data on the number of transitions over time and consequently the ability to reveal patterns of reverse causality and, especially, self-selection. Moreover, due to the long time lapse, unobserved events may have taken place that affect the 2012 values. Furthermore, more measurement points would enhance the ability to determine causal directions and the time that processes of residential self-selection and reverse causality take to fully materialise.

5.5 Policy implications

What do the findings of this study mean from a policy perspective? Residential developments in accessible distance to railway stations benefit people with positive public transport and bicycle attitudes. It does not seem necessary to densify within close proximity as groups with significantly more favourable attitudes towards these modes are identified no closer than 2.5 km, on average, from the railway station. The strong bicycle culture in the Netherlands probably allows for longer distances to the railway station. Developing bicycle-friendly neighbourhoods at longer distances from a railway station, and providing good connections by public transport and bicycle, is also effective and provides more opportunities for densification policies.

Campaigns that actively promote the favourable conditions for cycling and/or public transport in these neighbourhoods may encourage self-selection. A higher share of people with positive attitudes living within three kilometres of the station will increase the effectiveness of densification policies. In addition, for certain groups, attitudes also seem to be influenced by the built environment itself. This suggests that densification could encourage more sustainable travel behaviour, not only directly but for certain groups also indirectly through its effect on attitudes.

But how do we address the relatively large group of people with no positive attitudes towards travel modes within this 2.5 km distance range? Apparently, they do not consider the use of any of these modes as comfortable, flexible or fun, which may be related to their lower income levels. This calls for the identification of the specific needs of this group and research into better ways to accommodate them in a sustainable manner. However, it also makes sense to be realistic: a share of these households will not be sensitive to these policies, as they do not have positive attitudes towards sustainable travel modes. They could be encouraged to move to more remote areas, as their car use disturbs areas which have the potential for more sustainable travel behaviour.

Finally, about half of the sample attached importance to the distance to shopping facilities. Their satisfaction levels clearly dropped between one and two kilometres to these destinations. Thus, it is important that they are given the opportunity to live closer to these facilities. Policies to preserve small-scale retail in close proximity to residential areas could contribute to higher shopping satisfaction levels, as well as higher levels of sustainable transportation. However, after decades of protective national retail policy, such policies in the Netherlands have become more deregulated and decentralised since 2004. Consequently, large-scale peripheral retail developments and hypermarkets are starting to appear, which will probably increase average distances to shopping areas. The impact of these developments will also depend on the current e-shopping trend. This may lead people to become less sensitive to the distance to shops.

Overall, this study provides some support for land use policies that aim to influence travel behaviour. Given the importance of supportive attitudes, the combination of land use policies and promotional campaigns which enhance residential self-selection could be key for the effectiveness of these policies.

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Chapter 6: Conclusions and Discussion

6.1 Introduction

Land use policies have been applied for decades to encourage sustainable transportation. When sprawled car-oriented cities in for instance the USA and Canada are compared to compact and multimodal cities in Europe this seems to make sense. It is hard to believe that the built environment does not play a role in people's travel choices. Hence, modification of the built environment may reduce car use and encourage the use of sustainable transportation modes by creating proximity and providing good conditions for walking, biking and public transport. However, despite all the policy efforts ranging from nationwide policies (e.g. VINEX policies in the Netherlands) to local policies (e.g. New Urbanism in the USA), the evidence for the effectiveness of these policies is mixed at best. Previous research found that, ceteris paribus, people living in dense, mixed-use areas with good conditions for car alternatives drive less and use alternative modes more often (Ewing and Cervero, 2010), although to a limited extent. Furthermore, the causality of this relationship is under scrutiny. The significant association between the built environment and travel behaviour does not imply a causal relationship. To identify a causal relationship, it is important that the influence of confounding variables is controlled for. Most previous studies have controlled for sociodemographics such as age, income and household composition, but not for travel-related attitudes. As travel-related attitudes are believed to influence peoples travel behaviour and residential location choice, they may confound the relationship between the built environment and travel behaviour. Furthermore, the order of events is important to establish causality, a change in the built environment should precede a change in travel behaviour. This requires a longitudinal design with two or more measurement points. However, the majority of the evidence in this field is based on cross-sectional designs which include data only at one single point in time making it impossible to determine a cause-effect relationship. This thesis used a longitudinal design and focused on the intervening role of travel-related attitudes on the relationship between the built environment and travel behaviour.

Specifically, two hypotheses regarding the role of travel-related attitudes have been studied: the residential self-selection hypothesis and the reverse causality hypothesis. The first hypothesis assumes that people select a residential neighbourhood that suits their preferred travel behaviour. If this is the case, the built environment primarily *facilitates* people's pre-existing desire for travel behaviour. This does not mean that land use policies are irrelevant but it does mean that the impact of these policies would depend on the share of the population with supporting attitudes (Morrow-Jones et al., 2004; Cao et al., 2007). Where the first hypothesis assumes influence from travel related-attitudes to residential choices, the second hypothesis assumes the opposite direction of causality: people adjust their travel-related attitudes and preferences to the characteristics and circumstances in their residential neighbourhood. Hence, the built environment causes people to *modify* their travel behaviour and their travel-related attitudes. This means that land use policies are important because they not only have a direct influence on travel behaviour but also an indirect one via their influence on travel-related attitudes. The use of longitudinal approaches has been touted to test these hypotheses and some have also been conducted (e.g. Meurs and Haaijer, 2001; Krizek, 2003; Cao et al., 2007). However, few of them included attitudes at multiple moments in time. This impedes their ability to identify causality between travel-related attitudes, the built environment and travel behaviour. A recent study by Wang and Lin (2019) is a notable exception. They incorporated attitudes at multiple moments in time and found evidence for reverse causality. Despite this progress, the vast majority of evidence in this field still relies on cross-sectional analyses that assess associations at one moment in time. As a consequence, they have hardly been able to provide solid proof for causality. This thesis aimed to add to the debate regarding causality on the link between the built environment, travel-related attitudes and travel behaviour. Therefore, it adopted a two-wave longitudinal study design with data derived from household questionnaires and GPS surveys. The study area consists of a medium-sized city and two smaller municipalities in the Netherlands, comprising a wide range of different built environments. The central research question is: *how and to what extent do households match their travel behaviour with the characteristics of their residential neighbourhood and how is this influenced by bidirectional relationships with travel-related attitudes?*

Based on this central question, four sub-questions were formulated. The first involved a methodological literature review about the pros and cons of a range of multi-period study designs and their ability to infer causality on the link between land use and transportation. The other three sub-questions involved empirical testing of the direction of causality on the links between travel-related attitudes, the built environment and travel behaviour using different methodologies, data and approaches. The sub-questions were dealt with in four chapters.

6.2 Overview of Results

This section provides an overview of the results by summarising the main findings of the methodological and empirical chapters.

Chapter 2, *Multi-period Research Designs for Identifying Causal Effects of Built Environment Characteristics on Travel Behaviour*, departs from the notion that the use of longitudinal designs has been recommended for decades but that to date, few longitudinal studies have been applied in practice. Therefore, it provides an overview of quantitative multi-period designs and discusses their ability to infer causality and their practical applicability. A gradual relationship is demonstrated: the higher the ability for inferring causality, the lower the practical applicability of research designs. Importantly, no applicable design completely controls for confounding and selection bias. Therefore, additional statistical control is always necessary to identify causality. Natural experiments where the impact of exogenous spatial and infrastructural developments is assessed, provide the strongest evidence. The major challenge with natural experiments is that the introduction of new spatial and infrastructural developments is often delayed which creates challenges for the timing of before and after measurements. Therefore, close collaboration between researchers and planners is important. Furthermore, prospective longitudinal studies can be applied to assess the impact of residential moves. This approach is more vulnerable to selection bias as residential moves can be provoked by earlier changes in attitudes or life course events. Finally, it would be interesting to combine natural experiments and prospective longitudinal studies with behavioural change experiments. For instance, behavioural campaigns to encourage the use of cycling or public transport could be provided to a selection of people that move to new housing developments. This enables researchers to assess the impact of the behavioural campaigns and the impact of the built environment on travel behaviour and identify interaction effects.

In Chapter 3, *Causal Effects of Built Environment Characteristics on Travel Behaviour: a Longitudinal Approach*, the direction of causality on the links between travel-related attitudes, the built environment and car mode share is empirically assessed. A cross-lagged panel structural equation model was developed on the two-wave longitudinal dataset. Outcomes revealed that the built environment has a significant influence when confounding variables are controlled for. Living closer to a railway station leads to a reduction in the share of car use over time. Surprisingly, this influence was not only significant but also strong, relative to the influence of travel-related attitudes and sociodemographics. No evidence was found for residential self-selection. Instead, the analysis provided evidence for reverse causality; living closer to the railway station results in more positive attitudes towards public transport while the opposite holds for car-related attitudes. Interestingly, interrelationships between attitudes were not significant, in other words, if people develop a more positive attitude towards public transport, this does not affect their attitudes towards other transportation modes.

Chapter 4, *Causes and Effects between the Built Environment, Car Kilometres and Attitudes: a Longitudinal Analysis,* builds on the results of the previous chapter. It involved a methodological approach with an explicit comparison of cross-sectional and longitudinal analysis. In the structural equation models, two additional indicators were included, the car kilometres travelled (derived from two extensive GPS-based tracking surveys) and the surrounding address density. In line with results from the previous chapter, the influence of the built environment was significant when the effects of attitudes and sociodemographics were controlled for. Furthermore, reverse causality effects prevailed over residential self-selection effects. In contrast to the findings of the previous chapter, results indicated residential self-selection effects. A small but significant residential self-selection effect was found among movers: people with stronger car attitudes tend to end up in residential areas at larger distances from the railway station. Interestingly, the same applies to people that drive more kilometres by car. This indicates that people who feel that they are reliant on the car, self-select themselves in more suburban or remote areas. Results also show that the distance to the railway station is a stronger determinant for car kilometres driven than residential density. This means that when urban densification is considered, locations closer to railway stations are preferred. Interestingly, the cross-sectional model revealed that the influence of attitudes prevails over the influence of the built environment indicators. For the longitudinal models, this was the other way around. So, even though attitudes are strongly associated with travel behaviour, changes in travel behaviour are more strongly influenced by the opportunities and constraints provided by the built environment.

