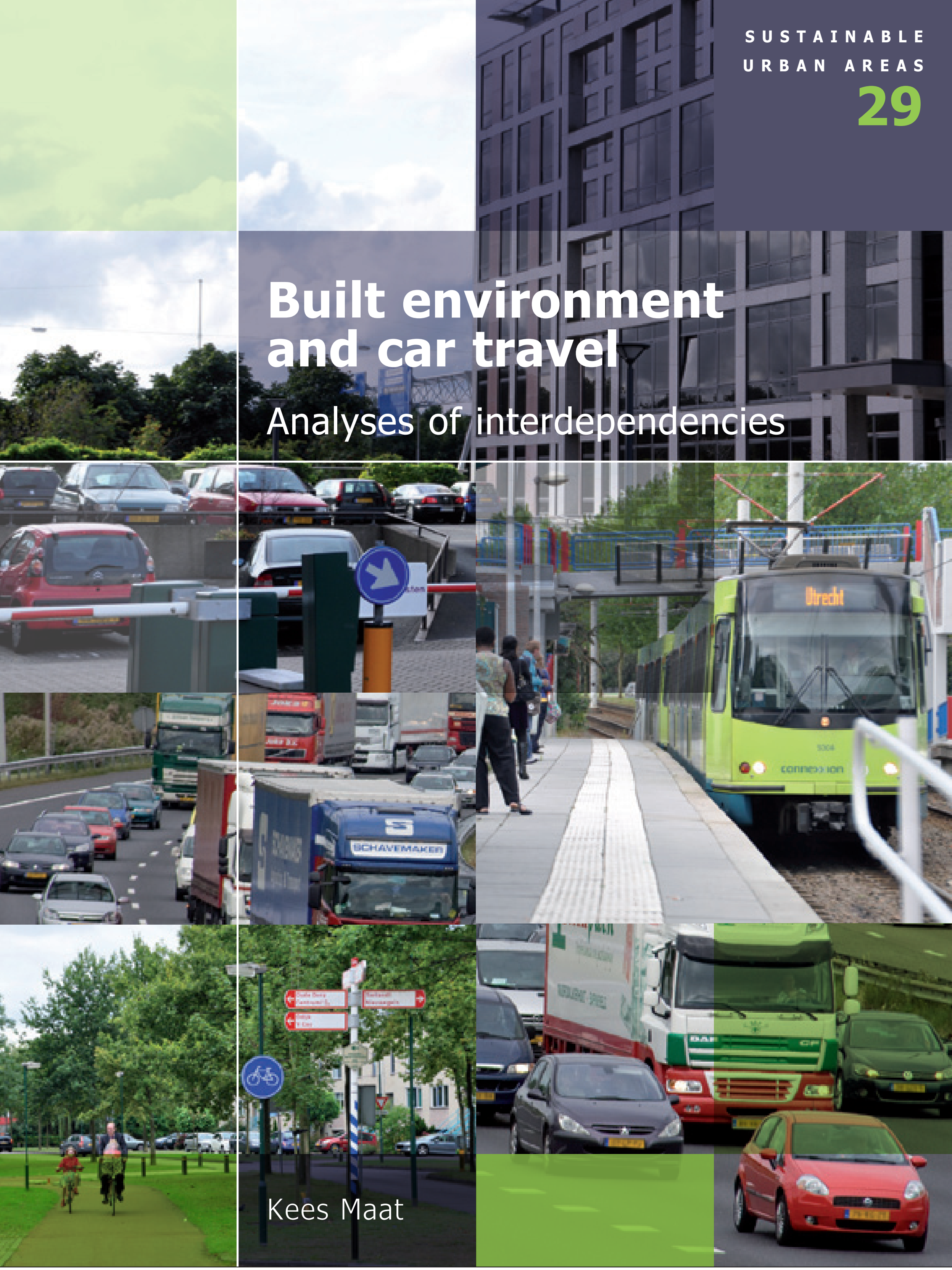

SUSTAINABLE URBAN AREAS
29

Built environment and car travel

Analyses of interdependencies

Kees Maat

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Built environment and car travel

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Analyses of interdependencies

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Preface

Being a 'choice traveller', I usually choose the most appropriate means of transport according to the distance involved, the environment, the weather and so on. The journey to Eindhoven is by train, the commuting trip to Delft is by bicycle (or by car if the weather is bad or if smart clothes are required). My preferred cycling route is, at 15 kilometres, a few kilometres longer than the shortest possible route, but it takes me through some pleasant countryside. There are parallels here with my doctoral research, because it was sometimes worth taking the 'scenic route', too.

After a number of years working for the Province of Zuid-Holland and the Netherlands Organisation for Applied Scientific Research (TNO), I was looking forward to the opportunity to write my thesis when I joined the OTB Research Institute for Housing, Urban and Mobility Studies. For the first few years, my research was wide-ranging, varying from geographical information systems and public housing to freight and passenger transport. The foundation for this thesis was laid at the end of the 1990s when I became involved in some initial research projects into the relationship between urbanisation and travel. With my then roommate, Rob Konings, I conducted research into the effects of urban densification in the province of Noord-Brabant; with OTB collegue Erik Louw, I participated in the EU project 'Designs to reduce the need to travel' (DANTE), led by professor David Banister (University College London); and with professor Hugo Priemus, I conducted research for the Ministry of Transport, Public Works and Water Management into integrated transport and land use policies.

The relationship between the built environment and travel behaviour is a wonderful subject for a geographer with an interest in transportation, and these research projects provided me with inspiration to write a PhD proposal on this subject. Funding for the research had not yet been forthcoming, but in 2000 the Netherlands Organisation for Scientific Research (NWO) allocated funding to the Amadeus research programme, led by professor Harry Timmermans (Eindhoven University of Technology), which enabled me to begin my doctoral research. Since then, however, I have not focused exclusively on completing my thesis as quickly as possible, but have been involved with a great deal of other work alongside it. As the shared data collection phase did not demand much of my time, I was able to work on various other research projects in parallel to my doctoral research. In particular the research I undertook into urban environments with Jan Jaap Harts of Utrecht University, commissioned by the Ministry of Housing, Spatial Planning and the Environment, which developed into a series of interesting projects lasting several years, took much of my time. From 2003 onwards, I have coordinated OTB's section of Urban and Regional Development. This is a pleasurable aspect of my job which involves me in the wider processes of my institute and university. In 2005, OTB became involved in setting up a new area of teaching – Land Use and Development – within the Faculty of Technology, Policy and Management, and my teaching load in this area (along with a number of existing lectures on transport) grew considerably. The 'research project' course that I teach (originally in collaboration with Eric Molin which I enjoyed) is particularly rewarding thanks to intensive interaction with the students. Around this time, under the impression that I was coming close to completing my thesis, I became the daily supervisor of two PhD candidates – first Wendy Bohte and later Eva Heinen – who are being supervised by professor Bert van Wee. I continued working on my own PhD thesis at the same time, and the end result is now in front of you.

As you can see from the description above, many others have contributed to the progression of my scientific work. My first thanks go to my supervisors. From the very start, Hugo Priemus explored the subject with me. He was somewhat less involved during the middle phase of the study, but during the last stretch his energy and drive were invaluable, as were the notes he scribbled in the margins as he was discussing my texts. I have benefitted very much his experience in doing research and from his wide range of knowledge, from housing and urban planning to transport. I also owe a debt of gratitude to Harry Timmermans for the successful application for NWO funding for Amadeus and for setting up the team in which I was able to carry out my research. Somewhat irregularly, I took the train to visit him in Eindhoven, where our discussions about my hypotheses, methods and papers enabled me to continue my work with confidence. My thanks also go to Theo Arentze (Eindhoven University of Technology), who played a particularly important role during the first years as the Amadeus post-doc, ensuring coordination between the projects, the extensive data collection, and not least his thoughts in all sorts of ways, inspired by the activity approach. I think back with great pleasure to collecting the data together, to our discussions and especially to the dinners with Theo and the other PhD candidates working on Amadeus – Stephan Krygsman, Chang-Hyeon Joh and Elenna Dugundji – which I would later miss when Stephan and Joh gained their doctorates in 2004 and returned to their respective home countries, South Africa and South Korea. Bert van Wee, although not one of my supervisors, always took a great interest in my work, encouraging me and helping me think through my hypotheses, all of which has resulted in several joint articles, including a theoretical contribution with OTB collegue Dominic Stead. Much of my gratitude goes to the stimulating environment that OTB provides, with its opportunities, variation and freedom of doing research, and with excellent supporting staff. Working there is particularly pleasant thanks to very nice colleagues, not in the least in my own research group.

Various conferences provided good motivation to have papers finished on time and were enjoyable stopping-off points along the way. These ranged from my first thoughts on the subject of the compact city at the NECTAR conference in Israel to the almost yearly TRB meetings in Washington, with many

others in between. The last location was the village of Hoenderloo, where, in a half-deserted holiday park, I finally found the peace and quiet to finish off my last articles with the aid of a brisk daily bicycle ride through the Hoge Veluwe National Park.

Finally, I would like to thank Jan van der Wolf and Michiel Hoff for agreeing to assist me at the defence of my thesis as ‘paranymphs’. And last but certainly not least, I would like to thank Trude, Michiel and Wouter for their patience during this long journey.

1 Introduction

Recent decades have witnessed an ongoing academic and policy debate on how and to what extent individual travel patterns are influenced by the built environment. The background to this debate is the turbulent growth of car travel in urbanised countries. It is assumed that the insights emerging from this debate can be used to frame spatial strategies aimed at reducing traffic congestion and balancing growing transport volumes against environmental conditions. Knowledge has been gained on the variations in travel behaviour in relation to characteristics of the built environment, while more recent studies have gone beyond direct associations and addressed interdependencies between trips, household members, locations of home and work, and other aspects. This dissertation aims at building on this research by analysing travel behaviour in the Netherlands. The introduction first explores the policy background and then identifies possible knowledge gaps, following this with a description of the aims and research questions. The chapter goes on to define the case study area and the survey and finishes with an outline of the thesis.

1.1 Background

Our welfare is closely related to the ability to travel. Travel is important for society as it enables people to engage in social and economic activities. The more accessible the activity locations are, the more people are able to participate in activities. People also derive benefits from travelling itself, such as a feeling of freedom, the status related to the type of car one drives, or health related to cycling. However, travel is also associated with adverse externalities. Besides the environmental drawbacks of air travel, the dominant role of the car is the particular cause of problems related to congestion and the environment. A daily problem is reduced accessibility due to congestion and lack of parking facilitates: this not only hinders individuals directly, but also affects the economic performance of urban areas (OECD, 2007). In the Netherlands, similar trends are being experienced to those in other urbanised countries: an ever-growing rise in car ownership and distances travelled by car, growing congestion in urbanised areas, and increasingly numbers of kilometres being driven on already heavily used roads (Hilbers *et al.*, 2006; Netherlands Institute for Transport Policy Analysis, 2008). Furthermore, transport has a direct impact on the quality of the environment and directly influences noise levels, air quality and safety. As heavier cars have cancelled out the effects of improved vehicle-fuel efficiency, carbon dioxide emissions and noise pollution levels have risen steadily with the increase in car kilometres (Van den Brink and Van Wee, 2001). The recent debate on climate change (TRB, 2003; Commission of the European Communities, 2009) and the need to reduce dependency on fossil fuels have made these issues all the more urgent.

The adverse health effects of living in car-dependent neighbourhoods is also an emerging issue (Handy *et al.*, 2002; Ewing, 2005).

Corrective steps are therefore seen as imperative to promote more sustainable patterns of travel, improve public health, enhance quality of life and support economic competitiveness. Many solutions have been put forward in recent years to channel traffic more effectively. Expanding the traffic infrastructure has been increasingly regarded as a less desirable solution since it is assumed that this would simply bring about more car traffic (Goodwin, 1996; Cervero, 2002; Banister, 2002). Consequently, for several decades the primary aim in many countries has been to reduce the demand for car travel or, at least, restrict its further growth. This requires mechanisms to reduce the distances travelled by cars, and clearly, recent years have seen a tremendous range of travel-demand measures to reduce and control car travel, such as telecommuting, parking policies, congestion pricing and high-occupancy lanes (*e.g.* Banister and Marshall, 2000).

Among these strategies, the idea of manipulating the built environment seems fairly plausible, since it is the spatial structure of housing, employment, services and leisure that creates the context within which people travel. Given that urban sprawl and car use have consistently reinforced each other in recent years (Banister, 1997; Maat, 2001; Geurs and Van Wee, 2006; Handy, 2005), it would be reasonable to suppose that, conversely, car use could be reduced by more concentrated, cohesive and diverse urbanisation. Accordingly, assumptions about the ways in which travel behaviour might be influenced by manipulating the built environment have found their way into various planning and design concepts. Although the spatial concepts share some basic principles, there are also differences between the concepts and the countries. The American Smart Growth principles aim to combat urban sprawl and car dependence by promoting compact, transit-accessible, pedestrian-oriented, mixed-use development patterns, mainly by redeveloping central cities, urbanised areas, inner suburbs, and areas that are already served by the infrastructure (American Planning Association, 2002). This movement emphasises the role played by government. Closely related are the American neighbourhood design principles as advocated by the New Urbanism movement (Congress for the New Urbanism, 2001), which has its roots in the architectural market and focuses far more on greenfield projects. Despite their different origins and policy orientation, both movements aim to develop cities and neighbourhoods in which everyday activities, such as housing, work, schools, shops and other amenities, are within walking distance of each other, in a pedestrian-friendly environment with alternatives to car use (Cervero, 2003; Handy, 2005).

Elsewhere, particularly in European countries, assumptions on planning and design underpin such concepts as the compact city (Jenks *et al.*, 1996; Naess, 2006). The European Union promotes the integration of transport and land use policies; the compact city was advocated in the Green Paper on the urban environment (Commission of the European Communities, 1990) and in the European Spatial Development Perspective (Commission of the European Communities, 1999); in the latter, the compact city was described as the city of short distances. The European Transport White Paper (Commission of the European Communities, 2001) still promotes policy integration, although it remains unclear how this can be achieved in practice (Geerlings and Stead, 2003). In the UK, national transport documents recognise that land use planning, such as influencing density, design and mixed uses, can help to reduce the need to travel (Stead, 2003), although only a few cities have put these concepts into practice (Burton, 2002). In Germany, Vance and Hedel (2007) report policy integration for some German cities.

An exception, however, is the Netherlands, where national urban planning concepts have been applied in urban regions to influence travel behaviour for decades (Dieleman *et al.*, 1999; Hajer and Zonneveld, 2000; Banister, 2002). Policies have aimed to prevent urban sprawl, but unlike the American urban designs, the focus is not primarily on the level of neighbourhoods, but on encouraging people to live and work largely at the level of the urban region. Initially, from the late 1960s, it was attempted to preserve cohesive urban regions, in which new developments were not always situated close to the existing city, but nevertheless in a concentrated form. This policy was referred to as concentrated deconcentration (Faludi and Van der Valk, 1994). In the 1980s and 1990s, this strategy was further intensified by aiming to reduce the growth of car use by introducing the compact city policy (Ministry of Housing, Spatial Planning and the Environment, 1991). Instead of a dispersed pattern of urbanisation, new housing developments were required to be situated within, adjacent to, or in the vicinity of existing cities. Compact designs were encouraged, with relatively high densities and mixed uses (Maat, 2001). In practice, this resulted in small residential parcels, mainly apartments and terraced houses and less parking facilities and green space. In addition, a business location policy was developed in which industries, offices, or services with a high intensity of use by personnel or visitors were required to be established at locations accessible by public transport (Priemus, 2000; Maat, 2000).

In recent years, however, it has increasingly been argued that activities take place in network structures, where living, working, leisure and amenities are becoming increasingly disconnected from one another, thereby implying interaction at higher spatial levels and shifting the importance of 'proximity' in favour of 'nodes' (Hajer and Zonneveld, 2000; *cf.* Anas *et al.*, 1998). National spatial policies are therefore shifting towards urban networks with concentrated employment and housing developments near public transport and motorway nodes (Ministry of Housing, Spatial Planning and the Environment, 2004; Priemus, 2007). Moreover, in contrast to previous policies, the latest national transport policies no longer aim to reduce car use, but seek to facilitate car travel as a condition for social and economic development (Ministry of Transport, Public Works and Water Management, 2004). Regional policies, however, still aim at reducing car use, partly by entering into agreements between governments and companies. All in all, although there have been limited policy shifts over the years, in general Dutch spatial and transport policies aim to manage car use by ensuring that urban development occurs in a fairly concentrated way.

When applying such planning approaches, it is crucial to determine whether they are effective in influencing travel behaviour. One reason is that intervening in the spatial structure in order to influence travel patterns is a demanding strategy. Changing the spatial structure of the built environment requires long-term planning, can be extremely costly, will have an impact for generations to come and, once developed, will not be easy to modify or adapt (Van Wee and Maat, 2006). Another reason for care is that research has shown that the majority of the households prefer to live in more spacious and car-friendly environments (Heins *et al.*, 2002; Maat, 2002; Howley, 2009). When they have no other option than living in compact neighbourhoods, households may exhibit other behaviour than may be expected on the basis of spatial concepts and designs. Hence, detailed understanding of individual and household travel behaviour is essential in order to assess whether built environment policies make a real contribution to the reduction of car travel.

1.2 Research insights into the built environment and travel

A lively and expanding body of academic literature on the relationship between the built environment and travel behaviour is already available (for overviews see Handy, 1996; Crane, 2000; Badoe and Miller, 2000; Stead and Marshall, 2001; Ewing and Cervero, 2001; Van Wee, 2002; Van Wee and Maat, 2004). Early studies regressed travel behaviour variables, such as trip frequencies, daily travel distance and mode choice, on urban form variables, while controlling for individual and household characteristics. The knowledge gained about how the travel behaviour varies with the characteristics of the built environment generally confirms the assumptions made in planning and design concepts. The academic studies available suggest that concentrated, dense and mixed built environments tend to result in shorter trip lengths, more use of slow modes and public transport, and less car use (Handy, 2005; Leck, 2006; Banister, 2007). However, the reported effects are generally limited and despite the vast quantity of empirical studies, the evidence remains mixed, making it impossible to draw clear conclusions (Handy, 2005; Bhat and Guo, 2007).

In this respect, it is remarkable that research in the Netherlands has been unable to support the supposed relationship between travel and the built environment with any more convincing evidence than elsewhere, although Dutch land use policies have been applied to influence travel behaviour for decades. According to Schwanen *et al.* (2004), the Dutch compact city policy has proven the most effective in retaining high levels of cycling and walking in medium-sized cities but has been less successful in shortening travel times and distances. These findings were confirmed by Snellen (2002), Meurs and Haaijer (2001) and Snellen and Hilbers (2007). The latter study indicates that residential location has only marginal effects on the travel behaviour of people who are relocated in new building schemes constructed according to the compact city principle. Conversely, they seem to be extremely mobile, as they not only travel above-average distances, but also make greater use of the car. Below-average levels of travel were found only for residents of new buildings in the existing built-up areas.

Although the argumentation behind these spatial concepts sounds plausible, other mechanisms may complicate the relationship between travel behaviour and the built environment (Handy, 2005; Van de Coevering and Schwanen, 2006; Bhat and Guo, 2007). Particularly when travel behaviour is studied in more detail, it may appear to be far more advanced. Rather than the built environment having a straightforward influence on trip frequencies, travel distances and mode choices, we may be dealing with endogenous relationships, in which individuals take into account other activities and travel, other people, and other locations. More recent studies therefore go beyond direct associations and address these interdependencies.

One theoretical framework which offers scope for studying a more complicated system, is the activity-based approach to travel demand (Bhat and Koppelman, 1999; Arentze and Timmermans, 2004). A fundamental insight gained through this approach is the assumption that travel is the result of a complex decision-making process through which individuals and households try to meet their basic needs and personal preferences. To achieve their goals, individuals engage in activities that are separated in time and space (*cf.* Hägerstrand, 1970), so travel is needed to connect them. Organising activities and travel involves a series of interrelated choices including the allocation of activities over the course of time, the choice of the destination, the way activities are linked in chains, and the choice of travel modes (Arentze and Timmermans, 2004). Although the built environment is increasingly included in activity research (*e.g.* Pas, 1984; Ma and Goulias, 1997; Golob, 2000; Snellen *et al.*, 2001; Krizek, 2003; Buliung and Kanaroglou, 2007; Bhat and Guo, 2007), many aspects have received little attention.

An important issue is that most studies presuppose the trip as the basic unit, which is defined as the connection between two locations. Activity participation, however, can be seen as a matter of time allocation (Pas, 1998; Bhat and Koppelman, 1999), which means that individuals do not consider separate travel choices, but rather the optimisation of their entire activity pattern. The spatial context sets the framework for the best allocation of activities, depending on the activity locations within reach, the ease of getting there and the availability of transport modes. It is expected that a more compact urban environment will result in shorter distances between activity locations and consequently shorter distances and journey times. However, when daily patterns are studied, the shorter travel distances appear to apply more to lower priority activities (Golob, 2000), thus outweighing the saved travel time.

Moreover, instead of single trips, we often make chains of trips with multiple activity destinations, referred to as tours. This is increasingly being applied in activity and travel behaviour research, but the influence of the built environment on chaining is not entirely clear (Bhat and Zhao, 2002). Shorter distances between home and activity locations, due to higher densities and mixed uses, may simplify the process of making complex tours (Nishii *et al.*, 1988; Ewing, 1995; Golob, 2000), but others found partly contradictory effects (Krizek, 2003).

To explain the role of land use, most studies analyse the residential environment but neglect the role of destinations. It has been argued, however, that the spatial configuration at the destination could be a much stronger determinant of travel behaviour (Badoe and Miller, 2000; Cervero, 2002; Chen *et al.*, 2008). As with the residential location, it can be assumed that remote and suburban industrial estates and office locations attract more car travel than compact ones. Indeed, the effects of compact residential environments may even weaken if the destination of the work trip is located in a less compact environment.

Another issue in the activity approach context is the emphasis on the household as a decision-making unit. It is assumed that household members perform activities together, such as having dinner, and that they divide tasks and share resources, such as a car (Gliebe and Koppelman, 2002; Zhang *et al.*, 2005). Some literature has paid attention to the interdependencies in the household related to dual earnership, including job and residential search behaviour (Sermons and Koppelman, 2001; Van Ommeren *et al.*, 2002) and the role of interdependencies in the household for car ownership (Bhat and Pulugurta, 1998) and mode choice decisions (Badoe, 2002). However, only a few studies have focused on the interdependencies between the built environment and the household related to travel (Potoglou and Kanaroglou, 2008; Ettema *et al.*, 2007). Since the share of dual-earner households is increasing, studying the interaction between the household partners gains in significance. For example, it is plausible that aspects of the built environment at the work location influence the interplay of the use of the car between the partners of dual-earner couples.

Besides the issue of interdependencies, two other aspects require attention. First, assumptions about the effects of built-environment characteristics involve a range of spatial scales, from the regional to the neighbourhood level. Though recent studies have taken the individual as the unit of analysis, the residential location and sometimes other locations visited are usually geocoded at the level of larger spatial units. As a consequence, built environment characteristics represent average figures for that specific spatial unit. In the US these are often neighbourhoods (Cervero and Kockelman, 1997) or census tracts (Boarnet and Crane, 2001; Chen *et al.*, 2008) or an even lower scale (Guo and Bhat, 2007). Dutch studies are often based on higher scales, such as postal code areas (Snellen and Hilbers, 2007), districts (Snellen *et al.*, 2001) or municipalities (Schwanen, 2003); an exception is Meurs and Haaijer (2001) who collected data at the dwelling level. Clearly, the spatial level is rarely chosen from a theoretical perspective, but rather on the basis of pragmatic considerations such as data availability. Only a few of the studies tested built environment indicators at different levels (*e.g.* Boarnet and Crane, 2001; Krizek, 2003).

Another issue that should be emphasised is that major differences exist between Europe and North America for both urban and transportation environments. As a consequence, behavioural responses to differences in the built environment may vary. American cities have grid-like street patterns, well-suited to cars and with many more parking space. Suburban neighbourhoods are extensive, mainly dotted with detached houses including garages, often lacking footpaths, while bicycle lanes are extremely rare. Even the more compact new urban designs in America are generally less dense than average European suburban neighbourhoods and activities such as walking and, in particular, cycling are far less common. Shopping facilities are more often concentrated in malls on city fringes, and since their fuel is cheaper, Americans are more inclined to drive bigger cars over longer distances. European cities, however, have higher overall densities (Gordon, 2008), and often have historic centres filled with narrow streets and limited space for parking. Residential neighbourhoods are more compact, with the majority of dwellings lined up in rows without garages. City centres, residential neighbourhoods and even the countryside are more suitable for walking and cycling (TRB, 2001; Giuliano and Dargay, 2006; Van de Coevering and Schwanen, 2006). In the Netherlands, in particular, there are special facilities for cyclists including separate cycle paths, bicycle racks and sheds in city centres at public services and public transport stops.

1.3 Aims, research questions and scope

This dissertation aims to provide knowledge for spatial planning and design policies that seek to develop a sustainable transport strategy. Such strategies enable individuals and households to participate in activities which contribute to the fulfilment of their needs and preferences, while simultaneously reducing environmental impact and easing traffic congestion. In general, such strategies seek to manage car travel. To this end, this study aims to identify empirically the ways in which travel behaviour is influenced by the built environment. It builds on the insights that were gained through recent research on the complexity of travel behaviour, as described in the previous section. As the role that interdependencies and other aspects play in the connection between the built environment and travel has hitherto received little attention, this thesis seeks to fill these gaps. It is only by clearly determining whether this connection is generated directly or through intervening variables that research can convincingly contribute to sustainable transport strategies.

The first aim is to ascertain whether and how the built environment influences various interdependencies in travel behaviour. This includes an analysis of daily travel patterns, tours – that is to say chains of activities, the interplay between partners in the household, and the relationships with the residential and work locations. The second aim relates to the dimensions of the built environment, including the implementation of comprehensive urban indicators for both residential and work environments, differentiating between spatial levels. The third aim is to study these issues in the Dutch context as foreign – in particular North American – evidence may not be easily transferable; the Netherlands are an example of a European context regarding land use and transport characteristics, but with a unique integration of land use and transport policies. To accomplish these aims, this thesis sets out to explore the following research question: *how and to what extent does the built environment of both residential and work locations influence travel behaviour, taking into account interdependencies between activities, household members, and locations?*

To guide the empirical analyses, specific attention is devoted to the following travel aspects: the daily distance travelled, tour complexity, car ownership and car commuting. All analyses take into account the characteristics of both the residential and the work environment, as well as the various spatial levels. The models of travel distance and tour complexity include the role of activity choices. The analyses on car ownership and use focus on the within-household relations.

1.4 Scope

The scope of this dissertation, which addresses the relationship between the built environment and travel behaviour, is defined and further discussed in this section. Firstly, it must be noted that this thesis is part of a larger programme, called *Amadeus*, in which other studies covered the multimodal aspects of public transport systems (Krygsman, 2004), short-term adaptation in travel patterns (Joh, 2004) and long-term choices influencing travel (Dugundji, forthcoming).

The present research was limited to the daily travel behaviour of persons, thus leaving freight transport and airline travel outside the scope. Since cars are the dominant transport mode, providing flexibility and freedom on the one hand, but producing undesirable effects on the other, they receive the most attention, although some analyses deal with travel behaviour in general. The unit of analysis is the individual traveller, although in some analyses the individuals are considered within the framework of the household. In this thesis (just as in the whole body of literature on this issue) the terms 'built environment', 'urban form' and 'land use' are used interchangeably, though there is a slight preference for the first term, as this may refer best to the whole man-made spatial structure, including its density, the mix of uses, the proximity to services and facilities, street patterns, the physical layout and the design of the urban area.

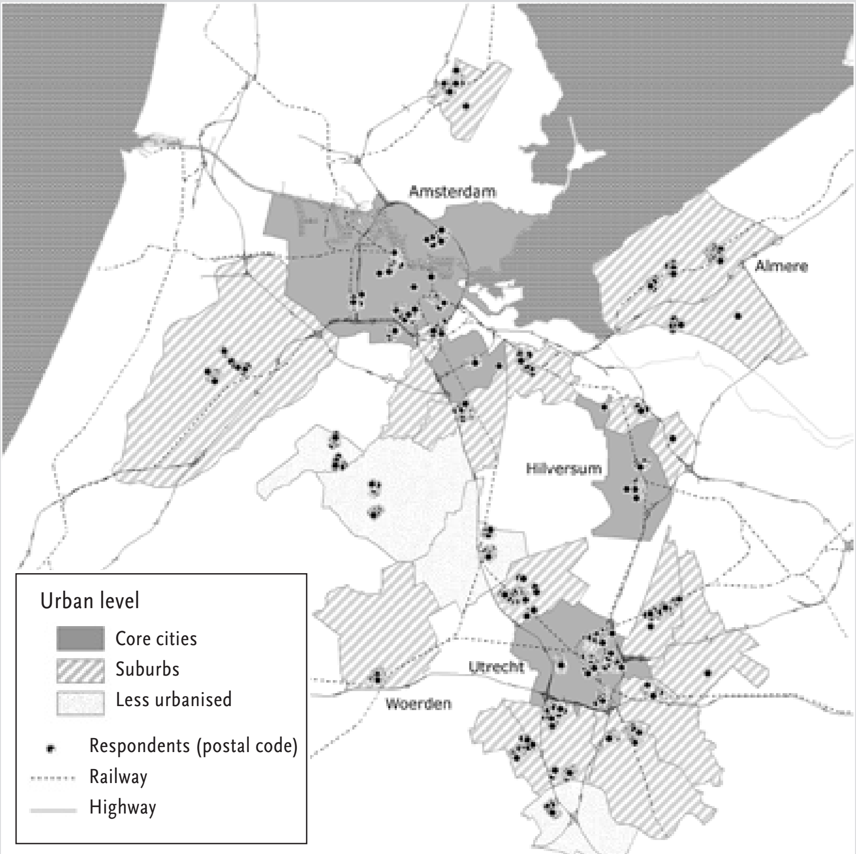
Case study area

All the analyses in this thesis and the other studies in the *Amadeus* programme draw on the same dataset. This required a broad range of data on activity and travel characteristics, individual and household characteristics and measures of the built environment. Existing data sources, such as the Dutch National Travel Survey (Statistics Netherlands), provide neither activity data nor more detailed identification of locations beyond the level of the municipality. In order to obtain the required data, a new, comprehensive dataset was collected. The study area was limited to selected neighbourhoods in the North Wing of the Randstad Holland, covering a wide variety of urban forms, and including the cities of Amsterdam and Utrecht, their surrounding suburbs, a number of medium-sized and smaller towns, and a few villages in rural areas. The Amsterdam region is denser in terms of both population and employment than the Utrecht region. One city, Almere, is a large polycentric 'new town', situated on reclaimed land surrounded by a border lake and connected with the mainland by two bridges, but consequently somewhat isolated (see Figure 1.1).

Data

The sample was drawn in the spring and fall of the year 2000. The survey consisted of several conventional questionnaires. Households were asked to fill out a questionnaire on household characteristics, as well as individual questionnaires for all household members over the age of 12. In addition, all individuals were asked to fill out an activity-travel diary for two days (this diary was newly developed by the current author, and compared with two other ones; for an evaluation see Arentze *et al.*, 2001). The survey included 3,412 individual questionnaires and diaries, which were reduced for the purposes of this thesis in order to obtain complete data, including two full diary weekdays, for individuals over the age of 18 from complete households, and for

Figure 1.1 Map of the study area



which the residential and work location (where applicable) of both partners were available. This resulted, depending on the specific analyses, in two samples of 1,211 and 1,094 individuals, respectively, covering 660 households. The questionnaires include characteristics of the individual, the household, the dwelling, the residential environment and characteristics of frequent activities, such as work. The dataset was completed with spatial data on housing, employment, shops and services, measured on the spatially detailed level of six digit postal codes, and road and railway transport networks, including railway stations. For each residential and work location, several urban form measures were calculated, including a composite density measure on the basis of housing, employment and retail, and a measure that combined mix and density for the work location on the basis of employment and retail. The urban density index is a proxy variable which may be assumed to reflect many factors, such as residential density, access to employment, mixed functions, the availability of amenities, the proximity of motorways, congestion levels, parking space and the availability and frequency of public transport (Guo and Bhat, 2007; Chen *et al.*, 2008). The density and land-use mix indicators were developed for three spatial levels, with diameters of 375 metres and 2.5 and 10 kilometres (Maat and Harts, 2001; Batty *et al.*, 2004), respectively. The first level relates to walking distance, as more or less used in the new urban designs (CNU, 2001) and guidelines for Dutch transport design (CROW, 2004), the second to ten-minutes cycling distance, and the third to a wider area in excess of one city and for which motorised transport is generally needed.

Methods

As this study has a quantitative, empirical nature, statistical models were estimated, including ordinary least squares regression for continuous data, (zero-inflated) Poisson regression and (zero-inflated) negative binomial regression for count data, binary and multinomial logit models for discrete data, all using Stata software. Structural equation models were applied, using Amos software. The spatial variables were prepared using geographical information systems, in particular ArcGIS.

1.5 Outline

The present thesis is a collection of one theoretical and four empirical studies. The research question is addressed in the following chapters of this thesis. Each chapter is based on a paper that has either been published or submitted to a peer-reviewed journal. Consequently, there is some overlap since the original papers have parts of the literature review and data description in common. Although the aim was to use the same terms throughout, some differences remain. However, the thesis is consistent in the use of numbering for chapters, sections, figures and table headings, and in the lay-out and reference style.

Chapter 2 positions the assumptions behind the concepts on the relationship between travel behaviour and the built environment in the framework of theoretical approaches and thinks through the potential consequences on travel behaviour. It provides an overview of these concepts on the level of urban regions and on the neighbourhood, and relates the Dutch approaches to the predominantly American ones. Utility and activity-based theories on travel demand are then introduced. Behavioural responses to variations in the built environment are considered in the light of these theoretical approaches, in particular the consequences for travel distance and mode choice on whether travel time is minimised, benefits maximised, or activity patterns optimised. Since it is hypothesised that the contribution of compact urban designs to reducing travel may not be as straightforward as is suggested by their advocates, it is argued that further research should go beyond a simple trip-based approach.

In Chapter 3 it is assumed that the relationship between the built environment is no more than a statistical association, as distances travelled are not travel choices in themselves, but the consequences of other decisions. Therefore, a causal model is presented which relates the built environment indirectly with daily travel times and distances through a series of activity and travel decisions. A structural equation model is developed for this purpose to simultaneously estimate direct and indirect causal relationships. Individual and household characteristics are included as exogenous variables. Activity choices, broken down in subsistence, maintenance and discretionary activities, as well as travel choices, are included as endogenous variables. In the light of the research question, the most relevant are the urban form variables of both the residential and work environments, which are also included as endogenous variables.

Chapter 4 proceeds by addressing the relationship between chain behaviour and the built environment. The influence of land use on chaining is not entirely clear since some effects may be partly contradictory. It is likely that compact urban designs stimulate both shorter trips and tour complexity and may consequently reduce daily travel distances. On the other hand, a trade-off between shorter and more frequent tours in more accessible areas is possible. This would mean that greater activity frequencies can be expected, resulting in more tours, more complex tours, and greater distances travelled. The hypothesis is investigated, taking into account both residential and work locations as well as differences in spatial scales. The data were analysed using various types of regression models – that is, Poisson and negative binomial regressions to analyse activity and tour frequencies, taking into account the possible occurrence of zeros by using zero-inflated models; continuous data, such as travel times, were analysed with OLS regressions.

