Temporal dependence in life trajectories and mobility decisions

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Temporal dependence in life trajectories and mobility decisions

De tijdafhankelijkheid van levensgebeurtenissen en mobiliteitskeuzen
(met een samenvatting in het Nederlands)

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Contents

Contents 3
Figures 5
Tables 7
Acknowledgements 9

Chapter 1: Introduction **11**
1.1 Background 11
1.2 Objectives of the study 13
1.4 Scope of the study 13
1.5 Organisation of the study 14

Chapter 2: Conceptual framework **17**
2.1 Introduction 17
2.2 Conceptual Framework 19
2.3 Methodology: Bayesian belief network 22
2.4 Data description 25
2.5 Analysis and results 26
2.6 Conclusion 32

Chapter 3: Survey design **35**
3.1 Introduction 35
3.2 Survey method 36
3.3 Features of the questionnaire 37
3.4 Sampling procedure 44
3.5 Sample description 45
3.6 Household and mobility events 47
3.7 Social network 49
3.8 Market perception 49
3.9 Conclusion 49

Chapter 4: Changing car ownership level: Household's adaption and anticipation **53**
4.1 Introduction 53
4.2 Literature review 54
4.3 Approach 56
4.4 Data and method 58
4.5 Results 62
4.6 Discussion 67

Chapter 5: Residential relocation: An analysis of history dependence 69
5.1 Introduction 69
5.2 Literature review 70
5.3 Data description and method 72
5.4 Results 77
5.5 Discussion 81

Chapter 6: Car commuting decision: An analysis of commute mode changing decision 83
6.1 Introduction 83
6.2 Research design 85
6.3 Data analysis 86
6.4 Results 87
6.5 Conclusion 91

Chapter 7: Bicycle commuting decision: An analysis of commute mode changing decision 93
7.1 Introduction 93
7.2 Analytical approach 96
7.3 Data 97
7.4 Results 102
7.5 Conclusion 105

Chapter 8: Residential, employment and car ownership decisions - An integrated model of dynamics 107
8.1 Introduction 107
8.2 Methodology 110
8.3 Data collection 112
8.4 Results 116
8.5 Conclusion 127

Chapter 9: Summary and discussion 129
9.1 Summary 129
9.2 Discussion 131
9.3 Direction for future research 132

References 135
Appendices 145
Samenvatting 169
Curriculum vitae 173

Figures

Figure 1.1 : Organisation of the thesis.
Figure 2.1 : Conceptual framework of long-term mobility decisions
Figure 2.2 : Conceptual framework of mobility decisions (cross-sectional)
Figure 2.3 : Network learning – relationship between events, states and decisions.
Map 3.1 : Survey area in the geographical context of Utrecht province.
Figure 4.1 : A sample showing the design of the questionnaire
Figure 8.1 : Analytical framework of data analysis
Figure 8.2 : Integrated model framework
Figure 8.3 : Structure of causal relationship among mobility decisions, household situation and events.
Figure 8.4 : Results of parameter learning in BBN
Figure 8.5 : Without any evidence from influential variables
Figure 8.6 : With the evidence for households living in apartments
Figure 8.7 : With joint evidence for households living in apartments and starting cohabitation
Figure 8.8 : With joint evidence for households living in apartments, starting cohabitation and expecting the first child next year

Tables

Table 2.1 : State dependency of apartment living and impact of income and age on the relocation decision and dwelling type preference
Table 2.2 : State dependency of terraced housing and impact of income and age on the relocation decision and dwelling type preference
Table 2.3 : Satisfaction level and probability of moving for different age and income categories
Table 3.1 : A sample format of the first section of the questionnaire.
Table 3.2 : A sample questionnaire asking about household status
Table 3.3 : A sample questionnaire asking about residential and work location
Table 3.4 : A sample questionnaire about a household's transport options and travel.
Table 3.5 : A sample of the prospective section of the questionnaire.
Table 3.6 : A sample of how social network information was collected.
Table 3.7 : Geographical distribution of the respondents over the survey areas
Table 3.8 : Highest education achieved by the respondent
Table 3.9 : Distribution of the income of respondents for 2010
Table 3.10 : History of household events
Table 3.11 : History of mobility events
Table 3.12 : Intended events
Table 3.13 : Residential, work and travel situation of peers from the respondents' social network
Table 3.14 : Market perception of the respondent
Table 4.1 : Descriptive statistics of event history
Table 4.2 : Results of panel data analysis of car ownership change
Table 5.1 : Event occurrence in the sample
Table 5.2 : Cross tabulation of residential relocation by household and other mobility events
Table 5.3 : Result of mixed logit analysis for residential relocation in a particular calendar year
Table 6.1 : Results of the bivariate analysis
Table 6.2 : Results of the panel analysis
Table 7.1 : Descriptive statistics of socio-demographic and other state variables in two samples
Table 7.2 : Modal shift occurrence
Table 7.3 : Descriptive statistics about life-cycle and mobility events
Table 7.4 : Result of modal shifts from and to bicycle commuting

Table 8.1 : Sample distribution over socio-economic characteristics and mobility states of the household
Table 8.2 : Occurrence of household and mobility events
Table 8.3 : The prediction (%) of moving up with evidences of dwelling type and household events (CURRENT year)
Table 8.4 : The prediction (%) of moving up with evidences of dwelling type and cohabitation (NEXT year)
Table 8.5 : The prediction (%) of car acquisition with evidences of household car ownership and household events (CURRENT year)
Table 8.6 : The prediction (%) of car acquisition with evidences of household car ownership and cohabitation (NEXT year)
Table 8.7 : The prediction (%) of employer change with evidences of household working status, cohabitation and age of the respondent (CURRENT year)
Table 8.8 : The prediction (%) of employer change with evidences of household working status, cohabitation and age of the respondent (NEXT year)

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Chapter 1:
Introduction

1.1 Background

Residential relocation, job switching and changing car ownership are life trajectory decisions that have a long-term impact on daily travel behaviour, in particular on commute mode switching decisions. The decisions may appear in isolation, they may however also be temporally dependent. For example, if the change of job involves a considerably longer work commute, this life trajectory event may trigger individuals or households to reconsider their current residential location or decide to switch to another transport mode. The latter, in turn, may imply that they buy a (or another) car. If the individual concerned is part of a larger household, such lifecycle events may even trigger more complex dynamics in the sense that it may trigger changes in the state of these conditions of other household members as well.

Arguing that the dynamics in these lifecycle events may be temporally dependent, is however not sufficient as it does not say anything about the temporal order of the relationship. Households may decide to move house in response to a change of job; they may also relocate in anticipation of a change of job. Ignoring these potentially interrelated dynamics in these household decisions that may have a long lasted effect may lead to less accurate predictions of individual and household activity-travel patterns and travel demand forecasts. The analysis of the dynamic relationship between these lifecycle events and their impact on daily activity-travel patterns will contribute to the changing focus in activity-based analysis on the dynamics of travel patterns along multiple time horizons (Arentze and Timmermans, 2008).

Although the analysis of interdependencies of lifecycle events can build on a long history in disciplines such as demography (e.g. Glick, 1947; Oppenheimer, 1974; van Wissen and Dykstra, 1999), the topic is relatively new and has received only scant attention in travel behaviour analysis. Van der Waerden, Borgers and Timmermans (2003a, b), attempting to conceptualise dynamics in activity-travel repertoires, argued that these repertoires may evolve into a state of disequilibrium due to *critical incidents* and *key lifecycle events* and that these may therefore be relevant concepts for studying the dynamics of activity-travel patterns. Critical incidents are events, such as an accident, that may cause a highly negative experience such that individuals reconsider their current behaviour. In contrast, key lifecycle events are (unavoidable) events in demographic, housing or job careers, such as reaching the age to have a driver's license, marriage, child birth, retirement, new job and new house. They represent structural transitions in an individual's and household's state that may lead to changes in needs and desires, in commitments, and in constraints, which in turn may trigger changes in

activity-travel behaviour and/or available resources acting upon travel behaviour (e.g. car possession).

Recently, some studies have examined the effects of life trajectory events on various aspects of travel behaviour, such as travel mode choice (Verhoeven, et al. 2005, Verhoeven, 2010), ownership of mobility resources (car, public transport pass, etc.) (Prillwitz, et al., 2006; Beige and Axhausen, 2008 and 2012), vehicle miles travelled (Prillwitz and Lanzendorf, 2006) and bicycle use (Chatterjee, et al., 2013). Verhoeven, et al. (2005, also Verhoeven, 2010), using Bayesian Belief network, modelled the effects of life trajectories on mode choice decisions. Based on retrospective event history data, they found that housing status, car availability, public transport season ticket holdership and income, as well as changes in these states are related to mode choice. Their findings also indicated the influence of time on the utility of mode choice. Analysing ownership of mobility resources, Prillwitz et al. (2006) found that birth of the first child and residential relocation are related to car ownership growth. Prillwitz and Lanzendorf (2006) analysed vehicle miles travelled and their dependence on relocation, job change, and life events in a regression analysis. They concluded that birth of a child, marriage, separation, retirement of the household's head and residential relocation characteristics influence vehicle miles travelled. Beige and Axhausen (2008), using hazard models, looked into mobility resource ownership, residential, employment and education durations. They concluded that changes in residence, education and employment decrease the probability of variations in the ownership of mobility resources. In a separate analysis, Beige and Axhausen (2012) analysed whether changes in mobility resource ownership are significantly related to changes in employment, education and residential location as well as in household demography. The results indicated significant associations between these events. For example, an increase in the distance between residence and education decreases the probability of changes in car availability. Based on interview data, Chaterjee, et al. (2013) also found that life-change events led to changes in bicycle use in various stages of the life course.

These studies point out the importance of lifecycle events in understanding dynamics in activity-travel patterns. However, some research gaps can be addressed. First, these studies fell short in providing detailed insight into the temporal dependencies among interrelated life trajectories and mobility decisions. These studies analysed temporal associations as lagged responses assuming that previous events influence future decisions and thereby ignored the possibility of pro-active behaviour and multiple temporal dependencies of a single event. For instance, relocation and car acquisition may occur simultaneously as well as at different times, depending on different household characteristics. We argue that neglecting these issues may lead to biased results in understanding interrelationship between lifecycle events, and therefore to biased prediction of their impact on travel demand. Second, insight into commute mode choice in relation to life trajectories is still rare, even though it is understandable that life trajectory decisions such as residential relocation and job switching may have direct implications for commute mode decisions. This study addresses these gaps.

To elaborate, this study contributes to the insight into the effect of lifecycle effects by extending existing analyses in a number of ways. First, in the context of residential relocation, we investigate how relocation not only depends on household and work related events, but may also be associated with changes in mobility resources. In addition, we explore not only concurrent but also lagged effects of these influences. In the context of car ownership changes, we test for similar influential events as a limited number of previous studies (job change, household events, relocation), but allow a greater flexibility in the sense that all events may have lagged effects on car ownership. In the context of structural commute mode change, the study stands out by the fact that we focus on mode change as the dependent variable, rather than on mode choice, as previous studies have done. Overall, in our analyses we allow for a wider range of temporal dependencies, by allowing for anticipated effects of life and mobility events on decisions regarding car ownership and commute mode choice. Analytically, our analyses based on year-to-year update of life trajectories decisions may provide better understanding of these decisions, since previous analyses based on event histories are very data driven and may fall short to explain the influence of a particular event on mobility choices. For instance, analysing changes in travel behaviour before and after an event does not account for the possibility that these changes may occur independently.

1.2 The objectives of the study

Based on the above discussion, the study aims to investigate temporal dependencies among interrelated decisions of residential relocation, job switch and car ownership change, and life events including demographic events and changes in work-status. The study contributes to the existing literature by answering three major questions

i. *to what extent are changes in residence, job, car ownership and commute mode interrelated?*
ii. *to what extent are these life trajectory decisions associated with life events?*
iii. *what is the temporal ordering of these processes?*

1.3 Scope of the study

The scope of the study is related to three particular long-term household decisions, viz. residential relocation, job switching and changing car ownership. It focuses on their dynamic interrelations across different time frames. To analyse these dynamic relationships, arguably, panel data would have been ideal. However, in light of the non-existence of relevant panel data and prohibitive costs and time constraints of collecting original panel data, this analysis is based on a retrospective survey. To reduce respondent burden, we focused on key aspects of demographic, professional, residential lifecycle events and had to sacrifice details, such as for example, working hours, changes in income, etc.

Simplifications were also made in the representation of the dynamics of these life trajectories events. In case of residential move, transitions were classified into moving to a

larger dwelling, moving to a smaller dwelling and not changing dwelling type. In case of job switch, change was simply recorded as change or not of the employment status of the respondents and/or his/her spouse. Change in car ownership was treated as an increase or decrease in the number of cars in the household. Commute mode switching decisions were operationalized as year-to-year switching behaviour.

1.4 Organisation of the study

The thesis starts with an elaboration of the conceptual framework and a detailed description of the data. Next, a series of chapters report the results of the analyses, focusing on simple relationships. The final analytical chapter reports an integrated representation of the temporal interdependencies between the life trajectory events using a Bayesian Belief Network (BBN). We end the thesis with a conclusion. Figure 1.1 illustrates the organisation of the thesis.

Chapter 2 explains the conceptual framework in detail, what type of relationship this study will depict and what factors are important for long-term mobility analysis. This chapter is based on the current literature and shows how existing theories and methods are conceptualised and how assumed relationships are explored using available data, based on a Bayesian Belief Network approach. Although the results are based on limited information available in existing data, it represents that BBN is an efficient way to disentangle direct and indirect relationships across multiple timeframe.

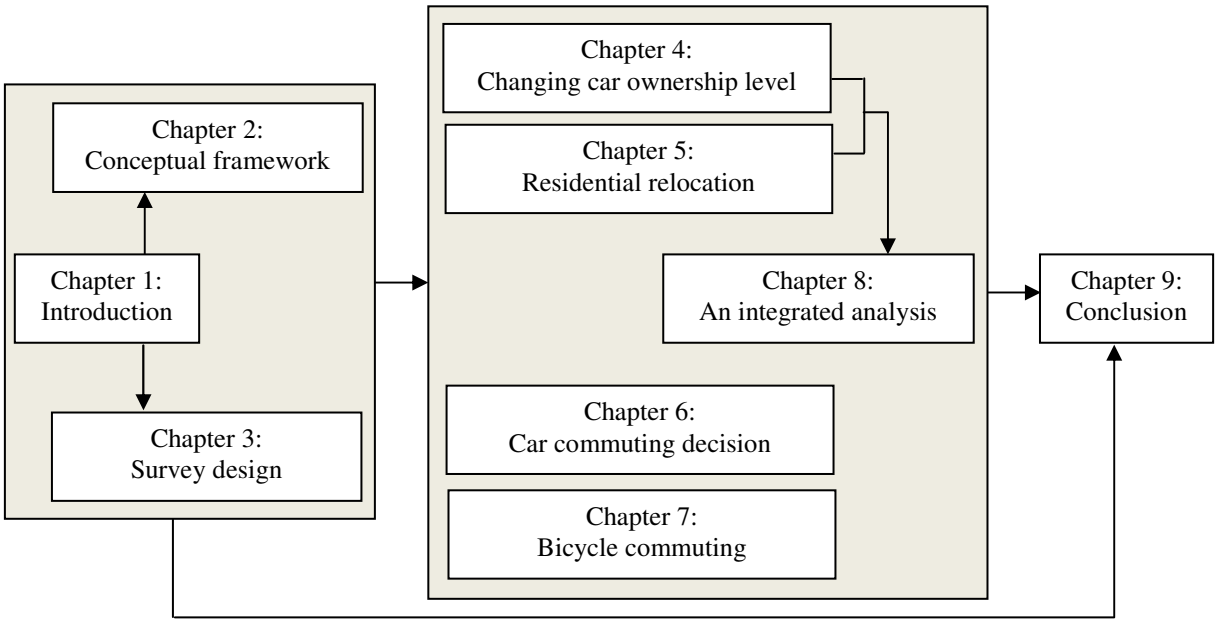


Figure 1.1: Organisation of the thesis.

Chapter 3 explains the survey design. Based on the conceptual framework, longitudinal data are required for this study. Retrospective data were collected in the Utrecht region of the Netherlands. This chapter elaborates on the survey procedures used to collect this data such

as sampling, distribution, collection, and questionnaire preparation. Features of the questionnaire are explained in detail and descriptive statistics are offered.

In Chapters 4 and 5, change in car ownership level and residential relocation are analysed and results are presented. The chapters examine lagged effects in response to previous events and lead effects as anticipation of future events. Two distinct analyses are performed based on a mixed logit analysis. First, changing car ownership level is investigated in relation with lagged (adaptation) and lead (anticipated) effects, where we find lagged, concurrent and lead effects of different life trajectory events such as lagged effect of employer change and lead effect of retirement. Second, residential relocation decisions are analysed depending on past residential relocations and considering the history of other life trajectory events, which shows that previous relocation has effect on relocation in a given year.

Chapters 6 and 7 investigate commute mode switching behaviour, in terms of both car and bicycle commuting, in response to a set of life trajectory events. These analyses are also based on a mixed logit analysis, where commute mode shift is analysed as a shift from and to car in Chapter 6 and as a shift from and to bicycle in Chapter 7. Findings show temporal associations as lagged and concurrent effects; however, lead effects are not found.

In Chapter 8, a model is developed for integrated representation of interrelationships and temporal dependencies among residential, job and car ownership decision. A Bayesian Belief Network is used to examine temporal direct and indirect relationships among the identified life trajectory events. In addition to the findings of other chapters, we show how an event is related to multiple events in multiple time frames.

Finally, a summary of the findings and a discussion of the concepts, data and analyses are presented in Chapter 9.

Chapter 2:
Conceptual framework

Reprinted from Oakil, A., Ettema, D., Arentze, T., and Timmermans, H. (2011). Longitudinal Model of Longer-Term Mobility Decisions: Framework and First Empirical Tests. J. Urban Plann. Dev., 137(3), 220–229. ©ASCE

Abstract

Recent advances in Integrated Land Use and Transport modelling have included a shift from aggregate level to disaggregate, household level. One potential advantage of this shift is that interdependencies of changes that influence household decisions can be more systematically modelled. Yet, existing models do not seem to have embraced this opportunity fully. Especially in the context of long term mobility decisions (relocation/car ownership) decisions made on various dimensions are modelled as independent and cross sectional, whereas in reality they are strongly interlinked. To address these shortcomings, this paper proposes a conceptual framework that offers a more general approach to modelling the dynamics and interdependences across different time horizons of household's lifecycle and mobility decisions. The framework incorporates the concept of stress, defined as a discrepancy between a household's present situation and its aspiration level, which in turn depends, amongst other things, on the household's social network. Bayesian Belief Networks are used to represent the complex direct and indirect dependencies between life cycle events, and long and short-term mobility decisions.

2.1 Introduction

A key assumption underlying Integrated Land Use and Transport (ILUT) models is that daily travel and longer–term decisions regarding the residential location, work status, work location and car ownership are inter-related. As a consequence, such longer-term decisions are a crucial element of ILUT models. With the advance of agent-based micro-simulation models, the options for realistically modelling longer-term mobility decisions have considerably improved. Currently, the predominant way in which ILUT models describe long-term travel decisions is by means of discrete choice models (DCM) that are based on utility maximisation theory (Salvini and Miller, 2005; Waddell, et al., 2003). A major shortcoming of this approach, however, is that decisions regarding residential location, work

location and car ownership are modelled independently as static decisions (Ettema and Timmermans, 2006; Ettema, et al., 2007; Ettema, Arentze and Timmermans, 2007). This approach, however, falls short in various respects, which may lead to biased evaluations of land use and transportation policies.

First, it has been shown that decisions regarding for instance car ownership and residential location (Pinjari, et al., 2007) and work and residential location (Waddell, et al., 2007) are interdependent. Neglecting these interdependencies may lead to false predictions of commute patterns or the spatial distribution of car ownership, leading to inaccurate travel demand forecasts. It is recognised that increasingly, discrete choice frameworks are proposed (e.g. Pinjari, et al., 2007; Waddell, et al., 2007) that describe choices across multiple dimensions in a single integrated model, thereby accounting for interdependencies between choices, such as residential location and car ownership. A drawback of such multi-dimensional models is, however, that the patterns of interdependency are specified a priori, without allowing for flexibility.

Second, discrete choice frameworks applied in current ILUT models ignore the history dependency that exists in longer-term mobility decision making. Longer-term mobility decisions such as relocation and car acquisition usually require considerable investment of time and money, and therefore occur infrequently. As a consequence, the history of such changes will have a strong impact on the probability of changing house, job or car in a given year. A related issue is the dependence of longer-term mobility decisions on lifecycle events, such as marriage, childbirth, divorce etc. To the extent that various longer-term decisions have been analyzed, most studies have used a cross-sectional approach, neglecting the time-dependency in the decision-making process (e.g., Bina and Kockelman, 2006; Waddell, et al., 2007; Pinjari, et al., 2007).

With respect to dynamics in daily travel patterns, Van der Waerden, Borgers and Timmermans (2003a, 2003b) argued that activity-travel repertoires evolve into a state of disequilibrium due to *critical incidents* and *key lifecycle events* and that these may therefore be relevant concepts for studying the dynamics of activity-travel patterns. Critical incidents are certain events such as an accident that often cause a highly negative experience such that individuals reconsider their current behaviour. In contrast, key lifecycle events are unavoidable (demographic) events, such as reaching the age to have a driver's license or planned events that occur during a lifecycle (leaving home, getting married, first child, retirement, new job, new house, etc). Such events may lead to changes in available resources and choice options. Results of qualitative studies support the relevance of the lifecycle approach in this domain. For example, Stanbridge, Lyons and Farthing, (2004) and Stanbridge and Lyons (2006) found that travel considerations are part of the prompt for the relocation itself, that travel entered the process of searching for a new property; and most importantly that relocation forced or prompted reappraisal of travel options once post-relocation journey experiences were encountered. Similar evidence has been found by Prillwitz and Lanzendorf (2006).

Very few studies have analysed the dynamics of related long-term mobility decisions. Most of these studies have used hazard models to examine the impact of duration on the occurrence of events (e.g., Feijten and Mulder, 2002; Beige and Axhausen, 2008), but have neglected the interdependency between different longer term decisions. Verhoeven, et al. (2005, 2006) suggested representing the interdependencies between life trajectory events, resources and activity-travel patterns in terms of a Bayesian network (see also Xie, Wang and Nozick, 2006). These approaches are heavily data driven and lack underlying constructs that may be useful in better understanding the underlying processes. For example, going back to an old literature in behavioural geography, Habib, Elgar and Miller, (2006) suggested the concept of stress as a mechanism to trigger changes in mobility decisions. Han, et al. (2007, 2008a, b) introduced the concept of aspiration level, influenced by the social network, as a key driver of change.