Chapter 5, *Residential Self-selection, Reverse Causality and Residential Dissonance. A latent class transition model of interactions between the built environment, travel attitudes and travel behaviour,* tested to what extent people adjust their attitudes and residential built environment depending on initial residential dissonance. Two latent class models were developed, the first including travel mode attitudes and the distance to the railway station, the second including the distance to the nearest neighbourhood shopping centre and the importance and satisfaction level attached to this distance. The classes identified in both models revealed no overall tendency for groups with 'favourable' attitudes to live closer to a railway station or the shopping centre. Instead, groups with 'favourable' and less 'favourable' attitudes are found at different distance ranges, yielding varying degrees of dissonance. Modelling of adjustment processes over time revealed that the number of adjustments in attitudes and residential location is limited. Contrary to expectations, higher levels of dissonance are not related to higher numbers of adjustments. Instead, adjustment processes reveal a mixed picture. In the first model, living close to the railway station encouraged adjustments from a 'favourable' car attitude towards more 'favourable' public transport and bicycling attitudes. This indicates reverse causality and provides support for sustainable built environment policies. However, this was only demonstrated for a small subgroup. For many others living close to the railway station, attitudes were not affected and dissonance remained. The second model revealed that the importance that people attach to the distance to facilities and their satisfaction with the current distance influence these adjustment processes. A share of unsatisfied people who lived far from the shopping centre reduced their dissonance by moving to residential locations closer to the shopping centre. Another share of this group reduced their dissonance by lessening the importance attached to the distances. Taken together, it seems that mismatches only trigger responses above a certain threshold, and on the condition that people have opportunities to reduce them.

6.3 Conclusions and Discussion

This section presents and discusses the main conclusions to answer the research question of this thesis: *How and to what extent do households match their travel behaviour with the characteristics of their residential neighbourhood and how is this influenced by bidirectional relationships with travel-related attitudes?*

First, all analyses show that built environment characteristics have a significant influence on travel behaviour *change*, also when sociodemographics and attitudes are controlled for. Living in neighbourhoods closer to railway stations and living in denser neighbourhoods, results in less car use. This supports previous findings in this field (e.g. Ewing and Cervero, 2010; Cao et al. 2009). Moreover, it demonstrates that they also hold in a longitudinal study, showing that previous decisions have an impact in later years, thus providing stronger evidence for causality. The influence of the built environment is not only significant but also relatively strong compared to the impact of travel-related attitudes and sociodemographics. Longitudinal evidence on the impact of the built environment also appeared to be stronger than cross-sectional evidence. So, even though the *associations* between travel-related attitudes and travel behaviour are strong, the built environment appears to be more influential on the *change* in travel behaviour over time. This finding is important as it was found in previous studies on the link between the built environment on travel behaviour, that the application of more advanced methods often resulted in a diminishing role of the built environment. The analysis also suggested that changes in built environment characteristics have to be quite substantial to break existing behavioural patterns and to significantly affect travel behaviour. The fact that moving house did not significantly affect travel-related attitudes or travel behaviour is likely because most people made short-distance moves which reduced their need to re-evaluate travel options.

Secondly, reverse causality clearly dominates over residential self-selection. The presence of reverse causality corroborates earlier findings (Bohte, 2010; Ewing et al., 2016; Lin et al., 2017; De Vos et al., 2018). Interestingly, the dominance of reverse causality was also found in another recent longitudinal study (Wang & Lin, 2019). So, the built environment not only has a direct effect on travel behaviour but also an indirect effect via its influence on travel-related attitudes. This implies that correcting for residential self-selection by incorporating attitudes in statistical models, as many studies did in the recent past, leads to underestimations of the impact of the built environment on travel behaviour because it neglects the fact that travel-related attitudes are endogenous to the characteristics of the built environment. Therefore, the impact of the built environment on travel-related attitudes should be incorporated in future studies. The fact that reverse causality is dominant does not mean that residential self-selection is irrelevant. Small but significant self-selection effects based on travel-related attitudes have been identified in subsamples of movers, indicating bidirectional effects between travel-related attitudes and the built environment. Furthermore, the significant influence of previous travel behaviour on built environment characteristics implies that self-selection can also be based on constraints, such as car dependency. People that use the car often, self-select themselves in areas where this is convenient, not necessarily because they favour car use but also because they perceive the car as a necessity to meet their daily needs.

Thirdly, the processes of residential self-selection and reverse causality are even more complex than often considered. Related adjustment processes depend on initial dissonance and on the extent to which this dissonance is considered a problem. What is more, opportunities to reduce the mismatch, such as financial resources, have to be available. The fact that adjustment processes do not occur easily is reflected in the high level of stability of dissonant groups that have been identified. Hence, residential self-selection and reverse causality are not universal processes. Rather, they are specific phenomena that occur in particular circumstances where mismatches are beyond a certain threshold and considered as a problem and where opportunities are available to reduce them.

6.4 Reflection

Before the implications for policy and recommendations for further research are discussed, methodological issues are addressed.

The research results strongly rely on the distance to the nearest railway station as an indicator of the built environment. It should be noted that a wide array of built environment indicators has been developed and tested. These included distance-related indicators to nearest shopping centres, municipal centres, highway ramps and bus stops, indicators for residential and employment density at different distance ranges around the residential location, and indicators for land use mix. We attempted to include multiple indicators for the built environment, but this increased model complexity and led to unexpected results due to the multicollinearity between the variables. The distance to the nearest railway station yielded the strongest results probably because of the significant differences in distances within the research sample and also because the distance to the railway station partially represents the distance to denser and mixed-used areas that are less conducive to car use and more conducive to bicycling and public transport. Thus, the distance to the railway station can also be considered as a proxy for these built environment characteristics. To reduce the reliance on this single indicator another indicator was tested in a separate model, the surrounding address density, from Statistics Netherlands. The impact of the distance to the railway station was a bit stronger but apart from that, the two models yielded comparable results, supporting the significance of the built environment as a relevant indicator for travel behaviour change.

The indicators for travel behaviour, the modal share of the car and the number of car kilometres driven reflect the overall travel behaviour patterns. This may mask underlying changes as travel behaviour is known for compensation mechanisms and constant travel time budgets (Maat, 2009; Van Wee et al., 2006; Zahavi and Ryan, 1980). Job changes to a work location closer to people's residential location may for instance reduce their car kilometres travelled, but they may counteract this by using the car for travelling long distances during the weekend. This may also explain why many small changes in household composition and socio-economic position did not have significant effects. On the other hand, the thesis aimed to assess the impact of the built environment on overall travel behaviour, controlling for the impact of general travel-related attitudes. So, in that sense, the operationalisation of the indicators is aligned with the study aims.

The research sample was taken from homeowners in small and medium-sized municipalities. Caution should be exercised when extrapolating these findings to other groups and areas. Only homeowners were selected as renters have less freedom of choice in the housing market in the Netherlands. As a result, middle- and older-aged groups and higher-income groups were overrepresented in our sample. The focus on small and medium-sized municipalities is representative for the majority of the Dutch population. While the four largest cities (Amsterdam, Rotterdam, The Hague and Utrecht) are of crucial importance, they hold only 15% of the total Dutch population (CBS, 2020). The rest of the population resides in medium-sized and small municipalities. The selection of homeowners in small and medium-sized municipalities is reflected in the travel behaviour of people in our research sample. Only 2.5% of the households did not have a car at their disposal and attitudes towards public transport and public transport use were low. The limited number of people that favour public transport in the sample may have contributed to the non-significant self-selection effects for this group. Previous studies have concluded that people that favour public transport are keen to self-select themselves into specific areas with a good level of public transport provision. Likewise, the self-selection effects of car-oriented people found in this study may originate partially from their strong representation in the research sample.

The longitudinal nature of the study also posed challenges. The most important ones are discussed according to the theoretical framework of the first review article. Drop-out is a prominent issue related to longitudinal studies. In our study, people dropped out because they moved house to unknown destinations, because of changed contact details or because they passed away. Especially younger and less educated respondents, females and respondents from households with young children were more likely to drop out. As only respondents that participated in both research waves were included in the analysis, this did not affect the internal validity. However, it did increase the selective nature of the research sample and thereby affected the external validity of the study. Furthermore, every effort was made to avoid periodic effects (e.g. differences in weather conditions) and effects from the technological developments in the GPS devices on the research outcomes. Therefore, the online questionnaires and the GPS surveys were conducted in the same months during the two research waves and the settings of the GPS devices in 2006 and 2013 were aligned. Furthermore, the same rule-based algorithms were used to interpret and analyse both data sources (see Biljecki et al., 2013). However, it was not possible to use the online validation portal that was used in 2006. Instead, respondents were asked to fill in a basic travel dairy in 2013. Even though we went to great lengths to manually validate the results, this could have affected the number of kilometres driven. A limitation of the research is that the online questionnaire and the GPS survey were not conducted at the same time. Although we did ask respondents to address important changes in household circumstances, some unobserved changes may have taken place in the meantime that could have affected the results from the GPS survey. In addition, unobserved contextual changes may have occurred between the research waves leading to periodic effects. For instance, weather conditions may have been different and the same holds for the economic situation. Although the latter is partially addressed in the socio-economic indicators, changes in the overall economic sentiment may have had a wider unobserved effect. Finally, the timing of the second research wave in 2012 was because the opportunity arose to build on the previous work of Bohte (2010) around that time. This did allow us to measure long-term effects but ideally it would have been better to have at least one intermediate measurement point. This would have allowed us to analyse developments over time and to apply additional statistical techniques that require at least three measurement points.

Finally, the ability to identify self-selection in this thesis may have been reduced by the sample composition. As described, a part of the drop-out between the two research waves could be contributed to people moving to other municipalities which reduced our opportunities to remain in contact with them. Consequently, most movers that remained in our sample moved to comparable neighbourhoods near their old residence. To statistically identify self-selection, movers should be able to self-select themselves into areas that are more aligned with their travel attitudes and preferences. As many people moved to locations close to their former residence, their neighbourhood characteristics did not change very much. However, the fact that this thesis only identified very limited residential self-selection *effects* does not mean that the *process* itself does not occur. Parallel to this dissertation a qualitative study with semi-structured household interviews was conducted by a student as part of a graduation thesis (Westerweele, 2015). This research has not been published as a peer-reviewed article and is therefore not part of this thesis. Nevertheless, the results are interesting. Fifteen households, mostly couples, were interviewed, yielding a total of 27 participants. Results revealed that travel-related factors are important and sometimes even decisive in people's residential location choice. Residential choices were based on distances to important destinations such as work, school, and shops, to infrastructure characteristics such as a quiet residential street and to parking availability. Furthermore, households selected residential locations based on their preferences for the use of specific travel modes. However, it is likely that people show a certain amount of consistency in their residential choices and therefore end up in comparable neighbourhoods, limiting the ability to statistically identify self-selection effects over time. So, more than an overall conclusion that reverse causality prevails over residential self-selection, the main contribution of this thesis is that it shows that reverse causality effects are present and should be taken into account as an alternative causal explanation for the observed associations in cross-sectional studies.