The subsequent two chapters analyse whether car ownership and the decision to commute by car are influenced by the built environment of residential neighbourhoods and, especially, of work locations, taking into account interdependencies between possible household partners.

Chapter 5 departs from the view that in a hierarchy of choices, car ownership can be considered as a mediating link, between long-term decisions such as the household composition and the residential and work locations on the one hand, and daily activity and travel on the other. The built environment is assumed to be relevant because it determines the accessibility of destinations and the relative position of alternative modes. Since most Dutch households own one car and generally regard it as a basic necessity, deviations from this pattern are particularly interesting: what factors are involved in not owning a car or in owning more than one car per household? This chapter assumes, in particular, that mutual dependence between the characteristics of the partners, for example child care and work characteristics, influences decisions on car ownership. In addition, some other work-related aspects are taken into account, such as work flexibility and the availability of a company car. Binary and multinomial logit models were estimated to test the assumptions.

Chapter 6 continues on the basis of the above assumptions, but applies them to decisions to commute by car. Commuting is not only interesting because it highly contributes to traffic problems, but it also requires the household partners to gear their activity and travel choices. This paper focuses in particular on households with two employed partners and only one car, although households with full flexibility, that is with at least as many cars as employed partners, are also analysed. Built-environment characteristics are again included for both the residential and work locations, as well as other household and work-related aspects. Logit models were estimated to test the hypotheses.

Variations in the built environment, controlled for household and work characteristics are highlighted and explained in all empirical chapters. Chapter 7 summarizes the chapters and presents the overall conclusions derived from this thesis, as well as recommendations for policy and further research.

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2 Land use and travel behaviour

Expected effects from the perspective of utility theory and activity-based theories

Maat, K., B. van Wee and D. Stead (2005), Land Use and Travel Behaviour: Expected Effects from the Perspective of Utility Theory and Activity-based Theories, *Environment and Planning B: Planning and Design, 3* (32), pp. 33-46. Reprinted with permission by Pion.

Abstract. Assumptions about the effects of various land-use characteristics on travel patterns have found their way into diverse concepts of planning and design, such as the compact city and neighbourhood-design principles. In general, these concepts aim at reducing travel distances and reducing car-travel speed, as it is assumed that as travel distances are shorter, individuals will travel less, and the relative competitive position of slower modes is increased. Although some literature supports the link between land use and travel behaviour, for the greater part limited effects have been concluded, whereas in others it has been concluded that there is virtually no effect. We argue that the effects fall short of the expectations advocated by the land-use concepts, because of shortcomings behind assumptions concerning the relationships between land use and travel behaviour. We argue that utility-based and activity-based theories add some extra insights. Various behavioural responses in terms of travel-time changes are possible, depending on whether travel time is minimised, benefits maximised, or activity patterns optimised. It is concluded that the contribution of compact urban designs to reduction on travel may not be as straightforward as is suggested by their advocates. In any case, a simplified distance-oriented and trip-oriented approach is unable to examine complex behaviour, and a broader framework of space and time is needed.

2.1 Introduction

Travel enables people to participate in societal and economic activities, but it is also associated with a loss of accessibility because of congestion and parking problems as well as with adverse externalities, including impacts on safety, the environment, and health. Many of these externalities are increasing in line with the growth in transport, despite the introduction of a variety of measures to address these problems. In addition, the growth in transport demand is taking place in the modes with high externalities, such as cars and aircraft. In the past, authorities have responded to the rising demand for travel by investing in infrastructure, in particular by increasing road and parking capacity (Banister, 2002). Gradually, however, policymakers have come to realise that many improvements are only temporary, as they may generate more traffic (Goodwin, 1996), and that new car infrastructure does not solve environmental problems. Conversely, solutions that reduce environmental damage, in particular technological solutions, do not solve congestion problems. These realisations have prompted a new response to the irrepressible demand for travel, sometimes called 'new realism', which attempts to reduce car travel – or at least its growth (Banister, 1997).

Among the strategies to reduce car travel, the idea of influencing land use seems plausible, as the spatial structure of housing, employment, services, and leisure forms the context within which people travel. Moreover, the empirical background for this assumption is derived from developments in the past. The increase in car travel, first in the United States and, after World War II, also in Europe, has occurred hand in hand with the dispersal of housing, work, and leisure, the thinning out of the city, and the urbanisation of rural areas. Rising prosperity brought the car and low-density sub-urban living within the reach of many people. The suburbanisation of housing was followed by the dispersal of employment, both of which were facilitated by transport and infrastructure. The resulting spatial form increased the need to travel. Moreover, it favoured the car, as the increased distances discouraged travel on foot or by bicycle, and the decreased densities proved to be too low for public transport. Furthermore, the scattered urbanisation pattern encouraged dispersed travel patterns, which are not easily served by public transport. Consequently, it would seem plausible to assume that a reversal of this situation, by compacting urbanisation, densification, and mixed-use development, will reduce the need to travel – in particular by car (*e.g.* Calthorpe, 1993; CEC, 1990; CNU, 1998; DETR, 2001; Katz, 1994; Ministerie van VROM, 1991).

There is a growing body of research concerned with the relationship between urban form and travel patterns. Studies originate from a diversity of sources, and encompass a variety of geographic scales and locations. To add to this diversity, many different characteristics of urban form have been examined in these studies, and travel patterns have been measured in a number of different ways. Some of this research supports the view that various aspects of land use are linked with travel patterns or travel behaviour (for example, Banister, 1997; Cervero and Kockelman, 1997; Ewing, 1995; Frank and Pivo, 1994; Meurs and Haaijer, 2001; Næss and Sandberg, 1996; Newman and Kenworthy, 1989; Stead, 2001), although in most of this literature only limited effects have been found. In addition, the evidence is not always consistent, and for every piece of empirical evidence demonstrating a link between urban form and travel patterns a counterclaim can almost always be found. This has brought some authors to the conclusion that most of this body of research suffers from methodological flaws, and that the precise nature of these relationships, and how they work, is often unclear from the research. Therefore, they have applied more sophisticated methods, but they have also reported lower effects than others, or have concluded that there is virtually no effect at all (for example, Bagley and Mokhtarian, 2002; Boarnet and Sarmiento, 1998;

Crane and Crepeau, 1998; Kitamura *et al.*, 1997; Schwanen, 2003; Snellen *et al*, 2002). For overviews of the literature, readers are directed to Ewing and Cervero (2001), Handy (1996), Stead and Marshall (2001) or, for a review of Dutch studies, van Wee and Maat (2004).

One of the reasons that the effects fall short of the expectations of advocates of compact urban design is that the assumptions behind travel behaviour have some shortcomings. It is expected that, because of the reduced distances between locations and an increased population base for public transport, travel distances will be reduced and mode choice shifted towards non motorised and public transport. However, such assumptions ignore other aspects of travel demand, as can be derived from utility and activity-based theories. For example, there is rarely mention of how people might use their 'spare' time if journey distances and times are reduced because of land-use changes, or what new travel patterns may occur within households if one member finds it more convenient to use public transport in place of the car because of improvements in access to public transport.

In this paper we demonstrate that the introduction of assumptions which are derived from utility theory and activity-based theories leads to assumptions about the relationship between land use and travel patterns other than those which traditionally underly the concepts of compact designs. The structure of this paper is as follows. First, concepts of planning and design are introduced. Next, some of these shortcomings are examined, and we then discuss how, given the theoretical assumptions, people may respond to the spatial concepts. Finally, some conclusions are drawn.

2.2 Concepts of planning and design aimed to influence travel behaviour

Assumptions about the effects of various land-use characteristics on travel patterns have found their way into diverse concepts of planning and design. Many different land-use characteristics have been included in these concepts, ranging from regional to local to neighbourhood scales. At the regional level, this involves the location of new development in relation to existing towns, cities, and other infrastructure, and the size and shape of new development, and the type of land use. At the local level, land-use concepts concern the level and scale of land-use mixing, density, and the extent to which development is clustered or concentrated into nodes. At the neighbourhood scale, notions on land use are concerned with urban design and movement networks, such as pedestrian-friendly and bicycle-friendly design and local services and facilities. Various land-use concepts that attempt to influence travel patterns are described below, each relating to different scales of urban form.

The scale of cities and urban regions: the compact city and the jobs – housing balance

In Europe the notion of the `compact city' has received attention from some individual countries and from the European Commission as a way of improving the urban environment and reducing car dependence at the national or regional scale. According to the European Commission, the dispersal of home, work, and leisure facilities entails an increasing need to travel, which implies that such trends need to be restrained. For that purpose, the Commission promotes the concept of the compact city and highlights the role of high urban population densities and mixed-use development. These measures, according to the Commission, should reduce the number of car-travel kilometres and improve the share of trips made by bicycle and public transport (CEC, 1990). The 2001 European transport white paper identifies urban and land-use planning policy as being able to "avoid unnecessary increases in the need for mobility caused by unbalanced planning of the distances between home and work" (CEC, 2001, page 6).

The Netherlands is a good example of a country where the compact-city policy is not only included in national spatial planning policies, but is also implemented in many cities. Spatial planning policies have aimed to influence travel behaviour here since the 1960s, and the concept of the compact city became a basic principle of urban planning in the 1990s (Ministerie van VROM, 1991). This strategy aims to reduce urban sprawl, and implies intensive land-use patterns and a predominantly monocentric structure at the level of urban regions, where residential, employment, and service functions are operating at the level of the city region. To achieve this, concentration at the urban regional level has been a major element in the Dutch compact-city concept. Instead of a dispersed urbanisation pattern, new housing developments were required to be sited within, adjacent to, or in the vicinity of the central cities. Compact designs were encouraged, with relatively high densities and mixed uses. Industries, offices, or services with a high intensity of use by personnel or visitors were required to be established at locations accessible by public transport. More recently, however, it has been argued that the process of urban sprawl is consistent with a transition to a multinucleated form (Dieleman and Faludi, 1998), which makes it difficult to implement the monocentric-oriented compact-city policy as a means of controlling mobility. The Dutch government now plans to introduce an adaptation of the concept, the so-called notion of `urban networks', which aims at concentrating new work and housing developments near to existing and potential public transport nodes and motorway intersections (Ministerie van VROM, 2004).

The attention to concentration on a regional scale brings to mind the jobs-housing debate in the United States in the late 1980s. The debate focused on two issues. First, it was found that suburban communities were fundamentally unbalanced, meaning that the amount of suitable housing differed substantially from the amount of employment, thus generating additional car traffic. In other words, the spatial distribution of employees differed strongly from the spatial distribution of jobs. Second, regardless of this spatial distribution, there was excess travel (sometimes referred to as 'wasteful commuting') because, with a better fit between the locations of employees and jobs, average travel distances and times could be much smaller. However, the extent to which this was really true depends upon assumptions about segmentations of the labour and housing markets as well as on temporal friction between job vacancies and job seekers (*e.g.* Cervero and Wu, 1997; Hamilton, 1982; 1989; Modarres, 2003; White, 1988). For the debate on the compact city, two aspects of the discussion are relevant. To prevent spatial mismatch, proponents of jobs – housing balancing have suggested that houses, shops, and jobs need to be built close to each other, preferably at the local level or at least at the regional level ('balancing'), so that commuting distances can be shortened. In order to achieve this, strictly separated land uses need to be exchanged for mixed-use development. Others found indications for the collocation hypothesis in that, over time, decentralised housing development is followed by decentralised employment (Giuliano and Small, 1993). It is clear that a strong mismatch between the locations of jobs and houses results in much forced commuting over longer distances. However, even if jobs and houses are spatially balanced, this does not guarantee that people will choose jobs near their residential location, or that people will choose a house near their work. According to Redmond and Mokhtarian (2001), many people like a commuting distance of around 15 to 20 minutes, and do not try to minimize their commuting time below this. Even if the overall number of employees and the related number of houses in a certain area is the same as the number of jobs, there is no guarantee that there will be a match between these jobs and these workers.

The neighbourhood scale: layouts for slow modes and new urbanism

It is assumed in concepts of urban design that the layout of urban areas at the neighbourhood level can also influence the travel patterns, by affecting the attractiveness of different modes of transport. For example, car use can be discouraged through designs that reduce vehicle speeds (and therefore increase travel time), such as traffic-restraint measures (for example, speed humps or indirect ingress or egress routes), or designs that reduce the availability of parking. On the other hand, the use of slow modes, such as cycling or walking, can be encouraged through the provision of facilities for these modes and dedicated, direct routes. In addition, reducing the speed of cars can make travel by slow modes safer and more convenient. In terms of public transport, increases in development density near public transport stops is assumed to increase potential rider ship. However, there is a more complex relationship: better access to public transport potentially encourages more travel, as well as potentially reducing car travel. On the other hand, with better access, public transport also competes with slow modes.

The success of the bicycle-friendly design of the new town of Houten, near the city of Utrecht in the Netherlands, is an example of this type of land use. This layout provides a direct railway service to Utrecht, a shopping centre and offices near the railway station, and all residential neighbourhoods within approximately 1.5 kilometres (cycling distance) of the town centre. A dense network of comfortable cycle routes connects the town centre and all neighbourhoods together, and through traffic by car is discouraged by being forced to use a ring road outside the built-up area (see also Maat, 2001).

The focus on designed communities is also seen in the so-called 'new urban designs' in the USA, such as pedestrian pockets, neotraditional design, and transit-oriented design – collectively known as 'new urbanism'. Advocates of these designs (for example, Calthorpe, 1993; Ewing, 1995) support a return to more traditional and urban-style development, that is: the creation of diverse, compact, and mixed neighbourhoods. Everyday activities, such as housing, work, schools, shops, and other amenities, are all ideally within 10 minutes' walking distance of each other. The aim is to provide a pleasant, comfortable, interesting, and safe environment for pedestrians, and to provide alternatives to car use – such as public transit and cycling facilities. A grid network and higher densities provide short walking access (CNU, 1998). "Together these strategies may reduce driving not only by encouraging alternatives – walking, biking, and transit – but also by reducing the distances that residents drive when they still get in their cars" (Handy and Clifton, 2001, p. 318).

2.3 Theoretical perspectives on travel demand

In Section 2.2 we suggested that there are a number of concepts of planning and design aimed at reducing car-travel kilometres. Car-travel reduction can be achieved through three strategies: (1) by mode shifting from car to walking, cycling, and public transport; (2) by reducing trip distance; and (3) by reducing the total number of trips. What the land-use concepts outlined above have in common is that they seek to reduce travel distances and to increase the share of public transport by increasing the population base for public transport. Situating residential, employment, and service locations closer to each other is generally assumed to reduce the distances which need to be covered. It is expected that the shorter travel distances will result in a reduction in the total number of kilometres travelled, an increase in the possibility of linking more destinations in one trip (`trip chaining'), and an increase in the attractiveness of walking and cycling in place of using the car. Higher densities are assumed to improve public transport use because distances to public transport stops are shorter.

It is assumed that, when nearby destinations are added to the choice set, average travel distances tend to get shorter because these destinations will be chosen rather than more distant ones. Moreover, as travel distances are shorter, individuals are assumed to be more likely to choose to travel by foot or by bicycle.

Although these are plausible assumptions, when other considerations are considered, the picture changes (see also Boarnet and Crane, 2001). One shortcoming is the single focus on the costs of travel, and not on the benefits. The theoretical foundation of travel demand can be found in the notion that most travel is derived from the need of individuals and households to participate in activities and, as they cannot all be conducted at the same location, travel is necessary. Participation in activities thus yields benefits and costs. As we know from utility-based theories on travel demand, individuals are assumed to make choices in which they maximise the utility they obtain by participating in an activity. This utility is the trade-off between the benefits (or net utility, which is the positive part of the utility) and the costs (or disutility) to bridge the distance to an activity location. Whereas the land-use concepts seem to emphasise the costs, the utility perspective also enters the benefits into the equation. For example, in choosing a shopping destination, the positive part of the utility is the attractiveness of the shop – such as choice or quality – whereas the disutility part is the cost of getting there. Thus, individuals may maximise their utility by opting for a more distant destination in order to get higher quality, greater choice, or cheaper products.

Second, individuals are not primarily interested in travel distance, but, rather in the costs of bridging that distance: namely, time, money, and effort. In particular, time is seen as a significant factor as an individual's available time is a scarce resource (*e.g.* Gonzales, 1997; Pas, 1998). Thus, individuals may choose a more distant destination if it can be reached in less travel time.

Third, in the traditional approach, trips are considered. In doing that, however, one loses sight of the broader picture within which travel decisions are made. From the perspective of travel as a derived demand, one would assume that such choices need to be considered within an integrated framework of activity participation (Golob, 1998). This is the basis of the activity-based approach, which assumes that people do not make separate decisions considering only trips, but that they try to schedule activities in a daily pattern. As a consequence, a fundamental difference between the trip-based approach and the activity-based approach is the way in which time is conceptualised and represented. In the trip-based approach, time is reduced to being simply a 'cost' of making a trip. The activity-based approach, on the other hand, treats time as an all-encompassing continuous entity within which individuals make activity and travel decisions (Bhat and Koppelman, 1999). Activity participation can thus be seen as a matter of time allocation (Pas, 1998), which means that individuals do not maximize utility for separate travel choices, but that they optimize their entire activity pattern.

Fourth, closely related to the previous point is the unrealistic assumption that individuals are free to choose the alternative they like best. Advocates of the constraint approach, however, propose that activity and travel are not only based on utility-maximising choices, but that they are also constrained by space, time, and the institutional context (Axhausen and Gärling, 1992; Timmermans, 2000). Hägerstrand's time geography (1970) showed that both space and time are scarce resources and constrain daily activity patterns. Such constraints relate to the amount of physical time in a day and the time required for personal care, eating, and sleeping, and the necessity to perform some activities, such as work, at a fixed place, at a certain time, and over a fixed duration. Other constraints include, for example, interdependencies between household members that determine daily activity schedules (for example, common activities such as eating).

Constrained time budgets also imply that time spent travelling cuts into the time available for other activities, thus limiting activity demand. This mechanism is termed the 'time-budget effect' (*e.g.* Golob, 2000). There are two hypotheses in time-budget research, which assume that time budgets are either fixed or flexible (see Kraan, 1998, for an overview). In the fixed travel budget approach, at an aggregate level, such as for a whole country, total travel time is considered as more or less constant (Schafer and Victor, 2000; Zahavi, 1979). Savings in travel time, achieved by travelling over shorter distances or by using faster modes, are allocated to other travel, resulting in more and longer trips. This implies that reducing distances by means of more compact land-use concepts induces the choice of more remote destinations, and thus longer travel times, or a shift to slower modes. Conversely, in the flexible travel budget approach, the time saved on travel can be allocated to other activities as well. Note that the assumption of constant travel time budgets is not consistent with utility theory, as there is no reason for an exact constancy. For example, assume all circumstances remain the same except for travel costs being reduced. This is likely to result both in an increase in travel and in an increase in travel time per person, according to utility theory. However, though exact constancy in travel time cannot be expected according to utility theory, a more or less stable average travel time per person could be expected at an aggregate level. One reason is that a person with a very short travel time might obtain a relatively strong increase in utility as a result of additional travel, but the more he or she travels, the lower the additional utility. Therefore, according to utility theory, it is unlikely that, on average, people will hardly travel at all, but it is also unlikely that, on average, people will travel two or three hours per day: the additional utility compared with less travel is low, but the additional costs are high. Another reason is that people prefer to travel for a certain time each day than not to travel or hardly to travel at all (Redmond and Mokhtarian, 2001).

In addition, the relative positions of locations determine spatial constraints. These constraints include the amount of travel needed, the feasible distances which can be covered, and even the possibility of engaging in activities (Kraan, 1998). A spatial environment that provides high accessibility to facilities may increase people's involvement in activities.

To summarise these theoretical notions, it is assumed that people attempt to meet their basic needs within constraints of space and time and in the context of the household and institutions, while performing trade-offs between utility and cost. As a consequence, an individual's aim is not primarily to minimise travel costs, but, rather, to maximise utility. Saved time can be consumed by increases in activity time, but also by the substitution of more preferred destinations that entail higher travel costs (in order to obtain a higher attractivity), or by scheduling more out-of-home activities. The last two options would lead to increased travel. This effect is often called 'latent' travel demand (Golob, 1998). In the next section, the notions mentioned above are used to hypothesise the effects of spatial features on activity and travel behaviour.

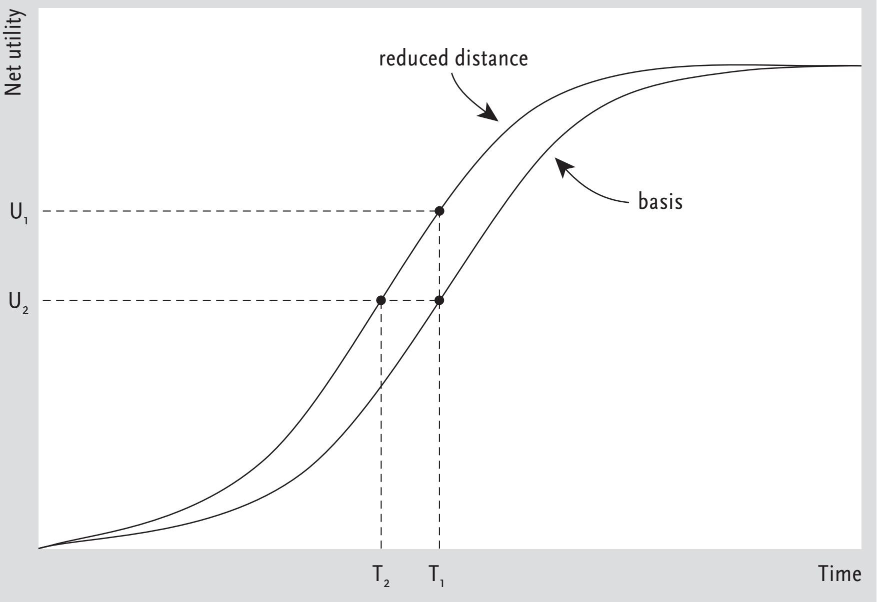
2.4 Behavioural responses to travel-time changes

Introduction

In this section the theoretical assumptions discussed above are used to deduce the outcomes that can be expected from the concepts of spatial planning and design, focusing specifically on two aspects of urban form – density and mixed use. As is evident from the foregoing discussion, it is assumed that the influence of urban form mainly runs through travel time. The simple model in Figure 2.1 illustrates this, with net utility as a function of travel time. Net utility includes all the benefits people gain from the activity, whereas disutility is represented by travel time.

The figure shows a given travel time T_1, with a given net utility, U_1. The utility is, by definition, positive, otherwise one would not spend travel time. It is assumed that utility increases with the travel time spent, otherwise one would not spend more time travelling. The further one travels, the more opportunities are within reach and the bigger the chance of being able to reach an opportunity with a higher utility. Furthermore, it is assumed that the curve is S-shaped. The first part of the trip is used in some initial actions, such as walking to the car, starting the engine, or unlocking the bicycle, so hardly any benefit can be expected. Then, utility increases. Third, it is assumed that the increase of utility slows down with increase in travel time because the additional benefits of travelling longer might be subject to the law of diminishing returns. For example, the second-nearest supermarket might be more at-

Figure 2.1 Stylised effects of travel-time changes

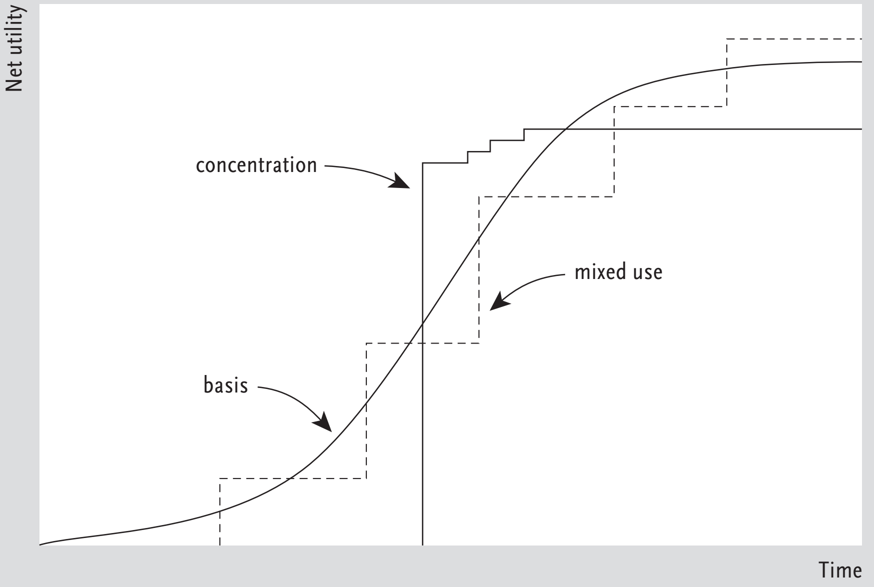


tractive than the nearest, perhaps because of lower prices or more variety in products, but the additional benefits of the fifth-nearest compared with the fourth-nearest might be smaller. (Note that the curve would have been bell shaped if distance was displayed, as initial actions do not affect travel distance.)

Travel time is dependent on travel distance and travel speed. The model illustrates the consequences for changes in travel distance and speed on the relationship between travel time and utility. The additional curves address the effects of shorter distances and reduced speeds on utility, as can be expected in compact urban designs. The rationale is as follows: if distances are shorter, utility is higher (assuming the same travel time), or travel time is shorter (assuming the same utility). For lower speeds, the effect is the other way around: one has to travel longer for the same utility (horizontal line) or obtains a lower level of utility from the same travel time (vertical line). Note that as travel time increases the curves get closer and eventually come together.

It should be noted here that, in the reasoning above, it is assumed that utility (for each activity type) is equally spread. However, uses are rarely perfectly mixed, so utility and travel time will change discontinuously. Figure 2.2 displays two utility curves. They are found by sorting locations by ascending travel times, where only locations which have a higher utility than the closer ones are displayed (see van Wee *et al.*, 2001). If uses are mixed, it becomes more likely that shopping needs can be satisfied in the immediate vicinity of the home. To receive some extra utility, a little amount of extra travel time is needed. However, if uses are concentrated, for example in a large commercial centre at the edge of the city, a larger amount of time may be needed to reach the nearest supermarket, but with only a little amount of extra time

Figure 2.2 Stylised effects of mixed use



the other supermarkets are reached. This explains the importance of considering the type of activities that can be spatially mixed or concentrated. For example, mixing supermarkets can actually result in shorter average travel times because the added value of a third or fourth supermarket is very small; many people will choose the nearest or second nearest supermarket for daily shopping. However, mixing jobs is unlikely to result in shorter travel times because the chance that the job with the highest net utility (utility of the job minus the disutility of travel) is nearer, because of the mixed job pool, is quite small. The same holds for specialised shops with a regional, or even larger, catchment area.

Effects on frequency and distance travelled

The effect displayed in Figure 2.1 shows a situation in which travel distances between locations are reduced, as may be expected in compact urban designs. Three types of behavioural response are possible. First, if one aims only at minimising travel time, and thus utility, U_1, remains unchanged, shorter distances will reduce travel times to T_2. Trip frequency may also decrease because trip chaining is more likely with shorter distances. Let us assume, for example, individual A, living in a remote suburb with a supermarket within 10 minutes' travel time. Another individual, B, living in a compact town, has a similar shop within 5 minutes' travel time. Hence it can be seen that compact urban designs offer the opportunity to travel less.

However, let us now consider individual B, living in the compact town. Although there is a supermarket within 5 minutes' travel time, there is also a cheap and large hypermarket in the city centre – within 10 minutes' travel time. If an individual aims to maximise utility, and thus accepts travel time T_1, no distances are reduced, but the higher utility, U_2, is obtained. This means that the potential travel-time savings are used for longer trips to get extra, latent, utility.

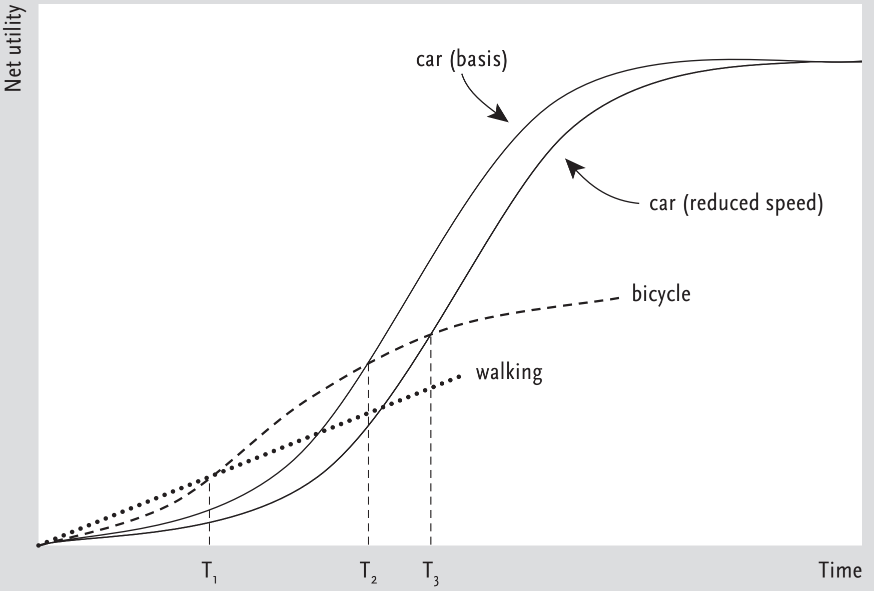
Third, if one reduces travel time towards T_2, and travel-time savings are not used for extra utility farther away (and thus remain as U_1), more activity time is left ($T_1 - T_2$) – which can be allocated to engage in other activities, either in the home or outside. Out-of-home activities may increase the number of trips, and consequently the kilometres travelled. In this option, not only the trip itself is considered, but it is also assumed that individuals consider their entire activity pattern, and thus may attempt to adapt their daily pattern by allocating additional time to activities with a lower priority. Evidence for such latent travel demand can be found in the work of Golob (1998; 2000): He found that time saved thanks to trip chaining was used for other activities, and that the time saved with shorter commuting times was used for other out-of-home activities. Another effect (not displayed in Figure 2.1) concerns the effect of reduced speeds on utility, speed reduction may be aimed at traffic calming, for instance in pedestrian-friendly and bicycle-friendly designs. Moreover, in compact designs, concentration and densification may unintentionally lead to more congestion and longer searching times for a parking space, and thus to lower average speeds. Because lower speeds increase travel times, the effects are mainly opposite to the effects of distance reduction. However, because travel reduction is targeted mainly at cars, effects on modal choice can be expected as discussed in the next section.

Effects on mode choice

Travel distance may change the relative cost of each mode, and thus also influence mode choice. Figure 2.3 (over) displays the relationship between utility and travel time for different modes. Pedestrians have hardly any initial actions, their average speed is low but constant, and, because of the physical effort involved, their maximum travel time is limited. Bicycles have higher speeds, so more utility is obtained with the same travel time. The curve for cars is strongly S-shaped. The figure shows that at a certain distance, the likelihood of choosing a certain mode changes. On the basis of travel time, the maximum utility for pedestrians and cyclists is reached at times T_1 and T_2, respectively.

Figure 2.3 also displays the effect of speed reduction for cars, such as might be expected in pedestrian-friendly or bicycle-friendly designs (or the US new urban designs). Although traffic lights and road designs may also reduce speeds for slow modes, traffic-calming measures are mainly targeted at car use. In fact, artificially extending distances for cars and slowing down car speeds in pedestrian-friendly and bicycle-friendly designs will extend car-travel costs – which makes walking and cycle routes relatively more attractive. As a consequence, speed reduction for cars increases the likelihood of a change to slow travel modes. Hence, shorter distances encourage people to

Figure 2.3 Stylised effects of mode changes



walk or cycle, relative to the use of motorised modes such as cars and public transport. However, as traffic calming and congestion are features mainly of urban areas, speed reduction occurs mainly over shorter distances. Consequently, after a certain distance, the curves become parallel. It may be concluded here that speed reduction for cars seems to reduce car travel from the perspective both of utility-based and of activity-based theories.

Additional comments

Three additional comments are warranted. First, because individuals maximise their utility, an increase in travel time is associated with an increase of the utility of an activity. However, this relationship is not necessarily linear. With a homogeneous distribution of activities over space, a doubling of travel time (assuming constant speeds) can potentially result in four times as many activities being within reach. However, the increase in activities is subject to the law of diminishing returns: the increase in utility of being able to choose between six supermarkets instead of five, for example, means a lower increase of utility than an increase from one or two supermarkets. The relationship between utility and travel time is further complicated because of the nonlinear relationship between time and distance. On average, speeds increase if average travel distance and travel time increase because of the larger proportion of faster roads being used. An additional complication is the nonlinear value of time (see Section 2.1), which may also vary by trip purpose. Thus, in practice, some of the lines in Figure 2.2 may have a different shape but the general pattern is likely to be similar and, generally speaking, there will be an increase in utility if travel distance increases. In the figure we have assumed that disutility is caused only by travel time, but we recognise that there are, of course, other types of disutility associated with different modes (for example, monetary costs, different levels of comfort, or the ability to carry out other activities during the journey). It should also be noted that, although the intersection of utility lines for different modes can be at a given point in space (for example, a destination which has an equal travel time for more than one mode), this does not necessarily have to be the case (for example, two separate destinations can provide the same level of utility). Second, car trips take less time if roads suitable for higher speeds can be used, even if distances are longer. Travel times for public transport are dependent on the quality of the connection, including frequency, transfers, access, and egress. Thus, from the perspective of travel-time reduction, shorter distances compete with faster modes and faster routes. This means that it might be an option for car drivers to choose another destination to obtain lower travel costs. Third, other costs, such as differences in effort for certain purposes, may change the likelihood of walking or cycling dramatically: for example, the necessity to carry goods or children. This may also vary with health or age. Moreover, personal preferences, for instance, a strong preference for the car, may weaken this (van Wee *et al*, 2002).

2.5 Conclusions

Among the strategies for reducing car travel, the idea of influencing land use seems an attractive one as the spatial structure of housing, employment, services, and leisure forms the context within which people travel. The increase in car travel has occurred hand in hand with urban sprawl. Consequently, it would seem plausible to assume that a reversal of this relation by compact urbanisation, densification, and mixed-use development, will reduce the need to travel – in particular by car. Such assumptions have found their way into diverse concepts of planning and design, such as the compact-city and neighbourhood-design principles.

In general, these concepts aim at reducing distances, as it is assumed that, when travel distances are shorter, individuals will travel less, and be more likely to choose walking or cycling. Furthermore, neighbourhood designs offer lower car-travel speeds which increase the relative competitive position of slow modes. Moreover, higher densities, especially near railway stations and other public transport stops, provide a better population base for public transport support.

There is a growing body of research concerned with the relationship between land use and travel patterns. Some of this research supports the link between land use and travel behaviour; however, most of the literature suggests only limited effects. In addition, the evidence is not always consistent. Authors who have applied more sophisticated methods have also reported limited effects, or have found virtually no effect at all.