Building on this recent work, we will introduce a comprehensive framework that incorporates the dynamics and the interdependency of longer-term spatial and travel decisions in an integral framework that gives a comprehensive overview of relevant factors and mechanisms. An important element of this framework is that discrepancies between the household's aspirations and actual situation (stressors) can be dealt with by different strategies. Also the role of social environment and households' aspiration levels on longer-term mobility decisions (e.g. Silvis, Niemeier and D'Souza, 2006; Arentze, et al., 2006) are incorporated in the framework.

Finally to demonstrate how the framework can be illustrated, a Bayesian Belief Network (BBN), which specifies the relationships between states and decisions regarding various dimensions in different points in time using conditional probability tables, is estimated. This model is applied to an existing, limited data set to demonstrate its basic characteristics.

2.2 Conceptual Framework

Dynamics in decision-making

Decisions regarding the residence, job or car ownership are dynamic in nature. This dynamics stem from various mechanisms. First, people take such decisions not only based on their current state but considering anticipated changes as well. This is necessary since changes in residence, work status or car ownership requires substantial investment of time and money and only takes place infrequently. As a consequence, choices made at one moment will shape the conditions/options for future longer-term decisions. For instance, the choice where to live and in what dwelling will have a strong impact on accessible jobs, the need to own one or more cars and the budget remaining for expenditures to consumption and daily travel. Note that this implies causal relationships both forward (path-dependency) and backward (anticipation) in time. Second, Brown and Moore (1970) and Salvini and Miller (2005) postulate that longer-term travel decisions are triggered by stressors, defined as discrepancies between the households' needs and the opportunities offered by the environment. However, stress triggered decisions require time to adapt, since the necessary investment of time and

money cannot take place instantaneously. This implies a lagged response to such needs. Also, it implies path dependency in the sense that a recent change (for example, relocation or car acquisition) may set limits to new changes due to limitations in financial, temporal or mental resources.

Apart from the dynamics, it is noted that limitations in time and money budgets imply a strong interdependency between longer term decisions (Ettema, et al., 2007; Ettema, Arentze and Timmermans, 2007). For instance, households/individuals have to trade-off between spending their income to the dwelling or to transportation options (cars), between working more hours (resulting in a higher income) and having more free time etc. This implies interdependencies beyond the path dependency effect, which is limited to the effect that earlier decisions create limitations/options for later choices. Finally, it is noted that longer-term mobility decisions are not only influenced by each other, but also by external events. These external events may either be out of control of the households (health problems, losing one's job, income changes, death) or more or less deliberate choices (household formation, childbirth, divorce). Such events will have a significant impact on decisions about housing, work status and car ownership, since they may necessitate the availability of certain facilities (a dwelling with certain characteristics) or define the options for longer-term decisions (ability to work and availability of income).

Keeping these issues in mind, the mobility choices of an individual or a household are conceptualised as a long-term decision making process, where individuals' or households' behaviours change within their life courses, decisions on various dimensions are interdependent and path-dependency and anticipation play an important role (Figure 2.1).

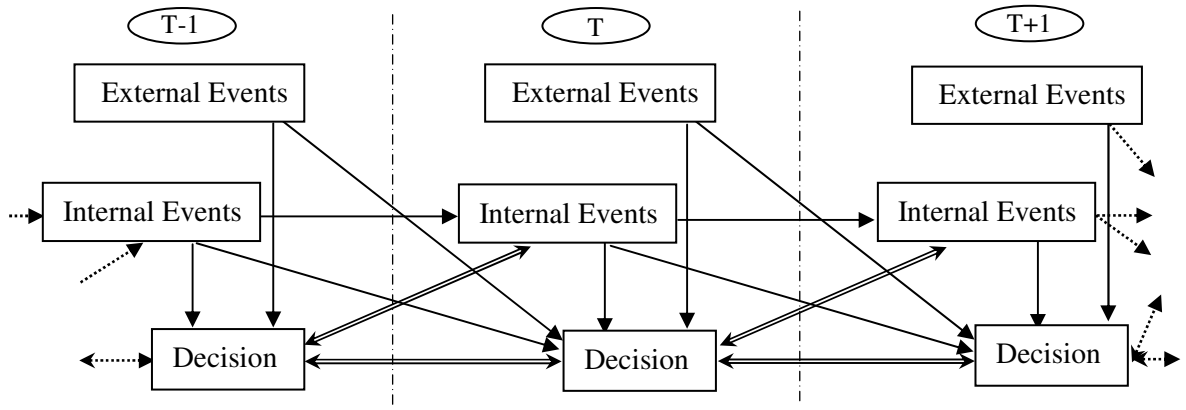


Figure 2.1: Conceptual framework of long-term mobility decisions

Accounting for path dependency and anticipation will be important in order to improve insight into the timing and sequence of households' decisions about housing, work status and car ownership in relation to demographic events. This aspect becomes increasingly important with the advance of agent based approaches in which households are maintained as individual decision making units throughout the simulation process. Apart from improving the insight

and predictive capability on the individual level, accounting for path dependency may also impact aggregate modelling results in case of larger scale simultaneous occurrence of events, such as young households moving into a newly built neighbourhood or responses to external system shocks, such as housing market disruptions.

A Stress-based approach to longer-term decision making

Having defined the interactions between various decisions and events at various points in time, this section discusses the interdependencies between decisions on different dimensions in more detail, taking into account also external factors that influence the decision process. The proposed framework builds on the stress-based approach (see Habib, Elgar and Miller, 2006), where a stressor is defined as a discrepancy between a household's aspiration level and its current circumstances. An important notion is that stressors can arise from different events and can be addressed by different longer-term decisions. For instance, a change in job location may increase commute distance (stressor), leading to a need to reduce travel time. This can be achieved by different actions such as changing residential location close to work (Bina and Kockelman, 2006; Van Ham and Hooimeijer, 2009) or owning a car or even combining both. If they recently changed their residential location, they would prefer a solution through a change in travel resources rather than changing residence again (e.g. Cao and Mokhtarian, 2005). The concept of stressors thus avoids a limited definition of one-to-one relationships between events that follow up in time. In particular, it recognises that it is not just the state change in a variable that causes a response, as is applied in some existing models (Waddell, et al., 2003), but the relationship between the new state and the aspiration level or between a changed aspiration level and the continued state. Although much work remains to operationalize this concept in applied modelling, the concept adds to the understanding of household decision making processes.

Changes in aspirations, leading to stressors, can arise from various sources. First, changes in the household composition, such as childbirth or homeleaving of children, may invoke a desire for large or smaller housing. Likewise, a changed physical condition or a change in household's resources (such as income) may lead to an increased aspiration for car ownership. It is important to note that changes in a household's situation, leading to changes in aspiration levels, may stem from both internal sources (i.e. decisions made by the household itself, such as household composition) and external sources (e.g. changes in the availability, quality and costs of travel options or a change in income due to losing one's job).

Another important factor in our framework is social interaction. Recent studies on the role of social networks suggest that households' aspiration levels are at least partially determined by valuations and decisions of other households in the social network (Dugunji and Walker, 2005). This influence stems from humans' need to feel a sense of belonging and acceptance, whether it comes from large social groups, such as clubs, office culture, religious groups, professional organizations, sports teams, or small social connections (family members, intimate partners, mentors, close colleagues, confidants). This need for belonging

also leads to a need for approval, which explains the influence of social network and community on long-term travel and residential decisions via households' aspiration level. This means that households will evaluate their current long term circumstances against some aspiration level, which is affected by the social network. An example is the phenomenon of 'keeping up with the Jones', which implies that satisfaction with the current circumstances depends on residential and travel circumstances of peers with whom the household interacts. As argued by Han, et al. (2007), awareness of choice options, aspiration level and preferences are updated over time, not only influenced by own experience but also by social contacts and information exchange. Also, appreciations of choice alternatives may change due to social interaction even if physical conditions stay the same.

The interaction between various longer-term mobility decisions, household characteristics and social environment, mediated by the concepts of stress and stressors, is illustrated in Figure 2.2. It is noted that many influences of socio-demographic characteristics on longer-term decisions fit well into this scheme. For example, young people are more likely to change tenure and dwelling than older (Habib, Elgar and Miller, 2006), which can be understood from changes in household composition and income, which take place more frequently during that stage of life. On the other hand, presence of children in a family means a higher commitment to place and thus less inclination to relocate (Feijten and Mulder, 2002).

2.3 Methodology: Bayesian belief network

Having defined the relationships between decisions on different dimensions and on different points in time using the stressor concept, the issue should be raised how these complex interactions can be represented in a formal mathematical framework that allows us to a) test empirically whether the assumed relationships are supported by observed longitudinal longer-term decisions b) apply the found relationships in the context of micro-simulation models to forecast future behaviours. Such a formal framework should meet the following requirements:

1. It should be able to describe how decisions on a variety of dimensions are made, which may mutually influence each other and are affected by a potentially large set of exogenous variables;
2. It should be able to describe relationships between decisions taken at different point in time in a dynamic fashion;
3. It should be flexible in determining which relationships (between dimensions and over time) actually occur, and not define relevant relationships a priori. This is especially relevant given the large number of theoretically possible relationships, which, if defined a priori, would make the system intractable.

In this regard, a BBN is considered an attractive alternative for econometric approaches due to its capability of defining the interdependency relationships among a set of variables in a flexible way. First, BBN do not assume a priori causal relationships between explanatory

and dependent variables, but derive these from the data. Especially in the domain of longer term household mobility decisions where state changes in one domain can be both cause and effect of developments in other domains, this constitutes an example since it avoids testing of multiple a priori defined model structures. In addition, BBN are capable of representing complex causal structures with direct and indirect effects occurring on different levels in a straightforward way.

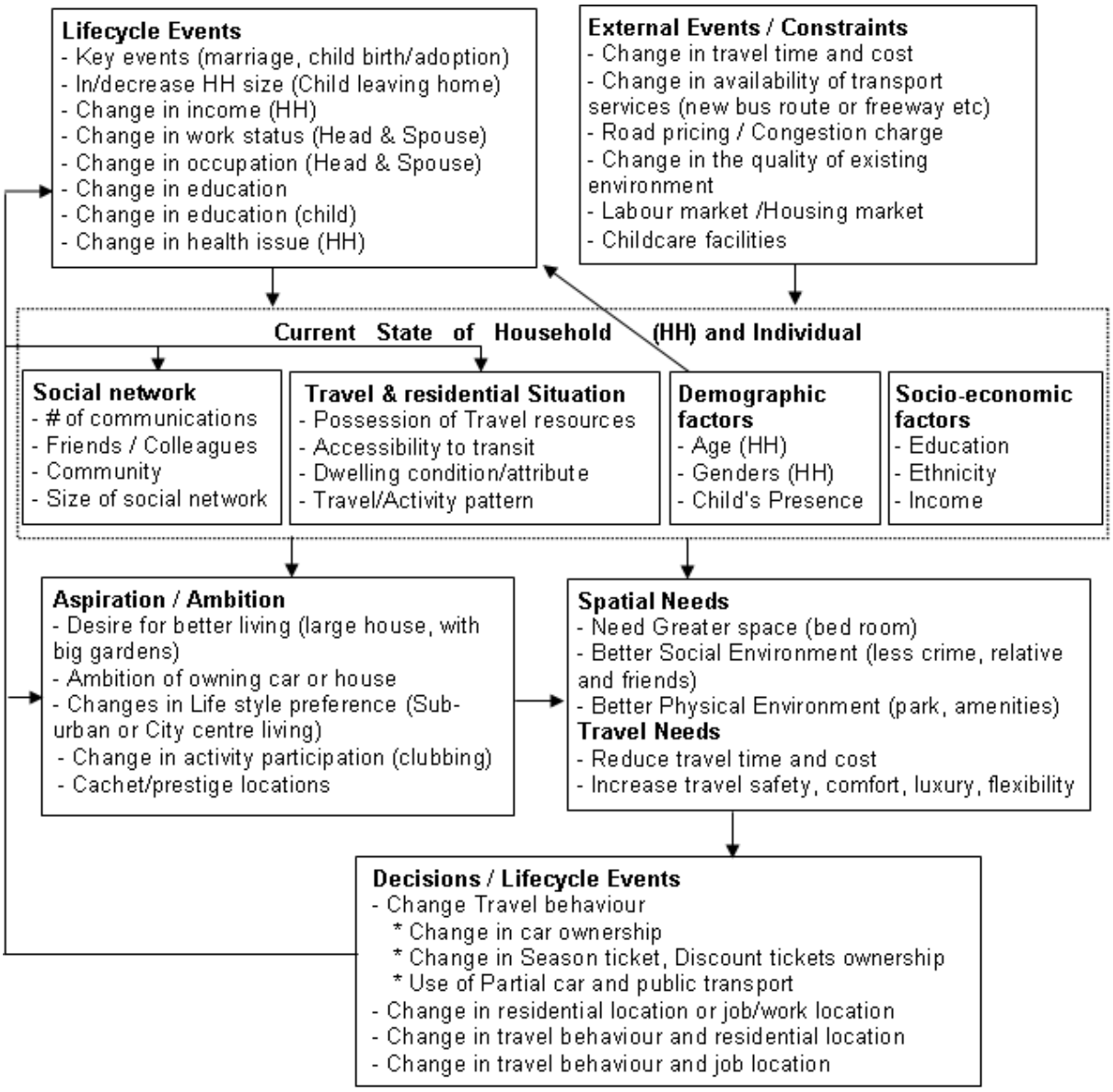


Figure 2.2: Conceptual framework of mobility decisions (cross-sectional)

The calibration of BBNs on a data set takes place in a two-step process: 1) learning the structure of the network, and 2) learning the CPTs at the nodes, given the structure. These steps are referred to as 'structure learning' and 'parameter learning' respectively and involve methods that have been developed independently from each other.

Parameter learning is rather straightforward. If there are no missing values in the data, it simply reduces to determining observed conditional frequencies for each child node and its parent nodes in the data. Therefore, machine-learning and data-mining fields have focused on algorithms for structure learning (Anderson, et al. 1989). Two groups of algorithms have emerged: 1) scoring-based learning methods, and 2) constraints-based learning methods (see Cheng, et al. 2002). Scoring-based methods view a BBN as a structure defining a joint probability distribution across the variables included in the network. These methods search for the structure that maximizes a goodness-of-fit on the observed joint probability distribution in the data. On the other hand, constraints-based methods rely on tests of conditional independency among nodes to determine whether or not the nodes should be interconnected. It has been shown theoretically that constraints-based methods are better suited than scoring-based methods for developing classifier networks. Therefore, we use a constraints-based method in the present study.

Limited space does not allow us to explain constraints-based methods in detail. For this readers are referred to the basic literature (e.g., Pearl, 1988, Heckerman, Mandani and Wellman, 1995, Spiegelhalter, et al., 1993). We will explain here some basic concepts only. A basic concept is the mutual information between two given nodes, which is defined as:

$$I(A,B) = \sum_{a,b} P(a,b) \log \frac{P(a,b)}{P(a)P(b)} \qquad (2.1)$$

Where $I(A, B)$ is the mutual information between nodes A and B; a and b represent possible states of A and B; $P(a, b)$ is the joint probability of $A = a$ and $B = b$; and $P(a)$ and $P(b)$ are the (marginal) probabilities of these states. Existence of mutual information is not a sufficient condition for a link between two nodes, as the influence may also run through other nodes. Constraint-based algorithms use the concept of *d*-separation: two nodes are *d*-separated when, loosely speaking, they are conditionally independent given possible paths through other nodes. The problem of finding the correct structure for a given set of variables is a nondeterministic polynomial-time hard (NP-hard) problem and, therefore, existing algorithms use heuristic search. The algorithm used in the current study, i.e., the Three-Phase Dependency Analysis (TPDA) (Cheng, Bell and Liu, 1997), uses a three-staged procedure: 1) drafting a network; 2) thickening the network, which adds edges to the draft; and 3) thinning the network, which removes unnecessary edges. The edges that result are undirected. In a final step, an algorithm is applied to direct the edges as far as possible by identifying so-called collider structures. Edges that remain undirected, if any, are presented to the user for making a decision (based on knowledge about the domain).

Furthermore, the TPDA algorithm uses a threshold parameter in conditional independency tests, meaning that conditional independence is falsified only if the (conditional) mutual information exceeds the threshold. This parameter has an influence on the complexity of a learned network: keeping everything else equal, the higher the threshold the lower the expected number of edges and vice versa.

Using a BBN in this case is especially useful since the causal relationships between various dimensions (residential location, car ownership, dwelling type, household composition) are difficult to determine a priori and should emerge from the data rather than being chosen a priori. Also, BBN offer the flexibility to describe how decisions made on different point in time may be interrelated.

Following an earlier work (Verhoeven, et al., 2006), a Bayesian Belief Network (BBN) is used to model the probabilistic interdependencies between events and mobility decisions. Regarding the choice of variables, we expand the approach by Verhoeven, et al. (2006) by explicitly adding satisfaction as an operationalization of the concept of stress.

2.4 Data description

An application of BBN to the conceptual framework will be illustrated using the Dutch Housing Preferences Survey (WBO). The WBO is a large scale national survey, which is held each four years. We use the WBO-2002 data set, which contains about 90,000 households. The aim of the WBO is collect extensive information on households' residential situation, such as to monitor processes on the supply and demand side of the housing market and support policies. The WBO includes detailed questions about the residential situation, such as characteristics of the dwelling and the neighbourhood, previous relocations and their underlying reasons, plans for relocations and changes in the dwelling, again with underlying reasons, and detailed questions about work, income and a set of socio-demographics such as income, education, ethnicity, age, household composition etc.

The WBO provides an attractive test case for the conceptual framework for various reasons. First, it includes information regarding many of the interrelated longer-term mobility dimensions identified earlier, such as dwelling type, residential area type, car ownership, work location (operationalized as commute distance). In addition, relevant socio-demographic variables, such as income, education, age, household composition are included. Second, it includes data for different points in time for some key variables. Apart from the current situation with respect to dwelling type, we know the previous dwelling type and time of last relocation, as well as intention to move within two years and the intended dwelling type. This allows us to test the possibility to investigate time-dependencies using BBNs. It is noted, though, that the historic and prospective data concerns only the residential status and is limited to one state backward and forward. Third, and most importantly, the WBO includes information about satisfaction with the current dwelling and the current neighbourhood, which we could interpret as indicators of stress. Data related to social networks is not captured in this survey. Unfortunately, our hypothesis about social network influence on mobility decisions cannot therefore be tested at this stage. An overview of the relevant variables has been included (Appendix-2.1).

Since the above variables are essential for our analysis, we selected cases without missing values on any of these. This reduced the original data set to a usable subsample of 37082 households. Missing values occurred especially in reporting income and in past and

anticipated relocations. Of the households in the remaining dataset about 25% changed residential location in the past three years and for about 10% household composition changed in the past three years. About 15% of the households intend to move within the next two years.

2.5 Analysis and results

As noted before, application of a BBN does not require one to define the existence of relationships between variables a priori, since the causal structure of relationships is derived from the data through evaluating mutual information between variables that cannot be explained by indirect relationships. However, it is possible, and in this case desirable, to impose certain restrictions to the model. In particular, we assume that a variable (the parent) can only influence another variable (the child) if the child describes a state simultaneous to or later than the parent. In other words, previous relocation or household change cannot be influenced by current variables and intended relocation cannot influence other variables. Other than that, the BBN establishes the relationships between the variables in our model given a threshold value of mutual information set by the analyst. The remainder of this section will first describe the network learning results, followed by some illustration of the parameter learning process. This is followed by discussing some simulation results for specific cases to illustrate the working of the model.

Network learning

The threshold parameter was set to 1.0, which is a usual setting in applications of the learning algorithm. The structure resulting from the network learning process is displayed in Figure 2.3. It has various interesting implications. First, it illustrates that at least in the current sample, time dependency does not appear to play a very important role. Previous relocation and household change are interdependent, but do not impact (directly) on current residential situation and car ownership or on intention to relocate in the near future. It is not clear to what extent this lack of time dependency is due to the limited longitudinal character of this data set, but some limitations of the data are important to note. For example, there is no direct time dependency relationship between previous residential status and current variables, but there could be relationships between previous socio-economic or car ownership variables and current variables, or between variables dating further back and current variables. These variables, however, are absent. Thus testing for longitudinal relationships should incorporate data over a longer timescale, covering more household and housing aspects of those timeframes.

A second implication is that many socio-demographic and residential variables are mutually related on a cross-sectional level in quite a complex way. For instance, household composition is influenced by education level, income and age and in turn affects number of children. Household income is influenced by age, education, household composition and number of workers. Car ownership is influenced by income, education level, household

composition, tenure, number of workers and dwelling type, but does itself not have a direct influence on any other variable. This would be an argument against spatial self-selection in car ownership models. Residential dimensions such as dwelling type and number of rooms are also influenced by various socio-demographic variables. Number of rooms is influenced by number of children, education, tenure and dwelling type. Dwelling type in turn depends on tenure, residential area type and age. Notable is the central role of age in this structure, while logically not being influenced by other variables, it has a direct impact on education, household composition, number of children, number of workers, dwelling type and desire to relocate. This confirms the importance of life cycle events as triggers for residential relocation which has been shown in numerous studies in this field. Noteworthy, however, is that age/life cycle impacts on relocation decisions also in an indirect way, e.g. via education level and residential area or via income, tenure and satisfaction with the dwelling.