6.5 Recommendations for Future Research

At the time of writing, this thesis was one of the few that assesses the impact of land use on travel behaviour and the hypotheses regarding residential self-selection and reverse causality over time. Based on the research findings, four recommendations for further research are offered.

First, due to its broad scope, this thesis focused on general determinants of travel behaviour and attitudes. To assess the impact of particular elements of the built environment, more detailed

determinants of travel behaviour including mode choices and kilometres travelled for different trip purposes are recommended. In addition, it would be interesting to include travel time as an indicator in longitudinal studies. By contrasting changes in kilometres driven and time spent on travelling, behavioural effects and compensation mechanisms can be uncovered. Including more determinants of behaviour such as perceptions, self-efficacy and social norms would also offer a more comprehensive picture of these mechanisms.
Secondly, emergent technologies and innovations could affect the impact of the built environment on travel behaviour and its relevance. The ever-increasing use of e-shopping puts small-scale shopping centres and even inner-city retail under pressure and at the same time modifies the relevance of retail proximity. Electric cars could mitigate air and noise pollution effects and their smaller distance range may provoke more reasoned travel behaviour choices. There is a strong belief that autonomous vehicles will provide major contributions to accessibility in cities, but a remaining question is to what extent their effects differ in compact and sprawled environments and what the impacts are for cycling and public transport. Moreover, much is expected from shared mobility and mobility as a service (MaaS) but to what extent is their effect dependent upon a supporting built environment or to what extent can they contribute to creating effective and sustainable urban compaction?

Thirdly, this thesis focused on the residential environment. In future research, it would be interesting to study the longitudinal impact of other environments such as the work environment and retail environments. As people connect their daily activities through increasingly complex personal network structures, studies focusing on the regional scale and the role of activity nodes such as train stations are also interesting.

Fourthly, more longitudinal studies and natural experiments are needed to validate the outcomes from this thesis in other environments and circumstances. Conducting longitudinal studies is hardly possible within the regular duration of a PhD study. This thesis used the unique opportunity to build upon the work of an earlier PhD study by Bohte (2010). This approach could be used more often and more systematically enabling multiple research waves and allowing for more detailed analysis of causal mechanisms over time. With the arrival of data collection methods such as online questionnaires and GPS surveys, extensive longitudinal studies within an acceptable respondent burden have also become easier. In the last decade new promising government and market lead initiatives have started for longitudinal research. The Netherlands Mobility Panel (MPN) started in 2013 and is one of the promising examples of web-based travel panel surveys that allow to analyse long term dynamics in travel behaviour (Ministry of Infrastructure and Water Management, 2020).

6.6 Implications for Policy

This study provides support for the notion that land use policies can contribute to more sustainable travel behaviour. While many previous cross-sectional studies provided abundant evidence for associations, outcomes of this longitudinal study show that living in proximity to a railway station and in compact environments leads to a reduction of people's car use over time. The net effect of the built environment indicators is modest, which is not surprising as travel behavioural choice is highly complex and involves many determinants and compensation effects. So, in that sense, modifying land use should not be considered as the holy grail that will, by itself, solve our accessibility and liveability issues. The challenge is to strike a good balance between short-term individual needs and preferences and longer-term issues related to sustainable travel behaviour and wider societal challenges. To solve this social dilemma, land use policies are just one, but an essential, part of the complex puzzle.

This study also highlights the importance of attitudes for the effectiveness of land use policies. Importantly, the built environment influences travel-related attitudes, thereby indirectly affecting travel behaviour. This implies that the application of land use policies is not restricted to people that already favour sustainable travel behaviour. Instead, land use policies can also be considered as one of the strategies to develop more positive attitudes towards sustainable travel behaviour. Furthermore, evidence for residential self-selection was found indicating that the direction of causality between travel-related attitudes and the built environment goes both ways. Finally, this study found evidence for varying degrees of mismatch between peoples travel-related attitudes and their residential built environment. These mismatches seem persistent over time and may cause nuisance such as parking problems and reduce the potential sustainable impact of compact urban developments. Aligning land use policies with accompanying policies seems of key importance to improve this match.

So, how can we implement land use planning and accompanying policies to encourage sustainable travel behaviour?
First, new compact housing can be developed in close proximity to railway stations. This is aligned with transit-oriented development policies that have been applied in the Netherlands since the 1960s. However, transit-oriented development traditionally focuses on developments in direct proximity to the railway station while many people with positive attitudes towards cycling and public transport live further from a railway station. To increase the scope of transit-oriented development, a better integration of the bicycle and the train modes seems very promising. Bicycle-friendly neighbourhoods could be developed at larger distances with comfortable and fast bicycle connections to the railway station, enabling efficient feeder transport by bicycle within an acceptable travel time. The current widespread emergence of micro-mobility devices, such as e-bikes and e-scooters, also brings new opportunities for better feeder transport to railway stations. This facilitates people who have a positive attitude towards sustainable travel modes but are not able to move in closer proximity to the railway station or have a preference for suburban or green urban living. These recommendations are aligned with the new national and regional land use policies that are currently being developed in the Netherlands with a focus on urban compaction, infill and multimodal accessibility (Ministry of the Interior and Kingdom Relations, 2019).

Secondly, it is important to be realistic about the modest impact of the built environment on car use and more in general, on people's travel behaviour choices. The effects of land use policies sometimes fall short of expectations. Lessons from the typical Dutch suburban VINEX neighbourhoods where people's car ownership was much higher than expected with fully parked sidewalks and parks and hence a deteriorated public realm are exemplary (RPB, 2005; Bohte, 2010). Land use policies such as densification can considerably improve people's proximity to destinations and hence accessibility, especially for cycling and public transport. However, people do not tend to minimise their travel but rather optimise their travel and activity patterns within available travel time budgets. In the current era with complex activity schedules and extensive daily urban systems, many people will rely on cars to be able to combine their daily activities. This could lead to an increasing tension with the focus on infill projects. In general, urban densification reduces overall car use and contributes to the reduction of global warming. However, this may not be enough by itself to offset the concentration of traffic with local environmental, liveability and congestion issues as a consequence. This is also referred to as the intensification paradox (Melia, 2011). What is more, the space consumption of the private car, which is on average parked for 23 hours a day, is at odds with the continued ambitions for infill locations because the provision of parking is expensive in dense environments. This thesis showed that car ownership is a mediator in the link between travel behaviour and land use. If people own a car, they tend to use it. Therefore, the extent to which infill projects encourage reduced car ownership and the development of multimodal attitudes and related behaviour will be key factors for their successful implementation.

Thirdly, to increase the impact of land use policies, synergy with accompanying policies is of key importance. While physical interventions shape our opportunities, accompanying policies are essential to create awareness and to promote attitudinal and behavioural change. First of all, accompanying policies can be implemented to strengthen the existing mechanisms of residential self-selection and reverse causality. While these mechanisms are often considered as methodological issues in research, they can be very valuable for policy purposes by reducing the mismatches between people's travel-related attitudes and their residential environment. Residential self-selection can be strengthened by enabling people to make a balanced residential choice and give more weight to mobility-related aspects in their decision-making process. For instance, information and awareness campaigns can be developed to highlight the various mobility options, such as available parking spaces, the accessibility provided by public transport and cycling, as well as shared mobility services. The reverse influence of the built environment on attitudes can be enhanced by awareness and promotional campaigns that target attitude change and motivate people to use sustainable ways of transport. For instance, promotional campaigns for public transport conducted among people that recently moved to an area with good public transport provision proved to be successful (Bamberg, 2006). In addition, accompanying policies can provoke stronger behavioural changes by improving the quality of sustainable travel alternatives. This includes improving facilities for cycling and public transport, but also the implementation of new mobility services such as shared services for cars and bikes and Mobility-as-a-Service (MaaS) concepts. When these mobility services are seamlessly integrated into the neighbourhoods, they may become a viable alternative for people's private car ownership. This is important as people's abundant car ownership and the consequently high need for parking spaces pose an important challenge for future compact housing developments. If stronger, non-voluntary, interventions in travel behaviour are necessary, legislation with regard to pricing and parking, such as limiting the number of parking permits in dense urban areas, are viable options to reduce car use.

Finally, this thesis shows the relevance of longitudinal approaches to evaluate the effect of the built environment on travel behaviour. This is not only important from a research perspective but also relevant for the effectiveness of land use policies that aim for sustainable travel behaviour. Today, policymaking still relies for a large part on common sense and the effects of interventions in the built environment are hardly assessed. Collaboration between applied researchers and governments is vital to assess and monitor these effects over time via longitudinal studies and natural experiments. The lessons learned from applied research will enable us to define well-designed, evidence-based policies that will accelerate the development of accessible, sustainable and liveable urban environments.

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Summary

Introduction

Governments around the world have implemented spatial policies and spatial planning concepts to keep cities compact and to promote sustainable travel behaviour. The Netherlands is known for its decades-long centralised spatial planning that has taken shape in the form of, for instance, the compact city policy, the VINEX policy and transit-oriented development. In other parts of the world, these spatial policies that aim for sustainable travel behaviour have often been implemented at the urban level. Well-known examples are cities such as Copenhagen, Stockholm and Curitiba. In North America, there is a stronger emphasis on the neighbourhood level with principles such as Smart Growth and New Urbanism. Although the nature of these policies differs somewhat from country to country, the basic idea is similar. Compact urban developments and function mixing bring origins and destinations closer together. This reduces travel distances and increases opportunities for the use of public transport, walking and cycling while reducing dependency on the car. This encourages people to use sustainable ways of transportation. In practice, the implementation of this policy is no easy endeavour. It requires solid policy commitment over a prolonged period of time. This makes it costly while the outcomes will affect people's lives for many decades to come. Therefore, a thorough analysis of the effectiveness of spatial policies that aim to influence travel behaviour is crucial.

In this context, it is somewhat surprising that the academic evidence for how and to what extent the built environment influences travel behaviour is not unequivocal. On the one hand, empirical studies have yielded different results regarding the role and impact of the built environment. Early aggregated studies which compared travel patterns between cities seemed promising. There appeared to be a strong correlation between the density of cities and their car and energy use. In later studies, travel behaviour was analysed at the level of individual persons and control variables such as social demographics and later travel-related attitudes were taken into account. The impact of the built environment was significantly smaller, or sometimes even absent, in these studies. Based on various meta-reviews, it can be argued that the built environment has a significant, but modest, impact on travel behaviour. In compact residential areas with land use mixing and good facilities for walking, cycling and public transport, people

use sustainable modes of transport more and the car less. In addition to the differences in empirical outcomes, the research methods and designs are under scrutiny. One fundamental problem at the heart of this thesis is that most studies to date are based on cross-sectional research designs. In these studies, data is collected at one moment in time. These studies show that residents of compact areas travel in a more sustainable way than their counterparts in other areas. However, these *differences* do not provide sufficient evidence for a causal relationship. In other words, correlation does not imply causation. For causal evidence, a cause-and-effect link must be established; a *change* in travel behaviour must be preceded by a *change* in the characteristics of the built environment.