We argue in this paper that the effects fall short of the expectations advocated by the land-use concepts, because of shortcomings behind the assumptions concerning the relationships between land use and travel behaviour. If it is assumed that people attempt to meet their basic needs within constraints of space and time, and performing trade-offs between utility and cost, it can be argued that an individual's aim is not primarily to minimise travel costs, but to maximise utility. Various behavioural responses to travel-time changes such those which can be expected in compact designs, are possible. First, if one just aims to minimise travel time, shorter distances will reduce travel times, and also, trip frequency may be decreased because trip chaining is more likely with shorter distances. As a consequence, compact urban designs offer the opportunity to travel less. Second, a fact which is often ignored is that compact urbanisation may result in people choosing more remote destinations. However, we argue in this paper that people perform trade-offs between the benefits of an activity (such as the variety or prices in a supermarket) and cost, so that travel-time savings may be exchanged for additional utility – such as a cheaper shop further away. Third, the fact that people may make more trips if distances are shorter is also often ignored. We argue that, following the constraints-based approach, people not only maximise utility per trip, but also attempt to optimise their whole activity pattern. Travel-time savings can be used to provide time for lower priority activities (including travel) that could not otherwise take place. Fourth, travel times may also change the relative cost of each mode, and thus also influence modal choice. Artificially extended distances for cars, and reduced car speeds in pedestrian-friendly and bicycle-friendly designs, will extend car-travel times – which makes walking and cycle travel relatively more attractive. Hence, shorter distances and reduced car speeds encourage people to walk or cycle, rather than use cars.

To conclude, the contribution of compact urban designs to travel reduction may not be as straightforward as is suggested by its advocates. From a theoretical point of view, mode shifts due to slow mode friendly designs contribute more to sustainable travel patterns than do merely denser cities.

Nevertheless, because the spatial structure forms the context within which people travel, land-use policies still offer some potential for influencing travel behaviour. However, as society becomes more complex – including developments such as multiple car ownership per household, double-income families, telecommuting, and population ageing – the relationships between urban form and travel behaviour are also likely to become more complex. In addition, travel-demand measures are becoming more complex, which adds to the complexity of the relationships between urban form and travel behaviour. As a consequence, land-use strategies (and research in this area) need to take into account both individual and household activity and travel decision making. A simple distance-oriented and trip-oriented approach cannot examine complex behaviour: on the contrary, such strategies need an approach that takes into account human behaviour in a broader framework of space and time.

Finally, it should be noted that in this paper we have considered only the effects of planning and design concepts from the perspective of travel behaviour. To determine the desirability of such concepts, more aspects need to be included in the considerations – including residential preferences, congestion, safety, and financial aspects.

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3 A causal model relating urban form with daily travel distance through activity/travel decisions

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Abstract. Urban form is often assumed to influence travel distance. However, as this is no travel choice in itself, but the consequence of other decisions, this paper tests, consistent with the activity-based approach, a causal model that does not relate urban form directly with daily travel distance, but indirectly through a series of decisions. A structural equation model was developed with urban form measures for both the residential and the work environment. The model demonstrates that indirect effects can steer a total effect in another direction, indicating that the apparent effects of one variable on another can be the trade-off of opposite effects. Effects from residential density suggest that people in a dense residential environment travel a little less, although this effect is partly cancelled out by extra activities. Workplace density/mix increases total daily distances, but decreases distances by car.

3.1 Introduction

The debate about the influence of urban form on travel behaviour pays, besides mode choice, particular attention to the daily distances travelled. It is assumed that situating residential, employment and service locations closer to each other, average travel distances tend to become shorter because these destinations will be chosen rather than more distant ones. Moreover, as travel distances are shorter, individuals are assumed to be more likely to travel on foot or by bicycle (*e.g.* Handy, 1992; van Wee, 2002; Naess, 2006). This argumentation seems plausible and was evidenced by many studies (*e.g.* Newman and Kenworthy, 1989; Banister, 1997; Cervero and Kockelman, 1997; Kenworthy and Laube, 1999; Ewing and Cervero, 2001; Stead, 2001; Schwanen, *et al.*, 2004) which found correlations between urban form and travel distance. However, one should realise that this relationship is no more than a statistical association, as distances are not travel choices in itself, but the consequence of other decisions.

Consistent with the activity-based approach, we propose a causal model that does not relate urban form directly to daily travel distance, but indirectly through a series of decisions. Within this framework it is assumed that travel is the result of a complex decision-making process by which individuals and households try to meet their basic needs and personal preferences. Needs and preferences are systematically related to the characteristics of individuals and households. To achieve their goals, individuals engage in activities, such as personal care, household chores, work, shopping or sports. Travel is derived from these activities, since activities cannot all be conducted at the same location. Organising activities and travel involves a series of interrelated choices including the destination, the travel mode and the way activities are linked in chains of trips. These choices do not necessarily follow a fixed sequence, but rather a complex process may evolve in which the separate decisions are taken simultaneously (Arentze and Timmermans, 2004). As time is a scarce commodity, participation in activities and travel can be seen in terms of time allocation (Pas, 1998; Bhat and Koppelman, 1999). Individuals and households aim to achieve their goals by allocating and prioritising their activities within a particular time horizon, or in other words, they allocate activities while they simultaneously control their time budgets. This implies, for example, that the time spent travelling cuts into the time available for other activities, thereby limiting activity demand (Golob, 2000).

As far as the spatial context is concerned, the relative position of locations is thought to determine the spatial constraints. These constraints include the feasible distances which can be covered, the possibility of engaging in activities, the amount of congestion and the access to transport facilities, such as parking and public transport stops. Moreover, it can be hypothesised that not only the urban form of the environment around the dwelling (referred to as the residential environment) but also the destination location are involved in the decision process. Nevertheless, although urban form is increasingly included (*e.g.* Pas, 1984; Ma and Goulias, 1997; Golob, 2000; Snellen, 2002; Krizek, 2003; Buliung and Kanaroglou, 2006), the urban form of the destination seems so far somewhat neglected in activity research. Strikingly, however, this is also true for research related to travel and urban form (Badoe and Miller 2000). Among the studies that do include the urban form of the work location are Nishii *et al.* (1988), Krizek (2003) and De Abreu e Silva *et al.* (2006).

As the framework described includes complex relationships, disentangling requires an appropriate method of analysis. In this study, we used structural equation modelling (SEM), a technique which enables us to use a large number of endogenous and exogenous variables to identify and simultaneously estimate complex causal interrelationships. It is a particularly useful technique as it allows us to break down the causal effects into direct and indirect effects *i.e.* mediated by at least one other variable (Arbuckle and Wothke, 1999; Golob, 2003). SEM has been applied to studies relating activity demand and travel, interrelationships between choices, and relations with urban form, all conditional on personal and household characteristics. Golob and McNally (1997) modelled the interactions of household heads in activity and travel demand. Lu and Pas (1999) took into account the structure of interrelated decisions by developing a structural equation model incorporating categories of in-home and out-of-home activities, travel indicators and sociodemographics, examining the direct and indirect effects. They showed that travel behaviour could be better explained by including activity participation, and not by sociodemographics alone. A similar model was developed by Golob (1998), who also included car ownership endogenously. Assuming that time budgets limit activity and travel, Golob (2000) included timebudget effects in a model of work and non-work duration. He further incorporated the urban structure by using accessibility indices, which added significant explanatory power to time use and trip generation. For more studies, we refer to Golob (2003), who reviewed a large quantity of transportation studies.

Other SEM studies did not include activities, but elaborately focussed on the influence of land use on travel behaviour. Bagley and Mokhtarian (2002) estimated a model to test not only the influence of the residential and work location, but also attitudinal variables. Cao *et al.* (2007) employed a quasilongitudinal design, using a SEM including residential preferences and travel attitudes, to identify the impact of residential self-selection. Simma and Axhausen (2003) demonstrated relationships between male and female household partners with regard to travel demand. De Abreu e Silva *et al.* (2006) modelled land use characteristics for the work and residential location to predict commuting distance and other travel variables. He found that both location types have a strong influence on car ownership and mode choice. In a model using Belgian travel data, van Acker *et al.* (2007) found only limited effects of land use on trip frequency, distance and time. In this paper we elaborate on the work of Golob (1998; 2000) and Lu and Pas (1999). The aim is to test whether the urban form of the residential and work location affects personal activity and travel decisions, and how these in turn affect the daily travel time and in the end the daily travel distance. In addition to previous studies, we include both the urban form of the residential and work environment as endogenous variables. We also analyse the indirect effects of participation in activities, travel decisions, travel time and distance.

As the model has been developed for a non-US situation – specifically the Randstad in the Netherlands – it relates to a different setting with regard to the urban environment and the spatial concepts behind. In general, European inner cities are much more compact and less well designed for cars than American cities; residential neighbourhoods are denser, have less parking space and are more suitable for walking and cycling. Moreover, while the European spatial concepts focus mainly on the scale of the urban region, the new urban designs which are gaining ground in the USA are based on the neighbourhood level (see also Maat *et al.*, 2005).

The remainder of this paper is organised as follows. The next section presents the conceptual background, which is also the basis for the initial model. This is followed by an overview of the research methodology and the data. Then the adjusted model, which fits with the data, is described and the difference with the hypothesised model is discussed. Finally, conclusions are drawn and discussed.

3.2 Hypotheses and the conceptual model

We assume that individual and household characteristics have their influence on residential and work location choice and on activity and travel decisions, while simultaneously controlling total travel time. Daily travel distance is just an outcome of the decision-making process, as individuals do not plan their activities and travel within a certain number of kilometres. The structure of the conceptual model, which is the basis of the initial model specification in SEM, is shown in Figure 3.1; the premises that underpin the causal relationships are explained below in numerical order.

We first assume that the differences in the characteristics of individuals and households are reflected in their tastes and needs and subsequently determine their behaviour. Besides gender, these characteristics reveal for the greater part long-term decisions, such as marital status, having children, dual-earnership, income and car ownership. Explicitly included in this model, is the long-term choice for a residential and work environment with certain characteristics. For example, we assume that higher income households and couples with children are more likely to choose a home in a low-density suburb and consequently resign themselves to living farther from urban amenities.

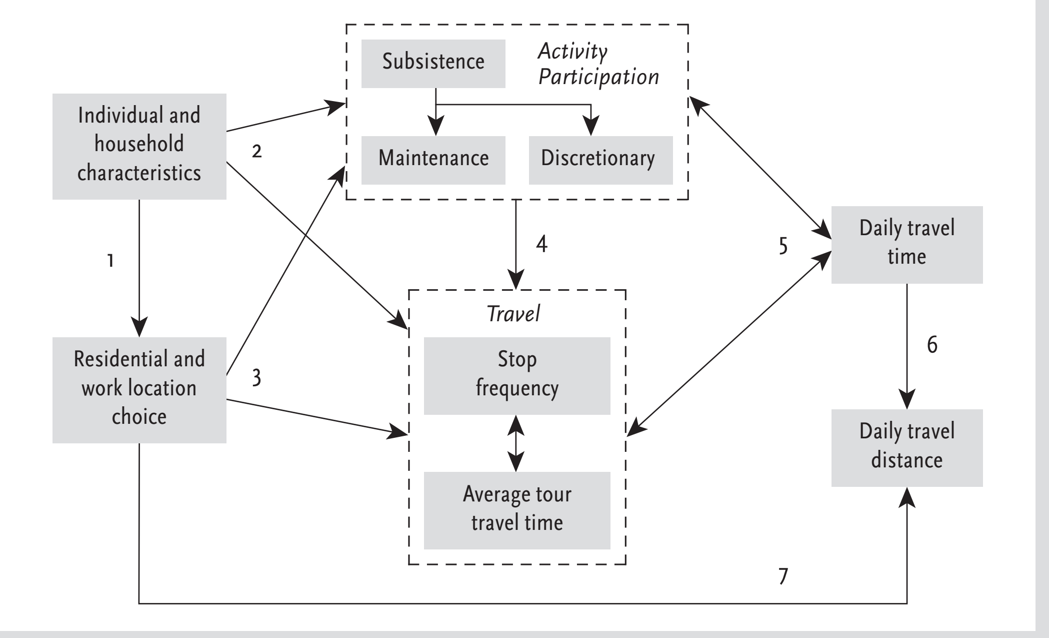
In the short run, individual and household characteristics determine both activity and travel decisions. For example, men are assumed to spend more time than women on subsistence activities, and will consequently spend less time on other activities. Likewise, extra travel time needs to be generated in young families because of the need to bring and get children to and from school and sport clubs which, in turn, leaves less time for other activities. Women may be more inclined to link more activities in a chain of trips (referred to as a tour), and thus have a higher stop frequency and consequently a higher tour time. The presence of a car directly influences the amount of time it takes to reach a destination.

The urban form of the residential and work location determines the ease of reaching destinations. The more compact and mixed the location, the more amenities are available and the easier it becomes to use them.

Direct influences of urban form on travel decisions are expected as well. The more compact the built environment, the shorter the distances and the greater the savings in distance and travel time. Moreover, there is a greater chance that several destinations can be combined in a single trip chain, which also significantly cuts distance and travel time.

One crucially important relationship in this model is that travel stems from the wish to engage in activities. First, it is assumed here that activity

Figure 3.1 Conceptual model of the relationship between individual characteristics, urban form, activity/ travel decisions, the daily time and distance traveled



participation is determined principally by the duration and frequency of subsistence activities. The amount of time spent on maintenance and discretionary activities depends on the time that is left. Second, while the number of activities equals the number of stops, individuals may combine stops in a chain of activities, and thus reduce the tour frequency, but as a consequence, the tour time may be longer. Third, the tour time can be seen as a proxy for destination choice, *i.e.* the farther the destination, the longer the tour times.

Activities and travel together determine the daily travel time. This relationship is complex because individuals are, while allocating their activities and travel, simultaneously controlling their total travel time budget. On top of that, time-budget relationships can be inferred: saved travel time frees up more time for other activities which, in turn, may lead to new trips. Alternatively, the saved travel time can be used for more favoured destinations, possibly with a greater value. Both forms are referred to by the term 'latent travel demand'.

Daily travel time is assumed to determine daily travel distance.

Nevertheless, it is assumed that there is still an influence of urban form: as an individual's behaviour is driven by time rather than distance, distance will also vary with speed. Mode choice (not included here) is one way to increase speed. Urban form affects the speed that can be reached, for example through congestion.

3.3 Data and method

Structural equation modelling (SEM)

SEM makes it possible to simultaneously estimate a series of linked regression equations (Bollen, 1989; Byrne, 2001; Golob, 2003). Such a series is also known as a 'structural' or 'path' model in which a causal relationship between two variables is called a path. Variables that are assumed to be independent of any of the other variables in the model are called exogenous. As the regression equations are linked, a predictor variable in one equation can be a dependent variable in another. These are called endogenous variables. In addition to a structural model with only 'observed' variables, it is also possible to specify 'unobserved' or 'latent' variables; however, this is not used in the present study. A structural equation model with only observed variables has the form:

$$y = By + \Gamma x + \zeta \qquad (1)$$

where
- y is a $p \times 1$ vector of endogenous variables
- x is a $q \times 1$ vector of exogenous variables
- B is a $p \times p$ matrix of the coefficients relating the endogenous variables
- Γ is a $p \times q$ matrix of the coefficients relating exogenous and endogenous variables
- ζ is a vector of errors in the equations

Furthermore, covariance matrices of x, denoted as Φ, and for ζ, denoted as Ψ are specified. The population covariance matrix of the observed variables Σ will now be reproduced in terms of functions of the unknown model parameters, *i.e.* B, Γ, Φ and Ψ matrices. As it is not possible to find unique values for all the parameters, the model needs to be constrained, so that there is enough information to get a unique solution, that is, making the model identifiable. A specified model is usually estimated using maximum likelihood estimation. In the search for the best-fitting model, it is tested whether assumed paths are significant. To improve a model that does not fit the data, a strategy of model-building and model-trimming is adopted. Modification indices are estimated as a means of indicating to what extent the model fit can be improved when a path that was initially assumed to be zero is freed (*i.e.* a coefficient is estimated for that path). Eliminating non-significant and weak parameters helps to find a parsimonious model. In addition to the path coefficients, R^2 values indicate how much of the variance of each dependent variable is explained by the variables in the model.

The effects can be interpreted in the same way as regressing coefficients. Moreover, the model allows the causal effects to be broken down into direct and indirect effects. The *B* and *G* matrices represent the direct effects between the variables, *i.e.* the influence of one variable on another that is not mediated by any other variable. The indirect effects, *i.e.* the effect that is mediated by at least one other variable, are derived from the direct ones. The total effect is the sum of the direct and indirect effects.

SEM is a confirmatory rather than exploratory method (Golob, 2003). It is suited to test a theory, represented as a model, although the initial hypothesis often requires adjustment because the model does not fit the data. Theory and good sense must guide model specification.

Overall fit measures indicate how well the model as a whole fits the observed data. A model's overall 'goodness-of-fit' can be tested by comparing the sample variance – covariance matrix with the variance – covariance matrix reconstructed from the model. The null hypothesis that both matrices are equal is tested; hence, non-significant chi-square and p values indicate that there are no significant differences between the matrices and thus that the model has not been rejected by the data. In addition, because chi-square tests are sensitive to large samples and because the assumption of perfect fit has proved to be unrealistic, other measures have been developed to indicate the overall fit (Byrne, 2001). A widely accepted measure is the root mean square of approximation (RMSA) index, which basically takes into account the error of approximation and has recently been recognized as one of the most informative criteria. In addition, a closeness of fit (*p*-close) is provided (Byrne, 2001). One should realise that model improvement may lead to models that will not represent the theory, but just a certain dataset. The models in this study were estimated using Amos software (Arbuckle and Wothke, 1999).

Sample

The need for data about activities, travel, personal and household characteristics and characteristics of the residential and work location, makes the task of collecting data a very demanding one. Existing data sources, such as the Dutch Travel Behaviour Survey, neither provide activity data nor a more detailed identification of the residential location beyond the municipality. In order to obtain the required data, a new, comprehensive dataset was collected based on a recently developed activity diary (Arentze *et al.*, 2001). In addition, land use indicators were developed from a variety of spatial data sources.

This research project covered 57 neighbourhoods in a central and highly urbanised region of the Netherlands, which encompasses the cities of Amsterdam and Utrecht as well as a number of smaller towns, suburbs and villages. The Amsterdam region is more densely populated and employed than the Utrecht region. One city, Almere is a large polycentric 'new town', situated on an isle of reclaimed land, and consequently somewhat isolated (see the map of the case study area - Figure 1.1). The neighbourhoods were selected carefully to ensure the inclusion of a wide variety of urban forms. The survey was conducted in the spring and autumn of 2000. It was preceded by a random sample mailing of 50,000 questionnaires to selected households requesting participants. In total, 3,300 households were willing to participate in the study. To prevent over and under-representation, the proportion of respondents over the age of 50 was reduced, and the proportion of public transport users was increased. A total of 3,412 individual questionnaires and diaries, covering 1960 households, were returned. However, the actual sample used for analysis was further reduced because of missing values and the need for diary entries relating to two full weekdays (weekend days are not comparable with working days). In addition, the study population was limited to individuals over 18. Finally, only individuals from complete households were selected, in order to add some extra household characteristics (and to use the same data as in our household analyses; Maat and Timmermans, 2007). This resulted in a sample of 1,211 individuals. The main survey involved a questionnaire with a list of questions related to the household and residential context, a personal questionnaire focussing on demographic and socio-economic characteristics, and an activity travel diary. All the respondents were asked to record their activities and trips in the diary for two consecutive days, with the pairs of days staggered across the seven days of the week.

The spatial data were derived from a variety of sources and pre-processed with the aid of a geographical information system (GIS). Dwellings were obtained from the Dutch National Database of Real Estate (LBV), and the number of employed persons from the LISA Register of Businesses. The Basic Register of Points-of-Sale contains detailed information on shops, including the amount of floor space devoted to sales, broken down for daily shopping and non-daily shopping. The data were assigned to their locational position, using postal codes, yielding highly detailed spatial information. Distances and travel times between origins and destinations were measured across the road network, using the Dutch Base Network.

Variables

Table 3.1 provides some descriptive statistics. Personal and household characteristics were included as exogenous variables and corresponded with the ones used in similar studies, namely: gender, household composition, the presence of children in the household, personal income, dual-earnership and car availability. Household composition indicated whether the household consisted of a single person or couple living in the dwelling; income was measured on a nine-point scale; a dummy indicated the presence of children in the household under the age of six (usually dependent on their parents for travel); another dummy indicated dual-earnership; car ownership was measured by the number of cars, *i.e.* zero, one and two-or-more cars. All other variables were included as endogenous. To reflect land use characteristics, we worked with the assumptions of land use concepts that assign an important role to density and mixed use. Two composite density measures were developed. All measures used one figure for each cell to express the total density of housing, employment and shopping floor space. Since these categories were measured in non-comparable units, the variables were standardised using the national totals (Maat and Harts, 2001; Batty *et al.*, 2004). Then, each measure was aggregated by calculating the spatially moving average for each cell, *i.e.* the average value of the cell itself and the values of the adjoining cells, using a 2.5-kilometre radius. In a previous study, various radii were tested, ranging from 750 metres to 10 kilometres; the one we apply here, 2.5 kilometres, proved to have the strongest correlation with the choice variables (see Maat and Timmermans, 2006). To reflect the mix of uses on work areas, a ratio was used to measure the mix of employment and shopping within a 2.5-kilometre radius. To take the density of this indicator into account it was weighted by the combined density of employment and shopping/consumer services. The resulting measure increases from zero to one with the increase of the combined mix and density.

$$Z_i = \begin{cases} \dfrac{f_i}{e_i} & if\ f_i \geq e_i \\ \dfrac{e_i}{f_i} & otherwise \end{cases} \quad \text{and} \quad Z_i{*} = Z_i \times \frac{f_i + e_i}{2} \qquad (2)$$

where Z_i* is the combined density and mixture in cell *i*, *f* is the proportion of shopping floor space and *e* the proportion of employment in cell *i*.

All the behavioural variables were measured and applied for two days. Activity participation was expressed as activity frequency and duration. The activities were classified according to three out-of-home categories (Reichman, 1976): subsistence (work and education), maintenance (*e.g.* shopping, visits to services such as the family doctor, bank, post-office, library and get/bring activities) and discretionary (*e.g.* leisure, social visits, sport). Travel behaviour was split into four variables: average tour time, average stop frequency, daily travel time and daily travel distance. Travel distance was measured across the road network using a geographical information system. The average time taken for each category of activity and the averages of the travel variables are shown in Table 3.1.

3.4 Empirical results

Model fit

The hypothesis that the relationship between urban form and travel distance runs through choices, as represented in the conceptual model, has been specified in the initial model. We then tested whether the data fitted this model.

Table 3.1 Descriptive statistics of the variables

Exogenous variables			N
Personal and household			
Gender	Female		643
	Male		579
Car ownership	No car		327
	One car		772
	Two/more cars		123
Young children			582
Dual-earner			682
Household status	Single		254
	Couple		968
Income (nett, Dutch guilders)	No income		83
	less than < f 10,000		48
	f 10,000 - f 20,000		78
	f 20,000 - f 30,000		130
	f 30,000 - f 40,000		177
	f 40,000 - f 50,000		185
	f 50,000 - f 60,000		170
	f 60,000 - f 70,000		103
	f 70,000 or more		248
		Mean	Standard Deviation
Urban Form			
Residential density (0-1)		0.14	0.14
Workplace density and mixture (0-1)		0.19	0.13
		For cases > 0	
	Percent cases > 0	Mean	Standard Deviation
Subsistence duration (hour)	79%	12.4	5.7
Discretionary frequency	80%	3.4	2.7
Maintenance frequency	68%	2.3	1.9
Average stop frequency	100%	2.7	1.1
Average travel time per tour (hour)	100%	1.1	0.9
Daily travel time (hour)	100%	3.2	1.7
Daily travel distance (km)	100%	110	93
N = 1222			

The chi-square value was 201.198 with 29 degrees of freedom, resulting in a p value of 0.000. Hence, the initial model did not describe the data well and requires adjustment to fit the data. As it was not our aim to obtain the best fitting model, but to identify whether it was possible to find a model that approximates our initial hypothesis, we carefully revised the model as follows.

Table 3.2 Proportion explained variance of the endogenous variables

Endogenous variable	R^2
Residential density	0.09
Work density	0.22
Subsistence duration	0.41
Discretionary frequency	0.07
Maintenance frequency	0.27
Average stop frequency	0.22
Average travel time per tour	0.49
Daily travel time	0.60
Daily travel distance	0.72

At first, some variables were changed: all activities were initially included as durations, but only the subsistence duration proved to be significant, while the maintenance and discretionary activities proved to be better represented as frequencies. In the next step, all non-significant paths and correlations were fixed at zero, *i.e.* removed from the model. The relations which were considered as essential elements of the theoretical structure could be maintained, with the exception of the feedback from travel time to activity participation, which proved to be non-significant. This means that the assumption that longer travel times cut into activity participation could not be maintained. Furthermore, paths and correlations that were not included in the model (*i.e.* were fixed to zero) were added insofar as the modification indices suggested that they would significantly improve the model and insofar as this was considered theoretically plausible. It is, for example, considered implausible in our conceptual model that an increase in discretionary activities would result in less subsistence; we assume that (for the greater part) people use the remaining time from the compulsory activities for discretionary activities.

The overall fit of the final model was good, producing a chi-square of 61.543 with 44 degrees of freedom, resulting in a p value of 0.041. Although the model could be rejected at the 5 per cent probability level yet, it was quite close. As other measures give a better indication, it was concluded that the model fits good with the data: RMSA = 0.018 (values of less than 0.05 indicate good fit), resulting in a p-close = 1.000; TLI = 0.994 and CFI = 0.997 (values > 0.90 is acceptable, but the closer to one, the better the fit).

The explained variances of the endogenous variables are listed in Table 3.2. The influence of personal and household characteristics on residential density appears to be small. It is remarkable, however, that the explanation of workplace density and mix is much better. Furthermore, the model seems to provide a reasonable explanation of the duration of subsistence, but maintenance and discretionary activities, however, are largely unexplained. The explanation of travel decision variables varies, with quite a good value for total daily travel time and a very good explanation for daily travel distance.

Model results

Describing the model results, the model was specified according to the conceptual model in Figure 3.1. The estimated direct (B and G), indirect and total effects are shown in Table 3.3. To show the parameters in such a way that we can compare the extent, they are displayed as standardised effects.

The choice for a residential or work location with certain characteristics is considered as a long-term decision that is part of the activity-travel decision-making process. It is assumed that households, when deciding where to live and work, choose for environments that fit with their desired mode of travel. For residential density a negative effect occurs with car ownership, indicating that the number of cars in a household is associated with residential density. Workplace density and mix seem more strongly related to household characteristics: couples are less inclined to use dense work locations, although the work locations of dual-earner households tend to be denser. Higher income is related with higher densities, probably because high income workers more often work in (on average intensively used) offices rather than (extensively used) industrial estates. As the car is more often used for suburban and low-density work locations, the effect on car ownership is negative.

Since needs and preferences vary with personal and household characteristics, these variables affect activity participation. Men, dual-earners and higher income groups show a clear positive direct effect on subsistence duration as well as workplace density. The higher the workplace density, the more time people spend there for work. However, it is also confirmed that the more time people spend on subsistence, the less time they have left for maintenance and discretionary activities. One effect which has both directly and indirectly the same sign is the decline in the number of maintenance activities with a rising income; here the indirect influence is exercised through the duration of subsistence. Interestingly however, certain outcomes can be caused by opposite effects: a direct effect shows that people working at dense and mixed locations exhibit more maintenance activities; however, an indirect effect appears that workers spend less time on maintenance, so the total effect of the workplace on maintenance is negative. The strongest household characteristic that encourages maintenance activities is the presence of young children, who clearly need to be brought to the kindergarten, school and sports, but also may increase the need for consumables.

Travel is derived from activity participation, so the more activities that take place at different locations the more stops are made. What is of interest, however, is how people organise their travel. It appears from the direct effects that the more maintenance and discretionary activities are performed, the higher the average stop frequency per tour, *i.e.* the more stops in a chain of trips. Strikingly, the total effect of work duration on trip chaining is limited. However, unravelling the direct and indirect effects, we can see that longer work duration has a direct effect on trip-chaining, indicating that people who spend a lot of time at work need to use their remaining time more efficiently, which could be done by creating travel chains. On the other hand, as working people have less maintenance and discretionary activities, their opportunities for chaining is limited, so an indirect effect is that work duration reduces the amount of chaining behaviour. Seeing that urban form characteristics run through activity generation, they hardly show direct effects on trip chaining. Income has a positive effect. The presence of children generates a small negative effect: although parents make more maintenance trips and thus increase their trip-chaining, having young children makes it also more difficult to complicate travel.

Another travel characteristic is the average time people spend on tours. This is partly a matter of destination choice, partly a matter of trip chaining. As expected, the higher the average number of stops, the longer the average tour durations are. Consequently, more maintenance activities increases stop frequencies and thus tour time; on the other hand, however, a direct effect from maintenance appears, showing shorter tour times as a result of the fact that shops and services are often closer by than work.

Decisions on activity participation and travel result in a daily travel time. The model displays in particular positive direct effects from tour time and activity participation. Stop frequency appears to reduce daily travel time insofar as it concerns a direct effect. However, since higher stop frequencies also lead to longer tours, the indirect positive effect of stop frequency on daily travel time is greater, which leads in the end to a total effect that encourages the total time travelled per day. Although it was assumed that urban form would have an effect, this appears fairly limited, neither direct nor indirect. Finally, it was hypothesised that people organise their travel within a certain time frame, and consequently take into account their daily total travel time. As a consequence, longer travel times would reduce activity participation, manifested by feedback loops. However, we could not prove this using the model.

The model shows a good explanation for daily travel distance. The best explaining variable is daily travel time, which shows a clear direct effect and indirectly passes on the effect of longer tour times. Stop frequency also explains daily travel distance, but to a lesser extent. Again, the urban form indicators do not have so much influence on the daily distance travelled; nevertheless, residential density is the only indicator with a reducing effect on travel distance. Workplace density and mix, however, show a small positive effect, which can be attributed to the fact that workers in higher densities make more extra trips.

In addition, since it is in particular car travel which causes undesired side effects, a model has been estimated for travel distance by car. As the model is equivalent to the previous one, except for the replacement of the total daily travel distance by the daily travel distance by car, Table 3.4 shows only the parameters for this variable. The model fit is comparable with the total model, though the explained variance of the daily distance by car is with 46 per cent lower than the previous model. The coefficients do not differ so much from the total distance model, except for the fact that the effect of residential density is almost twice as great, while also for work density and mixture, a direct effect is significant. This indicates that urban form affects in particular the distance travelled by car, not only in residential areas but also on work locations.

Table 3.3 Estimated direct, indirect and total effects

	Exogenous variables					
Endogenous variables	**Gender**	**Car ownership**	**Young children**	**Dual-earnership**	**Couple**	**Income**
Standardized Direct Effects						
Residential density		−0.226			−0.098	0.096
Work density	0.069	−0.054	0.126	0.384	−0.261	0.246
Subsistence duration	0.123			0.214	−0.113	0.273
Discretionary frequency			−0.058		−0.101	
Maintenance frequency	−0.072		0.218			−0.136
Average stop frequency			−0.092			0.151
Average travel time per tour					0.048	0.089
Daily travel time						0.088
Daily travel distance		0.068		−0.049	0.089	0.072
Standardized Indirect Effects						
Residential density						
Work density						
Subsistence duration	0.025	−0.005	0.046	0.140	−0.088	0.083
Discretionary frequency	−0.028	−0.022	−0.009	−0.067	0.029	−0.058
Maintenance frequency	−0.052	−0.018	−0.009	−0.109	0.052	−0.113
Average stop frequency	−0.011	−0.014	0.054	0.031	−0.057	−0.009
Average travel time per tour	0.034	−0.003	−0.095	0.056	−0.054	0.175
Daily travel time	0.001	−0.010	0.009	0.035	−0.009	0.125
Daily travel distance	0.021	0.007	−0.005	0.066	−0.021	0.214
Standardized Total Effects						
Residential density		−0.226			−0.098	0.096
Work density	0.069	−0.054	0.126	0.384	−0.261	0.246
Subsistence duration	0.148	−0.005	0.046	0.354	−0.202	0.357
Discretionary frequency	−0.028	−0.022	−0.067	−0.067	−0.073	−0.058
Maintenance frequency	−0.124	−0.018	0.210	−0.109	0.052	−0.249
Average stop frequency	−0.011	−0.014	−0.038	0.031	−0.057	0.142
Average travel time per tour	0.034	−0.003	−0.095	0.056	−0.006	0.264
Daily travel time	0.001	−0.010	0.009	0.035	−0.009	0.212
Daily travel distance	0.021	0.075	−0.005	0.017	0.068	0.286

All reported effects are significant at the $p = 0.05$ level

Endogenous variables							
Residential density	Work density	Subsistence duration	Discretionary frequency	Maintenance frequency	Average stop frequency	Average tour time	Daily travel time
−0.066	0.364						
0.100		−0.191					
0.071	0.071	−0.385					
		0.244	0.326	0.309			
				−0.335	0.646		
		0.154	0.209	0.416	−0.377	0.904	
−0.065		0.088		−0.043		0.074	0.746
0.013	−0.070						
0.026	−0.140						
0.051	0.045	−0.181					
	0.052	0.170	0.211	0.200			
0.035	0.043	−0.070	0.068	−0.239	0.584		
0.016	0.071	0.092	0.222	0.122	0.202	0.675	
−0.066	0.364						
0.113	−0.070	−0.191					
0.097	−0.070	−0.385					
0.051	0.045	0.063	0.326	0.309			
	0.052	0.170	0.211	−0.135	0.646		
0.035	0.043	0.084	0.276	0.177	0.207	0.904	
−0.049	0.071	0.180	0.222	0.079	0.202	0.748	0.746

Table 3.4 Estimated direct, indirect and total effects; model equivalent to Table 3.3, except for the equation of car travel distance

	Exogenous variables					
Daily travel distance by car	Gender	Car ownership	Young children	Dual-earnership	Couple	Income
Standardized direct effects		0.170		−0.108	0.133	0.123
Standardized indirect effects	0.006	0.023	−0.006	0.020	0.004	0.127
Standardized total effects	0.006	0.193	−0.006	−0.088	0.137	0.250

3.5 Conclusions

In recent years many studies have addressed the relationship between land use and travel behaviour. At the same time, the notion that travel demand stems from activity demand has been explicitly incorporated into activity based models. The role of spatial context in the activity-based approach is also increasingly included, although this is mainly true for the residential environment. This paper tested the influence of urban form on daily travel distance. As distances are not travel choices in itself, but the consequence of other decisions, we tested, consistent with the activity-based approach, a causal model that does not relate urban form directly with daily travel distance, but indirectly through a series of decisions. For this purpose a structural equation model was developed to simultaneously estimate direct and indirect causal relationships. Urban form was included as a combined urban density for the residential environment and a measure for mix and density for the work environment. The model was based on two-day diary data that was collected in the Randstad in the Netherlands.