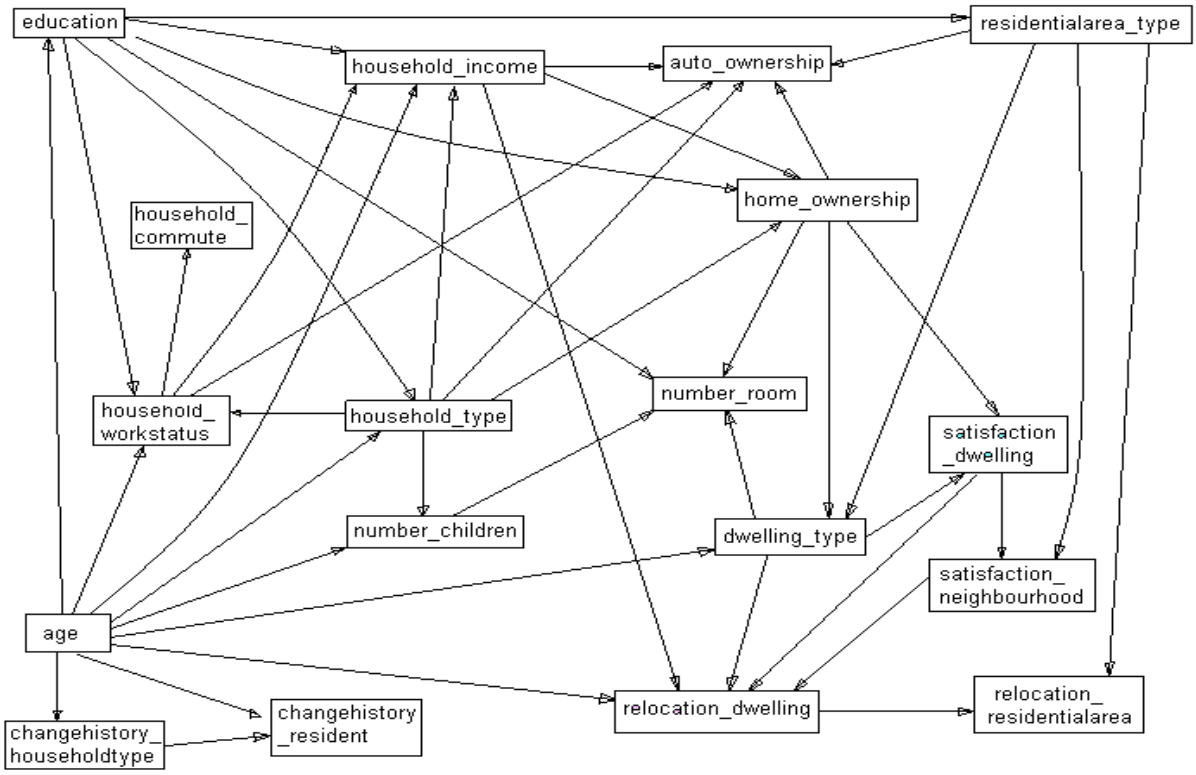


Figure 2.3: Network learning – relationship between events, states and decisions.

A final observation is that satisfaction with the dwelling and the neighbourhood play an important intermediate role in the decision to relocate. Apart from the direct effect of age, the impact of variables such as dwelling type, residential area and tenure on the relocation decision goes via satisfaction with the dwelling and the neighbourhood. This suggests that (dis)satisfaction (a concept closely related to stress) serves as an intermediate concept triggering (in this case) residential relocation. Given the casual structure suggested by the graph, one can derive that eventually (dis)satisfaction is influenced by a combination of

socio-demographic factors and residential characteristics, making it likely that satisfaction or stress describe a state of discrepancy between the desired and actual situation. Given the current data set, there is only one reasonably response to relieve the stress. In reality, however, it is possible that apart from relocation, also home improvement might be a way to deal with the dissatisfaction.

In general the structure illustrates that interdependencies between demographic and long-term mobility decisions are complex and manifold, and that using separate conventional linear models of relocation probability, work location and car ownership is a simplification that may potentially lead to biased predictions. Another implication is that (in this case) relocation decisions come about through a series of mutually related variables. For example, household type has no direct impact but it indirectly impacts on the probability of relocation to a particular dwelling. The impact goes directly to homeownership, then through current dwelling type to relocation decision.

To summarise, the model does not support our claim for longitudinal modelling of longer term mobility decisions, but the available data is too limited both in a longitudinal sense and in terms of behavioural responses to draw definitive conclusions. However, the model has depicted direct and indirect relationships among different domains, e.g. socio-economic, dwelling and/or car ownership decision domains. Most importantly, it supports the concept of stress, though not explicitly, by analysing how changes in household characteristics connected with housing situations, lead to (dis)satisfaction with the current state and thus to relocation decisions.

To further illustrate how the model represents complex interactions between long-term mobility decisions and life cycle events, we will provide more detail about the conditional probability tables (CPTs) of relocating dwelling type and relocating residential area together with an example of the concepts of aspiration and stress. It is noted that these CPTs are derived in the context of the complex structure of interactions displayed in Figure 2.3, and therefore differ from multi layered cross tabulations derived directly from the data. In particular, these CPTs form part of a system of interrelated CPTs that can be readily used to find probabilities of an event (e.g. a residential type) under specified conditions of other variables in the system.

Relocating dwelling type

Relocation and preference to move to a particular dwelling type have a direct relation with age, income, present state of dwelling type and satisfaction level with the dwelling and the neighbourhood. The complex and structural relationships of different variables with relocation decisions of people currently living in an apartment are presented in Table 2.1.

For people living in an apartment, we find that people younger than 35 and older than 65 are less likely to move than the group between 36 and 50. Income has a positive relation with relocation probability for all age classes. Overall probability to stay in an apartment is 40.2% for the lowest income group compared to 18% for the highest income group (figures not in

the table). Apparently, due to increased income, both aspiration levels and options increase. Aspiration level is also evident from the fact that elderly people do not opt for particular dwelling type even if their incomes go up.

Moving out from an apartment to a particular dwelling is mostly random (i.e. with an equal probability of moving to any dwelling type). For the oldest group, it is completely random. For the youngest group, the lowest income group prefers to move to a terraced house, whereas semi-detached is more preferred by households earning 2501-3500 Euro/month. In reverse, the same income group within the 36-50 age group prefers to move to terraced housing.

Table 2.1: State dependency of apartment living and impact of income and age on the relocation decision and dwelling type preference

People currently living in apartments							
Age	**Income**	**Don't move**	**Move to Particular dwelling type**				
			Detached	**Semi-detached**	**Corner**	**Terraced**	**No Prefer**
21-35	<=1500	47.9	9.15	8.41	9.69	**14.6**	10.2
	1501-2500	21.6	17.7	13.2	16.5	17.3	13.6
	2501-3500	17.6	15.4	**20.6**	15.4	15.4	15.4
	3500+	16.7	16.5	16.9	16.5	16.5	16.9
	No evidence	31.3	13.7	12.9	13.5	15.8	12.8
36-50	<=1500	26.1	14.9	13.8	13.8	13.9	17.5
	1501-2500	18.5	16.3	16.3	16.3	16.3	16.3
	2501-3500	18.7	15.9	15.6	15.6	**18.7**	15.6
	3500+	18.4	15.8	15.8	15.8	15.8	18.4
	No evidence	21.2	15.7	15.2	15.2	15.9	16.8
65+	<=1500	41.4	11.7	11.7	11.7	11.7	11.7
	1501-2500	20.2	16	16	16	16	16
	2501-3500	16.7	16.7	16.7	16.7	16.7	16.7
	3500+	16.7	16.7	16.7	16.7	16.7	16.7
	No evidence	34.0	13.2	13.2	13.2	13.2	13.2

The relocation probabilities of people living in terraced houses are summarised in Table 2.2. A general finding is that reluctance to move is much larger for this group than for inhabitants of apartments. Income has a strong impact on decisions in this case. The probability of moving increases as income increases. For all age groups, people with higher incomes demonstrate less probability to stay at terraced houses.

When moving, all age groups have the largest probability of moving to another terraced house. With increasing income, preference shifts from terraced house towards semi-detached or detached. 2501-3500 Euro/month earner households prefer mostly semi-detached and highest income groups tend to move to a detached house.

Table 2.2: State dependency of terraced housing and impact of income and age on the relocation decision and dwelling type preference

People currently living in terraced housing							
Age	**Income**	**Don't move**	**Move to Particular dwelling type**				
			Detached	**Semi-detached**	**Corner**	**Terraced**	**No Prefer**
21-35	<=1500	71	4.51	4.53	4.76	**10.3**	4.98
	1501-2500	75.8	3.49	6.4	5.03	5.7	3.55
	2501-3500	74.1	4.31	**8.2**	4.22	5.88	3.32
	3500+	66	**9.61**	**9.51**	4.28	6.59	3.97
	No evidence	72.9	4.77	6.93	4.63	6.9	3.86
36-50	<=1500	81.7	2.39	2.62	2.91	**6.89**	3.52
	1501-2500	81.6	3.39	4.06	3.54	4.89	2.48
	2501-3500	80.3	4.25	**6.51**	2.88	3.77	2.26
	3500+	73	**8.13**	6.89	4.26	3.85	3.87
	No evidence	79.9	4.16	4.8	3.34	4.91	2.91
65+	<=1500	88.6	1.55	1.46	1.55	**3.7**	3.12
	1501-2500	85.3	2.42	2.42	2.58	4.06	3.19
	2501-3500	77.8	4.98	3.75	3.76	4.5	5.17
	3500+	66.9	5.62	7.74	5.62	6.35	7.74
	No evidence	85.8	2.26	2.22	2.19	4	3.57

Greater probability of moving out of apartments and lower probability of moving out of terraced housing are also associated with their respective satisfaction level, as shown in Table 2.3. With increasing income, satisfaction with the apartment decreases slightly. This is consistent with our concept of differentiating aspiration level from the present state. It is more apparent for terraced houses, where people are more dissatisfied, than apartments. That is a good example of discrepancy between aspiration and current state, where state is probably higher than the present aspiration given the income. On the other hand, this represents the income constraint. But income has extra impact on relocation. Even though highest income people are satisfied with their dwelling, they show greater probability to move.

Relocating residential area

Relocation of residential area type is largely influenced by relocation decisions about dwelling type, but it is also state-dependent on the current residential location. Absence of neighbourhood characteristics may lead to limited reasoning of satisfaction of neighbourhood or other neighbourhood characters. Overall, people in the city centre are more likely to move than people in suburban or rural settings. The table also shows that inhabitants of a certain area type are most likely to relocate to a similar area type as the current. This trend is also visible for all dwelling types.

Table 2.3: Satisfaction level and probability of moving for different age and income categories

People at apartment				
Age	Income	Overall Satisfied	**Not move**	Overall dissatisfied
	<=1500	77.9	47.9	9.09
	1501-2500	77.4	21.6	9.09
21-35	2501-3500	76.8	17.6	9.09
	3500+	76.3	16.7	9.09
	No evidence	77.4	31.3	9.1
	<=1500	77.2	41.4	9.09
	1501-2500	76.3	20.2	9.09
> 65	2501-3500	74.9	16.7	9.09
	3500+	74.4	16.7	9.1
	No evidence	76.7	34	9.1
People at terraced				
Age	Income	Overall Satisfied	**Not move**	Overall dissatisfied
	<=1500	89.3	71	3.88
	1501-2500	93.1	75.8	2.3
21-35	2501-3500	94.8	74.1	1.61
	3500+	95.5	66	1.3
	No evidence	93.1	72.9	2.32
	<=1500	87.6	88.6	4.64
	1501-2500	90.2	85.3	3.52
> 65	2501-3500	93	77.8	2.34
	3500+	94.2	66.9	1.86
	No evidence	89	85.8	4.04

Concluding Remark

The resulting network (Figure 2.3) suggests that BBN are an appropriate tool to capture complex relationships between a series of dependent (and mutually related) and independent variables. This is especially an added value if causal structures are not immediately clear, also due to history dependency. The data set available for this paper allowed only for a first exploration of using BBN to model longer term mobility decisions, and had limited information regarding longitudinal behaviour and travel behaviour. Yet the complexity of the decision making is well represented. It should be emphasized that while Tables 2.1 – 2.4 in themselves are not extremely complicated, they are the outcome of probability distributions across a much wider set of variables, and are influenced by assumptions about other variables. For instance, the table giving the relationship between current residential area, current dwelling type and preferred residential area, which is here presented for average conditions, could be reproduced for a variety of combinations of socio-demographics such as

age, income, household composition etc. It is this interrelatedness between sets of conditional probability tables that creates the added value of the approach.

2.6 Conclusion

This paper has presented a comprehensive conceptual framework that describes the dynamics and interdependences in long-term mobility choices. This framework provides a basis for improvement in current ILUT models which treat longer-term mobility decisions as cross-sectional analysis and in isolation. Although earlier analytical studies have investigated dynamics of long-term mobility decisions and interdependence of events and decisions, this study contributes to the state-of-the art by treating dynamics and interdependencies in an integrated way.

To operationalize the conceptual model, BBNs are applied. These have the advantage to represent complex networks of causal relationships between a variety of factors, without a priori assuming some (causal) structure. This approach was used to derive a model based on the Dutch WBO data set which provides indicators of key variables for three points in time. Although the longitudinal character of this data is somewhat limited, the model application illustrates the potential of BBN-learning to reveal relationships between different dimensions of longer-term decision making that would not be seen using discrete choice or regression based models. The modelling outcomes support the proposed framework in that it shows that the residential situation, car ownership, work and commute status and household characteristics are mutually related according to a complex structure of direct and indirect interactions. Also, the dependence of satisfaction with the dwelling and the neighbourhood on housing and household characteristics gives an indication that aspiration levels in relation to current setting play a role in decision making, supporting the stressor concept. As indicated before, however, the data did not permit us to test the assumption of path dependency to its full extent.

The current study admittedly only gives a limited impression of the dynamics in longer-term decision making. Future work will focus on improving insights in this area in various ways. Most importantly, more appropriate data, involving retrospective data about various life domains, such as work and income, household events, residential situation, vehicle and license ownership, and most importantly about aspirations, social influences and stressors and stress, needs to be gathered to test the hypotheses underlying the conceptual framework. With respect to social influence, data collection will have to be extended to include information about mobility characteristics of peers (friends, family). Apart from eliciting the peers, information is needed regarding their housing situation, working status, vehicle ownership etc. It will be particularly interesting to investigate how such characteristics influence households' aspiration levels with respect these variables.

Furthermore, further research will address the issue of how the conceptual framework, operationalized using BBNs can be applied in predictive modelling. In principle, BBNs can be applied for micro-simulation in a straightforward way. Given the initial state of input

variables, probabilities of dependent variables (e.g. residential situation) follow directly from the BBN and may serve as a base for simulation using Monte Carlo simulation. However, application of the framework for agent-based micro-simulation involves additional issues. One issue is how the BBN should be combined with detailed models of e.g. housing choice and car choice. Another issue concerns how the BBN is combined with models of daily travel and activity participation, which may provide feedback in terms of e.g. satisfaction with the residential or commute status.

Chapter 3:
Survey design

Abstract

Longitudinal data covering both demographic events and different mobility events such as residential moves, employment change and car ownership change is scarce and difficult to collect. A retrospective survey is a useful and an efficient alternative for a panel. This chapter discusses the design of such a retrospective survey. Subsequent sections will outline how parts of the survey are developed in order to provide data about the various concepts introduced in the conceptual model. Next, the sampling strategy and fieldwork are discussed, followed by some sample characteristics and a discussion of the quality of the data.

3.1 Introduction

People take life trajectory decisions not only based on their current state but considering past events and anticipated changes as well. Residential relocation, switching jobs and changing car ownership do not happen frequently and instantaneously. The relationships between decisions on different dimensions may stretch across multiple years, implying that lagged responses and anticipation of events play an important role in the timing of such decisions. Thus, a proper description of dynamics in long-term mobility decisions should focus at changes in residential location, work location and car ownership over multiple time periods. Moreover, these decisions are household life trajectory decisions and therefore, require an integrated approach in terms of household decision-making. According to the conceptual framework, a proper representation of these decisions should account for interrelationships among multiple mobility decisions in a dynamic sense. In addition, demographic changes affect household responsibilities and activity patterns, which in turn may affect mobility decisions. To account for the fact that long-term mobility decisions are dynamic, time dependent and interrelated, the data needs to fulfil the following requirements

i. It should cover a longer period (multiple years) to capture dynamics in household decisions.
ii. It should include households' demographic situation in terms of
    - the number of persons in the household and their characteristics such as position in the household, age, gender , work situation and location.
    - a recording of important events such as cohabitation, separation, childbirth and child's home leaving

iii. It should have information of households' economic status over a longer period in terms of
   - the income of the members of the household
   - the working status of the members of the household

iv. It should have information regarding households' long-term mobility status in terms of
   - residential location over a longer period as well as characteristics of the particular residence.
   - work location over a longer period
   - car ownership level, driving license possession, availability of cars and public transportation over a longer period

v. It should cover daily mobility aspects such as
   - commuting time and mode over longer period

iv. It should incorporate households' intentions for the future with respect to the issues mentioned above.

v. It should facilitate analyses of external effects such as the effects of household's social network and perception of the housing and job market.

Following a description of the survey method, important features of the survey are explained in detail. Next, descriptions of the sampling procedure and the sample are provided.

3.2 Survey method

Although panel data are the best option for the purpose of the study, it is difficult to find such data incorporating household events in association with both long-term mobility events and travel decisions. Most available panel data is focused on single aspects, for example, either travel and household issues or residential change and household issues. Besides, information over a long period is required to cover different demographic and mobility events of a household, which is not possible to collect given the duration of the study. Therefore, we have applied a retrospective data collection approach. Previous studies (e.g., Verhoeven, et al., 2008; Beige and Axhausen, 2008) based on retrospective surveys indicate that retrospective surveys can provide reliable information about past events, if these events are important. Likely, the critical events asked for in this survey, such as residential relocation, car fleet changes and job changes may fall into this category and can be remembered with acceptable accuracy.

With respect to the method of administration of the survey issues such as ease of providing information by respondents and accuracy have been balanced against time and cost limitations. It is important to note that the required information is diverse and complex, and can in require reconstructing the household's history and checking for consistency (e.g. updating the housing history based on recalling demographic events). As a consequence, respondents may feel urged to provide additional information, for instance if their household

situation does not correspond to pre-coded categories. In addition, the formats in which data is recorded logically differ. While some questions involve simply checking a response option, other may require drawing a time line or a written answer to an open question. It was felt that a paper and pencil questionnaire, more than a web questionnaire, would provide respondents with flexibility to answer questions in various formats, provide additional information if needed and go back and forth through the questionnaire for consistency checks and memory reconstruction.

When using a paper and pencil questionnaire, the ideal option would be to conduct the survey as a face-to-face interview, so that the interviewer can provide explanation, check for consistency and notice if the situation of the respondent does not fall into pre-coded categories. Face-to-face interviews, however, were too costly and time consuming. Therefore, we opted for an approach where surveyors went door-to-door to distribute questionnaires and later pick them up when filled in. In this way, questionnaires could be collected in a cost-effective way, while leaving the opportunity to provide information before filling in.

3.3 Features of the questionnaire

The questionnaire is organised in five different sections – i. information of household members; ii. retrospective information regarding the households' work and income situation, household composition, residential, work and travel situation; iii. prospective information about households intentions regarding the same aspects; iv. information regarding mobility and residential decisions of households' social networks; and v. households' perceptions of the housing market, job opportunities, and travel costs. The survey was conducted at the household level. The original questionnaire is provided in Appendix 3.1 (in Dutch). We have used a calendar form constructing a diary of 21-year history of the aforementioned information. The important features and organisation of the questionnaire are described below.

Section 1:

This section includes information on the present status of all household members. Questions asked concern year of birth, gender, relationship with the respondent, highest education attained, current work status and work location as presented in Table 3.1.

Section 2:

This section concerns the collection of data regarding past states and events of the household. Events are defined as a change in the state in a particular year. Household events bring changes to household composition (e.g. marriage), household work situation (e.g. taking retirement) and/or to household resources (e.g. increase in income). Similarly, mobility events concern changes in job, home, car ownership level and/or commute mode. Both states and events were recorded for every calendar year starting from 1990 to 2010. The history data consists of

i. Household status (Table 3.2): Income and work status of the respondent and his/her partner; household events such as marriage, childbirth, children leaving the family home, and divorce;

Table 3.1: A sample format of the first section of the questionnaire.

	Year of birth	Gender	Position in the household	Education	Work status	Work location
Person 1		i. Male ii. Female	i. Respondent ii. Partner iii. Child iv. Parent v. Other	i. None ii. Elementary iii. Lower vocational iv. Secondary v. Preparatory mid-level vocational vi. preparatory higher vocational vii. mid-level vocational viii. preparatory scholarly ix. higher vocational x. University education xi. Other	i. Student ii. Looking for work iii. Part-time working iv. Full-time working v. Retired / Not working	
……..						
Person 6						

ii. Residential status (Table 3.3): The year one moved in, location, residential cost per month, number of rooms, building age, presence of a garden and parking facility;

iv. Work status (Table 3.3): Work location and starting year of the work of the respondent and his/her partner;

v. Travel situation (Table 3.4): Household car ownership level; car availability, commuting mode and commuting time of the respondent and his/her partner.

This resulted in a full 21 year retrospective diary of demographic, residential, professional and mobility events, permitting analyses of their mutual interaction in a longitudinal sense. In the Tables (3.2, 3.3 and 3.4), the organisation and structure of the questionnaire are shown.

Table 3.2 illustrates how we had asked the respondent to fill in the retrospective information. It is a calendar form. We provided the option to indicate that the respondent could not remember. In addition, income categorisation or other categorisation was included to reduce burden of the respondent.