The discussion regarding causality on the relationship between the built environment and travel behaviour has focused on the intervening role of travel-related attitudes in recent years. Two hypotheses have been defined. The first is the residential self-selection hypothesis. It states that people choose a particular residential environment that matches their travel-related attitudes. For example, someone who likes to travel by public transport chooses a residential environment that is within walking or cycling distance of a railway station and consequently uses public transport more often. In this case, the observed association between the built environment is, at least partially, spurious. Building compact neighbourhoods then primarily *facilitates* a desire for sustainable travel behaviour, but it does hardly *stimulate* it. The second hypothesis also acknowledges the relationship between travel-related attitudes and the built environment but assumes an inverse direction of influence; the built environment influences travel-related attitudes. When residents live in proximity to a railway station, they may experience that the car is less convenient and public transport and cycling are easier to use. Consequently, they may adapt their travel-related attitudes to the characteristics of their residential environment and start using sustainable ways of transport more often.

The residential self-selection hypothesis has been widely tested in empirical studies in recent years. Usually, these studies incorporated travel-related attitudes in statistical analyses to control for residential self-selection. These studies showed that the influence of the built environment on travel behaviour is attenuated when residential self-selection is controlled for. The second hypothesis that assumes a reverse direction of causality has received less attention to date, but several studies also found supporting evidence. How and to what extent travel-related attitudes influence causality on the relationship between the built environment and travel behaviour is of great importance for the effectiveness of spatial policies that aim for sustainable travel behaviour. If residential self-selection would be the strongest mechanism, and there would hardly be a direct influence of the built environment on travel behaviour, the effect of spatial policies would be limited to people who already have a preference for sustainable travel behaviour. If the reverse causal direction is stronger, then the influence of the built environment would be more important. It would not only have a direct effect on travel behaviour, but also an indirect effect through the positive influence on travel-related attitudes. Moreover, the two mechanisms are not mutually exclusive. They can both be present, with their influence depending on, among other things, personal circumstances and conditions in the housing market. This thesis focuses on the nature of causality on the relationship between the built environment and travel behaviour and the role of attitudes.

Research aim and central question

This thesis aims to advance the integration of land use and transport policies by creating a more in-depth understanding of the nature of causality on the relationships between the built environment, attitudes and travel behaviour. It builds on the work of Bohte (2010) who researched the role of travel-related attitudes on the relationship between the built environment and travel behaviour in 2005. The participants of this study were re-surveyed in 2012, creating a longitudinal dataset with two measuring points. The central question is:

How and to what extent do households match their travel behaviour with the characteristics of their residential neighbourhood and how is this influenced by bidirectional relationships with travel-related attitudes?

This dissertation starts with an exploration of longitudinal research designs. This demonstrates their opportunities for determining causality and for the practical application to the relationship between the built environment and travel behaviour. Subsequently, three empirical chapters are included. The second chapter tests the hypotheses around self-selection and reverse causality. Based on data from an online survey, the longitudinal relationships between the built environment, travel-related attitudes and the share of car use are modelled. The third chapter builds on this and uses data from a large-scale GPS survey to accurately determine the number of car kilometres driven by the respondents. In addition, this chapter explicitly compares the results of the longitudinal analyses with the results of cross-section analyses. The final empirical chapter focuses on the mismatches between travel-related attitudes and the residential built environment. It uses statistical analyses to identify groups of matched and mismatched inhabitants. Subsequently, it analyses how these mismatches develop over time.

The study area includes the municipalities of Amersfoort, Veenendaal and Zeewolde. Within these municipalities, central areas, mixed residential areas and suburban areas were selected, which provided a large degree of variety in terms of spatial characteristics. A random sample of homeowners participated in an online survey that provided information on sociodemographics, travel-related attitudes, housing preferences and travel behaviour. The longitudinal database includes 1,322 respondents. A subset of these respondents also participated in a GPS survey. During this survey, participants carried a GPS logger for one week, providing a detailed picture of their travel behaviour. This longitudinal GPS database includes 344 participants.

Results

Chapter 2 provides an overview of quantitative longitudinal research designs. It assesses their ability to determine causality and explores opportunities and challenges for their practical application to the relationship between the built environment and travel behaviour. In longitudinal studies, researchers repeatedly examine the same participants in the same way which enables them to detect changes over time such as an increase or decrease in car use. To date, studies on the relationship between the built environment and travel behaviour mainly used cross-sectional designs in which participants are involved only at one point in time. This enables researchers to identify relationships; for example, residents of high-density neighbourhoods use the bicycle more often. However, this does not yet provide evidence of a causal relationship in which, for instance, increasing density leads to increased bicycle use among residents. Longitudinal research designs are essential for this purpose. The results of this literature study show that applying longitudinal designs to the relationship between the built environment and travel behaviour is not an easy endeavour. Natural experiments, in which the influence of spatial developments or infrastructure interventions on travel behaviour are examined, provide the strongest evidence for causality. The main challenge here is that these interventions are not controlled by the researchers and that their implementation is often delayed. This makes it difficult to plan research waves before and after the introduction of these interventions and to align this with the timing of research and available resources. Therefore, applied research with effective communication between researchers and planners is essential. A second research design that enables the identification of causality follows participants during a period of time in which they are going through important transitions such as a residential move or job change. This observational design allows researchers to assess the influence of characteristics of the residential and working environment and their changes. In this type of research, it is important to control for other influences such as a change in life situation or a change in travel-related attitudes. These can be the cause of the desire to move house or change jobs and can also affect travel behaviour. If these influences are not controlled for, this may negatively affect the validity of the research results. Finally, natural experiments and observational designs can be combined with behavioural experiments. Campaigns to promote bicycling or public transport use can be aimed, for example, at people moving to a new residential area with good facilities for these modes of transport. This allows researchers to analyse the impact of the change in the built environment, the impact of the behavioural campaign and possible interaction effects.

Chapter 3 uses a longitudinal research design to test the extent to which the built environment influences travel behaviour. It controls for the influence of travel-related attitudes and various other determinants of travel behaviour such as income, education level, household composition, etc. This data is based on the online survey conducted among participants in 2005 and 2012. The analyses show that when people live closer to the railway station, the proportion of car use decreases. This significant impact of the built environment on travel behaviour supports the results of previous cross-section studies. An important added value is that this study shows that not only is there an association, but that the built environment also influences people's travel behaviour over time. Another important finding is that the built environment also affects travel-related attitudes: living in closer proximity to railway stations results in more positive attitudes towards public transport while the opposite holds for attitudes towards the car. Residential self-selection, in which people choose their residential environment based on their travel behaviour preferences has not been demonstrated. Finally, car ownership plays an intervening role with a significant influence on car use, proximity to the railway station and travel-related attitudes. This means that car ownership is important for policies that aim to promote sustainable travel behaviour.

Chapter 4 uses the results of a comprehensive GPS study to refine the analyses and insights. Participants in the GPS study were asked to carry a GPS device with them for one week to track their travel behaviour. Based on this data, the number of car kilometres driven was determined for each participant. As in the previous chapter, the analyses show that the built environment has a significant influence on the participant's travel behaviour and travel-related attitudes. Unlike in the previous chapter, the analyses revealed indications for residential self-selection: people with a stronger car attitude and people who drive more kilometres by car are more likely to move to a residential location at a larger distance from the railway station. Presumably, more spacious suburban residential areas are more conducive to their preference for, or their dependence on, the car. In this chapter, the results of the longitudinal analyses are also compared with the results of cross-section analyses among the same participants. The comparison shows an important difference. Travel-related attitudes have the strongest relationship with travel behaviour in the cross-section analyses but in the longitudinal analyses, the influence of the built environment on travel behaviour is stronger. It therefore seems that while travel-related attitudes have a strong relationship with travel behaviour, changes in travel behaviour are more strongly influenced by the opportunities and limitations offered by the built environment. Finally, in this analysis, a new indicator for the built environment was added, the environmental address density. This indicator also appears to have a significant impact on travel behaviour and travel-related attitudes, but its influence is less than the distance to the train station. This means that density plays a role, but that for new compact housing developments the proximity to the railway station is more important to encourage sustainable travel behaviour.

Chapter 5 takes a different approach by analysing the degree of mismatch between travel-related attitudes and the residential environment during the first research wave in 2005. Next, it analyses the way and extent to which people adapted their residential environment or travel-related attitudes between 2005 and 2012. People moving to a residential environment that is more in line with their travel-related attitudes indicates residential self-selection. If people adapted their attitude to the characteristics of their residential environment, it would indicate an inverse direction of causality. Mismatches are identified by grouping people into different classes. Two different types of mismatch were analysed. First, mismatches between the distance to train stations and travel-related attitudes regarding the car, public transport and the bicycle were studied. In a second analysis, mismatches between the distance to the nearest neighbourhood shopping centre, the importance that people attach to this distance and their satisfaction with the current distance were examined. Both analyses show that a good match between the residential environment and travel-related attitudes is not a matter of course. Groups of people with positive attitudes towards the car, public transport and bicycle live nearby but also at a larger distance from the railway station resulting in varying degrees of mismatch. Groups that consider the proximity of a shopping centre important also reside nearby and at longer distances from these centres. An assumption in this study was that groups with a higher degree of mismatch were more likely to adjust their attitude or their residential environment. However, the analyses of changes between 2005 and 2012 show that a higher degree of mismatch does not necessarily lead to more adjustments. For example, the mismatch of a group of people living in proximity to the station with positive attitudes towards the car, remained largely intact between 2005 and 2012. However, a part of this group developed a more positive attitude towards public transport. This influence of the residential environment on travel-related attitudes provides support for land use policies that aim to encourage sustainable travel behaviour. The second analysis with distances to the shopping centre shows that people's satisfaction with these distances plays a key role in the adaptation processes. When people experience an existing mismatch as a problem, adjustments occur more often. To reduce the mismatch, some people move to a residential location in closer proximity to the neighbourhood shopping centre while others adjust their attitude by reducing the importance that they attach to this distance. Taken together, it seems that mismatches only trigger a change in attitude or a residential move above certain thresholds that causes people to become dissatisfied with their current residential environment. In that case, people must also have sufficient opportunities to reduce this mismatch.