Although the initial model specification did not fit the data, the adjusted model did not differ that much from the initial one. The model fit was good, as was the explained variance of the activity and the travel variables. Relationships between personal variables, urban form, activity and travel could be estimated simultaneously. This means that we can confirm the hypotheses from activity-based theories that activities are derived from needs and preferences that are related to household and location choices; moreover, travel decisions are taken from activity participation; travel time and distance result for the greater part from these decisions. Nevertheless, there are some additional, although small, direct effects from household characteristic to daily travel distance, indicating some additional influence. This is also true for the direct effect from residential density, suggesting that people in a dense residential environment travel a little less, although this effect is partly cancelled out by extra activities. Workplace density and mix, however, show a small positive effect, which can be attributed to the fact that workers in higher densities make more extra trips. However, the effect on daily car distance is greater, and does not only include the urban form of the residential environment, but also of the work location, indicating that urban form affects in particular the distance travelled by car.

From a policy perspective, this effect of density on travel behaviour would mean that aiming at higher densities does slightly add to the aim of reducing

Endogenous variables							
Residential density	Work density	Subsistence duration	Discretionary frequency	Maintenance frequency	Average stop frequency	Average tour time	Daily travel time
−0.115	−0.084	0.087			0.119		0.520
0.018	0.059	0.051	0.182	0.129	0.108	0.470	
−0.097	−0.024	0.138	0.182	0.129	0.227	0.470	0.520

travel kilometres, although the effects are not substantial. In general, we can conclude that travel behaviour is rather complex. As has been demonstrated in this model, indirect effects can steer a total effect in another direction, indicating that the apparent effects of one variable on another can be the trade-off of opposite effects.

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4 Influence of land use on tour complexity

A Dutch case

Maat, K. and H. Timmermans (2006), Influence of Land Use on Tour-complexity, a Dutch case. *Transportation Research Record 1977*, pp. 234-241. Reprinted with permission by National Academy Press.

Abstract. It is assumed that in new urban designs and compact cities, average travel distances tend to be shorter and more activities are linked in chains. As there is relatively little empirical evidence about the relationship between chain behaviour and land use, especially from Europe, a study was done to obtain a better understanding of the influence of chains (referred to as tours) to test the hypothesis that compact urban forms reduce travel. The results indicate that higher densities lead not only to greater activity and greater tour demand but also to more complex tours. Although greater tour frequencies reduce mean tour distance, daily distance travelled increases. Moreover, complex tours have an encouraging effect on both tour distance and daily distance travelled. This confirms the hypothesis and previous evidence that more frequent tours and more stops per tour in high-density areas lead to more travel.

4.1 Introduction

Although there is a large body of literature that has examined the influence of land use characteristics on travel behaviour (Badoe, 2000; Ewing and Cervero, 2001; Crane, 1996; Van Wee and Maat, 2003), few studies have investigated the impact of land use on the extent to which trips are linked in chains (Ewing and Cervero, 2001; Bath and Zhao, 2002). Concepts of new urban designs in the United States and compact cities in Europe aim at reducing travel by situating residential, employment, and service locations closer to one another to reduce the distances that need to be covered. It is expected that shorter distances between locations not only will reduce trip length but also will increase the likelihood of linking more destinations in a chain of trips, which also may reduce daily travel distances (Banister, 1997). Hence, there is a clear need for further investigation of this issue.

Investigations in the relationship between chains of travel and land use bring to light some important considerations in this context. Most empirical studies in the field of land use and travel behaviour presuppose trips as the basic unit, which is defined as the connection between two locations. By contrast, a tour is defined as a chain of trips, starting and ending at home. In real life, people often make chains of multiple destinations (or even zero destinations, as, for instance, when walking the dog). This study subscribes to the view that travel results from activities in which people wish to participate, and accordingly, a tour is defined as a chain of activities (Arentze and Timmermans, 2000; Bhat and Zhao, 2002).

Activities in which people participate are derived from basic needs and preferences and are closely related to individual and household characteristics. For example, parents of young children tend to engage in many activities, including extra shopping, taking children to school and sport clubs, and picking them up afterward. Likewise, these characteristics influence chain behaviour, since parents may be inclined to link such activities with work in a single tour. For example, Clarke *et al.* (1981) found empirical evidence indicating that households with preschool children had a higher proportion of simple trips, whereas households with school-age children experienced more complex chains (Harms, 2005). Another household feature is the availability of one or more automobiles, which facilitates and thus encourages chain behaviour, as shown by Ma and Goulias (1999) and Golob (2000), although Nishii and Kondo (1992) argue that transit users make more stops because of the opportunities of the railway station.

The influence of land use on chaining is not entirely clear, since some effects may be partly contradictory. It is likely that compact urban designs encourage both shorter trips and tour complexity and, consequently, may reduce daily travel distances. Clearly, shorter distances between home and activity locations, due to higher densities and mixed uses, may simplify the process of making complex tours. The empirical evidence is mixed, however. According to Strathman *et al.* (1994), suburban residents tend to allocate a significantly larger share of their non work trips to simple chains than do urban residents. This is consistent with Ewing (1995), who found that households with high accessibility to a mix of land uses efficiently linked single trips to tours. However, Kitamura *et al.* (2001) did not find effects of accessibility on the number of trip chains. By estimating time use in a joint model of activity participation, trip demand, and travel time demand, Golob (2000) found that households with higher levels of accessibility exhibited more complex trip chaining. Nevertheless, shorter trips and chain trips do save travel time, and this saved time can be used for lower priority activities that might otherwise be impossible (Golob, 2000). This is why Crane postulated a trade-off between shorter and more frequent tours in more accessible areas (Crane, 1996), which leads to more travel. This was confirmed by Krizek (2003), who found that households living in neighbourhoods with greater levels of accessibility tend to leave home more often but make fewer stops when they do. Thus, ceteris paribus, greater activity frequencies can be expected, resulting in more tours, more complex tours, and greater distances travelled. Finally, compact urban forms and short distances may encourage individuals to travel less efficiently, resulting in more frequent but less complex tours and, consequently, more kilometres travelled (Maat *et al.*, 2005).

By analyzing the influence of land use on activity demand, one fundamental question is how best to reflect land use. (In this study, the term ‘land use’ is used as an equivalent of urban form or built environment.) Most previous studies on chaining behaviour used accessibility measures (Bhat and Zhao, 2002; Golob, 2000; Krizek, 2003), whereas previous research on the interaction of land use and travel assigns an important role to densities and mixed uses. Since the land use concept places a high value on the latter, this study does as well. In addition, various accessibility measures were tested that define the ease of reaching various activities, which connects land use and travel behaviour conceptually.

Another spatial dimension that needs to be included is the spatial scale. The assumptions about the effects of land use characteristics involve different scales, ranging from the regional to the local and neighbourhood levels. Krizek's study is one of the few studies that included spatial levels by differentiating between neighbourhood and regional accessibility. This study tested various spatial scales to examine the hypothesis that some activities are oriented more toward a lower spatial level, whereas others are oriented more toward higher levels.

To explain the role of land use, most studies analyzed the residential environment but neglected the destinations. This study, however, assumes that working people use the work location as another base that plays a role in their daily activity and travel patterns. An early study by Hanson showed that a large proportion of household travel is undertaken in conjunction with the journey to work (Hanson, 1980). Nishii *et al.* (1988) found that the propensity to link non work travel to the commute is positively related to the commuting distance and the density of non work opportunities.

As there is relatively little empirical evidence about the relationship between chain behaviour and land use, specially from Europe, this study focuses on the effect of activity demand on the number and complexity of tours. The study also analyzed whether tour behaviour affects the daily kilometres travelled. In doing this, land use characteristics of the residential and work areas, measured on different spatial scales, were considered.

The next section provides an overview of the research methodology and the travel and land use data. The data were analyzed by using various types of regression models. Poisson and negative binomial regressions were used to analyze the data, activity, and tour frequencies, taking into account the possible occurrence of zeros by using zero-inflated models. Continuous data, such as travel times, were analyzed with ordinary-least-squares (OLS) regressions.

4.2 Research design and data

Sample

As this paper is part of a range of studies, the need for data about activities, travel, socio demographics, and the characteristics of the spatial context makes the task of collecting data demanding. Existing data sources, such as the Dutch travel behaviour survey, provide neither activity data nor a more detailed identification of the residential location beyond the municipality. To obtain the required data, a new, comprehensive data set was collected on the basis of a recently developed activity diary (Arentze *et al.*, 2001). In addition, a range of land use and accessibility indicators was developed from a variety of spatial data sources.

This research project covered 57 neighbourhoods in a central and highly urbanized region of the Netherlands, which encompasses the cities of Amsterdam and Utrecht as well as a number of smaller towns, suburbs, and villages. The Amsterdam region is more densely populated and has higher employment than the Utrecht region. One city, Almere, is a large polycentric 'new town', situated on an isle of reclaimed land, and consequently it is somewhat isolated. The neighbourhoods were selected carefully to ensure the inclusion of a wide variety of urban forms. The survey was conducted in the spring and autumn of 2000. It was preceded by a random sample mailing of 50,000 questionnaires to select households requesting participants. In total, 3,300 households were willing to participate in the study. To prevent over- and under representation, the proportion of respondents over the age of 50 was reduced, and the proportion of public transport users was increased. A total of 3,412 individual questionnaires and diaries, covering 1,960 households, were returned. However, the actual sample used for analysis was further reduced because of missing values and the need for diary entries relating to two full weekdays (weekend days are not comparable with working days). In addition, the study population was limited to individuals over age 18. Finally, only individuals from complete households were selected, to add some extra household characteristics (and to use the same data as in a household analyses not reported here). This resulted in a sample of 1,211 individuals. The main survey involved a questionnaire with a list of questions related to the household and residential context, a personal questionnaire focusing on demographic and socioeconomic characteristics, and an activity travel diary. All respondents were asked to record their activities and trips in the diary for two consecutive days, with the pairs of days staggered across the 7 days of the week.

The spatial data were derived from a variety of sources and pre-processed with the aid of a geographic information system. Dwellings were obtained from the LBV national database of real estate and the number of employed persons from the LISA register of businesses. The basic register of points-of-sale contains detailed information on shops, including the amount of floor space devoted to sales, broken down for daily shopping and non-daily shopping. The data were assigned to their locational position, by using postal codes, yielding highly detailed spatial information. Distances and travel times between origins and destinations were calculated by using the Dutch base network.

Table 4.1 Descriptive statistics of activity participation and travel variables over two days

	All cases		Cases > 0		
	Mean	Standard deviation	Share	Mean	Standard deviation
No. of subsistence activities	1.95	1.66	79%	2.49	1.49
No. of maintenance activities	2.74	2.72	80%	3.42	2.72
No. of discretionary activities	1.58	1.96	68%	2.32	1.87
No. of tours	3.68	1.90	100%	3.69	1.95
Average no. of stops per tour	2.67	1.09	100%	2.67	1.07
No. of complex tours with work	0.52	0.72	39%	1.33	0.48
No. of complex tours without work	0.30	0.57	25%	1.21	0.45
Average tour distance (km)	38	57	100%	38	4.4
Daily travel distance (km)	110	105	100%	110	93

N = 1211

Data

All the behavioural variables were measured and applied for 2 days. The activities were classified into three categories: subsistence (work, education), maintenance (*e.g.* shopping, get and bring activities, visits to businesses and to services, such as the doctor, bank, post office, library), and discretionary (*e.g.* leisure, social visits, sports). This typology has been used many times in activity research (Golob, 2000; Reichman, 1976). As mentioned, travel was analyzed on the basis of complete tours, starting and ending at home. Of particular interest was the occurrence of complex tours, that is, tours connecting more than one activity. Moreover, differences were expected between complex tours including a subsistence activity and other complex tours (Arentze and Timmermans, 2000). Another indicator used was the chain length (the number of stops per tour). It is the purpose of this paper to determine whether the effect of land use on trip chaining results in less travel, so average travel times and distances per tour and total travel time and distance are analyzed. Travel times were measured across the road network, by using a geographical information system. Table 4.1 presents some descriptive statistics.

The socio demographic variables correspond to those used in similar studies. Obviously, age, gender, and household size were among the variables. Personal income was measured on a nine-point scale. Three dummies indicate the presence of children in the household, specifically children under the age of 6, those ages 6 to 12, and those 13 to 18. Individual access to a car was the measure used for car ownership. In the Netherlands, this is a better indicator of car use than actual car ownership or the possession of a driver's license. Finally, a dummy indicates whether the house is a single-family dwelling or a multi-story apartment.

To reflect land use characteristics, the assumptions of land use concepts that assign an important role to density and mixed use were used. As such measurements are sensitive to differences in shape and size, administrative and statistical divisions (*e.g.* neighbourhoods or postal code areas) proved inadequate. This problem was addressed by converting the data into grid cells, measuring 250 by 250 m. Three composite density measures were developed, at various spatial scales. All measures used one figure for each cell to express the total density of housing, employment, and shopping floor space. Since these categories were measured in non comparable units, the variables were standardized by using the national totals (Maat and Harts, 2001). Then, each measure was aggregated by calculating the spatially moving average for each cell, that is, the average value of the cell itself and the values of the adjoining cells, using various radiuses: 750 m, 2.5 km, and 10 km. To reflect the mix of uses on work areas, a ratio was used to measure the mix of employment and shopping within a 2.5-kilometre radius. To take into account the density of this indicator, it was weighted by the combined density of employment and shopping. The resulting measure increases from 0 to 1 with the increase of the combined mix and density.

$$Z_i = \begin{cases} \frac{f_i}{e_i} & \text{if } f_i \geq e_i \\ \frac{e_i}{f_i} & \text{otherwise} \end{cases} \quad \text{and} \quad Z_i{*} = Z_i \times \frac{f_i + e_i}{2} \qquad (1)$$

where $Z_i{*}$ is the combined density and mixture in cell *i*, *f* is the proportion of shopping floorspace and *e* the proportion of employment in cell *i*.

Finally, accessibility measures were developed, measuring the potential for interaction. These potential measures estimate the accessibility of opportunities in zone i to all other zones in such a way that more distant opportunities have diminishing influences, by using the following form:

$$A_i = \sum_i D_i f(c_{ij}) \qquad (2)$$

Potential accessibility measures are strongly influenced by the choice of a travel cost decay function and its parameters. Here, a log-logistic decay function was used, which was found to have the best fit with Dutch travel data (Geurs and Ritsema van Eck, 2003).

$$f(c_{ij}) = [1 + exp(a + b * \ln t_{ij})]^{-1} \qquad (3)$$

where tij is travel time between i and j and a and b are parameters estimated. Four accessibility measures were generated employment, daily shopping, non-daily shopping, and services, respectively.

In addition, a spatial division on a macro scale was included, which refers to the level of urbanization, viz. core cities, suburbs, and less urbanized areas. Analysis of variance was performed to test whether densities varied over the urban levels. Significant F-values for both density-mixture and density were found, although a Bonferroni post hoc test indicated only significant differences in density-mixture between cores and suburbs and cores and less urbanized areas.

Methodology

The activity and tour models developed in this research project used both the Poisson and the negative binomial model and explored the use of zero-inflated models. Poisson regression models represent the relationship between the observed count data that follow a Poisson distribution and a set of explanatory variables. Suppose a sample of n observations $y_1, y_2, \ldots, y_n$, which can be treated as realizations of independent Poisson random variables, with $Yi \sim P(\mu_i)$, and suppose one wants to let the mean μ_i depend on a vector of explanatory variables x_i. One could entertain a simple linear model of the form

$$\mu_i = x_i\beta \qquad (4)$$

However, this model poses a disadvantage: the linear predictor on the right side can assume any real value, whereas the Poisson mean on the left side, which represents an expected count, must be nonnegative. A straightforward solution to this problem is to model instead the logarithm of the mean by using a linear model, formulating a log-linear model as

$$log(\mu_i) = x_i\beta \qquad (5)$$

In this model, the regression coefficient β_j represents the expected change in the log of the mean per unit change in the predictor x_j. In other words, increasing x_j by one unit is associated with an increase of β_j in the log of the mean. Exponentiating the equation, one obtains a multiplicative model for the mean itself:

$$\mu_i = exp(x_i\beta) \qquad (6)$$

In this model, an exponentiated regression coefficient $\exp(\beta_j)$ represents a multiplicative effect of the *j*th predictor on the mean. Increasing x_j by one unit multiplies the mean by a factor $\exp(\beta_j)$. The use of this coefficient is derived from empirical observations that with count data the effects are often multiplicative rather than additive, because one typically observes small effects for small counts and large effects for large counts (Rodriguez, 2004). The model parameters are estimated by maximizing the log-likelihood function.

One limitation to the Poisson regression model is that the variance must equal the mean. If this condition is not met, the data is over dispersed and the Poisson model is not appropriate. In that case, the negative binomial model may offer a better modelling approach. Over dispersion is shown by the so-called α parameter. As alpha goes to zero, the negative binomial regression yields the Poisson regression.

In taking account of the possibility that the Poisson model may not accurately assign the probability that Y = 0, the study also considered the zero-inflated Poisson (ZIP) and the zero-inflated negative binomial (ZINB) models. These models account for the presence of two regimes, where the outcome is always zero in one regime and the Poisson or negative binomial process is at work in the other regime (Greene, 1994). The Vuong statistic (Vuong, 1989) was used to first test whether two regimes were at work and whether a ZIP or a ZINB model was appropriate. Large values favour a ZIP model, and values less than -1.96 reject the ZIP model.

The overall model fit can be assessed by various goodness-of-fit statistics. It is not possible to calculate the percentage of explained variance like the R^2 in linear regression. An acceptable approach is Cragg and Uhler's maximum likelihood R^2, which is referred to as R^2_{ML}. This measure compares a model with just the intercept to a full model with all parameters (Rodriguez, 2006).

4.3 Results

Activities

Models of activity frequencies were estimated for subsistence, maintenance, and discretionary activities. The mean and variance of the number of subsistence activities were fairly close, which suggests the adequacy of the Poisson model. A ZIP model was applied, because 25 per cent of the dependent consisted of zeros, mainly from individuals who could not engage in subsistence activities because they were neither employed nor studying. The appropriateness of the ZIP regression was confirmed by a significant Vuong value. The model fit was good with an R^2_{ML} = .44. As expected, subsistence frequencies were significantly influenced by personal and household characteristics. Negative effects were found for women, older people, and households with children younger than 6. An obvious positive effect was observed for income. In line with expectations, the density-mixture on work locations shows a clear positive sign, indicating that people with frequent subsistence trips choose denser work locations.

Overdispersion tests produced significant alphas for maintenance and discretionary activities. This indicates that negative binomial models are most appropriate, producing model fits of R^2_{ML} = .27 and .07, respectively. Coefficients indicate that men and individuals without subsistence activities are less likely to engage in non-subsistence types of activity. Living in a single household or having children below the age of 6 decreases the number of discretionary activities; however, having children increases the number of maintenance activities. Older people have more maintenance activities but fewer

Table 4.2 Regression results for subsistence, maintenance and discretionary activity frequencies

	Subsistence		Maintenance		Discretionary	
	Exp(β)	p-value	Exp(β)	p-value	Exp(β)	p-value
Gender (male)	1.26	0.00	0.81	0.00		
Age < 24 years	1.02	0.91			1.64	0.03
Age > 60 years	0.63	0.00	1.16	0.09	0.79	0.03
Couple	0.96	0.65	0.69	0.00	0.72	0.00
Children < 6 years	0.82	0.00	1.87	0.00	0.85	0.05
Children 6-12 years	1.02	0.74	1.68	0.00		
Children 12-18 years	0.94	0.37				
Double income family	1.05	0.46	1.18	0.01		
Income	1.06	0.00	0.93	0.00		
Share of subsistence days			0.72	0.00	0.77	0.00
Car availability	1.07	0.26	1.24	0.00	1.28	0.00
Single-family dwelling	1.04	0.46	1.22	0.00		
Residential density (2.5 km)	1.23	0.38	2.67	0.00	3.85	0.00
Work density/mix (2.5 km)	1.51	0.04				
Urbanisation level: core city	0.96	0.51			0.83	0.05
Urbanisation level: low urbanized	1.15	0.08				
	Vuong = 6.97: $p = 0.000$ $R^2_{ML} = 0.44$ N = 1211		Dispersion (α): $p = 0.000$ $R^2_{ML} = 0.43$ N = 1211		Dispersion (α): $p = 0.000$ $R^2_{ML} = 0.07$ N = 1211	

discretionary activities. As expected, the car brings more activities within reach. Density of the residential area was found to be an important determinant of maintenance and discretionary demand; this suggests that people make use of the greater activity supply in high-density areas (see Table 4.2).

Three sets of densities and density-mixture were tested. Models that included all these spatial indicators produced unexpected signs of some of the estimated parameters, caused by strong correlations between these variables. Consequently, various model specifications were compared, and the model that produced interpretable and consistent results is reported here. For both maintenance and discretionary activities, it was found that the low-level indicators (measured within a 400-m radius) did not perform well. For both residential and work location, the indicators with the highest positive coefficients were measured within a 2.5-kilometre radius. Although it was expected that accessibility measures would significantly influence activity demand, such results could not be identified. Clearly, density plays such a significant role because it works as a proxy for much more spatial characteristics that influence activity demand.

Since tours are derived from activity demand, tour frequency is assumed to be connected with the number of activities on the one hand and the way

Table 4.3 Regression results for number of tours (with and without activity demand)

	Tour frequency		Tour frequency (without activity demand)	
	Exp(β)	p-value	Exp(β)	p-value
Couple	0.89	0.01		
Children < 6 years	1.24	0.00		
Children 6-12 years	1.30	0.00	1.07	0.09
Income	0.94	0.00		
Car availability	1.11	0.01		
Single-family dwelling	1.17	0.00	1.07	0.08
Residential density (2.5 km)	1.59	0.00		
Mean stop frequency	0.86	0.00	0.69	0.00
Subsistence frequency			1.10	0.00
Maintenance frequency			1.12	0.00
Discretionary frequency			1.06	0.00
	$R^2_{ML} = 0.20$		$R^2_{ML} = 0.48$	
	N = 1211		N = 1211	

they are chained on the other. To identify relationships between tour frequency and land use, models were estimated excluding and including activities (Table 4.3). With a mean that equals the variance and insignificant alphas, Poisson models appeared to be appropriate with R^2_{ML} of .20 and .48, respectively. The model without activities shows effects that are clearly in line with the activity models, including a density effect. Although the positive sign for the car is related to the ease of traveling, one would also expect that the ease of trip chaining would have reduced the number of tours. The next model shows the derived nature of travel: by including activities in the model, it appeared that almost all other variables remain insignificant. It is obvious that the average number of stops in a chain reduces the number of tours.

To estimate the land use effects on the stop frequency, the mean chain length was modelled, which is the ratio of trip to tour frequencies. Given the continuous nature of the data, they were estimated by using OLS regression (Table 4.4). Unfortunately, with an adjusted R^2 of 0.06, the model is somewhat poor. Coefficients show that higher income workers and in particular car drivers are more inclined to make complex tours. In contrast to previous work, families with children were less inclined to make complex chains; although they participate in more activities, they may have less flexibility to chain them in complex tours. For land use, both higher residential densities and work area densities showed a small but significant positive sign, which is in line with the assumptions.

To add to these results, models were estimated for the share of complex tours, by using OLS regression (Table 4.4). Complex tours are defined as chains with at least two stops. The first model included a subsistence activity and at least one other activity, and the second model included at least two ac-

Table 4.4 Regression results for stop frequencies and the share of complex tours

	Stop frequency		Complex work tours		Complex non-work tours	
	β	p-value	β	p-value	β	p-value
Gender (male)					−0.09	0.01
Age < 24 years					0.10	0.00
Couple	−0.06	0.03	−0.06	0.03	−0.05	0.09
Children < 6 years					−0.07	0.02
Children 6-12 years					−0.07	0.02
Children 12-18 years	−0.11	0.00	−0.10	0.00	−0.06	0.04
Income	0.08	0.01	0.06	0.03	0.07	0.05
Share of subsistence days	0.06	0.07	0.37	0.00	−0.17	0.00
Car availability	0.11	0.00	0.07	0.01	0.07	0.02
Residential density (2.5 km)	0.06	0.04	0.05	0.04	0.10	0.02
Work density/mix (2.5 km)	0.06	0.10	0.05	0.08		
Urbanisation level: core city					−0.09	0.04
	adj. $R^2 = 0.06$		adj. $R^2 = 0.21$		adj. $R^2 = 0.06$	
	N = 1211		N = 1211		N = 1211	

tivities but no subsistence activity. Adjusted R^2 were .21 for the work model but with .06 weaker for the non work model. The results exhibit negative signs of couples, who may have less flexibility than singles. The observation that households with children have less-complex tours is confirmed in these models. In line with the previous model, car availability encourages chaining behaviour. Positive effects were observed for residential land use. Although it was expected that higher densities and mix of uses would also contribute to extra trips on the work location, the effect for work density was not significant. Remarkably, residents of the core cities were less inclined to make complex tours.

Finally, models were estimated in order to analyze the influence of tour frequency and complexity on average travel distances per tour and the total distance travelled (Table 4.5). Given the continuous nature of the data, travel distance was analyzed by using OLS regression. The models offered fairly good explanations, with an adjusted R^2 of .41 for mean tour distance and .22 for the daily distance travelled. It appeared that chain length has an increasing effect on both tour distance and daily distance. Although this is evident for the tour distance, it was expected that trip chaining would save the total distance travelled. Furthermore, it appeared that with higher tour frequencies, less distance was spent per tour. Conversely, total travel distance appeared to increase with higher frequencies. Regarding the question at the focus of this study, the residential density shows a weak negative effect on tour distance, whereas density-mixture on the work location show negative effects in both models: as density increases, both tour distance and daily travel distance decrease. Since policies primarily aim at reducing travel by car, daily car distance was modelled (insofar as a car was available). This model was more

Table 4.5 Regression results for travel distance

	Tour distance		Daily distance		Daily car distance	
	β	p-value	β	p-value	β	p-value
Gender (male)	0.06	0.02	0.06	0.06	0.07	0.09
Couple	0.09	0.00	0.07	0.01	0.20	0.00
Children < 6 years	−0.05	0.06			−0.06	0.06
Children 12-18 years	−0.04	0.06				
Double income family					−0.14	0.00
Income	0.13	0.00	0.19	0.00	0.16	0.00
Share of subsistence days	0.16	0.00	0.21	0.00	0.17	0.00
Car availability			0.07	0.01	n.a.	n.a.
Single-family dwelling	0.04	0.10				
Residential density (2.5 km)	−0.05	0.05				
Work density/mix (2.5 km)	−0.08	0.00	−0.07	0.02	−0.07	0.07
Urbanisation level: core city			−0.07	0.01		
Urbanisation level: low urbanized					0.06	0.09
Mean stop frequency	0.44	0.00	0.28	0.00	0.27	0.00
Tour frequency	−0.20	0.00	0.10	0.00		
	adj. $R^2 = 0.41$		adj. $R^2 = 0.23$		adj. $R^2 = 0.20$	
	N = 1211		N = 1211		N = 782	

or less similar to the previous one, except for a negative effect for families with young children.

Alternative models (not displayed here) with densities on different spatial levels and accessibilities were also tested, but the models with indicators measured with a radius of 2.5 km showed the best fit.

4.4 Conclusions

This study aimed at obtaining a better understanding of the relationship between tours (activity chains) and land use characteristics to test the hypotheses that compact urban forms reduce travel. A tour is defined as a chain of trips, starting and ending at home. Since land use is assumed to affect the complexity of chains, tours provide a better basis for analysis than single trips. To reflect the characteristics of urban form, this study adhered to the assumptions of land use concepts that assigned an important role to density and mixed use on several spatial levels. In addition, various accessibility measures were tested, and personal and household variables were controlled for. To this end, Poisson and negative binomial regression models were developed for count data, and OLS regressions were used for continuous data. The model was based on data from 2-day diaries, which were collected in the Amsterdam and Utrecht regions.

All activity and travel variables were significantly influenced by the personal and household variables and generally showed the expected signs. In particular, complex households (*i.e.* people with children, double-income families, or both) engaged in more activities, resulting in more tours. The same holds true for individuals with access to an automobile. Employment, on the other hand, reduced the number of activities in which people were involved. The model for subsistence frequency was not affected by residential density, but work density-mixture did affect it, suggesting that workers with a frequent travel pattern work in high-density areas. Maintenance and discretionary activities were significantly encouraged by residential densities. Since work and school are mandatory activities, the spatial environment can indeed be expected to have most influence on other activities. Being derived from activity demand, land use also influences tour frequency. This agrees with Handy's (Handy, 1993) and Krizek's (2003) observations that non work travel is influenced by land use.

Most relevant in the context of this paper are the assumed influences on the length of tours in terms of the number of stops. In contrast to previous work, families with children were less inclined to make complex chains; although they participate in more activities, they may have less flexibility to chain them in complex tours. Other household characteristics showed the expected signs. Chain length was influenced by residential density, which is in line with Golob's (2000) findings. Chain complexity was also tested by estimating the share of complex chains, including and excluding work activities. Residential density was shown to have an effect for both models. In line with previous studies, such as that of Nishii *et al.* (1988), work density also appeared to affect the complexity of trips.

Analyses of travel distance revealed that the more stops made in a chain and the more tours made in total, the greater the daily travel distance. Thus, indirectly higher densities encourage people to travel longer distances. Nevertheless, there are also significant negative effects on travel distance related to land use. As residential density increases, the average tour distance decreases. Although there are no significant effects of residential density, the daily distance travelled appeared to be lower in core cities than in suburbs. Remarkable is the effect of work density-mixture, which had a negative effect on both tour distance and daily travel distance. This suggests that land use has a stronger effect on the work environment than on the residential environment. Daily car distance was influenced by more or less the same variables.

Finally, comments are needed on the spatial variables and levels. Generally, densities that are measured on a scale with a radius of 2.5 km are more significant than either low-scale measures (radius of 750 m) or high-scale measures (radius of 10 km). This indicates that activity and travel behaviour in the Netherlands, at least for maintenance and discretionary activities, do not take place on a very low scale, as suggested by US urban designs. This is in line with Krizek (2003). Rather, the scale of these activities falls within a 15-minute bicycle ride or a car trip of several minutes.

What can be concluded about the role of land use and activity chains? In the concepts of new urban design, it is assumed that higher densities and land use mix will increase the likelihood of linking activities in chains, which also may reduce daily travel distances. This study has shown that higher densities result in greater activity and greater tour demand and also in more complex tours. Although greater tour frequencies reduce mean tour distance, daily distance travelled increases. Moreover, complex tours have an encouraging effect on both tour distance and daily distance travelled. This confirms the hypotheses and previous evidence that higher densities lead to more frequent tours and more stops per tour, and accordingly to more travel.

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5 Household car ownership in relation to residential and work locations

Maat, K., H. Timmermans and H. Priemus, Household car ownership in relation to residential and work locations. Submitted.

Abstract. This paper analyses the influence of the built environment – specifically the work environment – on car ownership, taking into account the work characteristics of both partners, if dual-earners are involved. Logit models were applied. The model results generally revealed plausible effects, consistent with the literature, with respect to socio-demographics and the residential environment. By addressing work indicators, it was also demonstrated that car ownership is inversely related to the compactness of the work environment. Other characteristics of the job also exert an influence, including the degree of work flexibility and, in particular, the company car. Additionally, it was shown that firms who provide company cars to their employees also tend to choose suburban locations. Finally, the paper also finds indications for within-household relationships. Dual earners tend to buy a second car if the female spouse has a long working week, suggesting that the first car is used by the male spouse. Furthermore, it is the male spouse that exercises the greatest influence on the likelihood of either zero or multiple cars with regard to the distance to the railway station. This is possibly because men tend to work further away, so they are more often dependent on the car or train, rather than the bicycle.

5.1 Introduction

The growth in car ownership and use is a source of concern for policy makers because it is associated with negative impacts on the environment, safety and traffic congestion. Nevertheless, widespread car ownership is an important driving force of social and economic life in modern societies. By using cars, households are able to access activities more easily, and accordingly, car owning households can make trips more frequently, have more flexible activity patterns in which they can chain activities more easily, visit locations further away and visit locations which are hard to reach by public transport (*e.g.* Salomon and Mokhtarian, 2001; Bhat and Pulugurta, 1998). Hence, car ownership has been recognised as a key determinant of the travel behaviour of households. Since cars are important for households, it is not surprising that the number of cars has been increasing tremendously in countries all over the world. This growth is partly attributable to more households buying a car and partly to the trend towards multiple cars per household. The purchase of a second car is a fundamental change for households because the car is no longer a household good, requiring agreements between household partners, but an individually available good, just like bicycles. This trend, which has been seen in the US for some considerable time and results in a high degree of car-dependency, is now increasingly being observed in Europe (Giuliano and Dargay, 2006). The role of the car in shaping travel behaviour is significant because households purchase their cars in order to be able to realise their desired activity patterns (apart from such aspects as status, privacy and pleasure that may be derived from car ownership; Salomon and Mokhtarian, 2001; Steg, 2005). They are constrained however, by long-term decisions (or circumstances), such as household composition, labour participation, residential and work locations. The more complex the household situation is, for example due to dual-earnership and long commute times, the more cars can help to cope with these constraints. Hence, in a hierarchy of choices, car ownership can be considered as a mediating link, between long-term constraints and daily activity and travel needs (Ben-Akiva and Atherton, 1977). Location decisions are assumed to be relevant because the characteristics of the built environment determine how accessible destinations are and the availability and attractiveness of alternative modes. Consequently, cars may make people less dependent on the constraints of the location in realising their activity patterns.

This paper contributes to the debate on the relationship between the built environment and travel by addressing the impact of the location on households' car ownership. The hypothesis that car ownership is inversely related to an urban living environment has been supported by many empirical studies (see Section 5.2). It is remarkable, however, that almost all attention has been devoted to the residential environment. Car ownership may not only be determined by decisions concerning the residential location, but also on the work location (*e.g.* Cervero, 2002). In this paper, therefore, the work location is specifically taken into account, including the distance between home and work, the built environment characteristics of the work location, and proximity to the nearest railway station. With work as a central aspect in this paper, other work-related issues are also included, including the number of working days, irregular working hours, working at home and the availability of a company car. Where dual-earner households are involved, the characteristics of both jobs and work locations are taken into account. This way, we investigate whether differences within households and interaction between the household heads play a role.

There are few European studies on the relationship between the built environment and car ownership (apart from Dargay's studies). It is an additional aim to establish whether the conclusions of North American studies can be transferred to the European situation. This paper examines this relationship from a Dutch perspective in that the analyses are based on activity diary data collected in the Amsterdam-Utrecht region in the Netherlands. To identify the impact of the discussed determinants, we assume that a car adds utility to a household, depending on income, children in the household, commuting distance, accessibility to work location, the number of workers in the household, the extent and flexibility of the jobs, and so on. Since most Dutch households own one car and generally regard it as a basic necessity, deviations from this pattern are particularly interesting: what factors are involved in not owning a car or in owning more than one car per household?

The paper is organised as follows. The following section begins with a theoretical exploration of the relationship between household car ownership and the built environment, underpinned with the recent literature. Differences in car ownership, travel and the built environment between the Netherlands and other countries, in particular North America, are assessed in order to frame this study within the international literature. The data and the methodology are then described. In the empirical section, a series of car ownership models is presented. It is demonstrated that attributes relating to the built environment of residential and work locations affect car ownership decisions, including interdependencies between the working partners in the household. Finally, conclusions are drawn and the results discussed.