Table 3.2: A sample questionnaire asking about household status

Please indicate in the calendar about important household issues/events –							
	1990	1991	1992	……	2008	2009	2010
Household status							
1. Please fill in your work situation for a particular year							
i. Student							
ii. Looking for work							
iii. Part-time working							
iv. Full-time working							
v. Retired / Not working							
vi. Cannot remember							
2. Please fill in your partner's work situation for a particular year, if applicable							
Categories same as above							
4. Please indicate your income (gross per month) for a particular year							
i. Less than 1500 euro							
ii. 1501-2500 euro							
iii. 2501-3500 euro							
iv. 3501-4500 euro							
v. More than 4500 euro							
vi. Cannot remember							
4. Please indicate your partner's income (gross per month) for a particular year, if applicable							
Categories same as above							
5. Mention number of person in household at 1990 and only when it is different from earlier.							
6. Please indicate in the calendar by "X" or "√" when you had experienced one or more of the following events.							
(1) You left parent home							
(2) Marriage/Cohabitation							
(3) Birth of children							
(4) Child's home leaving							
(7) Divorce/Separation							
(6) Death of household member (please mention the relationship with the person died)							
(7) Others (please specify)							
(8) Others (please specify)							

Table 3.3: A sample questionnaire asking about residential and work location

Please indicate your living and working situation from 1990 to the present, including the last residence and work location before 1990 –				
	Current residence	**Previous residence 1**	**…**	**Previous residence 5**
Please provide your residential situation				
7. Location (Postcode / address)				
8. When did you move to this address?				
9. Type of dwelling	i. Detached ii. Semi-detached iii. Corner-row iv. Row house v. Apartment vi. Room / Shared vii. Other (specify)	i. Detached ii. Semi-detached iii. Corner-row iv. Row house v. Apartment vi. Room / Shared vii. Other (specify)		i. Detached ii. Semi-detached iii. Corner-row iv. Row house v. Apartment vi. Room / Shared vii. Other (specify)
10. Type of ownership	i. Rented ii. Owned iii. Other (specify)	i. Rented ii. Owned iii. Other (specify)		i. Rented ii. Owned iii. Other (specify)
11. Net monthly cost				
12. Building age	i. Before 1900 ii. 1900-1930 iii. 1930-1960 iv. 1960-1990 v. After 1990	i. Before 1900 ii. 1900-1930 iii. 1930-1960 iv. 1960-1990 v. After 1990		i. Before 1900 ii. 1900-1930 iii. 1930-1960 iv. 1960-1990 v. After 1990
13. Number of rooms				
14. Garden facilities	i. Front-back garden ii. Back garden iii. No garden iv. Balcony v. None	i. Front-back garden ii. Back garden iii. No garden iv. Balcony v. None		i. Front-back garden ii. Back garden iii. No garden iv. Balcony v. None
15. Parking facilities	i. Own garage ii. Own lot iii. On-street iv. Others (specify)	i. Own garage ii. Own lot iii. On-street iv. Others (specify)		i. Own garage ii. Own lot iii. On-street iv. Others (specify)
	Current work	**Previous work 1**		**Previous work 5**
Please indicate about work situation				
24. Your work location				
25. Starting year of your work				
26. Your partner's work location				
27. Starting year of your partner's work				

In terms of residential and work location, the questions are organised based on the residences and jobs. For example, we asked the respondents about different attributes for a particular residence such as moving year or dwelling type. Table 3.3 represents how such questions are structured. This structure reduces respondents' burden, as they need not to fill every year for the same residence or work place. Moreover, it helps to avoid left censoring. For instance, even if a household does not move within the survey period, we know the moving year for that particular residence and thereby can calculate the length of stay.

For travel related questions, we used the calendar format, in order to obtain a year by year description of the car ownership, car and public transport season ticket availability and commute situation. Table 3.4 shows type and structure of travel related questions.

Table 3.4: A sample questionnaire about a household's transport options and travel.

Please indicate appropriate response for you in the calendar depicting last few years of your life and also mention the initial status at 1990 for each question –							
	1990	1991	1992	……	2008	2009	2010
Travel situation							
28. Please mention the number of cars available in your Household							
30. Please indicate which transport is available to you							
i. Full-time availability of own car							
ii. Full-time availability of business car							
iii. Part-time availability of own car							
iv. Availability of public transport season ticket							
31. Please indicate which transport is available to your partner							
Categories same as above							
32. Please mention the commuting time in minutes by the commute mode mostly used							
i. Yours							
ii. Your partner's							
33. Please mention the commuting mode							
i. Yours							
ii. Your partner's							

Section 3:

Apart from retrospective data, the questionnaire includes a prospective data collection section. This section asked about the targets and aspirations of the respondent for his/her family within a particular time period, with respect to residential, professional, mobility and

demographic developments. This extension permits one to investigate the impact of the household's aspirations regarding these dimensions. Prospective data include

i. Planned residential relocation, dwelling type, ownership and size;
ii. Planned car acquisition;
iii. Planned household events (e.g. plan to get married, have child);
iv. Planned job situation for the respondent and his/her partner (e.g. location change and working hour change); and
v. Planned travel situation for the respondent and his/her partner (e.g. getting a driving licence, commute mode change, reduce commuting time, target to avail full/part-time car).

In this section, respondents were asked to indicate their plan/target for the immediate future. This period covered 10 years, which are categorised into first year, second year, 3-5 Years, 5-10 years and more than 10 years as shown in Table 3.5.

Table 3.5: A sample of the prospective section of the questionnaire.

	Is it a target	When do you wish to achieve the target?						How certain are you? (1 to 3; 3 being the most certain)
		In 2010	In 2011	Within 3-5 Years	Within 5-10 Years	After 10 Years	Unknown	
Do you have plan ..								
36. to find a part-time work								
48. to get a driving license								
53. change the commute mode to								
i. Car								
ii. Public transport								
iii. Car + public transport								
iv. Bicycle + public transport								
v. Bicycle								
vi. Others								
63. to relocate								
64. to relocate in a different dwelling type								
i. Detached house								
ii. Semi-detached house								
iii. Corner house								
iv. Row house								
v. Apartment								
vi. Shared house								

Section 4:

This section is concerned with data about the respondents' social network and the residential, work and travel characteristics of the network partners, enabling us to investigate social influence on long-term mobility decisions, such as car ownership. However, the information consists of only the current state of the social network. We asked information for 4 peers of the respondent's network, which the respondent considers very important for his/her household decisions. The purpose was to involve the closest peers of social network in relation to mobility decisions. Table 3.6 shows how the information was collected.

Table 3.6: A sample of how social network information was collected.

	Person 1	Person 2	Person 3	Person 4
1. What is your relationship with this person?				
2. Please provide approximate age of this person				
3. Working status of this person				
i. Student				
ii. Looking for work				
iii. Part-time working				
iv. Full-time working				
v. Retired				
5. Pleas indicate income of this person (gross/month)				
i. Less than 1500 euro				
ii. 1501-2500 euro				
iii. 2501-3500 euro				
iv. More than 3500 euro				
6. Residential location of this person				
7. Moving year to this residence for this person				
8. Dwelling type for this person				
i. Detached house				
ii. Semi-detached house				
iii. Corner house				
iv. Row house				
v. Apartment				
vi. Other				
14. Number of household car of this person				
i. One				
ii. More than one				
iii. None				
15. Mostly used commute mode for this person				
i. Car				
ii. Public transport or bicycle				

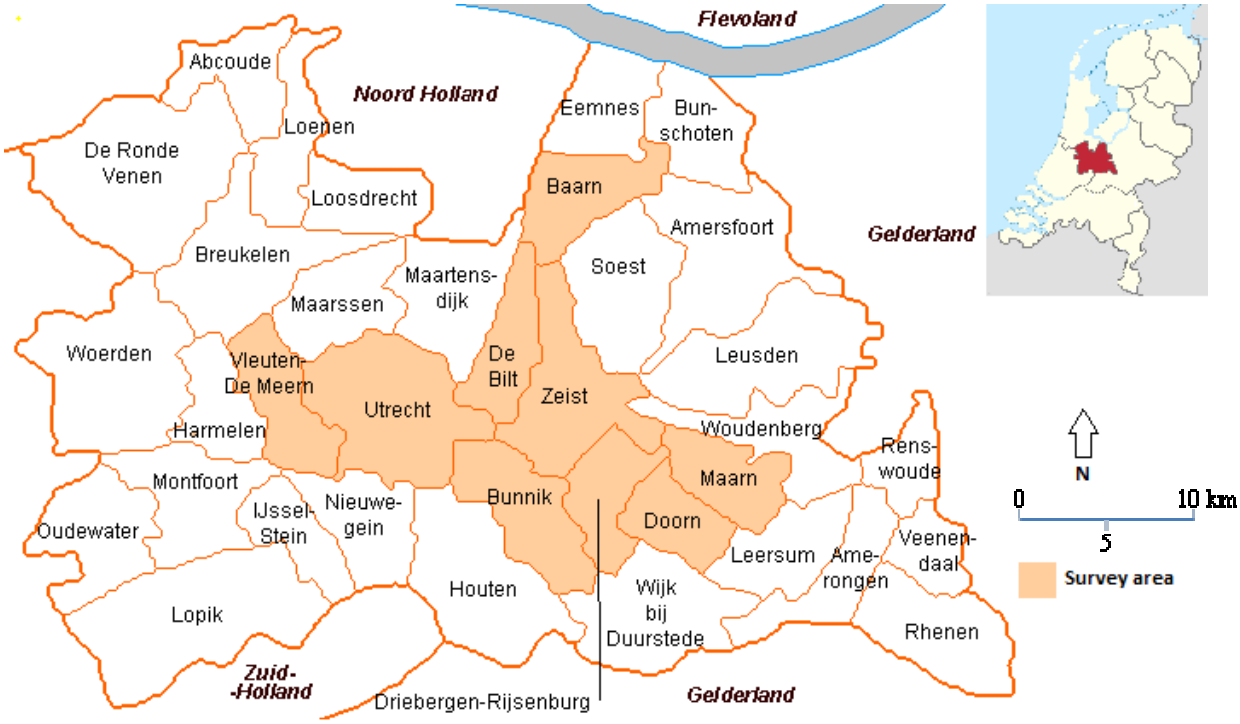
Section 5:

In this section, the respondent was asked to indicate his/her perception of the housing, job and mobility market. For example, the respondent indicated whether supply of social housing would increase, decrease or none; whether travel cost by car would increase, decrease or none; similarly for house price, job availability and commuting time. The idea is to account for external effects. We assumed that household perception regarding the market is more important than the exact market situation. Moreover, we required information about present and future market situation. The future situation is important in terms of long-term mobility decisions as such decisions are based on long-term perspectives.

3.4 Sampling procedure

We distributed approximately 1200 questionnaires to the candidate households based on expected return of 40%, i.e. about 500 questionnaires are expected to be returned. The expectation was based on a test distribution.

The survey was conducted in the Utrecht region in the Netherlands. The sampling strategy was to include municipalities (and streets within municipalities) that differ in terms of density, type of housing, accessibility to services etc., such as to obtain variations in spatial circumstances. In this regard, the survey includes residences of urban areas (Utrecht), suburban areas (De Bilt, Zeist, Bunnik, Driebergen and Baarn) and villages (Groenekan, Odijk, Werkhoven, Bosch en Duin, Maarn, Doorn and Austerlitz) as shown in Map 3.1.



Map 3.1: Survey area in the geographical context of Utrecht province.

We distributed the questionnaires as hand-to-hand delivery to the candidate households with a commitment that the candidate household would return the questionnaire. We assumed that taking a direct commitment might save time. Hand-to-hand delivery was estimated to be cost effective as well. Candidate households were selected based on the following procedures

i. From the map of the selected survey areas, streets were randomly selected to be geographically scattered and evenly distributed.
ii. Surveyors knocked on every 10th door of the selected streets and asked if they wanted to participate. If the household did not wish to participate, surveyors were instructed to knock on the next door until successful.
iii. The respondents should be at least 30 years in order to be able to report a relevant mobility history.

Given that we sampled individuals in random streets at random house numbers, the sample should be representative for the population in the study area, and range across various income and age classes and household types. However, response bias may lead to over- and underrepresentation of certain groups. In addition, while we sampled in different spatial settings, households' history may lead to inclusion of e.g. residential situations elsewhere, leading to over- or underrepresentation of certain spatial milieus across the 20 year period investigated.

3.5 Sample description

In total, we distributed 1186 questionnaires, of which 479 filled in questionnaires were returned. The return rate is 40.4%, as was expected. Since it is a retrospective questionnaire of the past 20 years, it leads to 10059 (479 * 21) observation-years per person including the survey year 2010. 44.1% of the respondents is male. However, our analyses are mostly conducted on the household basis.

The distribution of returned and filled out questionnaires over the survey areas is illustrated in Table 3.7. The table shows that the sample represents the survey areas well in terms of bringing spatial variation in our analyses.

Table 3.8 represents the distribution of highest education achieved by the respondents. Table 3.8 shows that the sample overly represents higher educated respondents. HBO and University education consist of about 80% of the sample. This might be an outcome of selective non-response to the complex questionnaire. This means that results from the analyses have to be carefully applied in the context of the Netherlands.

However, the respondent's income distribution, as shown in Table 3.9, in the survey year (2010) shows similarity with the distribution of personal income of that year in the Netherlands. It is difficult to explain over representation of high education with the income distribution. However, it is possible that the income may change over the age, but education may not.

Table 3.7: Geographical distribution of the respondents over the survey areas

	Population in 2010		The sample	
Name of the survey areas	**Frequency**	**Percentage**	**Frequency**	**Percentage**
Utrecht	**307081**	**61.8**	**173**	**36,1**
Utrecht			159	33.2
De Meern			8	1.6
Vleuten			6	1.3
De Bilt	**42017**	**8.5**	**68**	**14.2**
De Bilt			24	5.0
Bilthoven			39	8.1
Groenekan			5	1.0
Zeist	**60286**	**12.1**	**78**	**16.2**
Zeist			69	14.4
Austerlitz			1	0.2
Bosch en Duin			4	0.8
Huis ter Heide			4	0.8
Bunnik	**14459**	**2.9**	**48**	**10.0**
Bunnik			25	5.2
Odijk			12	2.5
Werkhoven			11	2.3
Baarn	**24317**	**4.9**	**27**	**5.6**
Utrechse Heuvelrug	**48801**	**9.8**	**84**	**17.7**
Driebergen-Rijsenburg			57	12.1
Doorn			16	3.3
Maarn			11	2.3
Total	**496961**	**100.0**	**479**	**100.0**

Table 3.8: Highest education achieved by the respondent

Highest education achieved	**Frequency**	**Percentage**
Lagere School (elementary school)	6	1.3
LBO (lower vocational education)	15	3.1
MAVO, MULO (general secondary education)	40	8.4
VMBO (preparatory middle-level applied education)	4	0.8
HAVO (preparatory higher vocational education)	13	2.7
MBO (middle-level applied education)	45	9.4
VWO, Atheneum, Gymnasium (preparatory scholarly education)	15	3.1
HBO (higher vocational education)	150	31.3
University Education (scholarly education)	182	38.0
Others	7	1.5
Missing data	2	0.4
Total	**479**	**100.0**

Table 3.9: Distribution of the income of respondents for 2010

Gross monthly income categories (in Euros)	Frequency	Percentage
No income	5	1,0
< 1500	105	21,9
1501-2500	89	18,6
2501-3500	87	18,2
3501-4500	59	12,3
> 4500	79	16,5
Cannot remember	13	2,7
Missing data	42	8,8
Total	**479**	**100,0**

3.6 Household and mobility events

Events are important issues in our analyses. As we intend to analyse dynamics of long-term mobility decisions, changes in the household context, which is defined as events, are very important. Changes are considered in demographic, professional and mobility aspects. Table 3.10 represents demographic and professional events and occurrence of these events for the past 21 years.

Table 3.10: History of household events

	Occurrence of the event					
	Yes		No		Missing	
Event type	Frequency	%	Frequency	%	Frequency	%
Start of cohabitation	167	1.7	9813	97.6	79	0.8
Birth of the first child	154	1.5	9686	96.3	219	2.2
Home leaving of the last child	109	1.1	9612	95.6	338	3.4
Separation	62	0.6	9918	98.6	79	0.8
Taking retirement (either or both of the partners)	180	1.8	8895	88.4	984	9.8
Taking retirement (respondent)	*127*	*1.3*	*9890*	*98.3*	*42*	*0.4*
Taking retirement (partner)	*76*	*0.8*	*9092*	*90.4*	*891*	*8.9*

Start of cohabitation, first childbirth, separation, last child's family home leaving, and retirement are included as demographic and professional household events. Compared to other statistics, the number of missing values for household events is small, since respondents were asked only to mention when any event had happened. However, a small number of missing values regarding household events is due to respondents not answering any of the household related questions. In terms of mobility events, residential relocation, car ownership changes and employment changes are recorded. Table 3.11 illustrates how often such events occurred. Table 3.11 indicates that mobility events occur more often than household events. This suggests that decisions about relocation, car ownership change or employment change

are often influenced by external factors such as policies, market, household activity pattern, changes in physical and environmental context etc.

Table 3.11: History of mobility events

	Occurrence of the event					
	Yes		**No**		**Missing**	
Event type	**Frequency**	**%**	**Frequency**	**%**	**Frequency**	**%**
Residential relocation	746	7.4	8369	83.2	944	9.4
Change in the numbers of household car	463	4.6	9125	90.7	471	4.7
Increase in the numbers of household car	*303*	*3.0*	*9288*	*92.3*	*468*	*4.7*
Decrease in the number of household car	*160*	*1.6*	*9428*	*93.7*	*471*	*4.7*
Change in the employment (Either or both of the partners)	943	9.4	6527	64.9	2589	25.7
Change in the employment by the respondent	*777*	*7.7*	*7805*	*77.6*	*1477*	*14.7*
Change in the employment by his/her partner	*350*	*3.5*	*8216*	*81.7*	*1493*	*14.8*
Commute mode shift of the respondent*						
To bicycle from other mode	*69*	*0.7*	*5837*	*58.0*	*4153*	*41.3*
From bicycle to other modes	*76*	*0.8*	*5830*	*58.0*	*4153*	*41.3*
To car from other modes	*86*	*0.9*	*5820*	*57.9*	*4153*	*41.3*
From car to other modes	*64*	*0.6*	*5842*	*58.1*	*4153*	*41.3*

* Commute mode change for partner is not shown as it consists lot of missing values and thus not considered for this study as well.

Apart from retrospective data, the survey asked also about the targets and aspirations of the respondent for his/her family within a particular time period, with respect to residential, professional, mobility and demographic developments. Table 3.12 illustrates households' intention or target regarding household and mobility events. The table depicts those intended events that are reported rather frequently by the respondents. In addition, we collected information of households' intentions regarding working situation, driving license, commuting mode and also about detail housing situation (e.g. target dwelling type, target home ownership, target size, bigger or smaller, of the dwelling). However, these events are mentioned infrequently by the respondents and therefore, are not reported in Table 3.12. Most of the events are planned 3-5 years ahead. Intentions regarding residential relocation and job change are more frequent than demographic events.

Table 3.12: Intended events

Target event type	2010	2011	3-5 years	5-10 years	>10 years	Unknown	Total
Residential relocation	11 (2.3%)	23 (4.8%)	57 (11.9%)	51 (10.6%)	44 (9.2%)	27 (5.6%)	215 (44.9%)
Car acquisition	1 (0.2%)	10 (2.1%)	9 (1.9%)	3 (0.6%)	3 (0.6%)	2 (0.4%)	28 (5.8%)
Start cohabitation	3 (0.6%)	4 (0.8%)	15 (3.1%)	5 (1.0%)	0 (0.0%)	7 (1.5%)	34 (7.1%)
Birth of a child	5 (1.0%)	9 (1.9%)	18 (3.8%)	5 (1.0%)	1 (0.2%)	6 (1.3%)	44 (9.2%)
Respondent's work relocation	11 (2.3%)	23 (4.8%)	29 (6.1%)	5 (1.0%)	1 (0.2%)	13 (2.7%)	82 (17.1%)
Partner's work relocation	5 (1.0%)	17 (3.5%)	13 (2.7%)	2 (0.4%)	0 (0.0%)	9 (1.9%)	46 (9.6%)

3.7 Social network

We collected information about work, travel and residential situation of 4 peers from the social network of the respondent. Respondents were asked to report about their peers who had influenced their decision making. Table 3.13 illustrates the answers to these questions.

The total number for this analysis is different because this is an account of 4 peers in the survey of 2010 rather person-year observation. It can be seen that missing values on every aspect are quite large. This affects our analysis on social network effect and thus we will not report the effects in the thesis. However, the description shows similarities with the information from the respondents. Most of the peers live in row houses, own at least one car and commute by car.

3.8 Market perception

As mentioned earlier, market perception regarding social housing, fuel price and job market were also asked to get an idea about external effect on mobility decisions. Table 3.14 shows the response on these aspects.

Table 3.14 shows a small number of missing values. Respondents expect that cost of travel will increase. Not surprisingly, high proportion of the respondents assumed decreasing job availability, yet most of them predicted in 2010 that housing prices would rise. The reason may be the long trend of housing prices in the Netherlands, although house prices started falling during 2009.

3.9 Conclusion

This chapter has outlined the data collection method that was used to obtain data for analysing households' long-term mobility decisions. Building on the conceptual framework, a questionnaire was developed that collected data regarding mobility aspects such as residential

situation, household car ownership level, work location, and commute mode and time; demographic aspects such as household size, and events of cohabitation, child birth, child's home-leaving and separation; professional aspects such as working status; and socio-economic aspects such as age and income. Given the non-existence of panel data including these items and impossibility to collect longitudinal data within the timeframe of the current study, we opted for a retrospective data collection covering the period 1990-2010.

Table 3.13: Residential, work and travel situation of peers from the respondents' social network

	Frequency	**Percentage**
Relationship with the peer		
Colleague	73	3.8
Friend	901	47.0
Family	77	4.0
Known	125	6.5
Missing values	740	38.6
Working status		
Student	23	1.2
Looking for work	28	1.5
Part-time working	395	20.6
Full-time working	467	24.4
Retired	254	13.3
Missing values	749	39.1
Dwelling type		
Detached	178	9.3
Semi-detached	181	9.4
Corner-row	131	6.8
Row	424	22.1
Apartment	223	11.6
Others	24	1.3
Missing values	755	39.4
Car ownership		
One	658	34.3
More than one	355	18.5
None	129	6.7
Missing values	774	40.4
Commute mode		
None	8	0.4
Car	681	35.5
Public transport and/or cycle	422	22.0
Missing values	805	42.1
Total	**1916**	**100.0**

Table 3.14: Market perception of the respondent

	Frequency	Percentage
Perception about social housing availability in 3 years		
Increase in your present area	63	13.2
Increase in other areas compare to your present area	35	7.3
No change	197	41.1
Do not know	167	34.9
Missing values	17	3.5
Perception about house price in 3 years		
It will increase significantly	15	3.1
It will increase moderately	173	36.1
It will remain same	87	18.2
It will decrease moderately	141	29.4
It will decrease significantly	21	4.4
Do not know	28	5.8
Missing values	14	2.9
Perception about job availability in 3 years		
Job will be more available	83	17.3
Job will be less available	120	25.1
No change	132	27.6
Do not know	117	24.4
Missing values	27	5.6
Perception about car use cost in 3 years		
Cost will rise significantly	195	40.7
Cost will rise moderately	230	48.0
No change	16	3.3
Do not know	24	5.0
Missing values	14	2.9
Perception about car travel time in 3 years		
Significant increase	133	27.8
Moderate increase	214	44.7
No change	66	13.8
Do not know	48	10.0
Missing values	18	3.7
Total	**479**	**100.0**

Since retrospective data can be memory biased, we have focused on household events deemed important to the household that can be recalled with acceptable accuracy. To minimize memory bias, we have checked for consistency in the dataset between related events. For example, we have checked whether the year of a relocation due to cohabitation matched with the reported year of the start of cohabitation. Based on such consistency checks, we believe that the data provides a sufficiently accurate account of household

dynamics for our purpose. We also understand that the household characteristics such as household income are difficult to recall. In this case, we have categorised the data into larger intervals to reduce the uncertainty about the reliability of the variable. Concern about memory bias has led to skipping detailed information such as neighbourhood characteristics, job location characteristics, and detailed commuting behaviour. In terms of sample representation, the sample has shown over-representation of higher educated and high-income households. This might be an outcome of selective non-response to the complex questionnaire. Although the level of detail of the data may prevent certain detailed analyses, the information collected are useful in analysing the interrelationship and timing of occurrence for long-term mobility decisions in relation to decisions made in other domains. In this respect, a unique data set has been collected in terms of the variety of household events, mobility decisions and locational decisions recorded, which allows for longitudinal analyses of relationships that have not been previously addressed.