Overall, it can be concluded that the built environment is important to promote sustainable travel behaviour. It has a significant impact on *changes* in travel behaviour, also when the influence of sociodemographic variables and travel-related attitudes is controlled for. Living in residential areas near railway stations and residential areas with higher densities leads to lower car use. This is in line with previous, mainly cross-sectional studies, in this field. The longitudinal approach in this study provides more evidence for a causal relationship. The longitudinal analyses also show that the built environment is one of the most important determinants of travel behaviour change. Nevertheless, its impact remains relatively limited in an absolute sense. This shows that travel behaviour is complex and determined by many factors. Furthermore, travel-related attitudes play an important intervening role. This study found evidence for a two-way relationship where reverse causality effects prevail over residential self-selection effects. This means that the built environment not only has a direct effect on travel behaviour but also an indirect influence on travel-related attitudes. Finally, people do not simply adjust their residential environment or travel-related attitudes when there is a mismatch between the two. Mismatches can last for a long time and seem to bring about a change in residential location or attitude when people are dissatisfied with their living situation and have the opportunity to reduce this dissonance.

Recommendations

The longitudinal approach in this thesis in which characteristics of the built environment, travel-related attitudes, travel behaviour and other determinants are measured at two moments in time provides a valuable contribution to the existing knowledge in this field. Nevertheless, there are still several recommendations for further research. This research focused on generic indicators of travel behaviour: the share of car use and the number of car kilometres. The understanding of the causal influences on the link between the built environment and travel behaviour can be strengthened by including indicators for multimodal travel behaviour and conducting more detailed analyses, for instance focusing on different travel purposes. In addition to travel-related attitudes, other behavioural indicators such as perceptions, social norms and self-reliance can be taken into account to increase the understanding of the nature of residential self-selection and reverse causality processes and how people deal with mismatches between travel-related attitudes and their environment.

Furthermore, this research focuses on the influence of people's residential environment. Future research may focus more explicitly on the influence of environmental characteristics on the destination side. The built environment characteristics of work, shopping and leisure locations are also likely to affect travel choices. In this respect, the role of activity nodes such as train stations is also interesting to investigate. Moreover, recent innovations and developments such as shared mobility services and Mobility-as-a-Service can provide new research avenues. The arrival of these services may reduce people's necessity to own one or more cars and may contribute to the development of accessible and liveable cities. In addition, the emergence of e-shopping and telecommuting can affect the importance of the proximity of shopping facilities and work locations. It seems evident that these and other innovations are going to influence the interplay between travel behaviour and the built environment. How and to what extent this will happen is a promising direction for future research.

Finally, more longitudinal studies and natural experiments should be conducted. In addition to the previously mentioned cooperation between researchers and policymakers, it is also important how research is organised. A lot of research in these areas is conducted by PhDs. They often have an appointment of four years and the scope of the studies is usually tailored to this term. This thesis used the unique opportunity to build on previous research by Bohte (2010). This method is also promising for future endeavours and offers additional opportunities for long-term longitudinal studies with multiple rounds of research. This enables additional and more thorough evaluations of the effects of the built environment on travel behaviour.

The results of this thesis support spatial policies that aim for more sustainable travel behaviour. By aiming for compact cities and by developing new residential developments within the catchment area of railway stations, governments can reduce car use and encourage the use of public transport and cycling. However, compact transit-oriented developments in close proximity to railway stations only provide for a small part of the qualitative housing demand. Preferences for quiet urban living, suburbs and green urban living areas are not accommodated. Furthermore, results show that people with positive attitudes towards cycling and public transport also reside at longer distances from railway stations. To accommodate a wider array

of qualitative housing demands and to facilitate people with positive attitudes towards sustainable travel behaviour living further from railway stations, the optimisation of bicycle connections towards railway stations seems promising. Reducing travel times and increasing the level of comfort on these connections will allow people to live further away in existing or newly developed residential areas while being within acceptable bicycle travel time of the railway station. By taking bicycle travel times to railway stations as a reference, the scope and potential impact of transit-oriented developments are significantly widened.
At the same time, land use strategies are not the holy grail to achieve sustainable travel behaviour because their impact is simply not large enough. This is important as many cities and regions have ambitions plans for urban intensification and compact neighbourhoods to increase sustainable travel behaviour and reduce individual car ownership and use. Only focusing on urban compaction may result in mismatches where car-oriented people end up in compact neighbourhoods which leads to undesirable effects such as noise and air pollution, parking problems and congestion. This is also known as the paradox of intensification. Lessons derived from the Dutch VINEX policies, where the influence of the compact design and reduced parking availability was overestimated, are exemplary. In this respect, land use strategies should not be considered as the main trigger for a transition towards sustainable travel behaviour. Instead, they provide the essential preconditions for these changes by increasing proximity, enabling people to reduce their travel distances and to use sustainable transport modes such as walking, cycling and public transport.
To encourage a stronger shift towards sustainable travel behaviour, land use strategies need to go hand in hand with accompanying measures. First, these accompanying measures can help people with positive attitudes towards sustainable travel behaviour to self-select themselves in conducive neighbourhoods. Residential self-selection can be strengthened by providing people clear information about, among other things, travel times by bicycle and public transport to important destinations, available transport facilities in the neighbourhoods such as available parking spaces, and the availability of shared mobility services. For new compact housing developments, an urban design that conveys a clear message regarding the opportunities for individual car ownership, supported by clear parking schemes in and around these locations, is also important to deter car-oriented people. Secondly, accompanying measures can strengthen the reverse causal influence from the built environment on travel-related attitudes. Awareness and promotional campaigns can add to the existing influence of the built environment and trigger positive attitudes towards sustainable travel behaviour and sustainable travel choices. For instance, campaigns to encourage cycling and public transport use can be conducted among people that recently moved to residential areas with good facilities for these modes. Thirdly, accompanying measures can be implemented to improve the competitive position of sustainable travel alternatives compared to individual car use. In addition to the provision of good facilities for walking, cycling and public transport, introducing shared mobility services for cars, bicycles and e-scooters and Mobility-as-a-Service (MaaS) seems promising. These new mobility services may reduce the need for individual car ownership and use which is one of the main challenges for urban intensification. If necessary, more rigorous interventions such as restrictive parking policies, downsizing car infrastructure and pricing policies can be implemented to restrict individual car use and encourage the use of more sustainable alternatives.

Finally, cooperation with researchers is essential to successfully implement land use policies that aim to encourage sustainable travel behaviour. To date, the effects of spatial and infrastructural interventions have been investigated primarily using ex-ante assessments. Based on forecasts and model estimates, the costs and benefits of interventions are compared. During and after the realisation of these interventions, there is often limited budget and capacity to evaluate their effects. In addition, it is important that the timing of the baseline and follow-up measurements are aligned with the timing of the introduction of the interventions. Close collaboration between researchers and policymakers is essential to conduct longitudinal studies and natural experiments that assess the effects of interventions during and after implementation. This opens the way to evidence-based policies that contribute to the development of sustainable and liveable urban areas with good multimodal accessibility.

Samenvatting

Inleiding

Wereldwijd zetten overheden in op ruimtelijk beleid en ruimtelijke planningsconcepten om steden compact te houden en daarmee duurzame mobiliteit te stimuleren. Nederland staat bekend om de decennialange gecentraliseerde ruimtelijke planning die vorm heeft gekregen in onder andere het compacte stadsbeleid, het VINEX-beleid en knooppuntontwikkeling. In andere delen van de wereld is dit ruimtelijk mobiliteitsbeleid vaak op stedelijk niveau ingezet. Bekende voorbeelden zijn steden als Copenhagen, Stockholm en Curitiba. In Noord-Amerika wordt nadrukkelijker op wijk- en buurtniveau ingezet met principes als Smart Growth en New Urbanism. Alhoewel de uitvoering en implementatie van land tot land verschilt is de basisgedachte achter dit ruimtelijk mobiliteitsbeleid vergelijkbaar. Met compacte ruimtelijke ontwikkelingen en functiemenging komen herkomsten en bestemmingen dichter bij elkaar te liggen. Dit verkort verplaatsingsafstanden, verbetert de mogelijkheden voor het gebruik van openbaar vervoer, lopen en fietsen en vermindert de afhankelijkheid van de auto. Hiermee worden mensen gestimuleerd om zich duurzamer te verplaatsen. In de praktijk blijkt het succesvol invoeren van dit beleid geen sinecure. Het vereist een stevige beleidsinzet over een lange tijdsperiode. Hiermee is het een kostbare aangelegenheid waarvan de effecten bovendien nog langdurig doorwerken in de praktijk. Daarom is een grondige analyse van de effectiviteit van dit ruimtelijk mobiliteitsbeleid cruciaal.

Het mag dan ook verrassend worden genoemd dat het wetenschappelijke bewijs voor de wijze waarop en de mate waarin de gebouwde omgeving het verplaatsingsgedrag beïnvloedt niet eenduidig is. Enerzijds leveren empirische studies tot op heden verschillende resultaten op ten aanzien van de rol en de impact van de gebouwde omgeving. Vroege geaggregeerde studies die verplaatsingspatronen tussen steden vergeleken leken veelbelovend. Er bleek een sterke correlatie te zijn tussen de dichtheid van steden en hun auto- en energiegebruik. In latere studies werd het verplaatsingsgedrag op persoonsniveau geanalyseerd en werden controlevariabelen meegenomen zoals sociaal demografische gegevens en later ook attitudes. De impact van de gebouwde omgeving blijkt in deze studies aanmerkelijk kleiner te zijn, of soms zelfs afwezig.

Op basis van verschillende meta reviews kan worden gesteld dat de gebouwde omgeving een significante maar beperkte invloed heeft op verplaatsingsgedrag. In compacte woongebieden met functiemenging en goede voorzieningen voor lopen, fietsen en het openbaar vervoer gebruik mensen deze duurzame vervoermiddelen meer en de auto minder. Naast de verschillen in empirische uitkomsten worden er vraagtekens gezet bij de gebruikte onderzoeksmethodes- en designs. Eén fundamenteel probleem dat centraal staat in dit proefschrift, is dat de meeste studies tot op heden gebaseerd zijn op cross-sectie onderzoekdesigns. In deze studies wordt data op één moment in de tijd verzameld. Deze studies tonen aan dat inwoners van compacte gebieden zich duurzamer verplaatsen dan hun tegenhangers in andere gebieden. Deze *verschillen* leveren echter nog niet voldoende bewijs voor een causale relatie. In andere woorden, correlatie is geen bewijs voor causaliteit. Voor causaal bewijs moet een oorzaak-gevolg verband worden aangetoond; een *verandering* in het verplaatsingsgedrag moet voorafgaan worden gegaan door een *verandering* van bepaalde kenmerken van de gebouwde omgeving.