5.2 Literature and hypotheses

The connection with the built environment

A handful of studies have now been published on the influence of the built environment on car ownership. Empirical evidence on this connection suggests that car ownership is inversely related to the extent of urbanisation and the proximity of transport facilities. In an overview of international cities, Kenworthy and Laube (1999) find that car ownership patterns are not strongly related with wealth but vary systematically according to land use patterns. Giuliano and Dargay (2006) compared the US and the UK and found that land use variables are important determinants of car ownership, although their effects are stronger in the US. Most of the literature has focused on smaller regions, but found comparable effects. Household income appeared to be a main determinant (Dargay, 2001, 2002; Meurs, 1993). Yet, in addition, research on the connection with the built environment has shown that car ownership is also positively associated with living in a single-family dwelling, neighbourhood density and mixed use, and the availability of public transport (for example, Schimek, 1996; Holtzclaw *et al.*, 2002; Bagley and Mokhtarian, 2002; Chu, 2002; Miller and Shalaby, 2003; Salon, 2009; Shay and Khattak, 2005; Cao *et al.*, 2007; Bhat and Guo, 2007; Van Acker and Witlox, 2008; Potoglou and Kanaroglou, 2008). The differences in household car ownership between residential neighbourhood types can be attributed to a number of reasons. In low-density and rural areas, distances from amenities are greater and there is less public transport, resulting in a greater need to have a car than in more urbanised areas. Moreover, car ownership is more difficult and more expensive in urban areas, due to limited parking space, more congestion, higher insurance premiums, and expensive parking (*e.g.* Giuliano and Dargay, 2006).

Like Boarnet and Crane (2001), some authors argue that the association observed between the built environment and car ownership may be the result of residential self-selection. According to this reasoning, the causal thread is not the influence of the built environment on car ownership, but the other way around, households choose a residential location which corresponds to their travel attitudes, including their attitudes towards car ownership. Households with a strong preference for cars – due to complex activity patterns involving children and dual-earnership for example, or simply because they enjoy car driving – and with sufficient purchasing power may be more inclined to purchase an extra car, and accordingly, they may choose for a car-friendly residential location. In other words, households choose neighbourhoods which not only correspond with their housing attitudes, but also with their attitudes towards car driving (Mokhtarian and Cao, 2008). Cao *et al.* (2007) tested a model based on cross-sectional data in which the influence of the built environment on car ownership vanished after the inclusion of preferences; and they tested a panel model in which residential self-selection did not account for all influences on car ownership; they concluded that land use policies will lead to a marginal reduction in car ownership. Bhat and Guo (2007) also tested the influence of residential self-selection (which they refer to as residential sorting), but found no effects.

The influence of work locations

Empirical research on the impact of the built environment has tended chiefly to examine the residential location. However, the clear relationship between car ownership and the choice of commuting mode suggests a link between work and car ownership decisions as well (Dargay, 2002). Several studies have found that the characteristics of the work location impact on commuting mode choice (Cervero, 2002; Frank and Pivo, 1994; Shiftan and Barlach, 2002; Chen *et al.*, 2008). It certainly seems plausible that how people commute is influenced by where they work, and likewise, it has also been suggested that car ownership is determined by the work location (*e.g.* Cervero, 2002; Bhat and Guo, 2007). So far, only Chen *et al.* (2008) have included the work location in a car ownership model, finding that car ownership decreases when the workplace is more accessible by public transport. In the present paper, we argue that households have a number of reasons to base decisions on car ownership on work-related factors.

First, households are assumed to be much more dependent on cars for commuting than for any other activity. This is because labour participation tends to structure individual and household activity patterns to a great extent. Work is a recurring activity, which consumes considerable time, and employees generally have no or limited flexibility in destination and working hours (Pas, 1996). It is therefore obvious that households choose their mode of transport more on the basis of commuting than for any other activity. It may be assumed that longer working days and less flexibility are factors that encourage car ownership. In addition, just as work location is an important reason to buy a first car, it is assumed that the propensity to buy a second car is also mainly related to whether the household has dual-earners who both need a car. The literature shows a positive relationship, controlled for income, between dual earnership and second car ownership (Bhat and Pulugurta, 1998; Claassen and Katteler, 1997; Ettema *et al.*, 2007). In the Netherlands, single earnership was long the norm, but for the past two decades, there has been significant growth in dual-earnership, with today more than three-quarters of the couples below the age of 65; still, in the majority of the dual-earner households, women have a part-time job (Statistics Netherlands, 2002). The growth in second car ownership seems to go hand in hand with the growth in dual-earnership.

Second, car ownership is not only determined by the commute in itself, but also by the way households have adjusted their residential and work locations in terms of travel distances or travel times between home and work. The longer the commute distance, the more attractive a faster mode of transport becomes, and this often means a car. Potoglou and Kanaroglou (2008) found support for the connection between car ownership and the number of household members who worked over six kilometres from their home.

A third aspect of the work location is its accessibility by car and alternative transport modes. If the work location is adequately accessible by public transport, it is less likely that a car will be used (Shiftan and Barlach, 2002; Chatman, 2003; Chen *et al.*, 2008). In the Netherlands in particular, the accessibility of the workplace by public transport is expected to have more impact than residential access, because a bicycle is usually available at the home allowing an easy connection to public transport, but hardly at the work end (Rietveld, 2000). Likewise, if the workplace is difficult to access by car because of traffic congestion, lack of parking space, and parking costs, as is often the case in high-density employment locations in city centres, this makes it less likely that the car will be used. Conversely, many offices and industrial estates are often situated in fairly isolated locations on the periphery of urban areas, which has precisely the opposite effect and encourages car use.

In a nutshell, it is assumed that household car ownership increases with the number of workers in the household, in particular with increasing commuting distances and restricted access to alternative modes at either the residential or the work location or both. To our knowledge, however, no car ownership study has yet investigated the role of both work locations within the household.

To avoid confusion, it should be mentioned here, that some studies (Bhat and Guo, 2007; Chu, 2002; Gao *et al.*, 2008) include the employment density of the residential area. Although easier access to jobs would increase the possibility of finding a job nearby the home, and accordingly, reduce commuting distance and therefore, possibly, the need for a car (see the discussion on the jobs-housing balance, *cf*. Cervero and Wu, 1997), this is not relevant to this paper as it does not test the influence of the actual work location of the household members.

Household interaction

Car ownership decisions are primarily taken at the household level and, consequently, almost all studies analyse car ownership at that level. For example, it has been shown that the higher the household income, the greater the probability that they can afford one or more cars. The absence of a car is found mainly in the lowest income groups, whereas more second cars tend to be found where household incomes are higher. The likelihood of one or more cars increases further when there are children and working partners in the household (Claassen and Katteler, 1997; Bhat and Pulugurta, 1998; Dargay, 2001; Giuliano and Dargay, 2006; Bhat and Guo, 2007).

In addition to characteristics at the household level, the individual characteristics of the household members are also assumed to influence car ownership decisions. Generally, these characteristics were aggregated. Bhat and Guo (2007), for example, included the number of employed persons and the aggregate commute time across all workers in the household; Potoglou and Kanaroglou (2008) counted the individuals with a commuting distance of over six kilometres. However, if we assume that there is mutual dependence between the characteristics of the partners (where a couple is involved), then the utility that is derived from a car may be assessed differently between the two partners. By including the characteristics of both partners, it is possible to identify whether work characteristics differ between the spouses in the household decisions on car ownership.

We are not aware of any studies on car ownership which take the characteristics of both partners into account, although in related fields many other studies have now been conducted involving relationships within households. In a study on task and time allocation, Ettema *et al*. (2007) included the characteristics of both partners in their models. In a study on job mobility among dual-earners, Van Ommeren *et al*. (2002) estimated an individual model, but as they were interested in dependency between the spouses, they included the commuting distances of both spouses as well as the ratio of both wages. Modelling commuting mode decisions, Badoe (2002) analysed the joint utility of both workers in a household.

Other work-related aspects

Some other work-related aspects are expected to influence car ownership, and should be taken into account. The company car is strongly related with employment and car ownership. These employer-provided passenger cars are primarily for the purpose of making business trips but can generally be used for private purposes, too. For many employees in Europe, the company car is the single most important benefit apart from their salary, and employers provide cars to their employees at a much lower price than they would pay in the car market (Van Ommeren *et al.*, 2006). For example, in the Netherlands, which takes an average position in Europe, about 9 per cent of the passenger cars are classified as company cars. The vast majority of such cars are provided to male employees. About 20 per cent of multiple-car households have at least one company car (KiM, 2007). The phenomenon of company cars may thus have a significant impact on car ownership (see also De Jong *et al.*, 2004). In this paper, we consider passenger company cars to be 'owned' by the household.

In the final assumption, we expect that the less freedom individuals have with respect to their work activities, the more dependent they will be on their car. Workers are considered to be less flexible when they work full-time rather than part-time; have irregular working hours, for example at weekends or at night; have fixed working hours – that is to say that they cannot decide themselves at what time they start and finish work; and do not have the opportunity to work one or more days a week at home.

5.3 The Netherlands in the international context

To frame this study within the predominantly American literature, and to prevent paralogising, it should be emphasised that major differences exist between Europe and North America in terms of both the urban and the transportation environment (TRB, 2001; Giuliano and Dargay, 2006; Van de Coevering and Schwanen, 2006). This section compares the Dutch context with other countries, in particular the US.

Car ownership

The ratio of cars per 1,000 inhabitants is relatively low in the Netherlands (427), compared to the US (766) and Canada (561), and even relative to the neighbouring countries of Belgium (464), Germany (546) and the UK (466) (UNECE, 2008; figures 2003). Although the Netherlands has the lowest car ownership ratio of the EU-15 countries, the number of cars has in fact grown rapidly from about 5 million in 1990 to 7.4 million in 2008 (Statistics Netherlands, 2008). Since the car is important for households, it is not surprising that in many countries the number of cars has increased over time. Trend data shows that between 1990 and 2003, car ownership increased in the Netherlands by 23 per cent, in Europe as a whole by 35 per cent and in the eastern part of Europe by 77 per cent, while in the US growth was limited to 5 per cent (UNECE, 2008). Using projections for 2015 concerning 26 countries, Dargay and Gately (1999) expect a substantial increase in most of Europe and rapid growth in countries with high income growth. In the US, however, the growth of car ownership is expected to slow down, as the saturation point is approached. In the Netherlands, the proportion of car-free households has gradually fallen to 21 per cent. At the same time, the number of households with one car has declined and the number with more than one car has risen: 22 per cent of households owned two cars, and 2.3 per cent had more than two (Statistics Netherlands, 2008).

Mode choice

The US do not only exceed Europe in car ownership, but to a much greater extent in car use. Kenworthy and Laube (1999) computed a ratio of 2.47 between large US and European cities. Conversely, with few exceptions, public transport has a more prominent role in Western Europe and Canada than in the United States. This is true not only in large cities, but also in many smaller communities and throughout entire metropolitan areas. Public transport is used for about 10 per cent of urban trips in Western Europe, compared with about 2 per cent in the United States (TRB, 2001). In the Netherlands, however, the prominent role of the bicycle means that transit use is relatively low at 5 per cent of the trips (Statistics Netherlands, 2008). About 80 per cent of the population has a bicycle, which is used for more than a quarter of trips on average (Statistics Netherlands, 2008). An interesting point in comparison with many other countries is that a large amount of bicycle use is utilitarian – for shopping trips, commuting and to connect up with public transport; particularly at the home end, the bicycle appears to play a large role as an access mode with a share of 35 per cent (Rietveld, 2000).

Built environment

Europe and North America differ significantly in their urban forms (*e.g.* Giuliano and Narayan, 2003). The great majority of the European cities have historic city centres with narrow streets and often little space for parking. Residential neighbourhoods are more compact, with the majority of dwellings in rows without garages. City centres, residential neighbourhoods and even the countryside are more suitable for walking and cycling: in particular in the Netherlands, there are many facilities for cyclists in city centres and at public services and public transport stops (Pucher and Buehler, 2008). Shopping centres are mixed within cities; in the Netherlands spatial retail policies discourage large-scale out-of-town shopping (Evers, 2002). American cities, by contrast, are characterised by grid-like street patterns, well-designed for cars and with much more parking space. Suburban neighbourhoods are extensive, and include mainly detached houses which include garages, with curvilinear and cul-de-sac street patterns that often lack sidewalks. Shopping facilities are more often concentrated in shopping malls on the outskirts of cities.

Land use policies

Literature concerning travel and the built environment often considers American and European spatial planning concepts as broadly similar, but in fact there are many differences between the concepts and the countries, despite some basic principles in common. First of all, the national governments of Western Europe have shown themselves willing to intervene in land use planning and regulation (TRB, 2001) to a greater extent than in the US. Against the background of urban sprawl, Dutch spatial policy has made a huge policy effort (*e.g.* Banister, 1994; Dieleman *et al.*, 1999) to retain cohesive urban areas and encourage modal shifts away from the car, a policy which was fine-tuned in the late 1980s with the introduction of compact urbanisation. The aim was to encourage people to live and work in largely mono-centric urban structures within the spatial scale of the urban region. Recently, national spatial policies have shifted towards urban networks with concentrated employment and housing developments near public transport and motorway nodes (Priemus, 2007).

In the US, the role of policy makers differs between states and cities, and is usually more limited than in Europe. Initiatives for land use concepts are generally supported by private movements, such as Smart Growth and New Urbanism, or architects. Moreover, these new urban designs are based on smaller spatial units, that is to say neighbourhood rather than regional level. These concepts encourage everyday facilities – such as housing, work, schools, shops and other amenities – to be located within walking distance of each other, in a pedestrian-friendly environment with alternatives to car use (Handy, 2005).

Other policies and regulations

The car remains less convenient and more costly to operate in Western Europe than in the US, especially in cities. Higher taxes on motor vehicles and fuel, several times higher than in the US, and high parking charges continue to make car ownership and use expensive. Many Western European cities have also taken direct steps to discourage driving, by reducing the number of parking spaces and restricting car use in city centres, for instance. Such policies are frequently part of an overall strategy to curb traffic congestion and preserve the traditional role of cities as economic, social, and cultural centres (TRB, 2001). Young people may begin driving at the age of 16 in the US, while this is 18 in most of Europe. In the Netherlands, a free annual public transport season ticket is given to students with the aim of discouraging them from driving cars.

5.4 Method and data

Model specification
To identify the influence of location choices on household car ownership levels, we developed a series of discrete choice models using Stata software. As Pulugarta and Bhat (1998) point out, both ordered-response models and unordered-response models can be applied. Both types have recently been used to estimate car ownership. Among the applicants of ordered-response models are Hess and Ong (2001), Giuliano and Dargay (2006), Bhat and Guo (2007) and Cao *et al*. (2007). These models represent car ownership as an ordinal variable. They are based on the hypothesis that the number of cars observed in the household is represented by a continuous variable, which reflects the latent car ownership propensity of a household. This propensity is a linear function of the explanatory variables – for example, the higher the income, the higher the propensity that an extra car is bought. Giuliano and Dargay (2006) consider cars owned as an ordered choice, since households generally increase or decrease cars one at a time, rather than choosing between a certain number of cars.

Unordered-response models have been applied by HCG (1989), Hensher (1992), Purvis (1994), Whelan (2007), HCG (2000, in: De Jong *et al*., 2004) and Potoglou and Kanaroglou (2008). In this model type, such as the multinomial logit (MNL) model, car ownership is represented as a nominal variable, which means that no ranking is assumed. An advantage of this approach is that coefficients are computed for each value of the independent variable – zero cars, one car and more than one car. Moreover, these models are framed in the solid theoretical and behavioural framework of random utility-maximisation (McFadden, 2001). The choice process can be viewed as a simultaneous choice between each alternative, with the choice determined by the alternative that offers the highest utility. Empirical comparison of car ownership models by Bhat and Pulugurta (1998) indicates that unordered models are a better representation of household car ownership than ordered models, which was recently confirmed by Potoglou and Susilo (2008).

For the purposes of this study, we chose the unordered-response model. We define k, the number of cars in a household, as a nominal variable of zero, one and more than one car. We test three situations in particular, in which none of the household partners, only one of them, or both of them, are employed. We assume that each choice – either zero, one or more than one cars – adds a certain utility, otherwise a household would not choose this option. The reason that we do not apply higher values than two is because we hypothesise that three or more cars do not play a role in reaching the work location. The random utility function for car ownership can be expressed as follows:

$$u_{nk} = \alpha_n x_n + \beta_n r_o + \gamma_n w_i + \delta_n y_{id} + \varepsilon_{nk} \qquad (1)$$

Specifically, u_{nk} is the utility of household n with k number of cars (k = 0, 1, 2+); x_n is a vector of household attributes, such as household income, household type, children in the household and the type of dwelling in which the household lives; this vector also includes the availability of a company car, since this variable is not available on the individual level; r_o is a vector of characteristics of the built environment of place of residence; w_i is a vector of the work characteristics of each working partner, with i as the number of working partners; y_{id} is a vector of the characteristics of the built environment of the work location of the working partners; if i = 2 in w and y, work characteristics for both the male and the female are included, with i = 1 for only one partner, and with i = 0, no work characteristics are included. The vectors of parameters α, β, γ and δ, to be estimated in the models capture the interest that a household attaches to the attributes and are the same for all households. Finally, ε reflects the random component that captures the unobserved utility and the uncertainty of the researcher.

We would prefer to model the three categories of car ownership (k) together in a multinomial logit model, however, we do not assume that the decision not to buy a car is influenced by the same factors as the decision to buy an extra car (a second or third car). Also, some variables are not available for households without a car (such as the availability of a company car). For these reasons, separate binary models were estimated for the situation of zero cars compared to one car, and more than one car compared to one car. For the probability P of no cars in the household, k = 1 denotes the occurrence of zero cars, while k = 0 denotes the occurrence of one car in the household. Likewise, for the probability P that there are at least two cars in the household, k = 1 denotes the presence of 2+ cars, while k = 0 denotes the occurrence of one car in the household. This is written as:

$$P_{nk} = 1/1 + e^{-z},\ where\ z = \alpha_n x_n + \beta_n r_o + \gamma_n w_i + \delta_n y_{id} + \varepsilon_{nk} \qquad (2)$$

Furthermore, the utility sets varied with the number of workers in the household. In the case of none of the partners working, i = 0, only the variables concerning the household level were included; in the case of a single-earner household, i = 1, only work variables for one individual are included; in the case of dual earners, i = 2, male and female work characteristics are included. As a consequence, separate models for non-working, single-income and dual-income households are estimated, each for zero-car and multiple-car households, compared to one-car households.

The unknown parameters are estimated by maximum likelihood with the likelihood ratio following a chi-square distribution. The likelihood ratio chi-square statistic indicates whether the log-likelihood differs from the null-model. Several measures of fit are available, of which the McKelvey-Zavoina pseudo R-square (ρ^2) is the best approach to the proportion variation explained (Scott Long and Freese, 2006).

As the logit is the link function of the binomial distribution, the coefficients estimated are in logit units and quite difficult to interpret. Let P the probability, then *P/1-P* is called the odds. In the zero car model, this is the probability that the household will own no cars rather than one car. Likewise, in the multiple-car model, this is the probability that the household will own two or more cars rather than one car. The natural log of the odds is called logit or log odds, which is rather difficult to interpret. However, by exponentiating the log odds, we obtain the odds ratio. This ratio of odds can be interpreted as the chance of $P = 1$ after a one-unit change in a predicting variable. Take for example the multiple-car model, with a variable indicating whether a household has children or not. An odds ratio of 1 implies that $P = 1$ is equally likely for households with or without children to own several cars rather than one, but an odds ratio greater than one, say 1.6, implies that it is 60 per cent more likely that a household with children will own more than one car. In the case of a continuous variable, each unit change of the variable is related to a unit change of the odds ratio.

Data sources

This paper is one in a series of studies requiring detailed travel data, geocoded at a low spatial level. The Dutch National Travel Survey does not provide sufficient detail, which meant that a specific survey had to be carried out. The dataset was named *Amadeus*. The sample was drawn in 2000, from the northern wing of the Randstad Holland. This region contains a wide variety of urban forms, including the cities of Amsterdam and Utrecht, their surrounding suburbs, a number of medium-sized and smaller towns, and a few villages in the rural areas. The Amsterdam region is more dense in terms of both population and employment than the Utrecht region. One city, Almere, is a large polycentric 'new town', situated on reclaimed land surrounded by a border lake, connected with the mainland by two bridges, but consequently somewhat isolated (see Figure 1.1).

The survey was conducted among households, of which the heads were asked to fill out the questionnaires. For the present study we selected complete households – that is to say, single-person households and households of couples in which both partners completed the questionnaire (we limited the analysis to man-women relationships), of which the work location was known. This resulted in 737 households, comprising 484 couples and 253 singles.

The spatial data were derived from a variety of sources and pre-processed with the aid of a GIS. Dwellings were obtained from the LBV National Database of Real Estate, and the number of employed persons from the LISA Register of Businesses. The Basic Register of Points-of-Sale contains detailed information on shops, including the amount of floor space. The data were assigned to their location using postal codes, yielding highly detailed spatial information. Distances and travel times between origins and destinations were calculated, using the Dutch Base Network.

Variable specification

A dummy indicated whether the respondent was single or part of a couple. Three dummies indicated the presence of children in the household, specifically under the age of 6, aged between 6 and 12, and aged between 13 and 18, broadly reflecting three stages of increasing independence, namely preschool, primary school and secondary school. Household income was broken down into lower, middle and higher-income groups. Work status refers to a non-working, single-income or dual-income household. Dwelling type indicates whether the house is a single-family dwelling or a multi-storey apartment. Car ownership was indicated as zero, one and more than one car. A dummy indicated whether one of the cars was a company car. For car owners, it was indicated whether cars were parked in a private garage, in the street or elsewhere.

For each working partner, the characteristics of the job are included: the number of working days, dummies on whether the job has irregular working hours, whether it is not allowed to vary working hours (thus to decide about the starting time), and whether teleworking or working at home are possible.

To reflect the built environment, we developed several indicators for both the residential location and the work locations of each working partner. The urban level indicates whether the home is in a core city, a suburb or a low urbanised area. The distance to the nearest railway station was examined and the commuting distance were examined as a continuous variables.

Three measures of urban density and mixture were developed. Since such measurements are sensitive to differences in shape and size, administrative and statistical divisions (*e.g.* neighbourhoods or postal code areas) proved inadequate. This problem was addressed by converting the data into grid cells measuring 250 by 250 metres. As there are inevitable discontinuities that take place from data that are originally represented by land parcels and fine postal codes, the moving average of the data was taken, which involves averaging the data in a window of cells defined around each cell. By varying the size of the window, the average is taken over various radiuses, reflecting different levels of spatial scale (Maat and Harts, 2001; Batty *et al.*, 2004).

The first measure, urban density index d, expresses the total density of housing, jobs and shopping floor space. The total amount of an activity k in cell i is defined as a_{ik}. In order to give all activities equal weight in the calculation of the index, the values were normalised as follows: $s_{ik} = a_{ik} / max_i\ (a_{ik})$, where s_{ik} denotes activity k in cell i as a proportion of the maximum cell value of k in the Netherlands. To arrive at the density value, the normalised values s_{ik} are summed and divided by the number of categories K that occur:

$$d_i = \frac{\sum_k s_{ik}}{K} \qquad (4)$$

The higher the value, the higher the composite density. The theoretical maximum is 1, if one cell has the highest number of dwellings, as well as jobs and shops. The second measure reflects the mix of uses on work locations. A ratio was used to measure the mix of employment and shopping, weighted by the combined density of employment and shopping. The resulting density/mixture index m_i increases from 0 to 1 with the increase in the combined mixture and density.

$$Z_i = \begin{cases} \dfrac{s_{i,shop}}{s_{i,empl}} & \textit{if } s_{i,empl} \geq s_{i,shop} \\ \dfrac{s_{i,empl}}{s_{i,shop}} & \textit{otherwise} \end{cases} \quad \text{and} \quad m_i = Z_i \times \frac{s_{i,empl} + s_{i,shop}}{2} \qquad (5)$$

The third measure, the entropy (Cervero and Kockelman, 1997) reflects the mixture of housing, jobs and shops. It is normalised relative to the natural log of the number of activities, and consequently varies between 0 (fully mixed) and 1 (fully specialised).

$$e_i = -\sum_k \frac{s_{ik} \times ln(s_{ik})}{ln(K)} \qquad (6)$$

Finally, in investigating the impact of the built environment, an additional issue must be taken into account, relating to the spatial scale of the aspects of the built environment. Most studies use available predefined spatial units, varying from census tracts and zip codes in the US (Boarnet and Crane, 2001), to municipalities (Schwanen, 2003) and postal codes (Snellen *et al.*, 2002) in the Netherlands. However, it is anything but clear at what spatial scale households are influenced by the built environment when making decisions (Krizek, 2003; Bhat and Guo, 2007). For that reason, the spatial indicators are tested on three levels of spatial scale, namely radiuses of 750 meters, 2.5 kilometres and 10 kilometres.

5.5 Results

The sample consists of 737 households, of which 179 do not own a car, 435 own one car and 123 own more than one car. These numbers reflect figures for the general population fairly closely (Statistics Netherlands, 2008), indicating a representative sample (Table 5.1). A first inspection of the data suggests that car ownership is positively related to the number of partners, the number of working partners and the household income class. Occupants of single-family dwellings have more cars than occupants of apartments. The average values of the residential environment indicators show the expected positive correlations with density and entropy, and negative with distance to the railway station. Job indicators suggest that households that are provided with a company car tend to have more than one car. Owning more than one car is also associated with jobs with fixed working hours, the possibility of working at home for at least one day a week and longer working weeks and work distances. With regard to the workplace, the data suggest that higher workplace densities and shorter distances between work and the nearest railway station go together with car ownership.

Binary logistic regression models were estimated for households with zero cars (compared to one car) for non-working, single-income and dual-income households; and for multiple cars (compared to one car), for single-income and dual-income households (Table 5.2). A multiple-car model for non-working households was omitted because there are only a few such cases in the sample. All models were significant at the .01 level according to the model chi-square statistic. The McKelvey and Zavoina ρ^2 proportions of explained variation were satisfying to good, varying between 29 and 43 per cent for the zero car models, and between 42 and 75 per cent for the multiple-car models.

Household income was the only variable to be significant in every model. This variable is important as it prevents or allows households to buy and maintain cars: not having cars is related to low incomes while having several cars is related to high incomes. Households with children were less likely to have no cars and more likely to have more than one car.

The residential environment plays a role in several effects. Spaciousness around the home encourages car ownership, as suggested by the negative effect of living in a single-family dwelling on zero car ownership for single earners, and the positive effects of having a single-family dwelling and a garage on owning more than one car for dual-earners. Likewise, higher residential densities increase the likelihood of having no car, in particular among non-working households and dual-earner households. The odds-ratio of 123 should be interpreted as follows: as density runs between the theoretical limits of 0 and 1, the likelihood of having no car to one car is 123 times higher if a full step from a density value 0 to value 1 is taken. For example, the average density gap between the suburban neighbourhoods in the Utrecht region (average density = 0.071) and those in the Almere region (average density = 0.091) produces a difference in the odds ratio of 0.02×123 = 2.46. Hence, this suggests that if the average density of the Utrecht suburbs were to increase to the average in Almere, the likelihood of owning zero cars rather than one

Table 5.1 Descriptive statistics

	Number of cars per household (incl. percentage)						
	No car		One car		Two/more cars		Total
Total							
Sample	179	(24%)	435	(59%)	123	(17%)	737
Population (Statline; 2000)		(25%)		(56%)		(19%)	
Sociodemographics							
Household type							
Single	117	(46%)	133	(53%)	3	(1%)	253
Couple	62	(13%)	302	(62%)	120	(25%)	484
Children							
Below 6	13	(10%)	85	(64%)	35	(26%)	133
6 to 12	16	(18%)	59	(66%)	15	(17%)	90
over 12	25	(27%)	45	(49%)	21	(23%)	91
None	125	(30%)	246	(58%)	52	(12%)	423
Work status							
No working partners	31	(35%)	51	(58%)	6	(7%)	88
Single earner	106	(34%)	162	(53%)	40	(13%)	308
Dual earner family	42	(12%)	222	(65%)	77	(23%)	341
Household income							
Low	81	(55%)	63	(43%)	4	(3%)	148
Medium	60	(20%)	212	(69%)	34	(11%)	306
High	38	(13%)	160	(57%)	85	(30%)	283
Dwelling							
Apartment	105	(44%)	125	(52%)	10	(4%)	240
Single-family dwelling	74	(15%)	310	(62%)	113	(23%)	497

would increase by 2.46 times. With regard to owning more than one car, higher densities reduce the likelihood that dual earners will have several cars. It also turned out that dual earners are more likely to buy a car as the distance to the nearest railway station increases. Together, dual-earners are more sensitive to residential densities than single earners.

There is clear sensitivity to the environment of the work location. Higher densities reduce the likelihood of both the first and the next car among single-earner households. Car ownership increased with the distance between the work location and the nearest railway station for both zero-car and multiple-car households. The odds ratios indicate that the likelihood of the household owning one or more than one car increases by about one third for every kilometre further away from the closest railway station. This effect concerns men rather than women, possibly because men tend to work further away, so they are more often dependent on the car or train. The more days per week worked

Table 5.1 continued

	Number of cars per household (incl. percentage)			
	No car	One car	Two/more cars	Total
Number and share of work characteristics				
Company car		46 (11%)	65 (56%)	
Irregular worker in household	44 (30%)	94 (24%)	34 (29%)	
Worker with fixed hours in hh	58 (39%)	187 (49%)	61 (52%)	
Home worker in household	56 (38%)	160 (42%)	67 (57%)	
Average value				
Residential density	0.20	0.12	0.09	
Residential entropy	0.85	0.81	0.77	
Distance home to railway station	1.56	1.95	3.00	
Working days				
Male	4.42	4.53	4.84	
Female	3.80	3.63	3.70	
Working distance				
Male	23.50	24.76	32.23	
Female	18.32	18.97	20.67	
Density work location				
Male	24.37	17.94	14.76	
Female	22.23	16.67	14.65	
Distance work location to railway station				
Male	1.52	1.84	2.17	
Female	1.81	1.93	2.18	

by a single earner, the less chance of owning zero cars, while for women, conversely, a longer working week increases the likelihood of several cars. This would seem plausible, since a longer working week means less time is left over for other activities and a car may allow time to be spent more efficiently. For single earners, the occurrence of irregular working hours increases the need for a second car. Remarkably, distance to work has no significant effect.

The company car variable is not included in the zero-car model, because having a company car is perfectly associated with owning one car rather than zero cars. As a consequence, it is not possible to estimate such a model. However, as Table 5.1 shows that only 11 per cent of the households with one car have a company car (against 56 per cent of the multiple-car owners), the influence is expected to be fairly limited. Hence, having a company car does not affect zero car ownership compared to one car ownership. This implies that, on average, one-car households with a company car would also have had one

Table 5.2 Logistic regression models for zero and multiple cars, divided by work status

	Zero cars			More cars	
	No worker	Single-earner	Dual-earner	Single-earner	Dual-earner
Sociodemographics					
Household type					
Couple					
Children below 6			0.380 **	8.581 ***	
Children over 12					2.977 **
Household income					
Lower	5.407 ***	2.883 ***	5.238 ***		
Higher				5.126 ***	2.291 **
Motor cycle in household					
Residential environment					
Single-family dwelling		0.412 **		22.558 ***	
Park in own garage					2.446 **
Residential density	138.371 **	8.794 *	122.534 ***		0.0134 ***
Distance to railway station			0.675 *		
Work characteristics					
Company car available				50.968 ***	10.038 ***
Irregular work				3.010 *	
Fixed working hours					
Sometimes working at home					
Work days		0.752 **			
Male					
Female					1.241 *
Work distance					
Male					
Female					
Work environment					
Work density		33.899 ***		0.004 *	
Male					
Female					
Work distance station				1.265 *	
Male			0.734 *		1.423 ***
Female					
N	72	221	264	169	295
Rho^2 (McFadden)	0.251	0.178	0.174	0.517	0.285
Rho^2 (McKelvey & Zavoina)	0.427	0.289	0.369	0.744	0.424

Significance: * p<.1, ** p<.05, *** p<.01

Table 5.3 Logistic regression models for company cars

	Single-earner	Dual-earner
Sociodemographics		
Household type		
Couple		
Children below 6		
Children over 12		
Household income		
Lower	0.140 *	
Higher		2.109 **
Motor cycle in household	4.468 ***	3.992 ***
Residential environment		
Single-family dwelling		
Park in own garage		
Residential density		
Distance to railway station		
Work characteristics		
Company car available		
Irregular work	3.069 **	
Fixed working hours		***
Sometimes working at home	2.533 *	3.275
Work days	2.100 **	***
Male		2.275 *
Female		1.276
Work distance	1.019 *	
Male		
Female		
Work environment		
Work density	0.966 *	*
Male		0.979 *
Female		0.070
Work distance station		
Male		
Female		
N	97	266
Rho^2 (McFadden)	0.261	0.189
Rho^2 (McKelvey & Zavoina)	0.460	0.371

Significance: * p<.1, ** p<.05, *** p<.01

car if the employer had not provided them with a car. However, in the multiple car model company cars appeared to be important determinants of car ownership. For single earners, the company car is by far the most important reason for owning more than one car: the odds ratio is 63, which means that the likelihood of having a second car instead of one is 63 times higher when a company car has been received. For dual earners, a company car is also important, but to a lesser extent.

In order to establish whether the built environment indirectly affects car ownership via company car availability, models were estimated for single and dual earners (Table 5.3). The results suggest that households with a company car are more wealthy, with higher incomes and more often have vehicles such as motor cycles. They more often work irregular hours and more often work at home, which may be due to a 'mobile' profession. Also, both spouses tend to work longer working weeks, probably because company cars are usually only provided for (nearly) full-time workers. The effects of the working environment show that company car-owning households tend to work in low-density neighbourhoods. It does not seem plausible that the working environment affects company car ownership, but that self selection occurs. Firms that provide company cars to their employees may be more inclined to choose suburban locations, which are more easily accessible by cars, rather than high-density locations, which are often subject to parking problems.

Finally, with regard to the built environment, not only density and distance to the railway station were included, but also measures of mixed use. However, these proved not to be significant in any of the models. The density and mixture indicators were also tested at three levels of spatial scale; micro density was included in all models as this consistently performed better, indicating that the direct environment had more impact than the wider environment.

5.6 Conclusions

This paper has analysed the influence of the built environment on car ownership. With the trend towards growing car ownership, particularly the growth of the number of households with more than one car, increasing car-dependency is being observed outside the US, too. By owning cars, households are less dependent on the constraints of location choices in realising their activity patterns. Hence, it is assumed that car ownership is partly determined by characteristics of the environment in which people live and work.

In this paper, the specific focus has been on the work environment. Apart from the socio-demographics and characteristics of the residential environment, we included features related to the job, such as the number of working days, flexibility, availability of a company car, distance to work, and built environment characteristics of the work location. Since dual-earner households deal with two work locations, the characteristics of both work locations were taken into account. This created the possibility of examining within-household differences. The empirical part of the study was based on household and land use data relating to the Netherlands. Since over half of all households own one car, we were particularly interested in factors relating to not owning a car and owning more than one car. To investigate this, binary logistic models were estimated, split up into zero-car households or multiple-car households, and non-working, single-income and dual-income households.