Chapter 4:
Changing car ownership level: Household's adaption and anticipation

Abstract

This paper analyses households' decision to change their car ownership level in response to actions/decisions regarding mobility issues and other household events. Following recent literature on the importance of critical events for mobility decisions, it focuses on the relationship between specific events (e.g. childbirth and buying an extra car), rather than trying to explain the status of car ownership from a set of stationary explanatory variables. In particular, it is hypothesized that changes in household car ownership level take place in response to stressors, resulting from changed household needs or aspirations. The study includes a broad range of events. Apart from changes in work status, employer and residential location, it analyses demographic events such as household formation and childbirth. Also, it scrutinizes the temporal sequence in which chains of related events are most likely to occur. To this end, data from a retrospective survey that records respondents' car ownership status, as well as residential and household situation over the past 20 years are used. A panel analysis has been carried out to disentangle typical relationships. The results suggest that strong and simultaneous relationships exist between car ownership changes and household formation and dissolution processes. Childbirth and residential relocation invoke car ownership changes. Changes are also made in anticipation of future events such as employer change and childbirth. Childbirth is associated with increasing the number of cars, whereas the effect of employer change goes the opposite way. Job change increases the probability of car ownership change in the following year.

4.1 Introduction

Insight into the factors that influence car ownership levels is important in order to achieve objectives of diminishing car traffic as well as negative effects such as emissions. In particular, to get insight into the development path of car ownership levels, it is important to focus on the dynamics in car ownership, which is a households' decision to acquire or dispose of a vehicle. It is assumed that such decisions are influenced by variations in travel requirements (e.g. related to job change or relocation), as well as by life cycle events (e.g. childbirth, retirement) that lead to reconsidering one's situation and change in mobility choices (Lanzendorf, 2003; van der Waerden, Borgers and Timmermans, 2003; Verhoeven,

et al., 2005; Beige and Axhausen, 2008; Oakil, et al., 2011a). Although dynamics of car ownership have been studied in several studies, they are mostly based on static variables such as the number of cars based on panel data or vehicle transaction based on cross-sectional data. Moreover, knowledge about the impact of life-cycle events on car ownership decisions is limited. In this regard, the aim of the paper is to investigate the mechanisms behind changes in household car ownership levels, including both increasing and decreasing the number of cars in the household, in relation to life cycle events in demographic, professional and long-term mobility domains. Importantly, this study includes the timing of influences on car ownership decisions by allowing not only for direct responses to explanatory variables, but also including anticipated and lagged effects.

4.2 Literature review

Increasing car ownership levels have gone hand in hand with increasing car mobility in industrialized and developing countries for decades. Consistently, car ownership shows up as a key determinant in mode choice models in favour of car use (e.g., Ben-Akiva and Lerman, 1974; Train and Lohrer, 1983; Train, 1980). Therefore, many studies have been undertaken over the last decades to understand car ownership.

Studies of car ownership can be classified into various categories. Some studies have sought to explain car ownership in a cross sectional sense at the household level (e.g., de Jong, 1990; Train and Lohrer, 1983; Ryan and Han, 1999) and at the individual level (e.g. Scheiner and Holz-Rau, 2012). In particular, in such studies, the number of cars in the household is modelled as a function of household characteristics and land use characteristics. These studies have revealed that the number of adults, the number of workers and the number of individuals with a driver's license in the household (Ben-Akiva and Lerman, 1974; Ryan and Han, 1999; Whelan, 2007), and/or land-use characteristics (Bhat and Guo, 2007; Cao, Mokhtarian and Handy, 2007; Van Acher and Witlox, 2010) are important determinants of car ownership at the household level. At the individual level, car availability can be seen as an allocation of available cars between partners (Anggraini, Arentze and Timmermans, 2008) or can be based on gender or economic structure of partners in the household (Scheiner and Holz-Rau, 2012). Increasingly, scholars have focused on the dynamics in car ownership, applying panel models (Woldeamanuel, et al., 2009; Kitamura, 2009; Nolan, 2010), vehicle holding duration (Gilbert, 1992; de Jong, 1996) and vehicle transaction (Hocherman, Prashker and Ben-Akiva, 1983; Mohammadian and Miller, 2003; Roorda, Carrasco and Miller, 2009) models.

Woldeamanuel, et al. (2009) applied a panel model based on the German Mobility Panel and found that residential location, accessibility of services and socio-demographics were important factors of car ownership. Kitamura (2009) estimated a joint model of car ownership and car trip generation on the Dutch National Mobility Panel. He found that both car ownership and car trip generation were influenced by lagged effects (i.e. car ownership, household composition and travel behaviour in the previous year). In particular, higher levels

of car ownership, larger number of drivers and more car use in the previous year led to higher car ownership levels in the current year. Nolan (2010) applied a panel model of car ownership to the Irish component of the European Community Household Panel (ECHP). She found that car ownership was affected by socio-demographic and land use variables, but also by cohort effects. In addition, car ownership in previous years determined car ownership of the household.

Another strand of literature describes dynamics in terms of the holding duration of vehicles. Gilbert (1992) estimated the distribution of automobile ownership duration based on panel data using characteristics of the household and the car and macroeconomic variables such as unemployment and inflation rates. She found that expected ownership lengths were shorter for households with an employed female head. Changes in life stage e.g. from couple to parents, showed no association with vehicle holding duration. De Jong (1996) incorporated vehicle type choice and usage into models of holding duration and found a relationship between vehicle holding duration and make and model of the car.

Finally, vehicle transaction studies take a more elaborate approach in the sense that they describe the decision whether to add, replace or dispose a vehicle. Hocherman, Prashker and Ben-Akiva (1983) examined vehicle transaction in terms of acquisition and replacement. They found that the decision to acquire a car is significantly related to household size, occupation and age. Pendyala, Kostyniuk and Goulias (1995) analysed the effect of income on car ownership based on Dutch National Mobility Panel Survey. They showed that forecasting car ownership based on cross sectional effects would be inaccurate, since changes in household type were often the reason for car ownership changes. They suggested incorporating transitions among household structures and lifecycle stages in travel demand forecasting. More recently, Mohammadian and Miller (2003) developed a dynamic transaction choice model that incorporated household attribute changes as covariates of the model. They investigated the effects of heterogeneity and state dependence in the dynamic automobile transaction model by distinguishing between heterogeneity and state dependence. They found that households that had recently replaced a vehicle had a lower probability of replacing or acquiring a new vehicle. A further advancement carried out by Roorda, Carrasco and Miller (2009) is the use of the activity/travel stress concept for their integrated vehicle transaction model. They improved the modelling concept by incorporating activity/travel stress measures, expressing whether household members demanded the same vehicle at the same time and no alternative provided acceptable utility. In a related way, Dargay and Hanly (2007) focused on changes in car ownership. Their analysis focused on events (changing the car ownership level), rather than on the status. Based on the British National Household Survey, they analysed to what extent changes in car ownership in a given year were related to changes in the number of drivers, number of employed persons, and change of employer or residence. They reported clear relationships between various changes in work status, the number of license holders within the household and changes in car ownership.

The vehicle transaction models reviewed above recognize that decisions about car ownership are related to decisions about other long-term decisions and events such as residential change, driver's license possession, working status, work location and household formation and dissolution, which have also been highlighted in more general studies of mobility decisions (e.g., Van der Waerden, Borgers and Timmermans, 2003; Lanzendorf, 2003; Verhoeven, et al., 2005; Prillwitz, Harms and Lanzendorf, 2006; Beige and Axhausen, 2008; Oakil, et al., 2011a). For instance, Lanzendorf (2003) proposed a mobility biography approach based on work of Salomon (1983) to explain travel behaviour by changes in life course stages. Empirically, for example, van der Waerden, Borgers and Timmermans (2003) and Verhoeven, et al. (2005) suggested that critical events and life cycle events, such as getting a driver's license or having children, might influence structural decisions about mode choice. They argued that activity-travel repertoires evolved into a state of disequilibrium due to *critical incidents* such as an accident or *key lifecycle events* such as demographic events; and that these might therefore be relevant concepts for studying the dynamics of activity-travel patterns.

Taking the discussion back to the investigation of car ownership decisions, the aim of the paper is to carry out an analysis of the relationship between car ownership decisions on the one hand and decisions regarding residential and work change and demographic events on the other hand. In line with the work on critical life cycle events (van der Waerden, Borgers and Timmermans, 2003a; Verhoeven, et al., 2005) and the stress based concept (Brown and Moore, 1970; Salvini and Miller, 2005; Habib, Elgar and Miller, 2006), the paper will focus on the relationship between events in the above mentioned domains and changes in household car ownership level. Rather than looking into the status of car ownership, for example number or type of car, the study will analyse the decision to change car ownership level either by disposing or acquiring car/s. In the context of car ownership, it will extend existing work by including a broader range of events that may influence car ownership decisions and scrutinizing temporal sequence in which chains of related events are most likely to occur. To this end, previous, current and future events may potentially influence car ownership decisions in our models.

The paper will start with an elaboration of the approach on which the analysis is based. Then a short description of data will be given, including survey method, content of the survey and sample description. Finally, the paper will present the results followed by a discussion.

4.3 Approach

Our analysis of dynamics in car ownership levels is based on a general approach to studying dynamics in longer term mobility aspects. We assume that the dynamics in residential situation, work status and location or car ownership stems from various mechanisms. First, people take such decisions not only based on their current state but considering anticipated changes as well. This is necessary since changes in residence, work status or car ownership require substantial investment of time and money and only take place infrequently. As a

consequence, choices made at one moment will shape the conditions/options for future longer-term decisions. For instance, the choice where to live and in what dwelling will have a strong impact on accessible jobs, the need to own one or more cars and the budget remaining for expenditures to consumption and daily travel. Note that this implies causal relationships both forward (path-dependency) and backward (anticipation) in time. Second, Brown and Moore (1970) and Salvini and Miller (2005) postulate that longer-term travel decisions (including car ownership decisions) are triggered by stressors. According to Habib, Elgar and Miller (2006), a stressor is defined as a discrepancy between a household's aspiration level and its current circumstances. However, stress triggered decisions require time to adapt, since the necessary investment of time and money cannot take place instantaneously. This implies a lagged response to such needs. Also, it implies path dependency in the sense that a recent change (for example, relocation or car acquisition) may set limits to new changes due to limitations in financial, temporal or mental resources. Apart from the dynamics, it is noted that limitations in time and money budgets imply a strong interdependency between longer-term decisions (Ettema, et al., 2007). For instance, households/individuals have to trade-off between spending their income to the dwelling or to transportation options (cars), between working more hours (resulting in a higher income) and having more free time etc. This implies interdependencies beyond the path dependency effect, which is limited to the effect that earlier decisions create limitations/options for later choices.

An important notion is that stressors can arise from different events and can be addressed by different longer-term decisions. For instance, a change in job location may increase commute distance (stressor), leading to a need to reduce travel time. This can be achieved by different actions such as changing residential location close to work (Bina and Kockelman, 2006; van Ham and Hooimeijer, 2009) or owning a car or even combining both. If a household recently changed its residential location, it is likely to prefer a solution through a change in travel resources rather than changing residence again (e.g., Cao and Mokhtarian, 2005). The concept of stressors thus avoids a limited definition of one-to-one relationships between events that follow up in time.

Changes in aspirations, leading to stressors, can also arise from various sources. First, changes in the household composition, such as childbirth or homeleaving of children, may invoke a change in the need for transportation options. For example, childbirth might generate an extra demand for car because one has to drop off and collect children from a day care centre; whereas home leaving of a child might mean a lower need for an additional car in the family. Likewise, a changed physical condition or a change in household's resources (such as income) may lead to an increased aspiration for car ownership. For instance, an income increase will reduce budget constraints, but it might also create additional demand, e.g. for a luxury car, a bigger car or an additional smart car. Moreover, aspiration level and preferences are updated over time by social contacts and information exchange as well (Han, et al., 2008). For example, knowing better travel options might change ones aspiration level and thus might induce stress. Besides, recent studies on the role of social networks suggest

that households' aspiration levels are at least partially determined by valuations and decisions of other households in the social network (Dugunji and Walker, 2005). This influence stems from humans' need to feel a sense of belonging and acceptance, whether it comes from large social groups, such as clubs, office culture, religious groups, professional organizations, sports teams, or small social connections (family members, intimate partners, mentors, close colleagues, confidants). It is important to note that changes in a household's situation, leading to changes in aspiration levels, may stem from both internal sources (i.e. decisions made by the household itself, such as household composition) and external sources (e.g. changes in the availability, quality and costs of travel options or a change in income due to losing one's job).

Following the above concept, changes in car ownership at the household level are envisaged as an action in response to certain triggers, such as residential relocation, changes in household composition and work status or location. In most cases, such changes will affect the household needs and may therefore cause discrepancies between the desired and the actual situation, termed stress in the above. Also, such triggers may increase household's options and thereby the aspiration level. Although the importance of stressors and aspiration levels is acknowledged, this paper will focus on the relationship between triggers and car ownership changes, as they can be found in our data set. However, the concepts of stressors and aspiration levels will be used to interpret the outcomes.

4.4 Data and method

Survey

For this study, a dedicated data collection was carried out, aiming at collecting information on households' longer-term mobility decisions over a longer time span by a retrospective questionnaire survey. The survey was conducted at the household level. It collected information about –

i. year of birth, highest education attained and current work status of all household members.
ii. a history calendar of the past 21 years from 1990-2010, in which respondents (both the respondent and the partner, if applicable) indicated their work situation (location, status, income), residential situation (location and dwelling characteristics, including motivations for relocation) and travel issues (car ownership, commute mode, commute time and driver's license possession) and household composition.
iii. demographic events such as marriage, childbirth, home leaving, divorce and death of a household member taking place over the past 21 years.

Resulting is a full 21 years retrospective diary of demographic, residential, professional and mobility events, permitting analyses of their mutual interaction in a longitudinal sense. The literature (e.g., Verhoeven et al., 2008) suggests that retrospective surveys can provide reliable information about past events, if these events are important. Likely, the critical events asked for in this survey, such as residential relocation, car fleet changes and job changes will

fall into this category and can be remembered with acceptable accuracy. It is realised that retrospective data may suffer from problems in recalling and can therefore be biased. To minimize memory bias, we have checked for consistency in the dataset between related events. For example, we have checked whether the year of a relocation due to cohabitation matched with the reported year of the start of cohabitation. Based on such consistency checks, we believe that the data provides a sufficiently accurate account of household dynamics for our purpose. We also understand that the household characteristics such as household income are difficult to recall. In this case, we have categorised the data into larger intervals to reduce the uncertainty about the reliability of the variable.

Apart from retrospective data, the survey asked also about the targets and aspirations of the respondent for his/her family within a particular time period, with respect to residential, professional, mobility and demographic developments. This extension permits to investigate the impact of the household history on households' current aspirations and plans on these dimensions. Finally, data was collected about respondents' social network and the residential, work and travel characteristics of the network partners, enabling us to investigate social influence on longer term mobility decisions, such as car ownership. For the purpose of the current paper, however, we will use the retrospective data with respect to car ownership and other household characteristics. The survey was a pen and paper questionnaire. The design of the questionnaire is illustrated by the example in Figure 4.1.

Please indicate in the calendar about important household issues/events –

	1990	1991	1992		2008	2009	2010
Household status							
5. Mention number of person in household at 1990 and only when it is different from earlier.							
6. Please indicate in the calendar by "X" or "√" when you had experienced one or more of the following events.							
(1) You left parent home							
(2) Marriage/Cohabitation							
(3) Birth of children							
(4) Child's home leaving							
(7) Divorce/Separation							
(6) Death of household member (please mention the relationship with the person died)							

Please indicate appropriate response for you in the calendar depicting last few years of your life and also mention the initial status at 1990 for each question –

	1990	1991	1992		2008	2009	2010
Travel and transport							
25. Please mention the number of cars available in your Household							

Figure 4.1: A sample showing design of the questionnaire

It was distributed personally to the candidate households with a return stamped envelope, to get word of returning the questionnaire, which has increased response rates significantly.

Data were collected in the Utrecht region in the Netherlands, and includes inhabitants of urban areas (Utrecht), suburban areas (De Bilt, Zeist, Bunnik, Driebergen and Baarn) and villages (Groenekan, Odijk, Werkhoven, Bosch en Duin, Maarn, Doorn and Austerlitz). Candidate households were approached using a random walk procedure. The sampling strategy was to include municipalities (and streets within municipalities) that differ in terms of density, type of housing, accessibility to services etc., such as to obtain a representative sample in terms of spatial circumstances. The only selection criteria was that the respondent should be at least 30 years in order to be able to report a relevant mobility history. 1200 questionnaires were distributed and 475 were returned.

Sample Description

The majority of the respondents (around 75% of the respondents) have a high education level, university education or higher vocational education (HBO). Age varies from 20 to 90 years with almost equal gender proportions. Just more than 30% are less or equal to 40 years old and around 15% are more than 60 years of age for person-year observations. More than 75% of the respondents are living with a partner and dual worker families account for about 60% of the person-year observations. The overrepresentation of highly educated persons has some implications for the conclusions we can draw. It is likely that opportunities and constraints pertaining to long-term mobility choices differ between high and low educated people. For instance, highly educated workers are more likely to move over longer distance in the case of changing jobs, invoking other changes such as residential relocation or car ownership. Also, financial constraints, due to higher incomes may be less of an issue for highly educated people. Thus, our outcomes cannot readily be generalized to the total population and more research is needed into the different opportunities and constraints of people with different education levels. It is noted that except for education and gender, personal characteristics such as age of the respondent, household income and work-status, household composition and number of car availability are specific to a particular calendar year as reported by the respondents. Therefore, the representativeness of these variables is difficult to assess. In terms of age bias, it should be noted that since we use a 21-year history of all individuals, a bias toward older aged respondents is at least partly offset.

The analyses are based on person-year-observations, i.e. every case is an observation from an individual for a particular year. The period covered here is reduced from 21 to 17 years because two years lag and lead effects of events are considered. Therefore, it is possible to have a total of 8075 (475 individuals*17 years) person-year-observations. However, consideration of missing values leads to 3656 person-year-observations from 312 households for the car addition analysis and 3096 person-year-observations from 283 households for car reduction analysis. In addition, people without a car are logically not included in the car reduction model.

Table 4.1 shows the frequency of occurrence of various events for the aforementioned samples, based on the total number of person-year-observation. Counts are the number of

events from all person-year cases. The percentage is the average percentage experiencing an event in a given year. Note that, since person-years may have been excluded due to missing value, the percentages should be interpreted with care.

Table 4.1 shows that a total of 157 car ownership changes (additions and reductions) have occurred out of 3656 person-year observations. Increasing the number of cars in the family occurred more often (3.2%) than decreasing the number of cars (1.4%). This suggests that people in the sample are less inclined to get rid of their cars. This is partly due to the fact that for the majority of the respondents, the 21 years observation period reflects a period of household and career development, which coincides with increased car ownership, as will be shown later on.

Table 4.1: Descriptive statistics of event history

	Sample: Extra car addition to household		**Sample: Reducing car to household**	
Number of households	312		283	
Number of observations	3656		3096	
Events	**Count**	**%**	**Count**	**%**
Start of living together	50	1.4	31	1.0
Birth of the first Child	62	1.7	55	1.8
Home-leaving of the last Child	42	1.1	40	1.3
Separation or divorce	11	0.3	11	0.4
Residential move	273	7.5	188	6.1
Employer change (both or either)	423*	11.6	341	11.0
Employer change for respondent	*305*	*8.3*	*230*	*7.4*
Employer change for partner	*140*	*3.8*	*129*	*4.2*
Retirement event (both or either)	61*	1.7	57	1.8
Respondent Took retirement	*37*	*1.0*	*34*	*1.1*
Partner Took retirement	30	0.8	28	0.9
Change in number of cars				
Extra car addition to household	*114*	*3.2*		
Reduction in car numbers in household			*43*	*1.4*

*if respondent & partner both took retirement/change employer in same year then count is 1.

Method

This section describes the method used to investigate whether certain types of events and their time of occurrence, are associated with any kind of change (decrease or increase) in car ownership. To analyse the timing of car ownership change, change has been considered in the following time periods relative to a potentially influential event: *Same year, 1-2 year/s after the event, 1-2 year/s before the event*. *"Same year"* indicates that an influential event and the change in the number of cars occur in the same calendar year. "*1-2 year/s after the event*" means that a car ownership change follows one/two calendar year/s after a potentially

influential event such as a residential relocation. "*1-2 year/s before the event*" expresses whether car ownership has changed in the year/s preceding an influential event or not. This would then imply that a car ownership change is made in anticipation of an influential future event. The analysis also includes state variables such as household composition, income and work status, number of cars available in the previous year, education level of the respondent and age of the respondent.