De discussie over causaliteit op de relatie tussen de gebouwde omgeving en verplaatsingsgedrag heeft zich de afgelopen jaren toegespitst op de interveniërende rol van attitudes. Hierbij zijn twee hypotheses gedefinieerd. De eerste is de residentiële zelfselectie hypothese. Deze stelt dat mensen voor een woonomgeving kiezen die aansluit bij hun mobiliteitsvoorkeuren. Iemand die graag met het openbaar vervoer reist, kiest bijvoorbeeld voor een woning die binnen loop- of fietsafstand van een treinstation ligt en reist vervolgens vaker met de het openbaar vervoer. In dit geval is er, in ieder geval deels, sprake van een schijnverband en is er geen directe invloed van de gebouwde omgeving op verplaatsingsgedrag. Compact bouwen *faciliteert* dan met name een wens tot duurzaam verplaatsingsgedrag maar het *stimuleert* het nauwelijks. De tweede hypothese onderkent ook het verband tussen attitudes en de gebouwde omgeving maar veronderstelt een omgekeerde richting van invloed; de gebouwde omgeving beïnvloedt de attitudes. Wanneer inwoners in de buurt van een treinstation wonen, kunnen ze ervaren dat de auto minder handig is en openbaar vervoer en fietsen juist gemakkelijker. Op basis hiervan kunnen ze hun attitudes aanpassen aan hun omgeving en zich vaker op een duurzame wijze gaan verplaatsen.

De hypothese rondom residentiele zelfselectie is in de afgelopen jaren veelvuldig getest in empirische studies. Meestal namen deze studies attitudes mee in statistische analyses om te controleren voor zelfselectie. Deze studies wezen uit dat de invloed van de gebouwde omgeving op verplaatsingsgedrag kleiner is wanneer voor residentiele zelfselectie wordt gecontroleerd. De tweede hypothese die een omgekeerde richting van causaliteit veronderstelt, is tot op heden minder onderzocht maar verschillende studies vonden ook bewijs hiervoor. De wijze waarop en de mate waarin attitudes de causaliteit op de relatie tussen de gebouwde omgeving en verplaatsingsgedrag beïnvloeden is van groot belang voor de effectiviteit van het ruimtelijk mobiliteitsbeleid. Als residentiele zelfselectie het sterkste mechanisme blijkt te zijn, en er nauwelijks een directe invloed is van de gebouwde omgeving op verplaatsingsgedrag, dan is het effect van ruimtelijke maatregelen beperkt tot mensen die al een voorkeur hebben voor duurzaam verplaatsingsgedrag. Als de omgekeerde causale relatie sterker is, dan zou in de invloed van de gebouwde omgeving belangrijker zijn. Het heeft dan niet alleen een direct effect op verplaatsingsgedrag, maar daar bovenop ook nog een indirect effect via de positieve invloed op attitudes. Beide mechanismen sluiten elkaar overigens niet uit. Ze kunnen beiden aanwezig zijn waarbij hun invloed afhangt van onder meer persoonlijke omstandigheden en de situatie op de woningmarkt. In dit proefschrift staat deze causaliteit op de relatie tussen de gebouwde omgeving en verplaatsingsgedrag en de rol van attitudes centraal.

Doelstelling en hoofdvraag

Dit proefschrift heeft tot doel om de integratie tussen ruimtelijk beleid en mobiliteitsbeleid te bevorderen door inzicht te bieden in de causaliteit op de relaties tussen de gebouwde omgeving, attitudes en verplaatsingsgedrag. Het bouwt voort op het werk van Bohte (2010) die onderzoek heeft verricht naar de rol van attitudes op de relatie tussen de gebouwde omgeving en verplaatsingsgedrag in 2005. De participanten van deze studie zijn opnieuw bevraagd in 2012, waarmee een longitudinale dataset is ontstaan met twee meetpunten. De centrale vraag is:

Hoe en in hoeverre passen huishoudens hun verplaatsingsgedrag aan de omgevingskenmerken van hun woonomgeving aan, en hoe wordt dit beïnvloed door de tweezijdige relatie met attitudes?

Dit proefschrift begint met een verkenning van longitudinale onderzoeksdesigns. Hierbij worden de mogelijkheden voor het vaststellen van causaliteit en de praktische toepassingsmogelijkheden op de relatie tussen de gebouwde omgeving en verplaatsingsgedrag in beeld gebracht. Hierna volgen drie empirische hoofdstukken. Het tweede hoofdstuk toetst de hypotheses rondom zelfselectie en omgekeerde causaliteit. Op basis van gegevens van een online enquête worden de longitudinale relaties tussen de gebouwde omgeving, attitudes en het aandeel autogebruik gemodelleerd. Het derde hoofdstuk bouwt hierop voort en maakt gebruik van data uit een grootschalige gps-survey voor een nauwkeurige bepaling van het aantal gereden autokilometers van de respondenten. Hiernaast vergelijkt dit hoofdstuk de resultaten van de longitudinale analyses expliciet met de resultaten van cross-sectie analyses. In het laatste inhoudelijke hoofdstuk staan de mismatches tussen attitudes en de woonomgeving centraal. Met statistische analyses worden groepen van gematchte en gemismatchte inwoners in beeld gebracht. Vervolgens wordt gekeken hoe deze mismatches zich door de tijd heen ontwikkelen.

Het studiegebied omvat de gemeenten Amersfoort, Veenendaal en Zeewolde. Binnen deze gemeenten zijn centrumgebieden, gemengde woongebieden en suburbane gebieden meegenomen waardoor er een grote mate aan variëteit is qua ruimtelijke kenmerken. Een aselecte steekproef van huiseigenaren heeft deelgenomen aan een online enquête die informatie opleverde met betrekking tot sociaaleconomische gegevens, attitudes, woningvoorkeuren en verplaatsingsgedrag. De longitudinale database omvat 1322 deelnemers. Een subset hiervan heeft ook deelgenomen aan de gps-survey. Hierin hebben deelnemers gedurende een week een gps-logger meegenomen waarmee een gedetailleerd beeld is verkregen van hun verplaatsingsgedrag. Deze longitudinale gps-database omvat 344 deelnemers.

Resultaten

Hoofdstuk 2 geeft een overzicht van de toepassingsmogelijkheden van kwantitatieve longitudinale onderzoeksdesigns voor onderzoek op de relatie tussen de gebouwde omgeving en verplaatsingsgedrag en bijbehorende uitdagingen. In longitudinale onderzoeken worden deelnemers herhaaldelijk en op dezelfde manier bevraagd waardoor een ontwikkeling in beeld kan worden gebracht zoals een toe- of afname van het autogebruik. Tot op heden maakten onderzoeken op het de relatie tussen de gebouwde omgeving en verplaatsingsgedrag voornamelijk gebruik van cross-sectie onderzoeksdesigns waarbij deelnemers maar op één moment in de tijd worden bevraagd. Hiermee kunnen relaties worden aangetoond; inwoners van wijken met een hoge dichtheid gebruiken bijvoorbeeld vaker de fiets. Dit levert echter nog geen bewijs voor een causale relatie waarbij bijvoorbeeld het verhogen van de dichtheid leidt tot meer fietsgebruik van inwoners. Hiervoor zijn longitudinale onderzoeksdesigns essentieel.

De resultaten van dit literatuuronderzoek laten zien dat het toepassen van deze designs op de relatie tussen de gebouwde omgeving en verplaatsingsgedrag geen sinecure is. Het sterkste onderzoeksdesign voor het aantonen van causaliteit is een zogeheten natuurlijk experiment waarin de invloed van ruimtelijke ontwikkelingen of ingrepen in de infrastructuur wordt onderzocht. Grote uitdaging hierbij is dat onderzoekers geen invloed hebben op deze interventies en dat de implementatie hiervan in de praktijk vaak vertraging oploopt. Daardoor is het niet eenvoudig is om voor- en nametingen te plannen en deze af te stemmen op de beschikbare tijd en middelen voor onderzoek. Toegepast onderzoek met een goede afstemming tussen onderzoekers en planners is hiervoor essentieel. Een tweede onderzoeksdesign dat inzicht kan bieden in de causaliteit volgt deelnemers gedurende een periode waarin ze een belangrijke transitie doormaken zoals een verhuizing of baanverandering. De rol van de kenmerken van de woon- en werkomgeving en de veranderingen hierin kunnen vervolgens worden onderzocht. Bij deze observationele onderzoeken is het belangrijk om te controleren voor andere invloeden zoals een verandering van levenssituatie of een verandering in attitudes. Deze kunnen immers de oorzaak zijn van de verhuiswens of wens tot baanverandering en tevens invloed hebben op de mobiliteit. Als niet wordt gecontroleerd voor deze invloeden, dan kan dit negatieve invloed hebben op de validiteit van de onderzoeksresultaten. Ten slotte kunnen natuurlijke experimenten en observationele designs ook worden gecombineerd met gedragsexperimenten. Campagnes om het gebruik van de fiets of openbaar vervoer te bevorderen kunnen bijvoorbeeld worden gericht op mensen die verhuizen naar een nieuw woongebied met goede voorzieningen voor deze vervoerwijzen. Hiermee kunnen onderzoekers de impact van de verandering van de gebouwde omgeving, de impact van de gedragscampagne en mogelijke interactie-effecten analyseren.

Hoofdstuk 3 toetst met een longitudinaal onderzoeksdesign in hoeverre de gebouwde omgeving invloed heeft op verplaatsingsgedrag. Hierbij wordt gecontroleerd voor de invloed van attitudes en diverse andere determinanten van verplaatsingsgedrag zoals inkomen, opleidingsniveau, huishoudenssamenstelling etc. Deze gegevens zijn gebaseerd op de online-enquête die in 2005 en 2012 is afgenomen onder de deelnemers. De analyses laten zien dat naarmate mensen dichter bij het station wonen, het aandeel autogebruik afneemt. Deze significante invloed van de gebouwde omgeving op verplaatsingsgedrag ondersteunt de resultaten van eerdere cross-sectie onderzoeken. Belangrijke meerwaarde is dat deze studie aantoont dat er niet alleen sprake is van een verband maar dat de gebouwde omgeving het verplaatsingsgedrag van inwoners na verloop van tijd daadwerkelijk beïnvloedt. Een andere belangrijke bevinding is dat de gebouwde omgeving ook invloed heeft op attitudes: wonen in de nabijheid van treinstations resulteert in positievere attitudes voor het openbaar vervoer terwijl het omgekeerde geldt voor attitudes voor de auto. Residentiele zelfselectie, waarbij mensen hun woonomgeving kiezen op basis van hun mobiliteitsvoorkeuren is niet aangetoond. Ten slotte speelt autobezit een interveniërende rol met een significante invloed op autogebruik, de afstand tot het treinstation en attitudes. Dit betekent dat autobezit belangrijk is voor beleid dat tot doel heeft om duurzaam verplaatsingsgedrag te stimuleren.