The results yielded by the model generally revealed plausible effects, consistent with the literature, with respect to socio-demographics and the residential environment. Having said that, some specific findings merit further discussion. First, the findings from the North American literature, demonstrating that a more compact residential environment (higher densities, more single-family dwellings) reduces household car ownership, were broadly confirmed. This is interesting because the travel context in the Netherlands is rather different from that in the US. The density gap between suburbs and traditional or neo-traditional neighbourhoods is smaller in the Netherlands, so an extra car provides less extra utility while the threshold is higher due to higher car purchasing costs. There are also more alternatives, such as bicycles and densely interconnected public transport networks. Nevertheless, this study demonstrates that in the Netherlands, too, the built environment has a clear impact. This seems clearly to confirm the hypothesis that density matters.

Second, it was suggested that residential self-selection plays a role, which means that it is not only the environment that influences car ownership, but that households with a preference for car travel may be more inclined to choose a car-friendly residential environment. However, attitudinal variables were not available to test this proposition. Alternatively, we assume that with rising incomes, it becomes easier to buy a second car and to select the preferred neighbourhood. As it appears from the data that household incomes are inversely correlated with compactness (density, living in a single-family dwelling, available parking space), then we can deduce that households tend to prefer to live in low-density neighbourhoods that enable them to own cars. Consequently, the effects of the built environment, as found in this study, may partly be attributed to self-selection.

Third, there is clear sensitivity to the work location, with car ownership being inversely related to density and positively related to the distance between the work location and the nearest railway station. Although the residential location has a much greater impact than the work location, from a sustainable policy perspective it would nevertheless be worth designing more compact employment locations. By designing compact residential neighbourhoods, there is the risk that car-oriented households will simply not choose them, but this risk is much smaller for work locations because people generally attach less importance to the characteristics of the work environment.

Fourth, the role of the company car is extremely important. Many households own a second car simply because it is provided by their employer. Since company car owners tend to work in low-density neighbourhoods, we can also conclude that firms who provide company cars to their employees are apparently more inclined to choose to locate in suburban areas which are well accessible by cars, rather than high-density locations which are often subject to parking problems. Limiting the phenomenon of company cars could be an effective measure to reduce car ownership and consequently car travel. Reducing company car ownership would also reduce the demand for suburban work locations. This would also favour those who work in suburban locations without having a company car.

Fifth, the analyses revealed some within-household relationships. Dual earners tend to buy a second car if the female spouse has a long working week, suggesting that the first car is used by the male spouse. Furthermore, it is the male spouse that exercises the greatest influence on the likelihood of either zero or multiple cars with regard to the distance to the railway station. This is possibly because men tend to work further away, so they are more often dependent on the car or train, rather than the bicycle.

To summarise, there appeared to be a clear link between the built environment and car ownership, both in terms of the residential and work environment. As car ownership forms a link between built environment choices and daily travel, this finding is relevant for policies aimed at reducing car dependency. Given that most households prefer to live in low-density areas, it may useful to concentrate urban design policies not only on residential neighbourhoods, but also, or even primarily, on the development of office areas and other employment locations.

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6 Influence of the residential and work environment on car use in dual-earner households

Maat, K. and H. Timmermans, Influence of the Residential and Work Environment on Car Use in Dual-Earner Households. *Transportation Research A: Policy and Practice 43 (7)*, pp. 654-664. Reprinted with permission by Elsevier.

Abstract. This paper analyses whether the decision to commute by car is influenced by built environment characteristics of residential neighbourhoods and, more especially, of work locations, taking into account interdependencies between household partners. It shows that the residential environment only affects car use among single-earners. Conversely, for all commuters, but in particular for dual-earners, characteristics of the work location affect whether they commute by car. Even in dual-earner households with two cars, work environment plays a role. We found that in cases of dual-earners with only one car, the partners with the longest commuting distances and the lowest density work locations are most likely to commute by car. Moreover, in households with young children, men are more inclined to leave the car at home. Other features relating to work also affect car commuting, including work flexibility and, especially, possession of a company car. We conclude that future policies aimed at reducing car use should place greater focus on work factors.

6.1 Introduction

Increasing car use is a worldwide trend. The international literature discusses a whole series of factors that have contributed to the growth in car ownership and use in the past few decades, such as population growth, economic growth, more people with driving licences, increasing participation of women in the workforce, more households, more singles and greater engagement in leisure activities outside the home (*e.g.* Banister and Marshall, 2000). The increasing sprawl of residential and business zones is also cited as an important factor (Cervero, 1996a; Geurs and Van Wee, 2006).

Commuting between home and work, in particular, has a major impact on car use and its adverse effects. In the United States, commuting trips account for only about a 20-25 per cent share of trips (Pisarski, 2007). However, because commuters travel mainly during rush hours, commuting is associated with severe traffic congestion (Redmond and Mokhtarian, 2001; Shiftan and Barlach, 2002; Horner, 2004). In the Netherlands, commuting accounts for only one-third of all trips, but for as much as around 60 per cent of all distances travelled; figures for commuting by car are even higher, at 73 per cent of trips and 85 per cent of distances travelled (Statistics Netherlands, 2005; Susilo and Maat, 2007). Over the past decade, frequency of travel has increased by 10 per cent, mainly at the expense of the car; total commuting travel, however, has increased by 30 per cent. On an individual level, the average commuting distance has grown from 14 to 17 km over the past decade for all modes of transport, and from 18 to 22 km for travel by car. The growth in car use has resulted in a more than 50 per cent increase in time loss due to traffic jams (KiM, 2007).

Commuting's impact on traffic problems has led to commuting mode choice becoming a thoroughly researched aspect of travel behaviour. In this paper, we study the relationship between the built environment and commuting mode choice. We assume that the commuting mode choice is not only influenced by the residential neighbourhood but also by the work location. Since many households involve two employed partners, it is assumed that they interact with each other about mode choice when it comes to work locations. Our research also investigated other work characteristics assumed to play a role in the relationship between the built environment and the commuting mode. These assumptions are elaborated below.

First, considerable research has been done on the relationship between the built environment and mode choice. It has been argued that the more compact the urban form, the shorter the average distance to destinations, thus making it easier to travel on foot or by bicycle. Moreover, compact urban forms are more favourable for public transport because of their larger customer base, while owning and using a car is more expensive and more difficult in urban areas owing to congestion and parking problems. Indeed, many studies have demonstrated that characteristics of the residential location exert a significant influence on mode choice (Cervero, 1996a,b, 2002; Badoe and Miller, 2000; Schwanen *et al.*, 2001, 2004). After reviewing a large number of studies, Ewing and Cervero (2001) came to the conclusion that, of all travel behaviour variables, mode choice is the one influenced most by land use characteristics. Likewise, findings have consistently shown that car commuting is inversely related to the density and mixture of residential neighbourhoods (Cervero and Gorham, 1995; Zhang *et al.*, 2004; Schwanen and Mokhtarian, 2005; Pinjari *et al.*, 2007; Dargay and Hanly, 2007). Some studies have also included the employment density of residential locations in their models, revealing significant effects and demonstrating that integration of housing and employment reduces commuting distances, and consequently car use for commuting purposes (Frank and Pivo, 1995; Pinjari *et al.*, 2007).

Second, this paper puts forward the hypothesis that car use is not only influenced by residential location, but also by work location. It could even be argued that the work location is actually more important than the residential location (*e.g.* Cervero, 2002). In a study conducted in Seattle in the US, Frank and Pivo (1995) showed that job density at the destination affects mode choice. Shiftan and Barlach (2002) demonstrated the same results for Haifa in Israel. Using national US data, Chatman (2003) found that, where car commuting is concerned, employment density at the workplace plays a greater role than does residential density. In a study in New York, Chen *et al.* (2008), also found that employment density at the work location exerts a greater influence than does residential density around the home.

Third, we furthermore assume that in households with two partners, the commuting mode choice of one partner is influenced by the other, particularly when two employed partners are involved. The increasing number of dual-earner households has been a major influence on overall patterns of travel, including on car use (*e.g.* Rosenbloom, 2006; KiM, 2007). Dual-earners are assumed to be more car-dependent because they are faced with greater difficulty in coordinating residential and work locations, with the result that the partners' average commuting distances tend to be longer than those of single-earner households (Van Ham, 2003). In addition, cars offer greater flexibility in combining work and necessary day-to-day activities than do other transport modes, thus mitigating increased time pressure and complex travel patterns. Studies have shown that possession of a second car is more frequent in dual-earner households, since these not only have a greater need for multiple cars, but are also more able to afford them (*e.g.* Giuliano and Dargay, 2005).

Over the past years, the academic literature on travel behaviour has paid increasing attention to interdependencies in households (Timmermans and Zhang, 2009; Bhat and Pendyala, 2005). This research has partly been related to dual-earnership. Various authors have examined job and residential searching behaviour of dual-earner households, and have found that the commuting distances of both partners play a role (Borgers and Timmermans, 1993; Van Ommeren, 2000; Sermons and Koppelman, 2001; Plaut, 2006). However, few studies have addressed the role that interdependencies within the household have in mode choice decisions. Badoe (2002) formulated a mode choice model at the level of the household in which he developed the idea that working partners try to minimise the combined total disutility of their commuting. Instead of 'mode choice' he uses the term 'modal bundle'. Other mode choice models that operate at the household level are included in activity-based models such as those of Arentze and Timmermans (2004) and Roorda *et al.* (2009). To date, the interdependencies between features of the residential and work locations of employed partners, and their influence on the commuting mode, has not been investigated in much depth. In this paper we therefore analyse whether work locations play a role in determining household mode choice decisions. Our basic assumption is that in dual-earner households with 'only' one car, car allocation is an important decision that involves interaction between the two partners. Various criteria may be relevant in this context, such as the ratio of working hours, the commuting distances and the work locations' accessibility for other modes of transport.

Fourth, though the present study focuses on commuting, other work-related aspects should also be accounted for. Despite rarely being factored into studies, it can be assumed that the availability of a company car strongly encourages use of the car as the commuting mode. Company cars are employer-provided passenger cars, primarily intended for making business trips, though they can generally be used for private purposes, too. For many employees, a company car is the single most important secondary employment benefit, and employers provide cars to their employees at a price far below market cost. Taxes aside, company car holders have no expenses for the use of their cars, such as maintenance or fuel costs, meaning it would be more expensive to choose an alternative commuting mode. In the Netherlands, about 9 per cent of passenger cars are classified as company cars (Van Ommeren *et al.*, 2006).

Another important consideration is the degree of flexibility employees have with respect to their work activities. We assume that full-time workers are less flexible than part-time workers because the work cuts into their available activity time (Golob, 2000), meaning they may be more inclined to choose a fast travel mode. Those with irregular working hours, for example during weekends or at night, cannot benefit from the high frequency public transport available during rush hours, and are consequently more dependent on cars, while safety considerations may also discourage bicycle and public transport use during nighttime commuting hours. Employees who have the opportunity to work at home one or more days a week may be less dependent on cars; however, it is also conceivable that working at home enables the other partner to take the car in dual-earner, one-car households.

Finally, underlying much of this type of research is the assumption that a well-designed built environment may influence travel behaviour. This study examines the relationship between the built environment and travel behaviour from a Dutch perspective, using data collected in the Amsterdam-Utrecht region. As most existing studies on the relationship between the built environment and car commuting are from North America, it is our additional aim to determine whether the conclusions of those studies can be transferred to the European situation. It should to be taken into account, however, that these two regions do not lend themselves to direct comparison where this issue is concerned. In the US, movements such as Smart Growth and New Urbanism encourage the situation of daily-use facilities such as housing, work, schools, shops and other amenities within walking distance of each other, in a pedestrian-friendly environment and with ready alternatives to car use (Handy, 2005). In the Netherlands, however, this is the preserve of national spatial planning, which does not primarily focus on the neighbourhood level but, rather, on the level of urban regions. Against the background of urban sprawl, Dutch spatial policy has made a huge policy effort in the past decades (*e.g.* Banister, 2002; Dieleman *et al.*, 1999) to retain cohesive urban areas in order to encourage modal shifts away from the car, a policy which was fine-tuned in the late 1980s with the introduction of compact urbanisation. The aim was to encourage people to live and work in largely mono-centric urban structures within the spatial scale of the urban region.

To understand the differences between Europe and North America, one should realise that major differences exist between both regions in terms of the urban and the transportation environment (Transportation Research Board, 2001; Giuliano and Dargay, 2005; Van de Coevering and Schwanen, 2006). Both in North America and the Netherlands (as well as in other European countries), housing and jobs tend to sprawl, accordingly encouraging car use. However, the US not only exceeds Europe in car ownership, but also – and to a much greater extent – in car use. The car remains less convenient and more costly to operate in Western Europe than in the US, especially in cities. In general, public transport plays a more prominent role in Western Europe, in both large cities and many smaller communities, accounting for about 10 per cent of urban trips in Western Europe, compared with about 2 per cent in the US. In the Netherlands, however, the prominent role of the bicycle keeps public transit use at a relatively low 5 per cent of trips. Here, most people have a bicycle, which is used for more than a quarter of trips on average (Statistics Netherlands, 2007). Higher public transport use in The Netherlands compared to the US may also be the result of financial support by the government. Added to this is the fact that European city centres and residential neighbourhoods are more compact and tend to have little space for parking, while American cities are characterised by grid-like street patterns, are designed to accommodate cars and offer significantly more parking space (Transportation Research Board, 2001). Finally, rising car ownership and use in the Netherlands may be a consequence of increasing dual-earnership. Single-earnership was long the norm, but for the past two decades, there has been significant growth in dual-earnership, with today more than three-quarters of the couples below the age of 65; still, in the majority of the dual-earner households, women have a part-time job (Statistics Netherlands, 2002).

This study builds on previous research by examining the extent to which built environment characteristics of the residential neighbourhood and work locations of employed partners affect household car use decisions related to commuter trips. In addition, we consider the role of several other work-related factors. Our main interest is in households with two employed partners and only one car – a condition that serves to restrict car use for commuting and that forces the household to decide which partner needs the car most or derives the most benefit from it. However, we also analyse households with at least as many cars as employed partners (i.e. employed singles, single-earner households with one car and dual-earner households with two cars), which therefore have full flexibility in deciding whether to use the car as commuting mode.

This paper is organised as follows. The ensuing section describes the data on which our empirical analysis was based. This is followed by three sections setting out the results of models on mode choices: which partner gets the car in dual-earner one-car households, and how is mode choice determined in dual-earner households with multiple cars? The final section presents the conclusions and a discussion.

6.2 Data and method

Data sources

This is one in a series of studies requiring detailed travel data geocoded at a low spatial level. The Dutch National Travel Survey does not provide sufficient detail, which meant that a targeted survey had to be carried out. The sample was drawn in 2000 from the northern wing of the urban Randstad region of the Netherlands. This region contains a wide variety of urban forms, including the cities of Amsterdam and Utrecht, their surrounding suburbs, a number of medium-sized and smaller towns, and a few villages in the rural areas. The Amsterdam region is more dense in terms of both population and employment than the Utrecht region. One city, Almere, is a large polycentric 'new town', situated on reclaimed land surrounded by a border lake, connected with the mainland by two bridges, but consequently somewhat isolated (see Figure 1.1).

The survey was conducted among households, whereby the head(s) of the household was/were asked to complete the questionnaire. For the present study we selected complete households – that is to say, single-person households and households with couples in which both partners completed the questionnaire (we limited the analysis to man-woman relationships) – of which the work location was known. Of these, we selected households with at least one employed partner, thus yielding 650 households, comprising 444 couples and 206 singles, for further analysis. Table 6.1 shows the breakdown into non-earners, single-earners and dual-earners in relation to the main commuting mode choice.

The spatial data were derived from a variety of sources and pre-processed with the aid of a GIS. Dwelling data were obtained from the LBV National Database of Real Estate, and the number of employed persons from the LISA Register of Businesses. The Basic Register of Points-of-Sale contains detailed information on shops, including the amount of floor space. The data was assigned to the appropriate location using postal codes, yielding highly detailed spatial information. Distances and travel times between origins and destinations were calculated using the Dutch Base Network.

Table 6.1 Commuting mode choice by work status and household type

Working type	Train	Car	Bicycle	Other	Total
Single man	16	22	23	14	75
Single woman	27	37	41	26	131
Male single earner	6	47	25	4	82
Female single earner	5	10	3	3	21
Male dual earner	77	134	108	22	341
Female dual earner	53	123	134	31	341
Total working households					650

Variable specification

The focus of our analysis was on the main mode of transport for commuting, for which we imposed the following hierarchy: if commuting mainly involves walking or bicycle use, it is coded as a slow mode; if a car is used, the main mode is the car; if at any point a train is used, the train is considered the main mode, even if a bicycle or car is used to get to or from the train; the remaining modes, including other public transport and mopeds, are categorised as 'other'. In addition, we selected the mode that is most commonly used, i.e. we ignored the fact that some commuters do not use the same mode for all their commuting trips (for example, using their car in the winter and bicycling in the summer).

The addition of a dummy indicates whether the respondent is single or part of a couple. Three different dummies are used to indicate the presence of children in a household, representing, respectively, a child under the age of 6 (pre-school), aged between 6 and 12 (primary school), or aged between 13 and 18 (secondary school), thus broadly reflecting three stages of increasing independence. Household income is broken down into lower, middle and higher-income groups. The category of work status refers to a non-employed, single-income or dual-income household. Dwelling type indicates whether the house is a single-family dwelling or a multi-storey apartment. Car ownership indicates the number of cars in the household, while another dummy indicates whether one of the cars is a company car. For each working partner, certain characteristics of their job are included: the number of working days, dummies on whether the job has irregular working hours, whether variation in working hours is permitted (and freedom in choosing starting/leaving times), and whether telecommuting or working at home are possible.

To reflect the built environment, we developed indicators for both the residential and work location of each employed partner. A measure of urban density was also developed. Since measurements are sensitive to differences in distribution and size, administrative and statistical divisions proved inadequate. This problem was addressed by converting the data into grid cells measuring 250 by 250 m. As there are inevitable discontinuities that take place when using data that originally reflected land parcels and fine postal codes, the moving average of the data was taken, which involves averaging the data in a window of cells defined around each cell. By varying the size of the window, the average is taken over various radiuses, reflecting different levels of

Table 6.2 Household and built environment statistics by household type

Variables	Household type		
	single	couple; single-worker	couple; dual-workers
N	205	103	341
Children			
None	80%	42%	41%
< 6 years of age	1%	31%	28%
Between 6 and 12	8%	16%	16%
> 12 years of age	11%	12%	15%
Household income			
Low	37%	8%	9%
Medium	47%	42%	40%
High	16%	50%	51%
Dwelling type			
Multi-family dwelling	58%	11%	18%
Single-family dwelling	42%	89%	82%
Number of cars			
None	46%	12%	12%
One	53%	52%	65%
Multiple	1%	36%	23%
Company car			
Not available	90%	74%	77%
Available	10%	26%	23%
Mode to work men			
Train	22%	7%	23%
Car	28%	57%	39%

spatial scale (Batty *et al.*, 2004). The urban density index d expresses the total density of housing, jobs and retail floor space. The total amount of an activity *k* in cell *i* is defined as a_{ik}. In order to give all activities equal weight in the calculation of the index, the values were normalised as follows: $s_{ik} = a_{ik}/max_i(a_{ik})$, where s_{ik} denotes activity *k* in cell *I* as a proportion of the maximum cell value of *k* in the Netherlands. To arrive at the density value, the normalised values sik are added up and divided by the number of categories *K* that occur: $d_i = \Sigma_k s_{ik}/K$. The higher the value, the higher the composite density, with a theoretical maximum of 1 where a single cell has the highest number of dwellings, jobs and retail floor space. In addition to this density measure, various measures of mixed use were also developed; however, these are not described here because they did not show any effects in the models. Other spatial variables that are included are the distance to the nearest railway station and the commuting distance, both examined as continuous variables (Table 6.2).

Table 6.2 continued

Variables	Household type: single	Household type: couple; single-worker	Household type: couple; dual-workers
Bicycle	31%	30%	32%
Other	19%	5%	6%
Mode to work women			
Train	21%	24%	16%
Car	28%	48%	36%
Bicycle	31%	14%	39%
Other	20%	14%	9%
Average residential density	0.18	0.10	0.11
Average distance to railway station (km)	1.60	2.70	2.10
Average number of work days			
Men	4.42	4.57	4.62
Women	3.98	3.81	3.55
Average distance to work (km)			
Men	21.60	25.30	27.40
Women	19.00	24.80	18.80
Average density work location			
Men	0.23	0.14	0.18
Women	0.20	0.14	0.17
Average distance to work railway station (km)			
Men	1.60	2.30	1.80
Women	1.80	2.00	2.00

Model specification

We developed three sets of models on mode choice and car use, taking into account household interactions. First, we test which variables determine mode choice for commuting for respectively men and women, single-earner and dual-earner households, and dual-earner households with only one car. Second, we test which partner uses the car for commuting in both one-car and multiple car dual-earner households, and third whether both cars are used in two-car dual-earner households. The analyses used binary and multinomial logit models. We assume that the commuters attach certain utilities to alternatives and choose the alternative providing the highest utility. The probability that alternative j will be chosen by household i is $P_{ij} = e^{\beta xij}/\Sigma_{m2C}e^{bxim}$ where x_{ij} is a vector of attributes for alternative j and characteristics of household i, β a vector of the coefficients, and C the set of available alternatives. The unknown b-parameters are typically estimated by maximum likelihood.

Table 6.3 Logit models of car mode choice

	Single-earner			
	Man		Woman	
	Train	Bicycle	Train	Bicycle
Socio indicators				
Children < 6 years of age		*41.393*		
Number of cars in the household	*0.046*	**0.023**	**0.027**	**0.052**
Residential indicators				
Single-family dwelling	7.897			
Residential density		*1110*		
Distance to railway station	*0.008*			
Work indicators				
Company car				
Number of work days		*0.444*		*0.516*
Allowed to work at home				
Work hours not flexible				
Commuting distance	*1.052*	**0.801**	**1.085**	*0.895*
Man higher commuting distance				
Density work location men				
Density work location women				63.5
Distance to work station	*0.183*	1.624		
N		138		123
ρ^2 (McFadden)		0.665		0.470
ρ^2 (Cragg & Uhler/Nagelkerke)		0.852		0.722

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

The binary model is simplified as $P_{ij} = 1/1 + e\beta^{x_{ij}}$. The raw β-coefficients estimated are in logit units and quite difficult to interpret. In a binary model, the logit is the natural log of the odds; this odds is the ratio of two probabilities, $P/1 - P$, for example the probability on occurring an event relative to not occurring. The ratio of two odds, say for men and for women, is the odds ratio. By exponentiating the logit, we obtain the odds ratio, which can be interpreted as the chance of $P = 1$ after a one-unit change in a predicting variable. In a multinomial model, the logit represents the ratio of a probability over the probability of a reference category, for example $P(y = 3)/P(y = 1)$, where $y = 1$ is the reference category, *e.g.* the probability of choosing the bicycle rather than the car. Exponentiating this ratio results in the relative risk. The ratio of two relative risks, say for men and for women, is the relative risk ratio (sometimes inaccurately referred as odds). For example, the likelihood of an individual travelling by bicycle as opposed to travelling by car, with the latter as the reference category. If the value is higher than 1, the probability of the bicycle

Dual-earner				Dual-earner, one car			
Man		Woman		Man		Woman	
Train	Bicycle	Train	Bicycle	Train	Bicycle	Train	Bicycle
1.973				2.115			
0.222	**0.176**	**0.111**	**0.158**				
0.084	**0.084**			*0.082*	**0.070**	*5.966*	4.012
		1.030	**0.909**			1.021	**0.928**
4.949	**0.149**			*7.109*	**0.132**	*0.300*	
781.677	*62.955*			**2529**	*598*		
		51.4	*27.2*			*1079*	*286*
		0.602	0.857				
	286		310		193		184
	0.334		0.324		0.314		0.224
	0.575		0.559		0.558		0.416

is higher, and vice versa. Several measures of fit are available, of which the Cragg and Uhler pseudo *R*-square (ρ^2) provides the best approach to the proportion variation described above, though it is not fully comparable with an R-square value in linear regression; for binary models, the McKelvey-Zavoina ρ^2 performs slightly better, but for comparison, we present the Cragg and Uhler measure (Scott Long and Freese, 2006).

6.3 Mode choice

In this section we examine the differences between the mode choices of single and dual-earner households and the effect that spatial characteristics of their residential and work locations have on their transport mode choice. Table 6.3 shows which variables significantly affect the choice of commuting mode in a series of multinomial logit models. Each model compares the four above categories of main commuting mode. The car serves as the reference category; that is to say, the parameters for the other modes are relative to the car. Thus each model comprises parameters for rail, bicycle and 'other' transport modes. As the last is a heterogeneous residual category it was decided not to represent it in the tables. Models were estimated for single-earners, dual-earners and single-car dual-earners, for both men and women separately. It was decided not to include the number of earners and cars per household as dependent variables because the difference in interaction between men and women is not measured if 'only' one car is available. The ρ^2 is satisfactory, with higher values for single-earners, indicating that dual-earner patterns vary with other, unknown, factors.

The models show that single-income, male-earner households use the bicycle far more when there are young children. Where dual-earner households have children under the age of six, men are more likely to take the train instead of the car. It may be that they leave the car for their spouse, as women are more commonly responsible for taking the children to school or day care on their way to work, for which a car offers a flexible mode of transport.

Residential density is only significant for single-earners: the higher the density, the higher the probability that men will use the train and women the bicycle. The decreasing probability of car use as density increases is in line with compact city theory. Increased distance from the station correlates – logically – to decreased probability of rail use. Interestingly, the residential environment has no effect in the case of dual-earners.

Not surprisingly, the model shows that commuting mode is strongly influenced by the number of cars a household possesses. Moreover, men who have a company car tend to travel by car far more, while women in households with a company car are much more likely to travel using other modes, suggesting that the company car is generally provided to men. It should be noted here that the (unexpected) absence of income as a determinant in the model is mainly explained by the inclusion of company cars.

It was also included in the model whether the number of working days and commuting kilometres would affect mode choice. Part-time work has only an effect on single-earners: the less days they work per week, the more they are inclined to use a bicycle. It seems likely that part-time jobs are more often found in the vicinity to the home location. Commuting distance has effects on all households, and is positively related with train commuting and negatively related with bicycle use. This effect is even stronger when men in dual-earner households have a greater commuting distance than their spouses. On top of that, in one-car households we see an interaction effect: when men travel by train because of their greater commuting distance, and thus leaving the car at home, women are more inclined to commute by car than by train.

Finally, the results underpinned the assumptions that the work location has a greater effect on commuting mode choice than does the residential built environment. Compactness of the work location, as indicated by density, has a clear impact in most cases. Dual-earners are more likely to opt for the train or bicycle when work location density is higher. Clearly, higher densities are related to better public transport coverage, shorter distances for bicycles and fewer facilities for cars. In the case of single-earners, however, the effect of densities is only observed in bicycle use among women. Finally, for both single and dual-earners, the parameters confirm that increased distance from the train station reduces the probability of train and bicycle use in favour of car use.

6.4 Car use in dual-earner households

When considering interaction within the household, the most interesting question is: Which factors determine why commuters take the car to work? We analysed which partner gets the car in one-car dual-earner households, and subsequently how car commuting is determined in the case of dual-earner families in general. The sample group comprised 341 dual-earner households, 222 of these being single-car households. In 121 households the car is used for commuting – specifically, by 71 men and 63 women – with 13 households in which both partners use the car, possibly travelling together or working part-time and taking turns using the car. In the other households the car remains at home. There were only 77 dual-earner households with a car available for both partners (i.e. at least two cars), so caution is called for here. Of these households, four leave both cars at home, 28 use one car and 45 use both for commuting.

One-car dual-earners

If a couple has ‘only’ one car (as is the case with the majority of couples), there is demand for the car from both partners. Especially if both of them work outside the home, there is likely to be some deliberation or negotiation about their commuting behaviour. We therefore assume that the characteristics of each partners’ work environment determines who gets the car. Multinomial logit models were estimated to test the relationships. The first model, represented as (a) in Table 6.4, explains 29 per cent of the variation, with the probability of either the men or women, respectively, taking the car shown in relation to a reference category where they both leave the car at home. It is interesting to note, however, that all significant parameters concern men, suggesting that characteristics and circumstances relating to the men, in particular, are what determine who uses the car for commuting. To gain further insight into relations between the partners, model (*b*) in Table 6.4 (ρ^2 is 32 per cent), examines the probability of the woman getting the car in relation to a reference category in which the man gets it (households in which the car remains at home were left out).

Table 6.4 Logit models: which partner uses the car for commuting in one-car dual-earner households (models a and b); whether both cars are used for commuting in two-car dual-earner households (model c)

	Model (a) man	Model (b) woman	Model (c) both cars
Socio indicators			
Children < 6 years of age	0.418 *		
Number of cars in the household			
Residential indicators			
Single-family dwelling			
Residential density			
Distance to railway station			
Work indicators			
Company car	17.89 ***	0.052 ***	3.296 **
Number of work days			
Allowed to work at home			0.219 **
Work hours not flexible	2.473 **	0.413 *	
Commuting distance women			1.071 **
Man higher commuting distance	2.815 **		
Density work location women			0.004 *
Man higher density work location	0.490 *	3.485 **	
Distance to work station			
Reference category	neither	man	less than two
N	205	105	73
ρ^2 (McFadden)	0.138	0.195	0.116
ρ^2 (Cragg & Uhler/Nagelkerke)	0.285	0.315	0.344

Significance: * p<.1, ** p<.05, *** p<.01

The likelihood of men taking the car is lower if there are young children in the household. This indicates that their partners have primary responsibility for activities such as taking the children to and from school before and after work, thus benefiting most from using the car. Both models show that if one of the partners has less flexibility in their work pattern due to inflexible work hours, this increases the probability that the man will commute by car. Clearly, these dual-earners have tight activity schedules, which serves to increase their reliance on a car. Though it would have been conceivable that the partner with the most weekly working hours would get the car, this effect was revealed not to be significant.

Possession of a company car appears to be an important determinant of car use. Where the car is a company car, it is 18 times more likely that the men commute by car. Note that it is mainly men who drive company cars. Moreover, the fact that men have the longest commuting distance, on average, increases the probability that they will take the car.

In none of the models, the residential neighbourhood shows an effect. Conversely, the work environment has a clear impact. The likelihood of using the car increases for men as the compactness of their work location decreases. In addition, a clear interaction is seen in the fact that when men have a more compact work location this also increases the likelihood that their spouses will take the car to work.

Multiple-car dual-earners

We expected to find different patterns in dual-earner families in which both partners have cars, given that they do not need to negotiate over car use. It seems reasonable to assume that the second car will have been purchased for commuting, especially in families with young children, where time is a scarce commodity. Nevertheless, in only 58 per cent of the households are both cars used for commuting. A possible explanation is that, in dual-earner households, a second car is bought as a luxury that can be afforded thanks to the two incomes, and not as a necessity. However, given that only 5 per cent of two-car households actually use neither car for commuting, dual-car households are undoubtedly more auto-oriented than single-car ones.

Model (c) in Table 6.4 is a binary logit model that examines the use of two cars in relation to a reference category where zero or one car is used. The ρ^2 is 34 per cent, with only a small number of variables significant. It is remarkable that none of the household characteristics, such as the presence of children, influence whether or not two cars are used. As with one-car households, the residential environment does not play a role. Rather, the explanation is provided by the work indicators, as was initially assumed. Having a company car triples the likelihood of using both cars. As many company car drivers have frequent business trips, it seems logical that the possible freedom to work at home has some impact. Both spatial determinants in the model are concerned with the female partner: women's commuting distance is positively related with the likelihood of using both cars, and the more compact the work location is, the higher the probability that one or both cars remain at home.

6.5 Conclusions and discussion

Until now, very few studies have analysed household dependencies on car use. The present paper posits that commuting mode choice depends on, among other variables, partners' employment status and work characteristics, the commuting distances involved and characteristics of the built environments. We hypothesised that it is not only the residential location that influences car use, but also work characteristics, including the work location.

The analysis was conducted at the household level, with households classified in terms of employment status and car ownership. Where employment status is concerned, a distinction was made between single and dual-earners, and between male and female partners. Car ownership was broken down into households without a car, those with one car (with dual-earners having to decide who gets to use it) and those in which both partners have a car and both work outside the home (and therefore have more flexibility in deciding whether or not to commute by car). Logit models were estimated to test the hypotheses.

The first hypothesis was concerned with the built environment of the residential neighbourhood. Only in the case of single-earners, higher residential densities and shorter distances between the home and railway station was there a significant increase in the probability that men would use alternatives to the car, thus supporting concepts of planning and design related to travel behaviour. However, no effects were found for dual-earners, which is inconsistent with the literature. One would expect household car ownership to reduce the relevancy of the residential environment, but even when this variable was removed from the models, the effects of the residential environment remain insignificant. Likewise, removing built environment indicators of the work location did not result in such effects. We must therefore conclude that dual-earners do not feel constrained by their residential neighbourhood when choosing a commuting mode.

In contrast with our findings concerning the residential environment, clear effects were identified in relation to the work location. In line with our second assumption, the compactness of the work location reduces car commuting. In particular, dual-earners are more likely to choose the train or bicycle over the car when their work location density is higher. Nevertheless, the effect of these densities is limited where single-earner households are concerned. Since most households have one car, it is to be expected that, in single-earner households, the employed partner would have the car at his or her disposal, whereas for dual-earners there is likely to be some deliberation about who gets the car, with partners perhaps evaluating who has better options for using an alternate travel mode – in respect of commuting distance and compactness of the work location.

This brings us to the third assumption, namely, that in households with two partners the commuting mode choice of one partner may be influenced by the other. Given that characteristics relating to both men and women are included in the models, and that the effects for men are compared with those for women, we were able to identify mutual interdependencies. When household composition is factored in, it becomes clear that in households with young children, men are more likely to leave the car at home. It is likely that women more often have responsibility for taking the children to school or day care, which they combine with their work activities, and for which the car is the most flexible mode of transport (this effect is not observed in households with older children, who are less dependent). Interdependencies are also observed in relation to spatial characteristics. In general, we see that commuting distance has a clear impact: longer commutes link up with rail travel and short commutes with bicycle use; likewise, compactness and railway station accessibility are inversely related to car commuting. More specifically, however, we see that partners take into account who has the longest commuting distance and/or the highest workplace density.

Interestingly, the question remains as to whether multiple car ownership among dual-earners results from the necessity or the desire of both partners to commute by car. Surprisingly, in more than 40 per cent of these households, the cars are not used for commuting by both partners. This suggests that the second car is by no means always intended for commuting, but serves another purpose or is simply an added luxury that these households can afford.

Finally, since we analysed travel for work purposes, we assumed that other work characteristics play a role and should be included in the analyses. An obvious additional factor, but nevertheless one rarely mentioned in the literature, is that possession of a company car strongly encourages car commuting (interestingly, this mainly relates to men). It should be noted here that the (unexpected) absence of income as a determinant in the models is mainly explained by the inclusion of company cars. In addition, the number of workdays, flexibility of work hours and working at home all have some impact on car use.