The study has used a Mixed Logit model to illustrate the relationship between changes in car ownership, other events and state variables. Biogeme 1.8 has been used to estimate the model. Given that we have multiple observations per respondent, a model with random effect correlation within an individual has been used, thus accounting for intra-personal dependence. Random effects across individuals are assumed to be independently and identically distributed. The dependent variable is a binary variable and the model is specified to estimate a threshold value for the non-change decision in addition to the factors affecting the decision to change (see equation 4.1).

$$u_{1it} = \sum_{k=1}^{n} \beta_{1itk} x_{1itk} + \sum_{k=1}^{n} \beta_{1i(t-1)k} x_{1i(t-1)k} + \sum_{k=1}^{n} \beta_{1i(t-2)k} x_{1i(t-2)k} + \sum_{k=1}^{n} \beta_{1i(t+1)k} x_{1i(t+1)k} + \sum_{k=1}^{n} \beta_{1i(t+2)k} x_{1i(t+2)k} + \lambda_{1i} + \varepsilon_{1it} \quad (4.1)$$

$$u_{0it} = \alpha_{0it} + \varepsilon_{0it}$$

where,

u_{1it} = the utility of choice 1 (changing car ownership level) at time t.

u_{0it} = the utility of choice 0 (not changing car ownership level) at time t.

i = an index for individual *i*.

t = an index of time of observation *t*.

k = an index of explanatory variables.

x_{1itk} = the value of explanatory variable *k* for choice 1 at time t.

α_{0it} = the threshold value of choice 0.

ε_{0it} = the random effect within individual choice 0.

ε_{1it} = the random effect within individual choice 1.

λ_{1i} = the random effect between individuals

4.5 Results

The estimation results, indicating the relationship between car ownership dynamics and residential, professional and demographic events are given in Table 4.2. Some event and state variables are excluded from the models for two reasons. First, it is found from cross-tabulation that some events are not at all related with car ownership changes in our sample. These variables yield erroneous parameter estimations. Second, very high correlations between some coefficients are found. Consequently, the two models do not include the same set of explanatory variables.

Table 4.2: Results of panel data analysis of car ownership change

	Car Disposal			Car Acquisition		
Variables	**Value**	**t-test**		**Value**	**t-test**	
Choice 0: No change to the number of car						
Threshold	**2.87**	**4.11**	**	**3.80**	**7.52**	**
Choice 1: Change in the number of car						
Random effect	-0.03 0.00	-0.04 fixed		-0.01 0.00	-0.01 fixed	
Age of the respondent						
i. less than 41 years (reference)						
i. 41 to 60 years	-0.60	-1.48		-0.33	-1.18	
ii. more than 60 years	**-1.65**	**-1.99**	*	**-2.18**	**-2.08**	*
Respondent is highly (University+HBO) educated	0.05	0.12		-0.18	-0.59	
Respondent is living with partner	-0.47	-0.81		0.14	0.32	
Dual working household	-0.55	-1.05		0.43	1.15	
Household income						
i. less than 1501 Euros/month (reference)						
ii. 1501-3000 Euros/month	**-1.23**	**-2.03**	*	0.71	1.56	
iii. 3001-4500 Euros/month	-1.03	-1.72		0.83	1.72	
iv. 4501-6000 Euros/month	**-1.16**	**-1.97**	*	**1.29**	**2.68**	**
v. 6001-7500 Euros/month	**-2.49**	**-2.16**	*	**1.32**	**2.17**	*
vi. 7500+ Euros/month	-0.56	-0.77		**1.33**	**2.33**	*
Household car ownership level						
i. no car (reference)						
ii. one car	-	-		**-1.22**	**-4.65**	**
iii. more than one car	-	-		**-3.01**	**-6.65**	**
Birth of the first child	-0.97	-0.75		-0.41	-0.67	
Birth of the first child 1 year before the change	0.27	0.25		0.31	0.53	
Birth of the first child 2 years before the change	0.25	0.27		-0.94	-1.18	
Birth of the first child 1 year after the change	-	-		**1.14**	**2.56**	**
Birth of the first child 2 years after the change	-	-		0.63	1.28	
Childbirth in the household	0.86	1.12		**1.56**	**3.34**	**
Child leaving home from the household	-0.06	-0.06		0.56	0.89	
Start of living together with partner	1.58	1.77		**1.40**	**3.25**	**
Start of living together with partner 1 year before the change	-	-		-0.01	-0.02	
Start of living together with partner 2 years before the change	-0.17	-0.15		-0.22	-0.34	
Start of living together with partner 1 year after the change	-1.42	-1.08		0.93	1.61	
Get divorced	**2.77**	**2.92**	**	-	-	
Get divorced 1 year before the change	**2.77**	**2.72**	**	-	-	

Get divorced 1 year after the change	-	-		0.20	0.14	
Changed employer[1]	**0.84**	**2.05**	*	0.30	1.13	
Changed employer 1 year before the change[1]	0.37	0.80		0.39	1.44	
Changed employer 2 years before the change[1]	-0.52	-1.04		0.42	1.61	
Changed employer 1 year after the change[1]	**1.20**	**3.07**	**	0.24	0.90	
Changed employer 2 years after the change[1]	-0.03	-0.07		0.12	0.43	
Residential relocation	0.48	0.97		**0.69**	**2.46**	**
Residential relocation 1 year before the change	**-1.83**	**-2.12**	*	-0.30	-0.92	
Residential relocation 2 years before the change	0.60	1.25		-0.03	-0.11	
Residential relocation 1 year after the change	0.16	0.30		0.14	0.40	
Residential relocation 2 years after the event	-0.11	-0.18		-0.02	-0.06	
Retired[1]	1.18	1.37		0.50	0.56	
Retired 1 year before the change[1]	0.48	0.43		-	-	
Retired 2 years before the change[1]	-	-		1.23	1.54	
Retired 1 year after the change[1]	-	-		-0.37	-0.35	
Retired 2 years after the change[1]	**2.01**	**3.43**	**	0.52	0.69	
Pseudo R^2	**0.16**			**0.19**		

[1] Either one of respondent and partner or both
* Significant at 5%
** Significant at 1%

The results suggest that various significant associations exist between car ownership changes and residential, professional and demographic events. The timing of the influence, though, differs between various types of triggers. Given the small number of event occurrences, one should be cautious that associations might occur by chance. However, most events show significant effects at the 99% confidence level including both lead and lag effects and significant events are also theoretically plausible.

Pseudo Rho-squares shown in Table 4.2 represent the fit compared to the threshold model. In general, the threshold represents a base-line probability. The higher the threshold, the lower the chance of a particular event to occur. In this case, it may represent costs (e.g. time, money or effort) associated with car acquisition or disposal, so that a higher threshold value means a higher cost for car acquisition or disposal and therefore a lower chance of happening that event. However, it is difficult to compare two models as the analyses represent two different samples and do not include a similar set of explanatory variables.

Both event and state variables significantly influence car ownership changes. Obviously, events can be interrelated and may lead to multi-collinearity problems between explanatory variables. The highest correlations between estimates of coefficients found are 0.55 in the car reduction analysis and -0.67 in the car acquisition analysis, which are within acceptable range for multivariate analyses (Field, 2009). However, we have excluded the car ownership variable in the car disposal model since it shows a high correlation (0.825) with the random effect estimate, which is crucial to the model in the context of repeated observations and thereby potentially leading to biased estimates.

Table 4.2 shows quite different results of event's association and effect for two different models. One exception is that respondents' age being over 60 years negatively influences both ways of change of car ownership, indicating that older people are less likely to change their situation compared to young people. Apart from age, state variables like the car ownership level (in the car acquisition model) in the previous year and household income show significant relationships with car ownership decisions. Households owning one or multiple cars are less likely to increase the number of cars next year compared to no-car households.

For car disposal, car ownership levels show a high correlation (0.825) with the random effect error term, as mentioned earlier, and are therefore excluded from the analysis. Income groups used in the models are compared to the lowest group (household income less than 1501 Euros/month). So, negative impacts of income on car disposal show that a higher income reduces the probability of disposing a car and the reverse is true for car acquisition. This is understandable as a higher income implies more opportunity to buy and use a car.

Events in demographic, residential and professional domains also have a significant effect on car ownership. Reasonably, different events are responsible for different types of change. For example, whereas cohabitation positively influences acquisition of an extra car, divorce increases the probability of disposal of car. Such changes in the number of cars are associated with marriage or divorce mostly during the same year. Most likely, this is because two adults come together in a household and bring their car(s) with them. In case of divorce, one leaves the surveyed family with his/her car(s) at the same time. Hence, the concept of stress reduction or changed aspiration levels is less obvious here, mostly since the decision-making unit in our theoretical framework (the household) is undergoing fundamental changes. Another example is childbirth, which is an event of increasing household size. The model shows that households are more likely to buy an extra car in response to such an increase in household size. However, it is not significant for car disposal. Obviously, the birth of a child implies new responsibilities, such as transporting the child to a day care centre and other locations, as well as an increased need to combine work and household tasks, which is easier done using a car. However, a child leaving home made no mark for car disposal, even though it means a reduction in household size. This can be understood from the fact that a child leaving home as an adult has a much more independent activity pattern, implying that home leaving will not impact much on the activity patterns and transportation needs of the parents.

Work related variables do not affect extra car acquisition. However, employer change increases the probability of reducing the number of cars. Obviously, the response will depend on the accessibility of the new job by alternative modes relative to the accessibility of the current job. The results also suggest that retirement is significantly associated with car ownership change and most likely with the event of reducing car(s), similar to the findings of Dargay and Hanly (2007), but in anticipation of the event only. Apparently, retirement implies a changed need for transportation on the household level for which fewer cars are

needed. Possible mechanisms are the availability of more time, making slow modes and public transport more viable options, but also an increased synchronisation of activities of the spouses, leading to more joint travel using one car. However, also a reduction in income and aging may play a role in the decision. The inclusion of income and age variables indicates additional influence of the retirement event on the decision. Unfortunately, change in work status could only be analysed for taking retirement. Data for other changes, for example part-time to full-time or the other way around, are insufficient in number.

Residential relocation also plays a role. Relocation increases chances of buying an extra car by the household in the same year and similarly it reduces chances to dispose a car, but one year after the relocation. Residential relocation may imply a change in accessibility of necessary locations by public transport, foot or bike, so that the household becomes more or less dependent on car travel. In response to decreasing accessibility, households may buy a car. In response to improved accessibility by public transport or slow modes, a household may get rid of a car, such as to save money and allow other needs/aspirations to be fulfilled. The table suggests only an increasing car ownership level. An explanation could be that most often residential move means climbing up the housing ladder and thus moving towards sub-urban or peripheral areas. Given that most of the car acquisition (about 50%), associated with relocation, happened at age between 28 and 30 years and most of cohabitation (about 50%) started at age between 24 and 30 years, this is a likely explanation. However, due to a lack of detailed information given about prior residential locations, density increase or decrease as a result of residential relocation could not be included.

In general, the inclusion of lead and lagged effects allows us to analyse temporal relationships between events. Three events affect car ownerships decisions in anticipation and one event shows a lagged effect. Birth of the first child only shows a lead effect for car acquisition, meaning that buying an extra car has taken place before the actual occurrence of the event. Although causal relationships cannot be derived from the data, it makes sense to interpret the relationship in terms of changing needs and stress reduction. For example, childbirth causes additional needs in terms of transporting children and undertaking family activities. To address this need and solve potential stresses, the dominant response is to have an extra car. Not only car acquisition, but also the reduction in the number of cars occurs in anticipation of a change of employer in the next year. Households even take action two years in advance for retirement. In the context of our theoretical framework, the outcomes suggest that car ownership changes in response to stress related triggers may precede the actual trigger if the trigger is well predictable and has clear implications. For both childbirth and retirement, this is the case. When changes are not well predictable, household might take action later, in this case, following a residential move. People might have some idea about the accessibility of their future residential location, but experienced accessibility might differ leading to decisions to change the car ownership level. However, the lagged effect of moving house has a negative effect on disposing a car only.

Effects of different events vary in size. Although the size of effects should be treated with care given the small sample size, it may serve well to provide insight in the relative impact of various events. Larger effects are found for the events of separation and retirement on car reduction and multiple car ownership on increasing car numbers. As mentioned, separation always means a division of the household and thus, in most of the cases, a division in car resources. In cases where car ownership change is a voluntary decision (when changing houses or jobs), the effects are smaller.

4.6 Discussion

This paper has presented results of an analysis of longitudinal data on residential, professional and household variables as well as car ownership status. The aim has been to identify relationships between car ownership changes on the one hand and residential, professional and demographic events on the other hand, and to learn about the timing of the car ownership change relative to various influential events. The underlying assumption is that car ownership changes (i.e. changes in the number of household cars) can be regarded as actions taken in response to stressors resulting from changes in the households' situation or its aspiration level (or both). In case of residential relocation, childbirth, job change and retirement, car ownership changes can be understood from changes in households' needs and/or aspirations. In case of marriage/living together and divorce, changes in car ownership can be understood more directly from household formation and dissolution processes. In case of childbirth, increasing the number of cars takes place in anticipation of the event, whereas in case of residential relocation, the negative effect on car disposal follows the event. These differences are potentially related to the predictability of the event as well as the accumulated experience of the outcome.

Although the results provide promising insights into car ownership changes in response to other household events, further research is needed to fully understand the dynamics in car ownership, demographic, residential and professional events. First, further research should aim at collecting data for a more diverse sample than could be used in the current study. For instance, low income groups, which were underrepresented in our sample, may show different responses to life cycle events, due to financial limitations. Second, while the current panel models suffice to investigate the impact of household dynamics on one type of behaviour (car ownership), more advanced techniques are required to analyse direct and indirect relationships among events and decisions in an integrated way. In this respect, more complex causal chains between various events will be investigated using Bayesian Belief Networks (BBNs). BBNs allow for the specification of flexible structures of interaction between variables. This makes it possible to distinguish between direct and indirect effects between events taking place in different years. A particular challenge will be to disentangle path dependent effects from life cycle and period effects. Second, spatial factors like attributes of residential location or public transport accessibility could be added to get a better picture. The final aim of this line of research will be to develop models that describe

decisions regarding car ownership, work status, job location and residential location in an integrated framework in a longitudinal way. BBNs provide a promising way of developing such models, which could serve as the backbone for integrated land use/transportation models.

Chapter 5:
Residential relocation: An analysis of history dependence

Abstract

Current land-use and transportation models often rely on state dependence with respect to age, income, household composition and car ownership to include the dynamics in residential relocation. Yet there is increasing evidence that residential mobility is driven by other life events and that time-lags can occur between these events and the residential relocation. This paper uses event history data to analyse the effect of the timing of events, distinguishing between concurrent and lagged effects. The results show the expected concurrent effects of marriage, divorce and change in employment. In addition lagged effects are found as divorce and change in employment also increase the probability to move in the year after. The birth of the first child only has a lagged effect two years after the event. Shifts in car ownership show a strong concurrent relation. Many households buy a first or second car in the year of the relocation, but there are also many who dispose a car in the same year. We also find a lagged effect of dual car ownership on relocation later. Variables like age, income or household composition are not related to residential mobility when these events have been taken into account, but we do find state dependence with respect to dwelling type, home ownership and urban density. The results could be used in developing dynamic agent based land-use and transportation models.

5.1 Introduction

Interactions between long-term mobility decisions such as residential relocation, car ownership change and job change should not be analysed on a cross-sectional basis, because people base such decisions not only on their current state but also consider past and anticipated changes. This is understandable given the requirement of substantial investment of time and money for changes in residence, work status or car ownership (Oakil, et al., 2011a). As a consequence, choices made at one moment will shape the conditions/options for future decisions. In addition, longer-term mobility decisions such as residential relocation are triggered by stressors (Brown and Moore, 1970; Salvini and Miller, 2005; Habib, Elgar and Miller, 2006). Stress triggered decisions require time to adapt, since the necessary investment of time and money cannot take place instantaneously. This implies a lagged response to such needs. Limitations in time and money budgets imply a strong interdependency between

longer term decisions (Ettema, et al., 2007). For instance, households/individuals have to trade-off between spending their income to the dwelling or to transportation options (cars), between working more hours (resulting in a higher income) and having more free time etc. This implies interdependencies among various decisions beyond the fact that earlier decisions create limitations/options for later choices. Moreover, stress can be addressed by different forms of adaptation. For instance, a change in job location may increase commuting distance (stressor), leading to a need to reduce travel time. This can be achieved by changing residential location closer to work (Bina and Kockelman, 2006; Van Ham and Hooimeijer, 2009), but also by buying a (second) car or a combination of both. If a household recently changed its residential location, it is likely to prefer a solution through a change in travel resources rather than changing residence again (e.g., Cao and Mokhtarian, 2005).

For these reasons we use a history dependence approach, in which we investigate how household events (including relocation) that took place in prior years influence current relocation decisions. On the one hand, it is realised that residential relocation is related to other mobility decisions such as car ownership and job change. For instance, buying a car may lower the inclination towards relocation as accessibilities to places are more flexible. On the other hand, household events such as marriage, child birth or divorce may trigger stress by causing discrepancies between households' needs and their current states. For example, the birth of a child may require an extra room and thus trigger relocation to a bigger house. The context of our analysis is the shift towards agent based approaches in land-use and transportation modelling. Parameters describing the dynamics in these models are often based on cross-sectional evidence, relating the probability of residential relocations to state variables like age, income, household composition, and car ownership. The purpose of this paper is to show that these models could be improved by accounting for event dependence instead of relying on state dependence.

The following sections provide a review of the literature, a description of the data and the results and a discussion of the implications for modelling.

5.2 Literature review

Many studies have addressed the issue of residential relocation and have investigated how residential relocation correlates with household conditions and events occurring in/to the household. Many of them still use a cross-sectional approach (Bina and Kockelman, 2006; Waddell, et al., 2006; Pinjari, et al., 2007; Zondag and Pieters, 2006; Bolt and Van Kempen, 2010).

However there is also a wide literature on more dynamic analyses of housing relocation decisions and their dependence on life-events such as marriage, childbirth, or divorce (e.g., Van Noortwijk, Hooimeijer and Dieleman, 1992; Clark and Mulder, 2000; Clark and Huang, 2003). Van Noortwijk, Hooimeijer and Dieleman (1992) looked into divorce and housing consumption. They found that divorcees lived in multi-rent dwellings more frequently than in single rent dwellings compared with those who remained married. They also pointed out that

apartments are the preferred dwelling unit for divorcees. Clark and Huang (2003) used data from the British Household Panel Survey and confirmed the value of using longitudinal models of residential change. Among others, they found that change of marital-status and birth of a child played important roles in households' moving decisions in the United Kingdom.

Duration analyses have also been applied to housing decisions (e.g. Mulder and Wagner, 2001). Focus of these researches was the timing of different housing events. For example, the timing of the first time home-ownership was analysed in connection to family formation by Mulder and Wagner (2001). In a comparative study between West-German and The Netherlands, they found that the way in which people synchronize home ownership with marriage or first parenthood differs substantially between the countries and across birth cohorts. Importantly, they found that becoming a homeowner before the birth of first child was very common. In the Netherlands, an increasing proportion of couples made the transition to home ownership before becoming parents. In a similar fashion, Feijten and Mulder (2010) analysed the timing of housing event in response to household events. In addition, they analysed the time lag of a housing event following a household event. An interesting finding was that the time lag for child birth was negative, which implies that moving to a family house happened before the actual event of child birth. Recently, Chen, Chen and Timmermans (2009) analysed residential location choice depending on location attributes. They found that people tended to adapt their preference to their experience. For example, people tolerated long commutes and viewed attributes like retail, open space, and retail opportunities as more valuable after having been exposed to those attributes in the past. However, they also found that household events, e.g. parenthood, prevailed in the decision of residential location. Taken together, the above studies provide evidence that life events and history dependence play an important role in housing relocation decisions.

An issue that has received less emphasis, however, is how housing relocation decisions also depend on other longer term decisions, in particular concerning car ownership and commute mode decisions. Such relationships exist not only in the sense that a relocation decision can be made in response to a decision in another domain (e.g. moving because you find a job in another town), but also as a result of substituting residential relocation by shifting one's transportation.

The interaction between various longer term decisions such as car ownership, residential location, work location etc. has been shown in various studies (Van Ommeren, Rietveld and Nijkamp, 1999; Pinjari, et al., 2007; Waddell, et al., 2007; Oakil, et al., 2011a). However, these studies have not looked into the temporal relationships between decisions made on the above dimensions. Temporal relations and history dependence are found to be important to properly understand households' relocation decisions and to be able to properly represent them in land-use and transportation models (Ettema and Timmermans, 2006; Ettema, et al., 2007; Oakil, et al., 2011b). For example, Oakil, et al. (2011b) found that long-term decisions like car ownership change are taken in adaptation as well as in anticipation, a lead effect.

They found that household acquired a car after the change of employer, a lagged effect, and before the birth of a child, a lead effect. Other events have immediate effects like employer change, residential relocation and cohabitation. Gordon and Molho (1995) investigated migration behaviour in response to duration of previous relocation and job change. They found an initial sharp rise in the chances of considering relocation with increasing durations of stay in the present dwelling. The analysis was based on moving intention and did not incorporate other household events and mobility resource like car ownership. Household events are important to consider when analysing relocation in longer-term perspective. De Groot, et al. (2011) found that household without any intention to move might actually move in response to unexpected household events. For instance, childbirth increased the probability to relocate even if there was no intention to move.

The contribution of this paper is twofold. First, it will look into the association of multiple long-term mobility events (car ownership and job events) with residential mobility together with other household events like marriage, child birth, divorce etc. Second, it will investigate the history dependency of such relationships, and establish whether the relocation decision is made in response to other decisions. In particular, it will be investigated how residential relocation decisions depend on the current state of the household (socio-economic status, current residential and job location etc.) and on the history of residential relocation itself along with life events (for example, marriage in earlier year/s) and mobility changes (for example, buying a car in earlier year/s). Learning how frequent and in what order households take such decisions has implications for land use modelling. For example, if a household's response is lagged (for example, relocation after a change in job), the effect is not captured by cross-sectional analysis. Likewise, events that happen after the actual relocation (for example, relocation in anticipation of child birth) go unobserved. Thus prediction of household's decision to relocate in a particular time will be biased. Moreover, relocation immediately after an event might have different implication than relocation with lagged or anticipated events. For example, relocation due to a divorce may lead to a temporary accommodation (Dieleman and Schouw, 1989), whereas decision in response to an anticipated event might be well prepared, for example, moving into a family house in sub-urban area before getting married or having a child (Feijten and Mulder, 2002). In this respect, this analysis will help in housing demand forecasting and management.