Hoofdstuk 4 gebruikt de resultaten van een uitgebreid gps-onderzoek om de analyses en inzichten verder te verfijnen. Deelnemers aan het gps-onderzoek is gevraagd om gedurende een week een gps-apparaatje mee te nemen om hun verplaatsingsgedrag te registeren. Hiermee is voor de deelnemers het aantal gereden autokilometers bepaald. Net als in het vorige hoofdstuk laten de analyses zien dat de gebouwde omgeving een significante invloed heeft het verplaatsingsgedrag en de attitudes van inwoners. Anders dan in het voorgaande hoofdstuk zijn er bij deze analyses wel indicaties gevonden voor residentiele zelfselectie: mensen met een sterkere auto attitude en mensen die meer autokilometers afleggen verhuizen vaker naar een woonlocatie op grotere afstand van het station. Vermoedelijk sluiten suburbane woongebieden met meer ruimte voor de auto beter aan bij hun voorkeur voor, of afhankelijkheid van, de auto. In dit hoofdstuk zijn de resultaten van de longitudinale analyses ook vergeleken met resultaten van cross-sectie analyses onder dezelfde respondenten. Uit de vergelijking komt een opvallend verschil naar voren. Attitudes hebben de sterkste relatie met verplaatsingsgedrag in de cross-sectie analyses maar in de longitudinale analyses is de invloed van de gebouwde omgeving op verplaatsingsgedrag sterker. Het lijkt er dus op dat attitudes weliswaar een sterke relatie hebben met verplaatsingsgedrag maar dat veranderingen in verplaatsingsgedrag sterker worden beïnvloed door de mogelijkheden en beperkingen die worden geboden door de gebouwde omgeving. Ten slotte is in deze analyse een nieuwe indicator voor de gebouwde omgeving toegevoegd, de omgevingsadressendichtheid. Deze blijkt ook een significante invloed te hebben op verplaatsingsgedrag en attitudes maar de invloed is minder sterk dan de afstand tot het treinstation. Dit betekent dat dichtheid een rol speelt maar dat bij nieuwe compacte woningbouwlocaties de nabijheid tot het station belangrijker is voor het stimuleren van duurzamer verplaatsingsgedrag.

Hoofdstuk 5 heeft een andere benadering en analyseert de mate van mismatch tussen attitudes en de woonomgeving tijdens het eerste meetmoment in 2005. Vervolgens analyseert het de wijze waarop en mate waarin mensen hun woonomgeving of hun attitudes hebben aangepast in 2012. Wanneer mensen verhuizen naar een woonomgeving die beter aansluit op hun attitudes dan is dit een indicatie voor residentiele zelfselectie. Wanneer mensen in plaats daarvan hun attitude aanpassen aan de woonomgeving dan duidt dit juist op een omgekeerde richting van causaliteit. Mismatches zijn in beeld gebracht door mensen te groeperen in verschillende klassen. Hierbij is gekeken naar twee verschillende typen mismatch. Eerst is gekeken naar de mismatches tussen de afstand tot treinstations en attitudes ten aanzien de auto, het openbaar vervoer en de fiets. In een tweede analyse zijn de mismatches tussen de afstand tot het wijkwinkelcentrum, het belang dat mensen hechten aan deze afstand en de tevredenheid over de huidige afstand onderzocht. Beide analyses laten zien dat een goede match tussen de woonomgeving en attitudes geen vanzelfsprekendheid is. Groepen mensen met positieve attitudes voor de auto, openbaar vervoer en fiets wonen zowel dichtbij als op grotere afstand van het station met verschillende mate van mismatch tot gevolg. Ook groepen die de nabijheid van een winkelcentrum belangrijk vinden, wonen zowel op korte als op langere afstanden van deze centra. Een assumptie in dit onderzoek was dat groepen met een hogere mate van mismatch eerder geneigd zouden zijn om hun attitude of hun woonomgeving aan te passen. Uit de analyses van veranderingen tussen 2005 en 2012 blijkt echter dat een hogere mate van mismatch niet zondermeer leidt tot meer aanpassingen. Voor een groep inwoners, woonachtig in de nabijheid van het station met positieve attitudes voor de auto, blijft deze mismatch tussen 2005 en 2012 bijvoorbeeld voor het grootste deel intact. Wel ontwikkelt een deel van deze groep een positievere attitude ten aanzien van het openbaar vervoer. Deze invloed van de woonomgeving op attitudes biedt ondersteuning voor ruimtelijk mobiliteitsbeleid. Uit de tweede analyse met afstanden tot het winkelcentrum blijkt dat de tevredenheid van mensen over de afstand een belangrijke rol speelt in deze aanpassingsprocessen. Wanneer er sprake is van een mismatch en mensen dit ook daadwerkelijk als een probleem ervaren dan treden er vaker aanpassingen op waarbij sommigen dichter bij het winkelcentrum gaan wonen terwijl anderen hun attitude aanpassen. Bij elkaar genomen ontstaat het beeld dat mismatches alleen een verandering in attitude of een verhuizing teweegbrengen boven bepaalde grenswaardes waarbij mensen ontevreden worden over hun huidige woonsituatie. In dat geval moeten mensen ook nog de mogelijkheden hebben om deze mismatch te verminderen.

Samenvattend kan worden geconcludeerd dat de gebouwde omgeving belangrijk is in het streven naar duurzamer verplaatsingsgedrag. Het heeft significante invloed op *veranderingen* in verplaatsingsgedrag, ook wanneer voor de invloed van sociodemografische variabelen en attitudes wordt gecontroleerd. Wonen in woongebieden in nabijheid van treinstations en in woonwijken met hogere dichtheden leidt tot een lager autogebruik. Dit is in lijn met eerdere, met name cross-sectie studies op dit gebied. De longitudinale benadering in deze studie biedt meer bewijs voor een causale relatie. De impact van de gebouwde omgeving is niet alleen significant maar blijkt in de longitudinale analyse ook een van de belangrijkste determinanten van veranderingen in verplaatsingsgedrag. Toch is deze impact in absolute zin bepekt. Dit laat zien dat de verklaring van verplaatsingsgedrag complex is en door vele factoren wordt beïnvloed. Verder spelen attitudes dus een belangrijke interveniërende rol. Er is bewijs gevonden voor zowel residentiele zelfselectie als omgekeerde causaliteit, waarbij de laatste dominant bleek in deze studie. Dit betekent dat de gebouwde omgeving niet alleen een direct effect heeft op verplaatsingsgedrag, maar ook een indirecte via de invloed op attitudes. Ten slotte passen mensen hun woonomgeving of hun attitudes niet zomaar aan wanneer er sprake is van mismatch tussen deze twee. Deze mismatches kunnen langere tijd voorduren en lijken met name een verhuizing of attitudeverandering teweeg te brengen wanneer mensen ontevreden zijn over hun woonsituatie en de mogelijkheid hebben om de dissonantie te verminderen.

Aanbevelingen

De longitudinale benadering in dit proefschrift waarbij kenmerken van de gebouwde omgeving, attitudes, verplaatsingsgedrag en andere determinanten op twee momenten zijn gemeten vormt een waardevolle aanvulling op de bestaande kennis op dit gebied. Desalniettemin zijn er nog verschillende aanbevelingen voor vervolgonderzoek. Het onderzoek heeft zich gericht op generieke indicatoren van verplaatsingsgedrag: het aandeel autogebruik en het aantal autokilometers. De inzichten kunnen verder worden versterkt door nader onderscheid te maken naar modaliteiten en reismotieven. Hiernaast kunnen naast attitudes ook andere gedragsindicatoren zoals percepties, sociale normen en zelfredzaamheid worden meegenomen om een beter beeld te krijgen van hoe de processen van residentiele zelfselectie en omgekeerde causaliteit werken en hoe mensen omgaan met mismatches tussen attitudes en hun omgeving.

Verder richt dit onderzoek zich alleen op de invloed van de woonomgeving. Toekomstig onderzoek kan zich nadrukkelijker richten op de invloed van omgevingskenmerken aan de bestemmingskant. De omgevingskenmerken van locaties voor werk, winkelen of vrijetijd hebben vermoedelijk ook invloed op de verplaatsingskeuzes. Ook de rol van activiteitenknopen zoals treinstations is hierbij interessant om te onderzoeken. Hiernaast kunnen recente innovaties en ontwikkelingen zoals gedeelde mobiliteitsdiensten en Mobility-as-a-Service, kansen bieden voor nieuwe onderzoeksrichtingen. De inzet van deze diensten kan mogelijk bijdragen aan het reduceren van het (tweede) autobezit en daarmee aan het realiseren van bereikbare en leefbare steden. De opkomst van e-shopping en telewerken kan de relevantie van de nabijheid van winkelvoorzieningen en werklocaties beïnvloeden. Dat deze, en andere, innovaties effect gaan hebben op het samenspel tussen mobiliteit en ruimte lijkt evident. De wijze waarop en mate waarin is een kansrijke richting voor toekomstig onderzoek.

Ten slotte is het belangrijk dat er meer longitudinale studies en natuurlijke experimenten worden uitgevoerd. Naast de eerder benoemde samenwerking tussen onderzoekers en beleidsmedewerkers is hierbij de wijze waarop onderzoek wordt ingericht van belang. Veel onderzoek op deze gebieden wordt verricht met behulp van PhD's. Deze hebben een aanstelling van 4 jaar en de scope van onderzoeken zijn meestal ook afgestemd op deze termijn. Bij dit proefschrift is gebruik gemaakt van de unieke mogelijkheid om voort te bouwen op eerder onderzoek van Bohte (2010). Deze werkwijze is ook voor toekomstige trajecten kansrijk en biedt extra mogelijkheden voor langdurige longitudinale onderzoeken met meerdere onderzoeksrondes. Hiermee kunnen de effecten van de gebouwde omgeving op verplaatsingsgedrag beter worden geëvalueerd.

De resultaten uit dit proefschrift bieden ondersteuning voor ruimtelijk mobiliteitsbeleid. Door compact te bouwen en door nieuwe woningen binnen het bereik van treinstations te situeren kunnen overheden het autogebruik afremmen en het gebruik van openbaar vervoer en fietsen stimuleren. Hoogstedelijke knooppuntontwikkeling in de directe nabijheid van stations voorziet echter maar in een klein deel van de kwalitatieve woningvraag. Voorkeuren voor rustige stadswijken, suburbaan en groenstedelijk worden hiermee niet bediend. Verder laten resultaten zien dat mensen met positieve attitudes voor fietsen en openbaar vervoer ook op grotere afstand van treinstations wonen. Om beter te kunnen voorzien in de kwalitatieve woningvraag en om mensen die verder van het trainstation wonen met positieve attitudes ten aanzien van duurzaam verplaatsingsgedrag beter te faciliteren lijkt het optimaliseren van de fietsroutes richting de treinstations kansrijk. Door fietsreistijden te verkorten en het comfort te verhogen kunnen mensen op grotere afstand van het station wonen in bestaande of nieuwe woongebieden en toch het station toch binnen fietsbereik hebben. Door de fietsbereikbaarheid van treinstations als uitgangspunt te nemen kan de scope en impact van knooppuntontwikkeling aanmerkelijk worden uitgebreid.