All in all, this study demonstrates that the relation between car use and the built environment is fairly complicated, in the first place because there are clear dependencies between the two partners in a household. They decide who needs the car most given such factors as the accessibility of the work location(s) in terms of distance and/or compactness of that location, and distance to the closest and destination railway stations. An implication, however, may be that less car use as a result of better accessibility by alternatives for the car, is outweighed by the partner's car use. Our analysis also found that in households with young children, which are characterised by complex activity patterns, female partners are more likely to use the car for commuting. The impact of the residential environment is limited in the case of dual-earner households; given that the proportion of dual-earners continues to grow, it can be concluded that this limited effect applies to the role of the residential environment in general. Nevertheless, it should be mentioned that residential environments may impact other travel activities, such as shopping.

The results of this study provide some valuable input for the development of car use reduction policies. What emerges as the best option, however, is to ensure that work locations are designed in a more compact manner and that they are easily accessible by bicycle and public transport – which all too often is not the case.

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7 Conclusions and discussion

7.1 Introduction

The question whether and to what extent travel behaviour is influenced by the built environment has been the subject of an intense academic and policy debate over the last decades. The background to this debate is the assumption that a more compact urban structure would reduce car use, and thus add to sustainable transport strategies, enabling people to participate in activities while simultaneously reducing environmental impacts and traffic congestion.

Nowadays, there is a vast body of research on the relationship between the built environment and travel behaviour, for the greater part testing the American principles of the Smart Growth and the New Urbanism movement. Initially, this research concentrated largely on the effects of the built environment on trip frequencies, trip lengths and mode choice. More recent studies, however, assume a more complex relationship and therefore pay more attention to interim choices and interdependencies between trips, locations and household members. This thesis elaborated this line of research, focusing specifically on the Netherlands, where urban concentration and density have been common goals in a long tradition of targeted spatial planning. These planning and design concepts need to be explored in order to determine whether compact urbanisation will actually meet the expectations of reducing car use.

It is assumed in this thesis that the theoretical framework of the activity-based approach offers scope for analysing these interdependencies. This approach assumes that individuals and households pursue their goals by making a series of interrelated choices involving the allocation of activities over time, destination choice, the linking of activities into chains, and the choice of travel mode. Although the built environment is being increasingly included in activity studies, certain aspects – particularly the spatial dimensions of interdependencies – appear to have been largely overlooked or have received only scant attention in most studies. To begin with, it is unclear how people deal with travel choices when optimising their overall activity patterns, particularly in terms of the implications for the daily distance travelled and the linking of destinations in trip chains. Second, as many studies only include residential built environment and thus ignore the spatial configuration of destinations, this thesis also investigated the role of the work location. Third, as the activity-based approach considers the household as the decision-making unit, the interaction between partners was explored with regard to car ownership and car use. Finally, the thesis also looked at whether the impact of the built environment manifests itself on different spatial scales. To test these issues, this thesis sets out to explore the research question: *how and to what extent does the built environment of both residential and work locations influence travel behaviour, taking into account interdependencies between activities, household members, and locations?*

The thesis takes the form of one theoretical and four empirical chapters; four papers were published in peer-reviewed journals, while one is currently under review. The chapters address the influence of the built environment on daily travel distance, the complexity of chaining behaviour, car ownership, and car commuting in relation to interdependencies between activities in tours and day patterns, between individual household members, and between residential and work locations (though not all aspects are considered in each paper). As cars are the dominant mode of transport, car travel received most attention. The analyses were based on a comprehensive dataset drawn from individual and household questionnaires, activity/travel diaries and detailed spatial data collected in 2000. The North Wing of the Randstad in the Netherlands was chosen as a study area, thereby affording opportunities to test the hypothetical relationships in a non-American setting.

7.2 Overview of the results

This section gives an overview of the results of this thesis, starting with a summary of the theoretical and empirical chapters, followed by highlighting the main findings in view of the research question.

Chapter 2, Land Use and Travel Behaviour: expected effects from the perspective of utility theory and activity-based theories, addresses some assumed effects of the planning and design concepts from a theoretical angle. It points out that these concepts aim at reducing travel distances and car-travel speed because it is generally thought that shorter travel distances will lead to less travel and enhance the attraction of slower modes of transport. The effects fall short of expectations because of shortcomings in the assumptions about the hypothesised relationship. Utility-based and activity-based theories suggest the possibility of various behavioural responses in terms of travel-time changes if travel time is minimised, benefits are maximised, or activity patterns are optimised. If the aim is solely to minimise travel time, it will be achieved through shorter distances; at the same time, trip frequency may be reduced because shorter distances are more likely to lead to trip chaining. Accordingly, compact urban designs should offer opportunities to cut down travel. But, as people tend to trade off benefits against costs, savings in travel time may be exchanged for additional utility farther away. Moreover, as argued in the activity-based approach, people do not only maximise utility per trip, but try to optimise their whole activity pattern. Travel time savings can therefore be rechannelled into lower-priority activities that otherwise could not take place. Finally, slower car speeds and shorter distances between activities in compact urban areas might entice people to use alternative modes of transport. Hence, the role of compact urban design in reducing travel may not be as straightforward as the planning and design concepts suggest. Distance-oriented and trip-oriented approaches are too limited to explain complex behaviour, thus a broader approach is needed.

In *Chapter 3, A Causal Model Relating Urban Form with Daily Travel Distance through Activity/Travel Decisions*, the assumption that the built environment influences travel distance is empirically tested. A structural equation model was developed that relates the built environment indirectly with daily travel distance through a set of activity/travel decisions. Both the residential and the work environment were included. The model demonstrated that the effect of the built environment on one activity/travel decision can be counterbalanced by another effect and as a result indirect effects can steer the total effect in another direction than one may expect. Effects stemming from residential density suggest that people who live in a dense residential environment travel a little less, but the reduction is partly cancelled out by their involvement in extra activities. Workplace density and mix increase the total daily distances travelled, but reduce the distances travelled by car.

In line with this, *Chapter 4, Influence of Land Use on Tour Complexity: a Dutch case*, assumes that, in new urban designs and compact cities, activities tend to be linked more in complex chains (tours), resulting in fewer daily travel kilometres. The results indicate that higher densities lead to more activity and a greater tour demand, and indeed, to more complex tours. Although higher tour frequencies shorten the average tour distance, the daily distance travelled still increases. In addition, as complex tours enhance both the tour distance and the daily distance travelled, the daily distance appears to be increased by residential density. In contrast, work density turned out to have a negative effect on both the tour distance and the daily distance travelled.

The next two chapters deal with car ownership and car-commuting decisions in households. *Chapter 5, Household Car Ownership in relation to Residential and Work Locations*, analyses the influence of the built environment – particularly the work environment – on car ownership, while accounting for the work-related characteristics of both partners in dual-earner households. The models revealed plausible effects that were consistent with the literature on socio-demographics and the residential environment. It was possible, by addressing work indicators, to demonstrate that car ownership is inversely related to the compactness of the work environment. Other work-related characteristics that exert an influence include degree of flexibility and, in particular, possession of a company car. Firms providing their employees with company cars tend to settle in suburban locations. Finally, car ownership turned out to depend on relationships within the household. Dual earners tend to buy a second car if the female partner has a long working week, suggesting that the first car is used by the male partner. Furthermore, it is the male partner who mostly decides whether the distance to the railway station requires the household to buy one or more cars. This finding can be explained by realizing that often the male partner works farther away from home and has to commute by car or train rather if this distance between home and job location is too far to travel by bicycle.

Chapter 6, Influence of the Residential and Work Environment on Car Use in Dual-Earner Households, follows from the previous chapter and investigates whether the decision to commute by car is influenced by characteristics of the built environment. Again, not only residential locations were considered but also the work locations of both household partners. The analysis shows that the residential location only affects car use among single earners, implying that dual-earners do not feel constrained by their residential location when choosing a commuting mode. Conversely, characteristics of the work location influence car use for commuters in general and for dual-earners in particular. It was found that, in dual-earner households with only one car, the partner with the longest commuting distance and the work location with the lowest density is most likely to commute by car. Two-car households are obviously more car-oriented than single-car households, but even then, at most only one car tends to be used for commuting. The work location also plays a role here. Apparently, in car-holding households with young children, men are more inclined to leave the car at home. Other work-related features that affect car commuting are flexible working times and, especially, possession of a company car.

All in all, the following conclusions can be drawn. First, it appears that the built environment affects travel behaviour, although different characteristics have different degrees of impact. As soon as the built environment becomes more compact, people tend to engage in more activities. This, in turn, leads to more tours, but with shorter travel times and distances it also leads to more complex tours, which actually take longer. This finding is largely consistent with previous findings obtained elsewhere (e.g. Krizek, 2003). The ultimate effect of the residential environment on total travel time and distance is therefore on balance relatively small. This finding confirms earlier research in the Netherlands that used different data and/or a different methodology (Snellen *et al*., 2001; Meurs and Haaijer, 2001; Schwanen *et al*., 2004; and Snellen and Hilbers, 2007). Higher density at the work location also tends to lead to more activities and hence to slightly greater travel distances which, however, are travelled less by car. Thus, eventually, a more compact pattern of work locations leads to fewer car kilometres. This aspect has not been examined in these previous studies. Overall then, the built environment does have an impact on daily travel distance, but the relationship between the built environment and activity-travel patterns is quite complex and characterized by many direct and indirect, both positive and negative effects, so that the ultimate overall impact – all things considered – is rather limited. This finding may be partly explained by the law of constant travel time (e.g. Schafer and Victor, 1997), which says that people are inclined to spend the benefits of more efficient transport on satisfying their latent demand for activity participation

(Golob, 2000). Recent research (e.g. Van Wee *et al.*, 2006) has even indicated that travel budgets in the Netherlands have slightly increased recently.

Conversely, the results broadly confirm existing empirical evidence that the built environment has a greater influence on car ownership and car commuting than on daily travel distance. The less compact the residential environment, the greater the probability of car ownership (Giuliano and Dargay, 2006). The same holds, albeit to a lesser extent, for the work environment. However, the residential environment has only a limited influence on the probability that the car will be used for commuting. This finding is inconsistent with some literature (e.g. Schwanen and Mokhtarian, 2005), however the work environment was shown to exert a greater influence.

Second, although only a few studies have paid attention to the work environment (Chatman, 2003; Chen *et al.*, 2008), this thesis has consistently demonstrated the impact of the work location. It has also shown that other aspects of the job also play a role.

Third, although the academic literature is paying increasing attention to interdependencies in households (e.g. Timmermans and Zhang, 2009), few studies have addressed car-related interdependencies between the working partners in the household (Badoe, 2002). This thesis confirms the assumptions of the activity approach and reveals a clear interaction in this domain. The longer the hours worked by the female partner, the greater the probability that dual earners will buy an extra car. This implies that the first car is used mainly by the male partner. The distance between the railway station and the work location of the male partner also has an influence on the decision whether to buy a car. In dual-earner households with one car the male partner will leave the car more often at home if the female partner assumes primary responsibility for the care of young children. The fact that the partners consider each other's needs is a clear indicator of interdependence: the partner with the longest commuting distance and/or the work location with the lowest density takes priority in use of the car.

Fourth, as the data for this study was available on various spatial scales (including a very low one), it was possible to demonstrate the relevance of spatial scale at which characteristics of the built environment were measured. Concepts such as mixed land use and density by definition depend on the choice of spatial entities and the demarcation of the study area. As the sensitivity of the relationship between the built environment and activity-travel behaviour to spatial scale has been largely ignored, the results of previous studies may be flawed. Effects of scales can be interpreted by assuming that people take different spatial scales into account when deciding on activities and travel. In the analysis of travel time and distance the spatial indicators that were calculated with a radius of two and a half kilometres provided the best-fit model. This is plausible, because the higher the density on this scale, the greater the probability that there will be enough activities in the neighbourhood; this density of activities does not appear when measurements are taken on a considerably lower scale. The models for car ownership and choice of commuting mode did, however, offer a better fit with micro density with a radius of less than half a kilometre. Apparently, this is the scale at which people decide whether to buy and use cars. As such decisions depend partly on the availability of parking space and public transport within walking distance, a greater distance is less relevant.

In conclusion, this thesis showed empirically that, as advocated in urban planning and design, the built environment has certain effects on travel behaviour. However, it also showed in line with activity theories (Chapters 1 and 2) that this relationship is quite complex and that in that sense the simple reasoning behind concepts such as compact cities and mixed land use is not supported by empirical findings. This thesis adds to the existing knowledge by demonstrating that the relationship becomes complicated when intermediate issues, such as compensation mechanisms and latent travel demand, interdependencies between household members, different spatial scales, and the role of the work location in addition to the residential location enter the equation. Ultimately, the effectiveness of these policies does not seem to depend primarily on the assumed primary effects, but on the secondary and even tertiary effects that are difficult to understand and reason in general, but depend on the specific constellation of land use, built environment, household characteristics and transport networks. In general, North American evidence that a more compact residential environment reduces car travel was broadly confirmed, although the effects seem weaker for the study area in the Netherlands, particularly in terms of travel distance. Clearly, the behavioural mechanisms operate in a similar way.

7.3 Reflections

This section touches on a number of behavioural and methodological issues that need to be placed in perspective or have been insufficiently addressed. This thesis concentrated mainly on car travel – including commuting – in relation to the work situation. Previous studies (e.g. Handy, 1992; Boarnet and Sarmiento, 1998) have shown that the built environment has even greater effects on shopping, leisure and other travel destinations that are not work-related. Future research could explore the impact of the characteristics of such non-work activities in a Dutch context.

Various aspects of the built environment are relevant in this study, namely: the work location as well as the residential location, the different scales on which the main indicators are measured; and the specification of only a limited number of variables, particularly an urban density index for the combined density of homes, access to employment, and retail surface and an index for the mix and density of access to employment and retail surface. Some of the models in the literature on the relationship between the built environment and travel incorporate a large number of urban-form variables (e.g. Cervero, 2002; Bhat and Guo, 2007) in an attempt to accurately estimate the aspects of the built environment that vary with certain aspects of travel. In that context, it should be emphasized that initially, a large number of indicators was tested in this study as well but most of them showed such strong collinearity. Consequently, some of the estimated parameters were difficult to interpret, even showed unexpected signs and proved more or less interchangeable (*cf.* Cervero and Kockelman, 1997). Of course, these are statistical effects and unlikely capture behavioural tendencies. A decision was therefore taken to apply, where possible, a few strong indicators such as the urban density index. In order to make the studies comparable, the same indicators were used in all analyses. The urban density index can be viewed as proxy variable which may be assumed to reflect many factors, such as residential density, access to employment, mixed functions, the availability of amenities, the proximity of motorways, congestion levels and shortage of parking space as well as the availability and frequency of public transport (Steiner, 1994; Boarnet and Crane, 2001).

The travel data for this study were collected in 2000 with the aid of conventional questionnaires and diaries in which the respondents recorded all their activities and movements for two days (Arentze *et al.,* 2001; Krygsman, 2004). It was a burdensome task to incorporate these data into a consistent and complete database which registers the exact location of activities and which matches times and places. Nowadays, most of this work could be avoided by providing the respondents with a GPS-based device. They would, of course, still need to keep a note of their activities (Bohte and Maat, 2009; Stopher *et al*., 2008).

The planning and design concepts presuppose that urbanisation patterns affect travel, and hence that travel behaviour can be manipulated by applying the right urbanisation principles. However, it is increasingly argued that the reason why individuals do not exhibit specific types of behaviour is not because the built environment leaves them no choice. On the contrary, they opt for a specific urban form because they prefer a specific travel pattern. This behaviour is referred to as residential self-selection (Boarnet and Crane, 2001; Cao *et al.,* 2007; Bohte *et al.,* 2009) and is displayed, for example, by people who live near a railway station because they enjoy travelling by train and by car-based households who prefer to live in the suburbs. As it would require an extensive study to explore this hypothesis – and as the database for this study does not have the required variables – no attempts have been made in this direction. However, there are indications, for example, as the household income increases and children are borne, households opt, on average, for car-friendly, low-density neighbourhoods. Assuming that the freedom to follow personal preferences increases along with earnings, the decision to travel by car could be linked to the choice of neighbourhood. It should ne noted, however that we deal here with indications, which can also refer to a spurious relationship, so more detailed research is needed.

The aim of studies in this field is to discover whether people change their travel behaviour after moving to another residential or work environment. The analyses in this study are cross-sectional; in other words, the relationships that were found between the built environment and travel variables apply to a specific moment in time. A cross-sectional study uncovers associations but it does not, strictly speaking, indicate causality. To identify causal relationships a longitudinal study would be preferable, which would focus on whether households change their travel behaviour after relocating to a different urban form.

Another question that needs to be explored is the long-term effect of compact urbanisation. In recent decades density has increased substantially in the Netherlands, most notably within the Randstad. At the same time, suburban urbanisation has emerged in the regions surrounding the Randstad (see Maat and Harts, 2001). Changes in urbanisation will affect not only travel trends but residential mobility trends as well. Will people flee the ever-increasing density in the Randstad or will they be drawn to better transport options than the car? This question has barely been addressed. Susilo and Maat have pioneered analyses of urbanisation and commuting behaviour for several decades (2007), but have not tackled the issue of residential mobility.

Though the American and European (or Dutch) concepts rest on the same basic principles, they exhibit significant differences, most of which can be traced to differences in spatial structure, transport options, culture and the costs of driving. One should therefore be wary about transferring American research findings to a European situation or vice-versa. But what about the many, seemingly remarkable similarities in behavioural mechanisms regarding the relationship between land use and travel? To date, Newman and Kenworthy (1989) and Kenworthy and Laube (1999) have compared travel patterns on the level of aggregate cities, while Giuliano and Dargay have (2006) compared the national travel surveys of the US and the UK, and Timmermans *et al.* (2003) compared travel diary data of sources from the US, Canada, Japan, the UK and the Netherlands. An unavoidable limitation of these studies is that they needed to rely on data sets that differed in their administration, classification of activities, sampling, etc. Consequently, at best, they allow global comparison, so it would be much better to design a comparative international study in which data on travel behaviour, the built environment and other individual and household characteristics are collected and analysed in the same way.

7.4 Policy recommendations

The study findings indicate that the built environment influences the travel behaviour of individuals and households in a complex manner. As urbanisation progresses, the use of the car in urban areas somewhat declines. But the effects are small. Less car travel is partly offset by other developments. Higher densities bring shorter distances and more chain trips, which cut travel time, but the freed-up time is spent on extra activities that are within reach. Similarly, people who work in a more compact work environment use alternative modes of transport to get to work, but this may be because their partner has a greater need of the car. One important lesson is that behavioural mechanisms are never simple; they invariably elicit compensation. Hence, there is no point in forcing households into compact residential environments that they do not want – it is better to invest time and energy in people who prefer a cycle-friendly environment or a location with easy access to efficient public transport (cf. Handy, 2005; Snellen *et al.*, 2001).

In the past few decades Dutch spatial planning policy has focused on concentration at the level of urban regions, while simultaneously encouraging densities and mixed-use development. More recently, attention has shifted to an even higher spatial scale: the polycentric network city. This study (and others, e.g. Schwanen *et al.*, 2004) revealed, however, that the greatest influence of the built environment is on mode choice. This is particularly evident on the micro scale. It would therefore be interesting to see whether more advanced neighbourhood designs, in terms of mode shifts, can be developed (as advocated by Marshall, 2005). Whereas Smart Growth and New Urban designs in the US focus on pedestrians, in the Netherlands the most obvious travel mode is the bicycle. This was actually applied once in the new town of Houten, where high car ownership and low densities go hand in hand with low car use (see Maat, 2000), but the experiment was never repeated.

More attention also needs to be paid to the work location. The literature offers very little empirical research on the influence of the spatial structure of the work location or other destinations. This study shows that the work location does exert an influence, albeit to a lesser extent than the residential location. It may be concluded that the Dutch government's policy to encourage worker-intensive businesses to settle at more compact locations and to improve accessibility to public transport is promising, although expectations should not be too high. The density of many low-density industry parks may be increased and new business sites may be better connected to public transport networks.

Finally, most policies concentrates on necessary activities, such as living and commuting. But these activities are such an integral part of people's lives that they adapt these to their personal preferences, which are often expressed in low-density neighbourhoods and commuting by car. Government policy that neglects these preferences will inevitably encounter resistance. Other factors that put pressure on the mobility system – and might be good candidates for targeted policies – include leisure travel (around 50 percent of all travel) and the excessive availability and use of company cars. Other initiatives that might assist the management of the adverse effects of car use include pricing policies to level off congestion in peak hours and technological improvements, such as electric mobility, which may sever the link between car travel and environmental damage.

What is wise for future policies? Although other policies may be more effective in the short term, urban sprawl needs to be prevented as this has long lasted impacts. Further concentration and densification do not reduce the need to travel as people tend to spend the benefits of shorter distances on satisfying their latent travel demand, but they do help to reduce car use. The challenge facing planners is to design cities and neighbourhoods that make it easier for people to drive less and are attractive to live in at the same time.

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Verstedelijking en autogebruik

Analyses van onderlinge afhankelijkheden

Kees Maat

Samenvatting

Achtergrond

In de afgelopen decennia is een wetenschappelijk debat gevoerd over de vraag of de gebouwde omgeving van invloed is op verplaatsingsgedrag. De achtergrond van dit debat wordt gevormd door de turbulente groei van het autoverkeer en de gevolgen daarvan voor bereikbaarheid en milieu. Verondersteld wordt dat door een compactere stedelijke structuur het gebruik van de auto verminderd kan worden. Immers, door stedelijke concentratie, hogere dichtheden en functiemenging is de kans groter dat de gewenste bestemmingen op loop- of fietsafstand liggen, terwijl hogere stedelijke dichtheden tevens het draagvlak voor openbaar vervoer vergroten. Tegelijkertijd is autogebruik minder aantrekkelijk in een compactere stedelijke omgeving, onder meer vanwege de hogere congestie en parkeerdruk en derhalve lagere reissnelheid. Deze assumpties hebben hun weg gevonden in de Amerikaanse Smart Growth en verwante New Urbanism principes. Vergelijkbare verwachtingen komen in Europa terug in noties over compacte verstedelijking. Vooral in Nederland is stedelijke concentratie al vele decennia een gangbaar beginsel in het nationaal ruimtelijk beleid: aanvankelijk in het streven tot samenhangende stadsgewesten, naderhand aangescherpt in het compactestadsbeleid en recenter in de ideeën over bundeling rond knooppunten van infrastructuur en verstedelijking. Nader onderzoek is nodig om te bepalen of stedelijke concentratie wel aan de verwachtingen over automobiliteitsreductie voldoet. Zorgvuldigheid is immers geboden, want interveniëring in de stedelijke structuur is een langdurige en kostbare aangelegenheid die generaties lang impact heeft. Bovendien prefereren veel huishoudens een ruim opgezette woonomgeving.

Vandaag de dag is er een groot aantal studies beschikbaar naar de relatie tussen de gebouwde omgeving en verplaatsingsgedrag, vooral uit de Verenigde Staten. Aanvankelijk werden vooral onderzoeken uitgevoerd die aantoonden dat de stedelijke vorm en structuur samenhangt met aantallen verplaatsingen, de lengte van verplaatsingen en vervoerswijzekeuzen. Niettemin bleek het moeilijk om ondubbelzinnig aan te tonen dat compactere verstedelijking zal leiden tot minder autogebruik. Recenter onderzoek veronderstelt daarom dat de relatie veel complexer ligt en richt zich meer op de tussenliggende keuzen en onderlinge afhankelijkheden tussen verplaatsingen, gezinsleden en locaties. In dit proefschrift wordt de activiteitenbenadering gehanteerd als theoretisch kader waarbinnen deze relaties bestudeerd kunnen worden. Deze benadering veronderstelt dat mensen hun doelen nastreven door deel te nemen aan activiteiten die veelal in tijd en ruimte van elkaar

gescheiden zijn. In een complex besluitvormingsproces trachten individuen en huishoudens hun doelen te realiseren door keuzes te maken over het alloceren van activiteiten in de tijd, naar locaties, naar de wijze waarop deze verbonden worden in ketens en de keuze van vervoermiddelen. Hoewel de gebouwde omgeving in toenemende mate deel uitmaakt van activiteitenonderzoek, zijn er nog diverse aspecten die aandacht behoeven, met name de ruimtelijke dimensies van de relaties tussen de verschillende aspecten van verplaatsingsgedrag.

Om te beginnen onderzoekt dit proefschrift wat de rol is van de omgeving op de wijze waarop mensen hun dagelijkse activiteiten- en verplaatsingspatroon organiseren. In een compacte stedelijke omgeving kunnen afstanden tot de gewenste activiteiten weliswaar korter zijn, maar de nabijheid maakt het tevens gemakkelijker om ook te participeren in activiteiten met een lagere prioriteit. Ook kunnen activiteiten gemakkelijker gekoppeld worden in verplaatsingsketens waarin meerdere locaties worden aangedaan (een zogeheten ‘tour’). Ten tweede, omdat veel onderzoeken zich beperken tot de woonomgeving en de ruimtelijke configuratie van de bestemming negeren, richt de aandacht zich ook op de rol van de werklocatie. Ten derde wordt ervan uitgegaan dat veel besluiten over activiteiten en verplaatsingen plaatsvinden in gezinsverband, bijvoorbeeld door het delen van voorzieningen, zoals een auto. Onderzocht wordt of er sprake is van interactie tussen partners ten aanzien van beslissingen van autobezit en -gebruik. Ten slotte wordt nagegaan of de invloed van de gebouwde omgeving zich afspeelt op verschillende ruimtelijke schaalniveaus.

Teneinde deze aspecten te toetsen, hanteert dit proefschrift de volgende vraagstelling: *in welke mate en op welke wijze is de verstedelijking van de woon- en de werkomgeving van invloed op verplaatsingsgedrag, rekening houdend met individuele en huishoudenskenmerken?* Het onderzoek is weergegeven in één theoretisch en vier empirische hoofdstukken. De invloed van de gebouwde omgeving is nagegaan voor de dagelijkse verplaatsingsafstand, ketengedrag, autobezit en autogebruik ten behoeve van de woon-werkverplaatsing. Er is rekening gehouden met onderlinge afhankelijkheden tussen activiteiten in ketenverplaatsingen en dagelijkse patronen, tussen de gezinshoofden onderling en tussen de woon- en de werkomgeving. De nadruk ligt op de auto omdat deze de dominante vervoerswijze vormt met de meeste effecten op congestie en milieu.

Het studiegebied omvat de Noordvleugel van de Randstad, te weten Amsterdam, Utrecht, Almere, Hilversum en Woerden, alsmede kleinere steden, voorsteden en dorpen. In de internationale literatuur biedt de keuze voor Nederland als studiegebied de mogelijkheid tot inzichten in een niet-Amerikaanse situatie met een jarenlange specifieke ruimtelijke-planningstraditie. Aangezien voor de analyses de bestaande databronnen tekort schoten, zowel voor de activiteiten- en verplaatsingspatronen als voor de ruimtelijke detaillering, is in het jaar 2000 een nieuwe, veelomvattende dataset verzameld. De respondenten hebben een tweedaags activiteitendagboekje bijgehouden en enquêteformulieren ingevuld. Tevens zijn gedetailleerde ruimtelijke indicatoren toegevoegd voor stedelijke dichtheid en functiemenging, gemeten op verschillende ruimtelijke schaalniveaus, voor zowel de woon- als de werkomgeving. Na selectie op complete huishoudens en woon- en werklocaties omvatte het databestand 1211 individuen in 660 huishoudens.

Conclusies

Hoofdstuk 2 bevat een theoretische beschouwing waarin ingegaan wordt op de veronderstelde effecten van planningsconcepten. Vanuit deze concepten wordt betoogd dat compactere verstedelijking leidt tot kortere verplaatsingsafstanden en meer mogelijkheden tot ketenverplaatsingen, waardoor mensen dagelijks minder hoeven te reizen en gebruik kunnen maken van langzamere vervoerswijzen. Deze benadering gaat er vooral van uit dat mensen verplaatsingstijden trachten te minimaliseren, doch schiet tekort. De micro-economische nutstheorie reikt daarentegen het inzicht aan dat mensen kosten, zoals reistijd, afzetten tegen de baten die het hen oplevert. Daarom kan verwacht worden dat mensen geneigd zijn om reistijdwinst om te zetten in extra nut verder weg, bijvoorbeeld een betere supermarkt. Indien we er op basis van de activiteitentheorie van uitgaan dat mensen niet slechts afzonderlijke ritten afwegen, maar complete dagelijkse activiteitenpatronen plannen, kunnen we veronderstellen dat reistijdwinsten worden omgezet in extra verplaatsingen die anders niet gemaakt konden worden (latente vraag). Beredeneerd kan worden dat compactere verstedelijking, als gevolg van lagere snelheden en kortere afstanden wel aanzet tot het gebruik van fiets en openbaar vervoer. De bijdrage van compacte verstedelijking aan automobiliteitsbeheersing is alles overziend minder eenvoudig dan gesuggereerd wordt door de planningsconcepten. De analyse van verplaatsingsgedrag schiet daarom tekort als alleen verplaatsingsafstanden en aantallen ritten worden bestudeerd en behoeft dus een bredere benadering.

In hoofdstuk 3 wordt getoetst in hoeverre de gebouwde omgeving van invloed is op de dagelijkse verplaatsingsafstand. Aangezien verplaatsingsafstand zelf geen keuze is, maar de consequentie van andere beslissingen, wordt in dit hoofdstuk een causaal model getoetst waarin deze tussenliggende keuzen worden opgenomen. Hiertoe is een structureel-vergelijkingsmodel (structural equation model) opgesteld met indicatoren voor de woon- en de werkomgeving, activiteiten in drie klassen, activiteitenfrequentie en reistijd per tour, dagelijkse reistijd en dagelijkse verplaatsingsafstand. Het model laat zien dat ogenschijnlijke effecten in een bepaalde richting opgebouwd kunnen zijn uit de wisselwerking tussen tegengestelde effecten, zowel direct als indirect. Analyse van de woonomgeving wijst uit dat mensen weliswaar kortere dagelijkse verplaatsingsafstanden hebben naarmate ze in hogere dichtheden wonen, maar dat dit effect gedeeltelijk weer teniet wordt gedaan omdat ze dan deelnemen aan extra activiteiten. Hogere dichtheden en menging rond de werkplek zorgen zelfs voor toename van de dagelijkse totale afstanden, maar het aantal autokilometers vermindert wel.

Hoofdstuk 4 bestudeert de invloed van een compactere gebouwde omgeving op ketengedrag, dus het aaneenschakelen van meerdere activiteiten in tours. De resultaten tonen dat hogere stedelijke dichtheden leiden tot meer activiteiten en meer tours. Bovendien zijn de tours complexer, dat wil zeggen dat er meer activiteitenlocaties worden aangedaan. De toename van het aantal tours doet de gemiddelde afstand per tour dalen, terwijl de toename van de complexiteit de afstand per tour doet stijgen. Per saldo doet het effect van een hogere stedelijke dichtheid via ketenverplaatsingen de dagelijkse verplaatsingsafstand toenemen.

De volgende twee hoofdstukken hebben betrekking op autobezit en autogebruik voor woon-werkverkeer vanuit het perspectief van huishoudens. Hoofdstuk 5 analyseert de invloed van de woon- en de werkomgeving op autobezit, rekening houdend met de kenmerken van het werk van de partners. Logit modellen zijn toegepast voor alleenverdieners en tweeverdieners. De modelresultaten voor de sociaaldemografische kenmerken en de woonomgeving zijn plausibel en consistent met de literatuur. Diverse kenmerken van het werk zijn geanalyseerd. Naarmate de werkomgeving compacter is en beter toegankelijk met de trein, neemt het aantal auto's in een huishouden af. In huishoudens met een leaseauto van het werk zijn vaker twee of meer auto's. Bedrijven die hun werknemers voorzien van een leaseauto kiezen vaker voor suburbane locaties. Er zijn diverse aanwijzingen gevonden van afwegingen tussen partners. Bijvoorbeeld, tweeverdieners neigen ernaar een tweede auto aan te schaffen als de vrouwelijke partner een lange werkweek heeft. De afstand tot het station nabij het werk van de man is van invloed omdat mannen vaker verderweg werken, derhalve de fiets geen optie is en de keuze gemaakt moet worden tussen openbaar vervoer en auto.

Hoofdstuk 6 analyseert of de beslissing om met de auto naar het werk te reizen afhankelijk is van de kenmerken van de woon- en de werkomgeving, waarbij ingeval van tweeverdienersgezinnen rekening gehouden wordt met beide partners. Een compactere woonomgeving blijkt alleen de kans op autogebruik te reduceren bij alleenverdieners, terwijl de mate van stedelijkheid van de werkomgeving voor zowel alleen- als tweeverdieners van invloed is, zelfs indien tweeverdieners beiden voorzien zijn van een auto. Andere aspecten die gerelateerd zijn aan het werk, zoals de mate van flexibiliteit van werktijden en de beschikbaarheid van een leaseauto, zijn eveneens van invloed op de vervoermiddelkeuze naar het werk. Tevens kunnen verscheidene interacties tussen partners worden aangetoond, zoals de grotere kans dat mannen de auto thuislaten wanneer er jonge kinderen in het gezin zijn. Interessanter is evenwel de interactie met betrekking tot ruimtelijke aspecten.

In tweeverdienershuishoudens met één auto blijken partners met de grootste woon-werkafstand en partners met de laagste stedelijke dichtheid op de werklocatie het meest geneigd om met de auto te reizen.

In alle analyses bleek het schaalniveau waarop de gebouwde omgeving gemeten, is van belang. Dagelijkse reisafstanden bleken het best passende model op te leveren op basis van ruimtelijke indicatoren die berekend zijn op een schaalniveau van tweeënhalve kilometer. Dit is niet onlogisch, want naarmate de dichtheid hoger is op dit schaalniveau, is het waarschijnlijker dat er voldoende activiteitenlocaties in de buurt zijn; deze activiteitendichtheid komt niet tot uiting op een lager schaalniveau. De modellen voor autobezit en vervoerswijzekeuze voor woon-werkverkeer verklaarden het best op basis van een stedelijke dichtheid gemeten op het lage schaalniveau van een kleine 400 meter; het is dus de directe omgeving die al of niet de ruimte voor een (extra) auto bepaalt.

Alles overziende blijkt uit dit proefschrift dat de gebouwde omgeving inderdaad van invloed is op het verplaatsingsgedrag van individuen en huishoudens, zoals verondersteld wordt in de concepten over mobiliteitsgedrag. Naarmate de stedelijkheid hoger is, neemt de mobiliteit enigszins af. De effecten zijn echter gering. Waar enerzijds kilometers worden gereduceerd, blijken deze anderzijds weer gecompenseerd te worden. Een hogere dichtheid zorgt voor kortere afstanden en meer ketenverplaatsingen, hetgeen de reistijd beperkt; anderzijds wordt de vrijgekomen tijd weer besteed aan extra activiteiten die binnen bereik zijn. Dit wordt mogelijk verklaard door de wet van behoud van reistijd: mensen zijn geneigd om de winst van efficiëntere verplaatsingen te gebruiken voor latente vraag.