5.3 Data description and method

Longitudinal data are a requisite to analyse history dependences. Panel data are the best option. However, panel data including all aspects in long-term mobility decisions and household events are not available. Thus a retrospective questionnaire survey was carried out in the Utrecht region of the Netherlands. The literature (e.g., Verhoeven, et al., 2008; Beige and Axhausen, 2008) suggests that retrospective surveys can provide reliable information about past events, if these events are memorable. Likely, the critical events asked for in this survey, such as residential relocation, car fleet changes and job changes will fall into this

category and can be remembered with acceptable accuracy. We also checked for consistency in the dataset. For example, when household mentioned that they moved due to cohabitation, we checked whether the year of the move actually coincided with the year of cohabitation. It is also argued that the more distant the event, the more fragmented the memory becomes (Schoenduwe, et al., 2009). We therefore performed a comparison of results from three different data segments – i) earliest dataset from 1990 to 1999; ii) latest dataset from 2000 to 2010 and iii) the complete dataset from 1990 to 2010 (Oakil, et al., 2011b). We found very few differences for three different segments of the dataset. Some household states are difficult to recall, for example, income. In these cases, we have categorised the data with wider intervals to reduce the uncertainty about the reliability of the variable.

The survey covered inhabitants of urban areas (Utrecht), suburban areas (De Bilt, Zeist, Bunnik, Driebergen and Baarn) and villages (Groenekan, Odijk, Werkhoven, Bosch en Duin, Maarn, Doorn and Austerlitz) and was distributed among 1200 candidate individuals in total. Details about the survey can be found in Oakil, et al. (2011b). It included both state and event variables for every calendar year from 1990 to 2010. Events are defined as a change in state in a particular year. Household events bring change to household composition (e.g. marriage), household work situation (e.g. taking retirement) and/or to household resources (e.g. increase in income). Similarly mobility events mean a change in job, home, car ownership and/or commute mode. Thus history data consists of

a. income and work status of respondent and partner
b. household events like marriage, childbirth, child's home leaving, divorce etc.
c. residential situation like the year one moved in, location, residential cost per month, number of rooms, building age, garden and parking facility
d. work location of respondent and partner
e. car ownership level
f. car availability, commute mode and time of respondent and partner.

One of the important features of the survey is prospective data. In this section respondents were asked to indicate their plan/target for coming future. Period covered was 10 years, which are categorised as first year, second year, 3-5 Years, 5-10 years and more than 10 years. This unique nature of the dataset enables to analyse actual and intended relocation in a single model. Prospective data includes

a. planned relocation
b. planned dwelling type, ownership, size
c. planned car acquisition
d. planned household events (e.g. plan to get married, have child)
e. planned job situation for both partners (e.g. location change and working hour change)
f. planned travel situation for both partners (e.g. getting a driving licence, commute mode change, wish to reduce commute time, target to avail full/part-time car) .

Sample Description

The description is based on person-year observations, meaning that every observation indicates a particular year of an individual. Although our survey covers the period from 1990 to 2010, this period varies over households depending on the information provided and on the household history. For example, we can only use data from 1992 onward as we have considered 2 years history of all events. However, if a household informs us about their last residential relocation, we can calculate the history from that year. For example, if a household mentions that they moved in 1988, then we can use information from 1993 for that household when we consider 5 years history of residential relocation. The total number of observations is 3782 from 305 households, excluding missing values. In this sample, most of the households are higher educated. About 40% of the respondents have a university degree. The overrepresentation of high educated persons has some implications for the conclusions we can draw. It is likely that opportunities and constraints pertaining to long-term mobility choices differ between high and low educated people. For instance, high educated workers are more likely to move over longer distance in case of changing jobs, invoking other changes such as residential relocation or car ownership. Also, financial constraints, due to higher incomes may be less of an issue for high educated people. Thus, our outcomes cannot readily be generalized to the total population and more research is needed into the different opportunities and constraints of different education.

Anyone in the household can be a respondent given that s/he is at least 30 years of age. We use age and education of the respondent as a proxy for household's stage in life course and socio-economic status respectively. Household composition indicates that couples, couples with children and single people with children make up 33.3%, 44.5% and 3.7% of the sample respectively. 11% of the respondents is under age 30 years and 18% is over 60 years of age. Most of the households have two working partners (55.1%). Homeownership (76.5%) and owning more than one car (31%) are quite common for our sample. About 20% of the households have an income less than or around 2000 Euros/month, whereas high income households earning more than 6000 Euros/month consist 17% of the sample. An overview of the frequency of events is given in the Tables 5.1 and 5.2. Table 5.1 shows the total number of reported occurrences of different events in this sample. The percentage shown is calculated from the total number of person-year observations.

Table 5.2 represents the relationships between different events and residential relocation. The counts are the number of residential relocations that occurred in relation to the particular event. For example, a count of 9 in the first row of Table 5.2 means that 9 residential relocations are associated with a birth of a first child. The ratio in the second column gives a comparison of two percentages. The first one shows the percentage of residential relocations where no event has occurred and the second is the percentage of residential relocation where the particular event has occurred. For instance, the ratio in the first row shows that percentage of residential relocation is 6% in any year where no event of first birth has occurred and this percentage increases to 15.5% in years when a first child is born. Significance of the impact

of the event is tested based on Fisher's one-sided exact test. Fisher's exact test is preferred over the chi-squared test of independence given that the event occurrence is low (Everitt, 1992).

Table 5.1: Event occurrence in the sample

Events	Count	%	Events	Count	%
Total observations	3782	100	Total observation	3782	100
Birth of first child	58	1.53	Household car acquisition	106	2.80
Birth of first child 1 year ago	59	1.56	Household car acquisition 1 year ago	116	3.07
Birth of first child 2 years ago	64	1.69	Household car acquisition 2 years ago	116	3.07
Marriage	44	1.16	Household car disposal	50	1.32
Marriage 1 year ago	52	1.37	Household car disposal 1 year ago	57	1.51
Marriage 2 years ago	61	1.61	Household car disposal 2 years ago	61	1.61
Divorce	9	0.24	Employer is changed	402	10.63
Divorce one year ago	11	0.29	Employer is changed 1 year ago	421	11.13
Divorce two years ago	23	0.61	Employer is changed two years ago	481	12.72
Last child left home	50	1.32	Took retirement	76	2.01
Last child left home 1 year ago	41	1.08	Took retirement 1 year ago	69	1.82
Last child left home 2 years ago	40	1.06	Took retirement 2 years ago	80	2.12
Last move is 1 year ago	285	7.54	Income decreased	83	2.19
Last move is 2 years ago	294	7.77	Income increased	269	7.11
Last move is 3 years ago	267	7.06			
Last move 4 years ago	234	6.19			
Last move 5 years ago	204	5.39			

Table 5.2 shows that certain events are directly related to residential relocation. For example, change of employer, acquisition of a car and disposal of a car have a significant association with relocation as well. Household events (divorce, marriage, childbirth, retirement) are also related to the relocation decision as shown in previous studies. The table also shows many lagged effects, like employment change in the years preceding the relocation. However, these bi-variate analyses do not account for confounding effects. Therefore, multivariate analyses were carried out to verify the findings.

Table 5.2: Cross tabulation of residential relocation by household and mobility events

Events	Residential relocation in a particular year	
	Count	Ratio (No-event : Event)
Birth of first child	9	6.0 : 15.5 ***
Birth of first child 1 year ago	2	6.2 : 3.4
Birth of first child 2 years ago	9	6.0 : 14.1 **
Marriage	25	5.5 : 56.8 ***
Marriage 1 year ago	10	5.9 : 19.2 ***
Marriage 2 years ago	9	6.0 : 14.8 **
Divorce	5	6.0 : 55.6 ***
Divorce one year ago	4	6.0 : 36.4 ***
Divorce two years ago	2	6.1 : 8.7
Added car/s to household	23	5.7 : 21.7 ***
Added car/s to household one year ago	17	5.8 : 14.7 ***
Added car/s to household 2 years ago	10	6.0 : 8.6
Disposed car/s from household	9	5.9 : 18.0 ***
Disposed car/s from household 1 year ago	8	6.0 : 14.0 **
Disposed car/s from household 2 years ago	7	6.0 : 11.5 *
Employer is changed	68	4.8 : 16.9 ***
Employer is changed 1 year ago	52	5.3 : 12.4 ***
Employer is changed two years ago	54	5.4 : 11.2 ***
Took retirement	4	6.1 : 5.3
Took retirement 1 year ago	1	6.2 : 1.4 *
Took retirement 2 years ago	1	6.2 : 1.2 **
Last move is 1 year ago	30	5.7 : 10.5 ***
Last move is 2 years ago	32	5.7 : 10.9 ***
Last move is 3 years ago	25	5.9 : 9.4 **
Last move 4 years ago	29	5.7 : 12.4 ***
Last move 5 years ago	18	6.0 : 8.8 *
Income decreased	7	6.1 : 8.4
Income increased	56	5.0 : 20.8 ***
Last child left home	3	6.1 : 6.0
Last child left home 1 year ago	2	6.1 : 4.9
Last child left home 2 years ago	2	6.1 : 50

*** Fisher's one-sided exact test significant at 99%
** Fisher's one-sided exact test significant at 95%
* Fisher's one-sided exact test significant at 90%

Method

Mixed logit analysis has been carried out. The data has a panel structure as the survey collected information of a household for the last 21 years retrospectively. So, a mixed logit model is formulated to consider random effect correlations for intra-person observations as these observations are not independent of each other. Biogeme 1.8 has been used to estimate

the model with such random effect correlation within an individual. Random effects across individuals are assumed to be independently and identically distributed. Residential relocation is a binary dependent variable – defined as whether a household moved in a particular calendar year or not. The model is specified to estimate a constant, which measures initial resistance to relocation. The utility function is defined as follows

$$u_{1it} = \sum_{k=1}^{n} \beta_{1itk} x_{1itk} + \sum_{k=1}^{K} \sum_{l=1}^{L} \beta_{1i(t-l)k} x_{1i(t-l)k} + \lambda_{1i} + \varepsilon_{1it} \qquad (5.1)$$

$$u_{0it} = \alpha_{0it} + \varepsilon_{0it}$$

where,

u_{1it} = Utility of choice 1 (residential relocation) at time t.

u_{oit} = Utility of choice 0 (no relocation decision is taken) at time t.

i = Individual.

t = Time of observation.

l = Time index for lag observation.

k = Index of explanatory variables.

x_{1itk} = Explanatory variables for choice 1 at time t.

α_{oit} = Constant to represent initial resistance.

ε_{1it} = Random effect for choice 1.

ε_{0it} = Random effect for choice 0.

γ_{1i} = Random effect related to an individual.

5.4 Results

The results of the multivariate analysis are presented in this section. Explanatory variables used for this analysis include the events, as shown in Tables 5.1 and 5.2, and some state variables. State variables describe the socio-demographic status of the household in terms of age and education of the respondent, household income and household type. To account for history dependence, past relocation is considered. This will depict whether a relocation decision taken in past will affect the present decision, given the financial and social costs involved in a relocation. This paper uses a five year history. Five dummy variables are created to represent whether a household relocated one, two three etc. years ago. State dependence is investigated by including housing attributes in the preceding year. These state variables include dwelling type, home ownership and population density of the residential area on a 4-digit postcode level.

The paper also considers employer change and car ownership as other long-term mobility events. For such events, a two year history is considered. For example, change of employer in the same year, last year and two years back are included as three explanatory variables. Household events like cohabitation, childbirth, divorce etc. also have two years of history.

Consideration of such history explores which variables or events have direct and/or lagged effect on the residential relocation. This is important as it may take time to materialise the decision after an event has occurred. For example, a household may want to move one or even two years after changing the job or birth of a child. The dependent variable combines both observed (before the time of the interview) and intended (at the time of the interview) relocation. We have used a dummy variable – planned relocation – to indicate whether the data is from 2010.

The pseudo rho-square shown in Table 5.3 represents the fit compared to the constant only model. In general, this constant represents a base-line probability of not moving. The higher the value of the constant, the lower the probability of a residential relocation event to occur in any given year. In this case, it may represent costs (e.g. time, money or effort) associated with a relocation, so that a higher constant value means higher costs for relocation and so a lower chance of that event to happen. Thus, in this case, the high constant value (2.44) compared to the effects for other variables indicates significant costs of relocation and a low probability to move. The model also shows significant improvement and association with different long-term events and residential situations.

Table 5.3: Results of the mixed logit analysis for residential relocation in a particular calendar year

Variables	Value	t-test	p-value	
Choice 0: No residential relocation occurred for a particular year				
Constant	2.440	5.55	0.00	***
Choice 1: Residential relocation occurred in a particular year				
Random parameter	0.288	0.88	0.38	
	0.000	fixed		
Respondent's Age <= 30	0.264	1.11	0.27	
Respondent's Age >= 60	-1.050	-2.05	0.04	**
Approx. Household Income (Euro/mon)				
i. Income <= 2000	-0.381	-1.06	0.29	
iii. Income 2001-4000	-0.450	-1.59	0.11	
iv. Income 4001-6000	0.149	0.59	0.56	
ii. Income > 6000 (base)				
Household Type				
i. Couple	-0.198	-0.60	0.55	
ii. Family with children	0.153	0.47	0.64	
iv. Single (base)				
Dwelling Type (t-1)				
i. Apartment	1.350	5.29	0.00	***
ii. Detached/Semi-detached	-0.850	-2.98	0.00	***
iii. Room (shared housing)	1.630	4.28	0.00	***
iii. Terraced (base)				

Ownership of the Dwelling (t-1)	-1.030	-4.44	0.00	***
Population Density (pop/sq.km) (t-1)				
i. Density <= 1000	0.213	0.66	0.51	
ii. Density 1001-3000	-0.221	-0.79	0.43	
iii. Density 3001-5000	-0.668	-2.37	0.02	**
iv. Density 5001-7000	-0.595	-1.95	0.05	**
v. Density 70001-9000	-0.646	-2.12	0.03	**
vi. Density 9000+ (base)				
Marriage	2.170	5.11	0.00	***
Marriage (t-1)	0.614	1.23	0.22	
Marriage (t-2)	0.730	1.53	0.13	
Birth of first child	0.228	0.47	0.64	
Birth of first child (t-1)	-1.240	-1.55	0.12	
Birth of first child (t-2)	0.824	1.86	0.06	*
Last child left home	1.110	1.68	0.09	*
Last child left home (t-1)	1.090	1.41	0.16	
Last child left home (t-2)	1.240	1.61	0.11	
Divorce	2.820	3.59	0.00	***
Divorce (t-1)	1.740	2.38	0.02	**
Divorce (t-2)	-0.010	-0.01	0.99	
Added car/s to household	0.798	2.46	0.01	***
Added car/s to household (t-1)	0.290	0.80	0.43	
Added car/s to household (t-2)	-0.245	-0.61	0.54	
Household Disposed car/s	1.030	2.19	0.03	**
Household disposed car/s (t-1)	0.498	1.04	0.30	
Household disposed car/s (t-2)	0.359	0.75	0.45	
Employer is changed	0.902	4.78	0.00	***
Employer is changed (t-1)	0.441	2.17	0.03	**
Employer is changed (t-2)	0.206	1.02	0.31	
Took retirement	0.841	1.37	0.17	
Took retirement (t-1)	-0.090	-0.09	0.93	
Took retirement (t-2)	-0.652	-0.61	0.54	
Last move is 1 year ago	-0.626	-1.73	0.08	*
Last move is 2 years ago	-0.350	-1.05	0.29	
Last move is 3 years ago	-0.312	-0.98	0.33	
Last move 4 years ago	0.322	1.07	0.28	
Last move 5 years ago	-0.053	-0.16	0.87	
Household had more than 1 car (t-1)	0.501	2.10	0.04	**
Planned relocation	-1.130	-2.09	0.04	**
Pseudo Rho-square (compare to constant only model)	**0.27**			

*** P value < 0.01; ** P value = 0.01–0.05; * P value = 0.05–0.10.

Dwelling type, homeownership and population density of the residential area are found to be significant determinants of residential relocations. Home owners are less likely to move compared to renters. People living in large houses, in this case detached or semi-detached houses, are less likely to move compared to people living in terraced houses. Apartment dwellers and those sharing accommodation are more likely to relocate from their present house. This can be interpreted in two ways. One is household's satisfaction regarding the house, as an intermediary concept of stress. Given the age and income, households are more satisfied with detached house compare to terraced houses and thus less inclined to move. They are less satisfied with apartments than with terraced houses and therefore have a greater probability to move. Another explanation is the concept of a housing career in which people are climbing up housing ladder, i.e. going from shared accommodation to an apartment to a terraced house to a (semi-)detached house.

Population density has been used as a proxy of accessibility of services, where lower density means less access. Results did not show any significance for lower density areas (population density less than 3000 inhabitants per km^2). However a density between 3000 to 9000 inhabitants per km^2 showed a negative impact on relocation compared to higher density areas. This could mean that people have a preference for medium density areas. This is understandable in the sense that the lowest density means less access to jobs and services, whereas medium density means greater access to bigger houses and open spaces compared to the higher densities.

The results suggest that many household and mobility events are also significant. Cohabitation and divorce have a significant impact on moving. Both events increase the probability to move and impacts are among the highest in magnitude. Cohabitation is only significant for the same year, whereas divorce has both a direct and a lagged effect. One reasonable explanation is that cohabitation means an instant need for additional space. A more pertinent one is that at least one of the partners has to move to start the cohabitation, implying a direct effect of the event. Also, it is possible that partners start living together only when they find an appropriate house. The direct effect of a divorce is also self-evident, at least one partner needs to move in case of a separation. The lagged effect may be explained by the required time for agreements and arrangements between partners after separation and might include the partner that stayed behind initially. Also, a divorcee may be forced to relocate to an immediately available house, which may not be satisfactory; leading to a second move the year after. Employer change has both a concurrent and a lagged effect on residential relocation. Change in employment means a change in accessibility, which may lead to a stressful commute. Results indicate that relocating residence is one of the solutions to this. The results further indicate that people can take a decision in the years after the change of employment, which is plausible given the required time to move in general and also the time required for experiencing the commute related stress. Beside employer change, change in car ownership is also considered in the analysis. It is found that disposing and acquiring a car are very significantly associated with relocation. The magnitude of the effect

of car disposal is greater than that of acquiring car/s. This may imply that people tend to move to places with higher accessibility and also to compensate long commutes, which may lead to a lower requirement of cars. This is in line with the preference for medium density and with relocating in response to employer change. Whereas mobility events are important, having more than one car in the household also affects relocation positively. Households, who had more than one car last year, are more likely to move compared to household with one car or no car. Taking retirement has the expected sign but the group of retirees is too small to produce a significant effect.

Although residential relocation involves costs and households do not want to move often (Nordvik, 2001), most of the analysis in long-term mobility decisions has ignored history dependence. Here, we assumed that previous residential relocations play a role in the decision to relocate again. However, only last year's move is negatively influencing the relocation decision for a particular year at 90% significant level. This means that households are less inclined to move if they moved last year, which is to be expected given the high costs of relocating. Another cause for this effect might be that the relocation resolved an existing stressor (e.g lack of space) and therefore reduced the need for further relocations.

The dummy indicating whether the measurement took place retrospectively or at the time of the interview, also distinguishes between observed and intended relocations. The negative effect of anticipated or planned residential relocation could indicate that an intended decision is less probable than an actual relocation in one year but could also mean that mobility in 2010 was lower than before. However, given the magnitude of the parameter it is plausible that many relocation decisions are triggered by unforeseen events.

The analysis uses household income, household type and age of the respondent as state variables. With one exception none of these variables is significant. Only respondents aged over 60 are less likely to move. Surprisingly, income did not show any significance, which may be because dwelling type, household type and home ownership are included in this model. Change in household type seems more important than the state of household type. For example, becoming a couple, rather than being a couple, has a significant positive impact on relocation.

5.5 Discussion

The objective of this paper is to explore the relationship between residential relocation and events in different domains including history dependence of residential relocation. Various household events, for example, cohabitation, divorce, child birth, and mobility events, in this case change in car ownership and employer change, are significant. The history of these events also plays an important role. However, residential relocation history is only significant for last year's relocation, and affects residential relocation negatively. In addition, planned relocation is significantly less likely than observed relocation. Altogether these outcomes support the concept that relocation often takes place in response to household events, and that some of these events are not foreseen a priori. In line with previous researches, dwelling

attributes like home ownership and dwelling type together with location attributes like density give significant plausible results. Socio-demographic variables like age of the respondent, household income and household type are not significant, except for the effect of older households who are less likely to relocate. Primarily, events that bring change to households' situations (or lead to stress) are more significant than state variables in our analysis. For example, starting a cohabitation is significant but being a couple is not and childbirth is significant but being a couple with children is not.

The results have direct implications for agent based land-use and transportation models that need to capture the dynamic relation between employment change, household change, car ownership, and commute mode choice. Many models rely on probabilities derived from cross-sectional data and from state rather than event dependence. Our results show that state dependence disappears once the correct event dependence is included in the model. More importantly we found substantial lagged effects, which are not observed in cross-sectional analyses but have a substantial effect on the outcomes. Using stated rather than revealed intentions for moving does not solve this problem. Many events like divorce or a change employment might not be foreseen, yet do affect residential mobility both directly and in the slightly longer run. Models based on stated intentions may very well underestimate residential mobility.

The relation between the acquisition and disposal of cars with residential relocation requires further analyses. The causality is probably reversed. People dispose of their car if they have moved to a more accessible location, rather than the other way around. Yet we do find puzzling lagged relations between dual car ownership and relocations in the year to come. To some having an extra car might be a way to postpone relocation and provide an alternative to resolve commuting stress, in which case causality would point the right way. The relation between the various long-term mobility decisions is probably more complex than we assumed in the model in this paper. Future research should advance through a focus on more comprehensive model formulations to overcome the present limitations. We intend to use Bayesian Belief Networks to develop an integrated framework, where direct and indirect relationships among different long-term events of different time-frame; i.e. past and/or future events; will be investigated.

Chapter 6:
Car commuting decision: An analysis of commute mode change decision

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Abstract

This paper aims at increasing the understanding of the dynamics in mode choice decisions, by studying changes in commute mode in relation to decisions regarding changes in residential location, work status and location, vehicle ownership as well as changes in household composition and critical events, such as children reaching school going age, marriage or divorce. To study the path dependence of commute mode on preceding decisions and events, we will use a unique data set containing detailed retrospective and prospective data collected over individuals' 20 year lifespan in the Utrecht region in 2010. A panel model is used to investigate how change in commute mode in a given year is related to mobility and life cycle events in previous years or to anticipated events in future years.