Wel is het netto-effect van bovengenoemd ruimtelijk mobiliteitsbeleid klein. Het heeft dus nut, maar het is tegelijkertijd ook niet de heilige graal om duurzame stedelijke mobiliteit te stimuleren. Dit is belangrijk omdat steden en regio's ambitieuze plannen hebben voor stedelijk verdichting en compacte woongebieden om duurzame mobiliteit te stimuleren en individueel autobezit en gebruik te reduceren. Het zondermeer verdichten van steden kan leiden tot mismatches waarbij mensen die op de auto zijn georiënteerd terechtkomen in compacte woongebieden. Dit kan leiden tot ongewenste effecten zoals geluidsoverlast, luchtvervuiling, parkeerproblemen en congestie. In dit kader wordt ook gesproken over de intensiveringsparadox. Lessen uit de Vinex-wijken waarbij de invloed van de compacte opzet en de krappe parkeernormen werd overschat zijn exemplarisch hiervoor. In deze zin zou ruimtelijk mobiliteitsbeleid niet moeten worden gezien als de belangrijkste trigger voor een transitie naar duurzaam verplaatsingsgedrag. In plaats daarvan biedt het essentiële randvoorwaarden voor deze transitie door de stimulering van nabijheid waardoor mensen in staat worden gesteld om hun verplaatsingsafstanden te verkleinen en duurzame vervoerwijzen te gebruik zoals lopen, fietsen en openbaar vervoer.
Om een sterkere transitie naar duurzaam verplaatsingsgedrag mogelijk te maken moet ruimtelijke mobiliteitsbeleid hand in hand gaan met flankerende maatregelen. Ten eerste kunnen flankerende maatregelen eraan bijdragen dat mensen met positieve attitudes tegenover duurzaam verplaatsingsgedrag een woning selecteren in woongebieden met goede condities voor het gebruik van duurzame vervoermiddelen. Residentiele zelfselectie kan worden versterkt door mensen duidelijke informatie te geven over onder meer het aantal parkeerplekken, de reistijden voor het openbaar vervoer en de fiets en beschikbare services voor gedeelde mobiliteit. Voor nieuwe compacte woningbouwlocaties is een compromisloos stedenbouwkundig ontwerp, dat een duidelijke boodschap uitstraalt over de mogelijkheden voor individueel autobezit, ondersteund door duidelijke parkeerregulering rondom deze locaties, essentieel om te voorkomen dat er mensen gaan wonen met een sterke oriëntatie op de auto. Ten tweede kunnen flankerende maatregelen worden ingezet om de omgekeerde causale invloed van de gebouwde omgeving op attitudes te versterken. Bewustwordings- en promotiecampagnes kunnen bijdragen aan deze bestaande invloed en de ontwikkeling van positieve attitudes voor duurzaam verplaatsingsgedrag en bijbehorende duurzame

verplaatsingskeuzes versterken. Dit kan bijvoorbeeld met campagnes voor het stimuleren van het gebruik van fietsen en openbaar vervoer onder mensen die recent zijn verhuisd naar woongebieden met goede voorzieningen voor deze vervoerwijzen. Ten derde kunnen flankerende maatregelen de concurrentiepositie van duurzame vervoerwijzen ten opzichte van individueel autogebruik versterken. In aanvulling op het verbeteren van de voorzieningen voor lopen, fietsen en openbaar vervoer is ook de introductie van nieuwe deelmobiliteit voor de auto, fiets en e-scooters en Mobility-as-a-Service (MaaS) kansrijk. Deze nieuw mobiliteitsdiensten hebben de potentie om de behoefte voor individueel autobezit en -gebruik te reduceren wat een van de belangrijkste uitdagingen is bij stedelijke verdichtingsopgaven. Indien nodig kunnen sterkere interventies, zoals parkeerregulering, het downsizen van auto infrastructuur en prijsbeleid worden geïmplementeerd om individueel autogebruik te beperken en het gebruik van duurzame vervoermiddelen te stimuleren.

Ten slotte is voor een succesvol ruimtelijk mobiliteitsbeleid samenwerking met onderzoekers essentieel. De effecten van ruimtelijke en infrastructurele ingrepen worden tot op heden met name ex-ante onderzocht. Op basis van prognoses en modelschattingen worden hierbij de kosten en de baten van de interventies vergeleken. Tijdens en na de realisatie van deze ingrepen is er vaak minder budget en capaciteit om de effecten te evalueren. Hiernaast is het bij het evalueren belangrijk dat de timing van de voor- en nametingen zijn afgestemd op het tijdstip waarop de interventies worden geïntroduceerd. Door goede samenwerking tussen onderzoekers en beleidsmakers kunnen longitudinale onderzoeken en natuurlijke experimenten worden opgezet waarbij de effecten van de ingrepen gedurende het proces en na afloop worden geëvalueerd. Dit opent de weg naar ‘evidence-based’ beleid dat bijdraagt aan de ontwikkeling van duurzame en leefbare stedelijke gebieden met een goede multimodale bereikbaarheid.

About the author

Paul van de Coevering (1979) received his bachelor's degree in Transport Engineering from Breda University of applied sciences and his master's degree in Urban Geography from Utrecht University. He started his career at a consultancy firm where he focussed on public transportation. Then he moved to the Netherlands environmental assessment agency (PBL) where he worked as a researcher, focussing on transportation and the interaction with land use. Most of his research concentrates on the relationships between urban planning and (active) transportation including topics such as accessibility, liveability, spatial quality, public transport, bicycling, parking policies and road pricing. He currently works as a professor (lector) of Urban Intelligence at Breda University of applied sciences. His professorship focusses on integrated multimodal transport and the interaction with the built environment using innovative research approaches such as GPS tracking, data combination and GIS. He has published in peer-reviewed journals and books. His ambition is not only to acquire new knowledge but also to share this knowledge with the (upcoming) professionals in the field. Therefore, he combines his research activities with lecturing while keeping strong connections with the industry.

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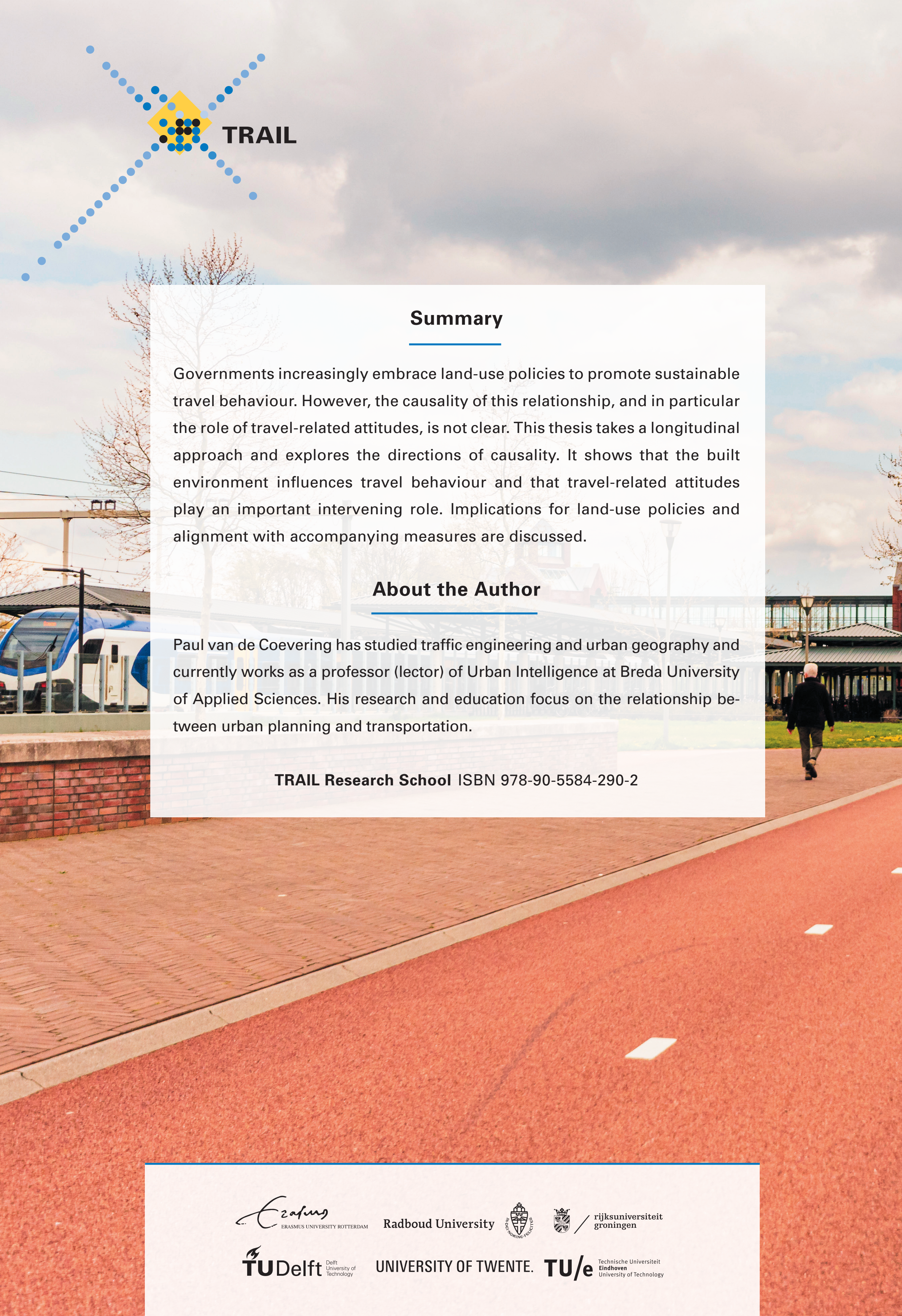

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Summary

Governments increasingly embrace land-use policies to promote sustainable travel behaviour. However, the causality of this relationship, and in particular the role of travel-related attitudes, is not clear. This thesis takes a longitudinal approach and explores the directions of causality. It shows that the built environment influences travel behaviour and that travel-related attitudes play an important intervening role. Implications for land-use policies and alignment with accompanying measures are discussed.

About the Author

Paul van de Coevering has studied traffic engineering and urban geography and currently works as a professor (lector) of Urban Intelligence at Breda University of Applied Sciences. His research and education focus on the relationship between urban planning and transportation.

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