De gebouwde omgeving is duidelijker van invloed op het bezit en gebruik van de auto. Naarmate de woonomgeving minder compact is, blijkt de kans op autobezit flink toe te nemen; hetzelfde geldt in iets mindere mate voor de werkomgeving. In de mate van autogebruik voor woon-werkverkeer is de werkomgeving zelfs sterker van invloed dan de woonomgeving. Echter, als werknemers in een compactere werkomgeving met alternatieve vervoermiddelen naar het werk komen, is dit nogal eens omdat de partner de auto harder nodig heeft. Immers, indien een partner meer moeite moet doen om werktaken te verrichten, of tevens zorgtaken heeft te vervullen, of meer moeite heeft om de werklocatie te bereiken, wordt de auto eerder aan hem of haar toebedeeld of wordt er juist een (extra) auto aangeschaft.

Aanbevelingen

Hoewel dit onderzoek diverse nieuwe inzichten heeft opgeleverd, kunnen er niettemin nog suggesties gegeven worden voor toekomstig onderzoek. Steeds vaker wordt betoogd dat mensen niet een bepaald verplaatsingsgedrag vertonen omdat ze door de gebouwde omgeving daartoe worden aangezet, maar dat ze voor een bepaalde omgeving kiezen omdat deze een bepaald verplaatsingsgedrag mogelijk maakt (residentiële zelfselectie). Bijvoorbeeld, wie graag met de trein reist gaat nabij het station wonen. Er zijn aanwijzingen dat mensen met hogere inkomens, en dus meer vrijheid in de keuze van een woning, kiezen voor buurten die in lagere dichtheden zijn uitgevoerd en tevens autogebruik makkelijker mogelijk maken. De toetsing hiervan is een onderzoek op zichzelf en kan met de dataset in dit onderzoek niet beantwoord worden.

De analyses in deze studie zijn cross-sectioneel van aard, dat wil zeggen dat de relaties voor één moment zijn bestudeerd. Hierdoor komen wel samenhangen aan het licht, maar strikt genomen geen causaliteit. Longitudinaal onderzoek, waarin nagegaan wordt of huishoudens na verhuizing naar een ander verstedelijkingstype ook hun verplaatsingsgedrag aanpassen, geeft verdergaand inzicht. In het verlengde hiervan: in de afgelopen decennia heeft in Nederland een sterke verdichting plaatsgevonden, met name in de Randstad, terwijl in de ring rondom de Randstad een meer suburbaan verstedelijkingstype is ontstaan. Analyse of compactere verstedelijking aanleiding geeft voor verhuisgedrag, is een vraag waaraan nog nauwelijks aandacht is besteed.

Hoewel de Amerikaanse en Europese/Nederlandse concepten dezelfde uitgangspunten delen, zijn er grote verschillen in ruimtelijke structuur, de beschikbare vervoersmogelijkheden, de kosten van de auto en culturele verschillen. Het is daarom onverstandig om al te lichtvaardig Amerikaanse onderzoeksresultaten toe te passen op de Europese situatie en vice versa. Niettemin blijken veel gedragsmechanismen ten aanzien van de relatie tussen verstedelijking en mobiliteit verrassend goed met elkaar overeen te komen. De beste manier evenwel om te toetsen of dit werkelijk zo is, is een internationale studie, waarin op eenzelfde wijze data verzameld wordt over verplaatsingsgedrag, de gebouwde omgeving en andere individuele en huishoudenskenmerken.

De resultaten uit dit proefschrift kunnen bijdragen aan verdere beleidsvorming. In de afgelopen jaren is het Nederlandse beleid verschoven van compactestadsbeleid naar een beleid gericht op stedelijke netwerken. De focus ligt daardoor minder op nabijheid en meer op bereikbaarheid in het netwerk en derhalve minder op afstandsreductie. Dit is in lijn met de resultaten uit deze studie, die uitwijzen dat beleid om reisafstanden te reduceren nauwelijks werkt. Verdere concentratie en verdichting op de schaal van de stedelijke regio reduceert geen dagelijkse verplaatsingsafstanden, want mensen zijn steeds weer geneigd om de bespaarde kilometers om te zetten in nieuwe kilometers voor latente activiteiten. Een belangrijke les uit dit proefschrift is dat gedrag nooit eenvoudig is, maar altijd compensatiemechanismen oproept. Het heeft daarom geen zin om huishoudens te forceren in compacte buurten te wonen indien ze die behoefte niet hebben. Beter is het om de inspanning te richten op hen die wel een fietsvriendelijke buurt of een omgeving met goed openbaar vervoer prefereren. Ruimtelijk mobiliteitsbeleid werkt immers beter om bezit en gebruik van de auto wat af te buigen naar alternatieve vervoerswijzen en daarvoor is vooral aandacht voor de microschaal, dus de korte afstanden, nodig. In de Verenigde Staten richt die inspanning zich op wandelen, in Nederland zou deze zich meer kunnen richten op fietsverkeer.

Verder behoeft de werklocatie meer aandacht. Terwijl de literatuur nog heel weinig empirisch onderzoek laat zien naar de invloed van de ruimtelijke structuur van bestemmingen, blijkt uit deze studie dat werklocaties wel degelijk van invloed zijn, soms wat meer, soms wat minder dan de woonomgeving. Er kan dus geconcludeerd worden dat het Nederlandse beleid om werknemersintensieve bedrijven op compactere locaties te huisvesten, juist is. Deze bevinding is een aansporing om de vele bedrijventerreinen die nog in zeer lage dichtheden zijn uitgevoerd, te verdichten.

Een zorgvuldig ruimtelijk beleid maakt het mogelijk om de mobiliteit enigszins te beheersen. Steeds dient echter de gedragsrespons van de reiziger doordacht en geanalyseerd te worden. Het is de uitdaging voor planners om steden en buurten te ontwerpen die het mensen gemakkelijker maakt om minder van de auto gebruik te maken en die tegelijkertijd aantrekkelijk zijn om in te wonen.

Appendix Questionnaires and diary

Household questionnaire

VRAGEN OVER UW HUISHOUDEN EN WOONSITUATIE

1. Wat is uw naam (initialen/achternaam)? ....

2. Wat is uw postcode? ....

1. Welke inkomenscategorie is het best van toepassing op het inkomen van uw huishouden?	❑ beneden modaal ❑ gelijk aan modaal (40 – 50 duizend gulden bruto per jaar) ❑ tussen 1 en 2 keer modaal ❑ 2 keer modaal (ca. 90 duizend bruto per jaar) ❑ meer dan 2 keer modaal ❑ weet niet
2. Hoe lang woont u in uw huidige buurt?	............................maanden/jaren*
3. Welk type woning bewoont u?	❑ flat ❑ twee onder een kap ❑ appartement ❑ vrijstaande woning ❑ rijtjeswoning ❑ anders, ...
4. Is dit een huur- of koopwoning?	❑ huurwoning (*beantwoord vraag 4a*) ❑ koopwoning (*beantwoord vraag 4b*)
4.a. Wat betaalt u iedere maand aan kale huur? (*exclusief service kosten*)	*f* ....
4.b. Hoe hoog schat u de huidige verkoopwaarde van uw woning?	Ongeveer *f* ....
5. Hoeveel (woon- en slaap-)kamers telt uw woning?	.... kamers
6. Welke faciliteiten heeft uw woning? (*meerdere mogelijkheden*)	❑ een balkon ❑ een schuur ❑ een garage ❑ een tuin, ongeveer .... vierkante meter
7. Bent u van plan te verhuizen binnen twee jaar?	❑ ja, niet actief op zoek ❑ ja, actief op zoek ❑ nee
8. Zijn er in uw huishouden fietsen en/of bromfietsen aanwezig? Zo ja, hoeveel?	❑ nee ❑ ja, ... fietsen ❑ ja, ...brom/snorfietsen
9. Zijn er in uw huishouden auto's en/of motoren aanwezig? Zo ja, hoeveel?	❑ nee ❑ ja, ... auto(s) eigen bezit ❑ ja, ... auto(s) lease of van de zaak ❑ ja, ...motor(en)
10. Waar parkeert u deze auto(s)/motor(en) wanneer u thuis bent?	❑ op de oprit ❑ garage aan/bij woning ❑ parkeerplaats op straat voor de deur ❑ parkeerplaats (op ca. ...... min. lopen vanaf woning) ❑ individuele garage (op ca. ..... min. lopen vanaf woning) ❑ collectieve garage (op ca. ..... min. lopen vanaf woning) ❑ anders, nl ....
11. Wat is de reisduur tot de dichtsbijzijnde bushalte vanaf uw woning?	.... minuten lopen

*doorhalen wat niet van toepassing is

z.o.z.

12. Wat is de naam van het dichtstbijzijnde treinstation vanaf uw woning?	....
13. Wat is de reisduur tot dit treinstation vanaf uw woning?	.... minuten lopen/fietsen/per bus/per tram/per auto*
14. Wat is de reisduur tot de dichtstbijzijnde oprit van autosnelweg vanaf uw woning?	.... minuten per auto
15. Heeft uw huishouden betaalde hulp in de huishouding? Zo ja, voor hoeveel uur per week?	❑ nee ❑ ja, ... uur per week
16. Indien jonge kinderen aanwezig, maakt uw huishouden gebruik van betaalde oppas?	❑ nee ❑ ja, dagelijks ❑ ja, enkele malen per week ❑ ja, enkele malen per maand ❑ ja, één keer per maand ❑ ja, minder dan één keer per maand

S.v.p. cijfer omcirkelen

17. Hoe beoordeelt u het groen in uw wijk?	1	2	3	4	5	6	7	8	9
	zeer laag				neutraal				zeer hoog
18. Hoe beoordeelt u de bereikbaarheid van uw wijk per auto?	1	2	3	4	5	6	7	8	9
	zeer laag				neutraal				zeer hoog
19. Hoe beoordeelt u de bereikbaarheid van uw wijk met het openbaar vervoer?	1	2	3	4	5	6	7	8	9
	zeer laag				neutraal				zeer hoog
20. Hoe beoordeelt u de fietsvriendelijkheid van uw wijk?	1	2	3	4	5	6	7	8	9
	zeer laag				neutraal				zeer hoog
21. Hoe beoordeelt u de aanwezigheid van parkeervoorzieningen?	1	2	3	4	5	6	7	8	9
	zeer laag				neutraal				zeer hoog
22. Hoe beoordeelt u de sociale veiligheid in uw wijk?	1	2	3	4	5	6	7	8	9
	zeer laag				neutraal				zeer hoog
23. Indien van toepassing, hoe beoordeelt u de verkeersveiligheid van de route van huis naar de basisschool van uw kinderen?	1	2	3	4	5	6	7	8	9
	zeer laag				neutraal				zeer hoog
24. Hoe beoordeelt u de verkeersveiligheid in uw wijk?	1	2	3	4	5	6	7	8	9
	zeer laag				neutraal				zeer hoog

Individual questionnaire (only relevant pages)

deel 1

ALGEMENE VRAGENLIJST

Allereerst vragen wij u enkele gegevens over uzelf. In de envelop zit ook nog een los vel toegevoegd met een aantal vragen over uw huishouden en uw woonsituatie in het algemeen. Het is de bedoeling dat één van de leden van het huishouden deze als vertegenwoordiger van uw hele huishouden invult.

1.	Wat is uw geslacht	❑ man ❑ vrouw
2.	Wat is uw beroep?	....
3.	Zou u aan willen geven in welke klasse uw persoonlijk netto jaarinkomen valt?	❑ geen inkomen ❑ tot *f* 10.000,- ❑ *f* 10.000,- tot *f* 20.000,- ❑ *f* 20.000,- tot *f* 30.000,- ❑ *f* 30.000,- tot *f* 40.000,- ❑ *f* 40.000,- tot *f* 50.000,- ❑ *f* 50.000,- tot *f* 60.000,- ❑ *f* 60.000,- tot *f* 70.000,- ❑ *f* 70.000,- of meer
4.	Heeft u een handicap, die u beperkt in de vervoermiddelen die u kunt gebruiken?	❑ nee, *ga door naar vraag 5* ❑ ja
4.a.	Zo ja, welke vervoermiddelen kunt u vanwege deze handicap niet of beperkt gebruiken? (*meerdere mogelijkheden*)	❑ auto, als bestuurder ❑ auto, als passagier ❑ bus ❑ tram ❑ metro ❑ trein ❑ fiets ❑ anders. ....
5.a	Heeft u de beschikking over een fiets?	❑ nee ❑ ja
5.b.	Heeft u de beschikking over een brom- of snorfiets?	❑ nee ❑ ja
6.	Heeft u een rijbewijs? (*meerdere mogelijkheden*)	❑ nee ❑ ja, ik heb een autorijbewijs (*beantwoord vraag 7.a.*) ❑ ja, ik heb een motorrijbewijs (*beantwoord vraag 7.b.*)
7.a.	Kunt u over een auto beschikken?	❑ nee ❑ ja, wanneer ik maar wil ❑ ja, in overleg met mensen binnen/buiten* het huishouden
7.b.	Kunt u over een motor beschikken?	❑ nee ❑ ja, wanneer ik maar wil ❑ ja, in overleg met mensen binnen/buiten* het huishouden
8.	Indien u werkt, krijgt u een vergoeding van uw werkgever voor gemaakte reiskosten in het woon-werk verkeer?	❑ ja ❑ ja, alleen voor OV ❑ nee
9.	Heeft u een openbaar vervoer abonnement of kortingkaart? (*meerdere mogelijkheden*)	❑ nee ❑ ja, ik heb een week/maand/jaarkaart* voor de bus ❑ ja, ik heb een kortingkaart voor de trein ❑ ja, ik heb een pas-65 ❑ ja, ik heb een studentenweek/weekendkaart* ❑ ja, ik heb een maand/jaartrajectkaart* voor de trein ❑ ja, ik heb een NS/OV-jaarkaart*
10.	Wat is de naam van het door u meest gebruikte treinstation, hoe gaat u daar meestal naar toe en hoe lang doet u hierover?	❑ ik maak nooit gebruik van de trein ❑ NS station: .... vervoermiddel(en) naar station .... reistijd naar station .... minuten

*Doorhalen wat niet van toepassing is

deel 2

UITGEBREIDE ACTIVITEITENLIJST

Voor een aantal activiteiten willen wij graag weten **hoe vaak** deze door mensen worden gedaan en hoeveel tijd eraan wordt besteed. Daarom vragen wij u in de onderstaande vragenlijst voor de vermelde activiteiten aan te geven hoe vaak u deze activiteiten gemiddeld per dag, per week, per maand of per jaar verricht en **hoeveel tijd** u daaraan besteedt. Daarbij telt u alleen de tijd die u besteedt aan de activiteit zelf. **De reistijd telt dus niet mee.** U kunt zelf per activiteit kiezen of u per dag, per week, per maand of per jaar invult. *Zo vult u bijvoorbeeld in dat u 2 keer per dag wandelt in uw direkte omgeving (bv. hond uitlaten) en dat u daar in totaal 30 minuten per dag aan besteedt, of dat u 2 keer per jaar een tandarts bezoekt dat in totaal 1.5 uur per jaar kost.* Doet u een activiteit nooit, plaats dan een kruisje in de laatste kolom. Grijze vakjes kunt u overslaan.

categorie	activiteit	aantal keer				totale tijd	nooit of zelden
		per dag	per week	per maand	per jaar		
1. Werk en/of school/studie	werk buitenshuis (ook vrijwilligerswerk!)						
	werk thuis (ook vrijwilligerswerk!)						
	studie/school buitenshuis						
	thuis studeren, huiswerk maken						
2. Medische zorg	bezoek huisarts						
	bezoek tandarts						
	bezoek specialist						
	bezoek fysiotherapeut, ergotherapeut, etc.						
3. Boodschappen doen winkelen	dagelijkse boodschappen (supermarkt, groenteboer, slager, etc.)						
	winkelen (alle andere inkopen)						
4. Wegbrengen/ ophalen	kind(eren) naar school/opvang brengen/ophalen						
	kind(eren) ergens anders heen brengen/ophalen						
	gezinsleden of andere personen ergens heen brengen/ophalen						
5. Sport	wedstrijd kijken (niet op TV)						
	gaan joggen						
	buitensport beoefenen (bijv. voetbal, wielrennen, zwemmen)						
	sport beoefenen in sporthal/gymzaal						
	fitness-centrum / aerobics-centrum bezoeken						

deel 3
VEEL VOORKOMENDE ACTIVITEITEN

Voor enkele veel voorkomende activiteiten willen wij verder graag weten **waar** u deze meestal uitvoert, op welk **tijdstip** en **hoe** u daar naar toe gaat. U vindt in dit deel vragenlijsten voor de activiteiten **werken, school en/of cursus/opleiding, dagelijkse boodschappen, winkelen, sport en/of clubactiviteiten** en het **brengen en halen van kinderen**. We verzoeken u die lijsten in te vullen die voor u van toepassing zijn.

Op de eerste pagina van deze enquête vindt u een lijst met vervoermiddelen. Wilt u zo vriendelijk zijn de op deze lijst vermelde codes te gebruiken?

Voorbeeld
Op de volgende pagina vindt u een voorbeeld van een ingevulde vragenlijst **werken**. De persoon van dit voorbeeld, we noemen haar Anja, heeft de volgende zaken ingevuld op het formulier:

- de werklocatie:	Anja heeft twee werklocaties
- de werktijden:	Op maandag, dinsdag en woensdag werkt ze bij ITOBA BV en op donderdag en vrijdag bij Jansen Advies; bij Jansen Advies heeft Anja vaste werktijden; bij ITOBA kan ze de tijden gedeeltelijk zelf bepalen.
- het vervoermiddel:	Om naar ITOBA te gaan fietst Anja meestal naar het station, dit duurt 18 minuten. Na 3 minuten wachten neemt ze de trein (30 minuten) en na aankomst moet ze dan nog een stukje lopen (7 minuten). Soms gaat ze met de auto, dit duurt 45 minuten. Naar Jansen Advies gaat ze meestal per auto (12 minuten, ze rijdt zelf) en soms per fiets (20 minuten).

WERKEN (ook vrijwilligerswerk)

1. Werkt u (betaald/vrijwillige)? ❑ nee, *ga door naar de volgende pagina* ❑ ja, *ga door met het invullen van dit formulier*

	Locatie 1 (*Uw belangrijkste werklocatie*)	Locatie 2 (*Uw eventuele tweede werkplek*)
2. Waar werkt u?	bedrijf/instelling: .... adres: .... postcode/plaats: .... ❑ geen vast werkadres	bedrijf/instelling: .... adres: .... postcode/plaats: .... ❑ geen vast werkadres
3. Wat is de aard van het werk	❑ betaald werk ❑ vrijwilligerswerk	❑ betaald werk ❑ vrijwilligerswerk
4. Geef aan op welke tijden u op deze locatie(s) werkt?	ma di wo do vr za zo	ma di wo do vr za zo
aanvangstijd		
eindtijd		
aantal keer per maand		
	❑ ik werk in ploegendienst/onregelmatige uren, ... uur per week/maand*	❑ ik werk in ploegendienst/onregelmatige uren, ... uur per week/maand*
5. Kunt u in enige mate zelf uw werktijden bepalen?	❑ nee ❑ ja, helemaal ❑ ja, met enkele vaste uren ❑ ja, in overleg	❑ nee ❑ ja, helemaal ❑ ja, met enkele vaste uren ❑ ja, in overleg
6. Heeft u de keuze om thuis te werken?	❑ nee ❑ ja, maximaal .... dagen per maand ik doe dit .... dagen per maand	❑ nee ❑ ja, maximaal .... dagen per maand ik doe dit .... dagen per maand
7. Hoe gaat u meestal naar deze locatie toe?	*Vul in welke vervoermiddelen U achtereenvolgens gebruikt en hoelang de reis per vervoermiddel duurt. Gebruik hiervoor de vervoermiddelen op de eerste pagina. LET OP! U moet ook het wachten invullen als onderdeel van de verplaatsing.*	
vervoermiddel	OF	OF
tijdsduur in minuten		
aantal keer per maand	.... keer/maand .... keer/maand	.... keer/maand .... keer/maand
8. Reist u in de regel alleen en/of met anderen naar uw werk en met hoeveel personen?	❑ alleen, ... keer per maand ❑ met anderen, nl ...... personen (*mijzelf niet meegerekend*) .... keer per maand	❑ alleen, ... keer per maand ❑ met anderen, nl ...... personen (*mijzelf niet meegerekend*) .... keer per maand

*Doorhalen wat niet van toepassing is

SCHOOL EN/OF CURSUS/OPLEIDING/LES

1. Gaat u naar school of volgt u een cursus of opleiding?	❑ nee, *ga door naar de volgende pagina*	❑ ja, *ga door met het invullen van dit formulier*

	Locatie 1 (*Uw belangrijkste schoollocatie*)	Locatie 2 (*Uw eventuele tweede schoollocatie*)
2. Waar gaat u naar school of volgt u een cursus of opleiding?	school: .... adres: .... postcode/plaats:	school: .... adres: .... postcode/plaats: ....
3. Geef aan op welke dagen en welke tijden u naar school/opleiding gaat?	ma di wo do vr za zo	ma di wo do vr za zo
aanvangstijd		
eindtijd		
aantal keer per *maand*		
4. Bent u verplicht op deze tijden aanwezig te zijn?	❑ ja, alle uren ❑ niet alle uren ❑ nee	❑ ja, alle uren ❑ niet alle uren ❑ nee
5. Hoe gaat u meestal naar deze locatie toe?	*Vul in welke vervoermiddelen U achtereenvolgens gebruikt en hoelang de reis per vervoermiddel duurt. Gebruik hiervoor de vervoermiddelen lijst op de eerste pagina. LET OP! U moet ook het wachten invullen als onderdeel van de verplaatsing.*	
vervoermiddel	OF	OF
tijdsduur in minuten		
aantal keer per maand	.... keer/maand OF .... keer/maand	.... keer/maand OF .... keer/maand
6. Reist u in de regel alleen en/of met anderen naar school en met hoeveel personen?	❑ alleen, ... keer per maand ❑ met anderen, nl ..... personen (*zelf niet meegerekend*) .... keer per maand	❑ alleen, ... keer per maand ❑ met anderen, nl ..... personen (*zelf niet meegerekend*) .... keer per maand

*Doorhalen wat niet van toepassing is

DAGELIJKSE BOODSCHAPPEN DOEN

Onder dagelijkse boodschappen verstaan we boodschappen die u doet in een supermarkt, bij een bakker, slager of groenteboer.

1. Doet u wel eens dagelijkse boodschappen?	❑ nee, *ga door naar de volgende pagina* ❑ ja, *ga door met het invullen van dit formulier*
2. In hoeverre bestelt u dagelijkse boodschappen via bezorgdiensten?	❑ zelden of nooit ❑ regelmatig, nl .... keer per maand

	Locatie 1 (*meest bezochte locatie*)	**Locatie 2**	**Locatie 3**
3. Waar doet u boodschappen?	winkel(centrum): .... adres: .... postcode/plaats:	winkel(centrum): .... adres: .... postcode/plaats:	winkel(centrum): .... adres: .... postcode/plaats: ....
4. Hoeveel tijd besteedt u hier gemiddeld aan boodschappen doen? (*Reistijd niet meegerekend*)	.... minuten per keer	.... minuten per keer	.... minuten per keer
5. Wanneer en hoe vaak per *maand* doet u hier meestal boodschappen (*meerdere mogelijkheden*)?	❑ door de week 's ochtends ...... keer ❑ door de week 's middags .... keer ❑ door de week 's avonds ....keer ❑ op koopavond .... keer ❑ op zaterdag .... keer	❑ door de week 's ochtends ...... keer ❑ door de week 's middags .... keer ❑ door de week 's avonds ....keer ❑ op koopavond .... keer ❑ op zaterdag .... keer	❑ door de week 's ochtends ...... keer ❑ door de week 's middags .... keer ❑ door de week 's avonds ....keer ❑ op koopavond .... keer ❑ op zaterdag .... keer
6. Vanaf welke locaties gaat u hier dan boodschappen doen, wat is hierbij het belangrijkste vervoermiddel en wat is de reistijd van deur tot deur?	❑ vanaf thuis .... keer per maand vervoermiddel:.......................... reistijd:...................... minuten ❑ vanaf werk .... keer per maand vervoermiddel:.......................... reistijd:...................... minuten ❑ vanaf elders.......... keer per maand	❑ vanaf thuis .... keer per maand vervoermiddel:.......................... reistijd:...................... minuten ❑ vanaf werk .... keer per maand vervoermiddel:.......................... reistijd:...................... minuten ❑ vanaf elders.......... keer per maand	❑ vanaf thuis .... keer per maand vervoermiddel:.......................... reistijd:...................... minuten ❑ vanaf werk .... keer per maand vervoermiddel:.......................... reistijd:...................... minuten ❑ vanaf elders.......... keer per maand
7. Gaat u hier samen met anderen boodschappen doen (*meerdere mogelijkheden*)?	❑ alleen, ...keer per maand ❑ met partner, ...keer per maand ❑ met kinderen, ... keer per maand ❑ met anderen, ...keer per maand	❑ alleen, ...keer per maand ❑ met partner, ...keer per maand ❑ met kinderen, ... keer per maand ❑ met anderen, ...keer per maand	❑ alleen, ...keer per maand ❑ met partner, ...keer per maand ❑ met kinderen, ... keer per maand ❑ met anderen, ...keer per maand

WINKELEN VOOR KLEDING, SCHOENEN, KADO'S ETC.

1. Gaat u wel eens winkelen voor niet-dagelijkse goederen?	❑ nee, *ga door naar de volgende pagina*	❑ ja, *ga door met het invullen van dit formulier*
2. In hoeverre doet u inkopen per postorder of internet?	❑ zelden of nooit ❑ regelmatig, nl .... keer per maand	

	Locatie 1 (*meest bezochte locatie*)	Locatie 2	Locatie 3
3. Waar gaat u meestal winkelen voor kleding, schoeisel, kado's, etc.?	winkel(centrum): .... adres: .... postcode/plaats:	winkel(centrum): .... adres: .... postcode/plaats:	winkel(centrum): .... adres: .... postcode/plaats: ....
4. Hoeveel tijd besteedt u hier gemiddeld aan winkelen? (*Reistijd niet meegerekend*)	.... minuten per keer	.... minuten per keer	.... minuten per keer
5. Wanneer en hoe vaak per maand gaat u hier meestal winkelen (*meerdere mogelijkheden*)?	❑ door de week 's ochtends .... keer ❑ door de week 's middags .... keer ❑ door de week 's avonds ....keer ❑ op koopavond .... keer ❑ op zaterdag .... keer	❑ door de week 's ochtends .... keer ❑ door de week 's middags .... keer ❑ door de week 's avonds ....keer ❑ op koopavond .... keer ❑ op zaterdag .... keer	❑ door de week 's ochtends .... keer ❑ door de week 's middags .... keer ❑ door de week 's avonds ....keer ❑ op koopavond .... keer ❑ op zaterdag .... keer
6. Vanaf welke locaties gaat u hier winkelen, wat is hierbij het belangrijkste vervoermiddel en wat is de reistijd van deur tot deur?	❑ vanaf thuis .... keer per maand vervoermiddel: .... reistijd: .... minuten ❑ vanaf werk .... keer per maand vervoermiddel: .... reistijd: .... minuten ❑ vanaf elders.......... keer per maand	❑ vanaf thuis .... keer per maand vervoermiddel: .... reistijd: .... minuten ❑ vanaf werk .... keer per maand vervoermiddel: .... reistijd: .... minuten ❑ vanaf elders.......... keer per maand	❑ vanaf thuis .... keer per maand vervoermiddel: .... reistijd: .... minuten ❑ vanaf werk .... keer per maand vervoermiddel: .... reistijd: .... minuten ❑ vanaf elders.......... keer per maand
7. Gaat u hier samen met anderen winkelen (*meerdere mogelijkheden*)?	❑ alleen, ...keer per maand ❑ met partner, ...keer per maand ❑ met kinderen, ...keer per maand ❑ met anderen, ...keer per maand	❑ alleen, ...keer per maand ❑ met partner, ...keer per maand ❑ met kinderen, ...keer per maand ❑ met anderen, ...keer per maand	❑ alleen, ...keer per maand ❑ met partner, ...keer per maand ❑ met kinderen, ...keer per maand ❑ met anderen, ...keer per maand

Travel/activity diary (only relevant pages)

REIS- EN ACTIVITEITEN
DAGBOEKJE

onderzoek naar
activiteiten- en verplaatsingspatronen

Naam	:
Leeftijd	:
Datum dag 1	:
Datum dag 2	:

Technische Universiteit Delft
Technische Universiteit Eindhoven
Universiteit van Amsterdam
Universiteit Utrecht
April 2000

Ik ben onderweg ... Dag 1

VERTREK

Vertrekuur: :

Medereizigers: ❑ geen ❑ partner ❑ kinderen ❑ anderen

reis:
❑ autobestuurder ❑ autopassagier ❑ taxi
❑ bus ❑ tram ❑ metro ❑ trein
❑ lopen ❑ fiets ❑ anders : ________________

Overstap / Tussenstop

Aankomsttijd: :

naam station + plaats OF straat + (huisnummer) + (postcode) + plaats

Wat doe ik hier? (er kunnen meerdere opties aangekruist worden)

❑ in-/uit-/overstappen ❑ iets kopen ❑ iets of iemand ophalen of wegbrengen

Vertrekuur: :

reis:
❑ autobestuurder ❑ autopassagier ❑ taxi
❑ bus ❑ tram ❑ metro ❑ trein
❑ lopen ❑ fiets ❑ anders : ________________

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❑ bus ❑ tram ❑ metro ❑ trein
❑ lopen ❑ fiets ❑ anders : ________________

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Vertrekuur: :

reis:
❑ autobestuurder ❑ autopassagier ❑ taxi
❑ bus ❑ tram ❑ metro ❑ trein
❑ lopen ❑ fiets ❑ anders : ________________

Indien méér overstappen: ga verder op de volgende 'ik ben onderweg' pagina!

AANKOMST

Aankomsttijd: :

Ik ben onderweg ... Dag 1

VERTREK

Vertrektijd: :

Medereizigers: ❑ geen ❑ partner ❑ kinderen ❑ anderen

reis: ❑ autobestuurder ❑ autopassagier ❑ taxi
❑ bus ❑ tram ❑ metro ❑ trein
❑ lopen ❑ fiets ❑ anders ________________

Overstap / Tussenstop

Aankomsttijd: :

naam station + plaats OF straat + (huisnummer) + (postcode) + plaats

Wat doe ik hier? *(er kunnen meerdere opties aangekruist worden)*

❑ in-/uit-/overstappen ❑ iets kopen ❑ iets of iemand ophalen of wegbrengen

Vertrektijd: :

reis: ❑ autobestuurder ❑ autopassagier ❑ taxi
❑ bus ❑ tram ❑ metro ❑ trein
❑ lopen ❑ fiets ❑ anders : ________________

Overstap / Tussenstop

Aankomsttijd: :

naam station + plaats OF straat + (huisnummer) + (postcode) + plaats

Wat doe ik hier? *(er kunnen meerdere opties aangekruist worden)*

❑ in-/uit-/overstappen ❑ iets kopen ❑ iets of iemand ophalen of wegbrengen

Vertrektijd: :

reis: ❑ autobestuurder ❑ autopassagier ❑ taxi
❑ bus ❑ tram ❑ metro ❑ trein
❑ lopen ❑ fiets ❑ anders : ________________

Overstap / Tussenstop

Aankomsttijd: :

naam station + plaats OF straat + (huisnummer) + (postcode) + plaats

Wat doe ik hier? *(er kunnen meerdere opties aangekruist worden)*

❑ in-/uit-/overstappen ❑ iets kopen ❑ iets of iemand ophalen of wegbrengen

Vertrektijd: :

reis: ❑ autobestuurder ❑ autopassagier ❑ taxi
❑ bus ❑ tram ❑ metro ❑ trein
❑ lopen ❑ fiets ❑ anders : ________________

Indien méér overstappen: ga verder op de volgende 'ik ben onderweg' pagina!

AANKOMST

Aankomsttijd: :

Codelijst Activiteiten

Activiteiten BUITENSHUIS

Code	Activiteit
werk	werken
zakelijk	zakelijk bezoek
onderwijs	onderwijs volgen (school, studie, zwemles, muziekles, ...)
vrijwillig	vrijwilligerswerk doen
boodschap	boodschappen doen (supermarkt, slager, bakker, ...)
winkel	winkelen (alle overige inkopen)
voorz	voorzieningen (postkantoor, bank, snackbar, bibliotheek, kapper, videotheek, etc)
medbezoek	medisch bezoek (huisarts, tandarts, etc)
sport	sport beoefenen (ook fitness, aerobics, etc)
kerk	kerkelijke (levensbeschouwelijke) activiteit
verenig	overige georganiseerde activiteiten (vereniging, politiek)
sociaal	sociale activiteiten (familie, kennissen bezoeken)
horeca	horeca bezoek (uit eten, café, discotheek, etc)
cultuur	culturele activiteit (bioscoop, museum, concert, ...)
recreatie	recreatieve activiten (zwembad, pretpark, natuur, park, ...)
pbreng	personen brengen
phalen	personen ophalen
gbreng	goederen brengen
ghalen	goederen ophalen
overig	overige activiteiten buitenshuis
wachten	wachten

Activiteiten BINNENSHUIS

Code	Activiteit
slapen	slapen
pv	persoonlijke verzorging
eten	eten (ontbijt/lunch/diner)
huishoud	huishoudelijk werk (ook klussen in huis, tuinieren, auto wassen, etc)
verzorg	verzorgen van kinderen
visite	visite, vrienden, familie ontvangen
werk	thuis werken (voor uw baan)
studeren	thuis studeren/huiswerk maken
thvrijwillig	thuis vrijwilligerswerk verrichten
telebank	tele-bankieren
teleshop	tele-shopping
vrijetijd	vrije tijd (lezen, TV kijken, Internet, niets specifieks doen, ...)
overig	overige activiteiten thuis
wachten	wachten

Curriculum Vitae

Kees Maat (1964) received his Bachelor's degree from the College of Education in Delft and his Master's degree in Human Geography from Utrecht University, specialising in spatial planning and geographic information systems. At the end of the 1980s, he bridged the shortage of employment opportunities as a teacher at an automation company and as an automation advisor for the Province of Zuid-Holland. He then moved to the Institute of Spatial Organisation INRO-TNO where he worked as a spatial researcher, mainly on housing and business location models. Since 1993, he has been working with the OTB Research Institute for Housing, Urban and Mobility Studies at Delft University of Technology, where he is a senior researcher and head of the Urban and Regional Development Section. From the end of the 1990s, his research area is urban development and travel behaviour, particularly the relationship between them, about which he has published in peer reviewed journals and books. He carried out contract research for the European Union, national, provincial, regional and local governments as well as for businesses. Furthermore, he supervises PhD candidates and teaches various courses in the field of land use and transportation at the Faculty of Technology, Policy and Management (also at Delft University of Technology). Since 2008 he is also connected with the section Transport Policy and Logistics' Organisation of this faculty.

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An academic and policy debate has been running in recent decades on whether and to what extent travel behaviour is influenced by the built environment. This dissertation addresses the influence on daily travel distance, chaining behaviour, car ownership, and car commuting. As cars are the dominant mode of transport, car travel received most attention. The analyses were based on a comprehensive dataset collected in the North Wing of the Randstad in the Netherlands. The study findings indicate that a more compact urban structure reduces car use. However, the effects are small. One important lesson is that behavioural mechanisms are never simple but invariably elicit compensation. The challenge facing planners is to design cities and neighbourhoods that make it easier to drive less and that are attractive to live in.

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