6.1 Introduction

Modal shift from car to public transport or slow transport modes has important environmental benefits. However, mode choice is often habitual (e.g. in the context of commuting) and not easy to break in the short-term. Although life cycle events may lead to reconsidering one's travel behaviour, little is known about the impact of such events on commute mode decisions. Analyses ignoring such issues may lead to biased outcomes. In this regard, the objective of this paper is to investigate whether these life cycle events lead to changes in commute mode. Life cycle events include household events like marriage, child birth, child home leaving and divorce as well as long-term mobility events like relocation and job change. For example, a job change may imply a longer commute distance such that cycling is no longer possible.

Numerous studies have addressed mode choice decisions. Most are cross-sectional in nature, focusing on the impact of residential characteristics like land-use and accessibility

(e.g. Hanson and Schwab, 1987; Frank and Pivo, 1994; Cervero, 1996; Chen, Gong and Paaswell, 2008), travel related attributes like cost, time etc (e.g. Yagi and Mohammedian, 2007) and issues like parking or/and congestion (Washbrook, Haider and Jaccard, 2006) on mode choice. However, these analyses have regarded mode choice in a cross sectional way as the outcome of a set of explanatory variables, and have not considered changes in mode choice as a result of a change in travel conditions.

Recently the focus has turned to the dynamics in transportation (e.g. van der Waerden, Borgers and Timmermans, 2003a, b; Verhoeven, et al., 2005; Dargay and Hanly, 2007; Kitamura, 2009). Dynamic analyses are based on panel data, and have studied primarily the effects of socio-demographic characteristics and household car ownership (e.g. Goulias and Kitamura, 1992; Dargay and Hanly, 2007; Kitamura, 2009). Very few dynamic analyses have however been carried out regarding commute mode in association with long-term life events. The daily decision of commute choice is often a habit and thus difficult to change. However, such daily behaviours may also vary over time for particular individuals (Dargay and Hanly, 2007), leading to considering long-term decisions in association with commute decisions.

Van der Waerden, Borgers and Timmermans (2003a, 2003b) argued that activity-travel repertoires may bifurcate into a state of disequilibrium due to critical incidents and key lifecycle events and that these may therefore be relevant concepts for studying the dynamics of activity-travel patterns. Critical incidents (e.g. an accident) often cause a highly negative experience such that individuals may reconsider their current behaviour. In contrast, key lifecycle events are unavoidable (demographic) events, such as reaching the age to have a driver's license or planned events that occur during a lifecycle (leaving home, getting married, first child, retirement, new job, new house, etc). Such events may lead to changes in available resources and choice options. Van der Waerden, Borgers and Timmermans (2003a, 2003b) found that of mobility events (like relocation, work change) and mobility associated events (like getting driving license) had an effect on mode switch. Verhoeven, et al. (2005) found that life cycle events influenced mode choice decisions, but in some cases with a time lag.

Clark, Huang and Withers (2003) looked into residential change and commute distance. However, their focus was on choosing the work location in association with the residential location in response to commute distance. Stanbridge, Lyons and Farthing, (2004) and Stanbridge and Lyons (2003) considered travel behaviour change during residential relocation. They found that travel considerations are part of the prompt for the relocation itself, that travel entered the process of searching for a new property; and most importantly that relocation forced or prompted reappraisal of travel options once post-relocation journey experiences were encountered. Similar evidence has been found by Prillwitz and Lanzendorf (2006). They analysed commute distance and its interaction with relocation, job change, life events like marriage, divorce, child birth, child's moving out etc. These analyses focused on different life cycle domains in relation to travel behaviour, however, mode choice decisions are not considered as such. Nonetheless, it is likely that long-term mobility decisions in

association with other lifecycle decisions impact on structural travel mode decisions. In this respect, this study intends to contribute to the state of art by analysing dynamics of mode choice decisions. Dynamics would be captured explicitly focusing on modal shift rather than explaining mode choice as done in the above mentioned research. This study also investigates the influence of different events both mobility events and household events on the timing of events. Incorporation of anticipated events' effect is an extension of earlier work in this area of research.

The following sections will start with the research design, followed by an explanation of data and methods of analysis. Results of data analysis will reveal outcomes of bivariate and panel analyses. Finally, conclusions will be drawn based on these results and future research intentions will be discussed.

6.2 Research design

This study builds on the conceptual framework and first empirical analyses on a limited dataset presented in previous work by Oakil, et al. (2011a), where it is assumed that the dynamism in residential situation, work status or location and car ownership or mode choice stem from various mechanisms. First, people take such decisions not only based on their current state but considering anticipated changes as well. This is necessary since changes in residence, work status or car ownership require substantial investment of time and money and only take place infrequently. As a consequence, choices made at one moment will shape the conditions/options for future longer-term and short-term decisions. For instance, the choice where to live and in what dwelling will have a strong impact on or will be constrained by accessible jobs, the need to own one or more cars and thus the budget remaining for expenditures to consumption and daily travel. Note that this implies causal relationships for both forward (path-dependency) and backward (anticipation) events in time (Oakil, et al., 2011a). Second, longer-term travel decisions are triggered by stressors (Brown and Moore, 1970; Salvini and Miller, 2005; Habib, Elgar and Miller, 2006), which have repercussion on short-term decisions as well. Stress triggered decisions require time to adapt, which implies a lagged response to changing needs. Also, it implies path dependency in the sense that a recent change (for example, relocation or car acquisition) may set limits to new changes due to limitations in financial, temporal or mental resources. Apart from the dynamism, limitations in time and money budgets imply a strong interdependency between longer term decisions (Ettema, et al., 2007). For instance, households/individuals have to trade-off between spending their income to the dwelling or to transportation options (cars), between working more hours (resulting in a higher income) and having more free time, etc. This implies interdependencies beyond the path dependency effect, in the sense that earlier decisions create limitations/options for later choices.

Stressors can arise from different events. For instance, a change in job location may increase commute distance (stressor), leading to a need to reduce travel time. This can be achieved by different actions such as changing residential location closer to work (Bina and

Kockelman, 2006; van Ham and Hooimeijer, 2008) or owning a car (Oakil, et al., 2011b) or even combining both. If a household recently changed its residential location, it is likely to prefer a solution through a change in travel resources rather than changing residence again (e.g., Cao and Mokhtarian, 2005). The concept of stressors thus avoids a limited definition of one-to-one relationships between events that follow up in time. On the other hand, changes in aspirations can lead to stressors. First, changes in the household composition, such as childbirth or home leaving of children, may invoke a change in the need for transportation options. For example, childbirth might generate an extra demand for cars because one has to drop off and collect children from a day care centre; whereas home leaving of a child might mean a lower need for an additional car in the family. Likewise, a changed physical condition or a change in household's resources (such as income) may lead to increased aspiration for car ownership. For instance, an income increase will reduce budget constraints, but it might also create additional demand, e.g. for a luxury car, a bigger car or an additional smart car. Obviously, if life events trigger changes in car ownership, driven by a need for transportation, they are likely to influence mode choice decisions in a similar fashion.

In this regard, this study will look further into dynamics of commute mode by investigating shifting commute mode in association with long-term decisions and events. The main research question is then which factors significantly influence shifting commute mode decisions. Two different investigations will be carried out. One will depict factors responsible for switching commute mode towards public transport or non-motorized mode, whereas the second will warn about factors behind mode switching behaviour towards car.

Apart from long-term mobility decisions like relocation, job change and car ownership decisions, this paper includes household long-term events such as parental home leaving, marriage, divorce, birth of a child and child's leaving home. In addition, the analysis uses changing work status such as starting a full-time job and switching to a part-time job. In the socio-demographic part, age, education and sex are included. The study examines lagged responses, i.e. whether past events have influenced mode choice and advanced response, i.e. whether mode choice is decided in expectation of some anticipated events.

6.3 Data analysis

Data collection was based on a pen and pencil questionnaire. The questionnaires include four forms of information: i) historical information of 21 years for individuals and households; ii) anticipated events information; iii) social network information and iv) information about market perception. A detailed description can be found in Oakil, et al. (2011b). Historical information of respondent's work, home and household events are used. Partner's information consist lot of missing values, thus excluded.

The analysis started with 390 individuals. After consideration of missing values and other requirements, the suitable sample was less than 200. As mentioned, this study intends to analyse two forms of modal shift – one illustrates factors that encourage one to stop using the car as the commute mode and the second explains reasons to start using the car as the

commute mode instead of other modes like bicycle, motor bike, bus, train or walking. The study only considers commute mode as car use and non-car use. This dichotomy was necessary given the small number of mode change events that were observed. Samples are also different for two analyses – i) *Modal Shift from Car*, which means that individuals changed from car to other modes like bus, train, bicycle, motor bike or walking and ii) *Modal Shift to Car*, which means that other commute modes are replaced by the car.

Analyses excluded years when a respondent has retired. In two different samples, events occurrences are quite similar, with mode shift happening in 2-3% of respondent years. Modal shift from other mode to car (2.8%) is relatively higher than car to other mode (2.4%), which indicates that people are switching to the car more and more. Variables used in the analysis are mostly events. In addition, one lag and lead of these events are considered, for example, child birth one year before and after the event of modal shift. Apart from the events, state variables are also incorporated such as age, gender, education, working status of the respondent and car ownership level and household composition (whether living with partner or not).

The study will use panel models to illustrate the relationship between commute mode change decision and other events and states. This study takes every episode of using particular commute mode as a segment of repeated observations. For example, in the panel analysis of modal shift to car repeated observations consists of those consecutive years when a respondent used public transport, bicycle or motor cycle as the commute mode and thus multiple groups of repeated observation is possible for an individual within 21 years. So, random effect correlation is considered for within that group rather than within an individual. Biogeme 1.8 has been used to estimate a Multinomial Logit Model with such random effect correlation within a group. Random effects across those groups are assumed to be independently and identically distributed. The dependent variable is a binary variable and the model is specified to estimate a threshold value for the non-change decision in addition to the factors affecting the decision to change.

6.4 Results

Before conducting the panel analysis, results from a bivariate analysis between commute mode change and long-term events are shown below. As occurrence of some events is infrequent, the level of significance for this analysis is based on the one-sided Fisher's exact test. Fisher's exact test is more accurate than the chi-squared test of independence when the expected numbers are small (Everitt, 1992).

From the bivariate analysis, five factors can be identified that have a significant positive relation with the mode switching decision from the car and seven for shifts towards the car (Table 6.1). Change of employer is the only event that shows a lagged effect for shifts from the car, but for shifts to the car relocation has both lag and lead effects. As conceptualised, switching to a part-time job means more time for different activities but less income at one's disposal. Such constrained budget may affect car ownership, e.g. disposal of a car and this

may lead to mode switch from the car to other. As expected, switching to part-time job has a significant positive relation with stopping commuting by car and using other modes. On the other hand, starting a full-time job encourages shifting towards the car.

Table 6.1: Results of the bivariate analysis for commute mode shift from and to car

Event	Modal Shift from Car (Y/N*)	Modal Shift to Car (Y/N*)
Left parental home	0.0/0.1	0.0/0.3
Left parental home 1 year before Mode change	0.0/0.2	1.9/0.7
Left parental home 1 year after Mode change	0.0/0.1	0.0/0.3
Start living with partner/cohabitation	0.0/1.6	5.8/2.0
Start cohabitation 1 year before Mode change	6.1/2.0	5.8/2.4
Start cohabitation 1 year after Mode change	0.0/1.3	1.9/2.1
Birth of first child	**8.2/2.3 +**	**9.6/1.9 ++**
1st child born 1 year before Mode change	4.1/2.4	1.9/2.0
1st child born 1 year after Mode change	6.1/2.2	1.9/1.9
Last child left home	0.0/0.9	1.9/0.9
Last child left 1 year before Mode change	0.0/0.8	0.0/0.9
Last child left 1 year after Mode change	0.0/0.9	0.0/1.3
Separation/Divorce	4.1/0.9	1.9/0.9
Separated 1 year before Mode change	4.1/0.9	3.8/0.8
Separated 1 year after Mode change	0.0/0.8	0.0/0.8
Change of employer	**40.8/9.6 ++**	**40.4/9.7 ++**
Changed employer 1 year before Mode change	**24.5/11.3 ++**	**25.0/11.1 ++**
Changed employer 1 year after Mode change	14.3/9.9	7.7/9.1
Start or resume Fulltime work	2.0/1.3	**9.6/1.8 ++**
Start or resume Fulltime work 1 year before Mode change	8.2/3.2	3.8/3.7
Start or resume Fulltime work 1 year after Mode change	4.1/0.8	1.9/1.4
Switch from Full to Part time work	**10.2/1.2 ++**	0.0/1.5
Switch from Full to Part time work 1 year before Mode change	0.0/1.3	3.8/1.5
Switch from Full to Part time work 1 year after Mode change	2.0/1.3	1.9/1.2
Change of residence	**18.4/7.1 ++**	**19.2/8.7 +**
Relocated 1 year before Mode change	10.2/8.6	**19.2/9.5 +**
Relocated 1 year after Mode change	10.6/6.6	**15.4/7.5 +**

++ means positive correlation with Fisher Exact Sig. < 0.01 (One-sided).
+ means positive correlation with Fisher Exact Sig. < 0.05 (One-sided).
* Numbers indicate observed percentage for modal shift given the event has occurred (Y) and not (N).

However, anticipated events do not show any significant association with switching from the car. One reason might be that mode choice is a short-term decision and may not require significant resources, at least when the switch is towards public transport or bicycle. Modal shift towards the car is only associated with relocation in the next year, but it should be noted

that this bivariate analysis cannot account for any confounding effects that may cause relationships to be spurious. To gain a more correct insight, a panel analysis was therefore conducted. Main results are summarised in Table 6.2. The included variables are based on a preliminary analysis. Some variables were excluded from the analysis because they were never associated with a mode change, leading to unreliable t-test outcomes and non-converging models.

As one would expect, change in employer has a significant positive effect as has a change in employer one year earlier (Table 6.2). Both increase the probability to switch commute mode. These variables have a positive impact on both changes; switch to car and from car. This is because a change in job may mean both an increasing and decreasing commuting distance or improved or decreased accessibility by different modes. Results do indicate however that these events lead to a higher probability of switching to the car. As mentioned earlier, taking a part-time job instead of a full-time job will reduce budgetary flexibility and thus increase the probability to give up car commuting, but only in the same year. On the other hand, starting or switching to full-time work does not have any significant impact on the two types of mode changes. However, having a full-time job encourages a shift towards car commuting.

It is to be noted that relocation and birth of the first child are no longer significant in the panel analysis for the shift from the car towards other modes. However, birth of the first child has a positive influence on switching to the car. Birth of a child means that household require increased flexibility, for instance, for baby's regular check-up or day care drop off and pick up. This may lead to increased car ownership and thus commuting by car. However, car ownership already showed a significant positive impact on switching to the car, implying that childbirth creates additional requirements to commute by car. This can be explained by the fact that, for example, parents could drop their babies at the day care on the way to work and pick them up on the way back home. On the other hand, car ownership has a negative impact on the probability to choose another mode instead of car. However, relocation showed no significant impact on mode change decision. This contrasts with the results of previous studies. This is possibly because a residential move does not by definition imply an increase or decrease in commute time or distance. It could also mean that residential relocation is a self-standing decision, which is taken independent of commute mode decision. Quite likely, people may change dwelling because of housing career considerations related to longer-term decisions and commute mode is dependent on job characteristics and available resources.

The study conceptualised that anticipated events might have an impact on mode shift decisions. However, results defer from the assumption. This might be because of uncertainty about the future scenario and because mode shift is not a long-term decision to consider. Except for owning a car, mode shift decisions do not need significant resources and the model considered car ownership explicitly. Also people might feel comfortable taking decisions after the event as can been seen for job change event and divorce.

Table 6.2: Results of the panel analysis for commute mode shift from and to car

	Shift from car			**Shift to car**		
Variables	Value	t-test	p-value	Value	t-test	p-value
Random parameter for Panel data	0.29 0.00	0.16 Fixed	0.87	-0.11 0.00	-0.10 Fixed	0.92
Older than 50 years	-0.30	-0.59	0.56	-0.17	-0.34	0.73
Birth of first child	0.30	0.41	0.68	1.78	3.08	**0.00****
Last child left home	-	-	-	1.87	1.67	0.09
Cohabitation/marriage	-	-	-	0.25	0.34	0.74
Starting / resuming full-time job	-0.48	-0.43	0.66	0.72	1.18	0.24
Separation/divorce	1.50	1.70	0.09	0.60	0.48	0.63
Full-time to Part-time work	2.04	2.70	**0.01***	-	-	-
Has a full-time job	-0.30	-0.59	0.55	0.81	2.08	**0.04***
HBO + University Education	0.63	1.36	0.17	0.47	1.06	0.29
Change of employer	2.06	5.63	**0.00****	1.99	5.42	**0.00****
House and Job change interaction	-1.26	-1.49	0.14	-1.12	-1.40	0.16
Birth of first child 1 year after Mode change	0.79	1.02	0.31	-0.03	-0.03	0.97
Start cohabitation 1 year after Mode change	-	-	-	-0.51	-0.46	0.65
Starting or resuming full-time job 1 year after Mode change	0.86	0.96	0.34	0.98	0.88	0.38
Full-time to Part-time work 1 year after Mode change	0.54	0.48	0.63	0.40	0.36	0.72
Changed employer 1 year after Mode change	0.26	0.55	0.59	-0.33	-0.56	0.58
Change of residence 1 year after Mode change	-0.14	-0.25	0.80	0.50	1.06	0.29
Birth of first child 1 year before Mode change	-0.81	-0.81	0.42	0.14	0.13	0.90
Start cohabitation 1 year before Mode change	0.45	0.56	0.58	0.03	0.04	0.96
Starting or resuming full-time job 1 year before Mode change	0.90	1.42	0.15	-	-	-
Separation/divorce 1 year before Mode change	1.89	2.02	**0.04***	1.97	2.18	**0.03***
Changed employer 1 year before Mode change	0.87	2.25	**0.02***	0.91	2.37	**0.02***
Left parental home 1 year before Mode change	-	-	-	0.66	0.54	0.59
Change of residence 1 year before Mode change	-0.80	-1.41	0.16	0.38	0.84	0.40
Change of residence	0.62	1.11	0.27	0.79	1.42	0.16
Own more than one car	-1.04	-2.95	**0.00****	1.71	4.81	**0.00****
Respondent is living with partner	0.31	0.58	0.56	0.23	0.52	0.61
Respondent is a male	-0.18	-0.44	0.66	-0.03	-0.08	0.94
Threshold	4.55	7.08	**0.00****	5.92	9.00	**0.00****
Final log-likelihood	-191.47			-192.80		
Log-likelihood (only threshold)	-227.36			-236.23		
Pseudo Rho-square (compare to threshold only model)	0.16			0.18		

Apart from child birth and the lag effect of divorce, other household events and household characteristics turned out to be non-significant (for the present sample size). Socio-demographic factors like age, sex and education did not show any significant influence. Though there are few significant influences of mobility and life cycle events on modal shift, a relative high threshold value suggests a high probability of no change for both types of modal shift.

6.5 Conclusion

The study explicitly analysed the dynamics in mode choice using retrospective survey data. Results of the analyses identify some variables, significantly influencing mode switching behaviour. Job characteristics such as change in working status and employer change and mobility resource like car ownership turned out to be important factors for mode shift decisions. Socio-demographic variables are not significant. However, birth of first child is a significant determinant for shift towards car. Surprisingly, residential mobility did not show any effect except a significant association in the bivariate analysis. This is also true for anticipated events. Relocation in the next year showed association with modal shift towards car, but only in the bivariate analysis. The short-term nature of mode choice is probably the reason behind insignificant lead effect of events. Only one lagged variable is significant suggesting that any interrelated decisions between the considered events are not made within one year. Although a good number of events has been included in the analyses, many household events and characteristics are not significant. This may be in part due to the small sample size in connection with some low event frequencies.

Even though some important findings are presented, further research is necessary to better understand mode switching behaviour. Further research will investigate time dependence and also lag and lead effect beyond one year. In addition, we plan to further examine how modal shift decisions can be incorporated into an integrated long-term mobility framework, where long-term life cycle and mobility events are interrelated in association with short-term decisions and actions.

Chapter 7:
Bicycle commuting decision: An analysis of commute mode change decision

Abstract

This paper investigates the influence of both mobility events and household events on modal shift decision for bicycle commuting using data collected from a retrospective survey in the Netherlands. The results from a mixed logit analysis illustrate the influence of several life events on commute modal shifts in addition to changes in commute time and socio-demographic variables. Job characteristics such as changes in work status and employer, mobility resource, long-term mobility events, and household events are seen to influence commuting decision by bicycle.

7.1 Introduction

Commuting by bicycle is encouraged in the Netherlands by policy makers for its environmental and health benefits. Policy makers put much effort into creating better cycling conditions, for example, by building safe and specialized infrastructure. Furthermore, they provide financial aid in order to encourage bicycle use (e.g. tax exemption offered by the employers in the Netherlands to buy a bicycle). These policies have been found to work well given the high building densities and mixed land-use schemes in The Netherlands, which result in many services and amenities falling within cycling distance. Yet, even in a bicycle friendly country like the Netherlands, the share of bicycle commuter amounts to only 25% (Fietsberaad, 2009). In addition, 36% of all journeys up to 7.5 km is made by cars (Fietsberaad, 2009), and the bicycle may be an attractive alternative to them. This suggests that there is still a considerable growth potential for bicycle use. However, it is often overlooked that the effects of policy measures depend on other factors, such as household dynamics with respect to residential location, vehicle ownership, working status and household composition. It is important to understand the effects of such dynamics on cycling in order to develop successful policies for promoting cycling. A focus on the changing behaviour is crucial in order to understand whether the direction of change is in favour of or against sustainability. However, knowledge of such long-term dynamics is very limited, especially in the context of cycling and household dynamics.

Numerous studies have addressed mode choice decisions and are therefore potentially relevant for understanding cycling decisions. These studies have addressed how mode choice is affected by residential characteristics such as land-use and accessibility (e.g. Hanson and

Schwab, 1987; Frank and Pivo, 1994; Cervero, 1996; Chen, Gong and Paaswell, 2008); neighbourhood preferences (e.g. van Wee, Holwerda and van Baren, 2002; Schwanen and Mokhtarian, 2005); travel related attributes such as cost, time and comfort (e.g. Yagi and Mohammedian, 2007); and issues such as parking and/or congestion (Washbrook, Haider and Jaccard, 2006). In the context of cycling, analyses have addressed the effects of socio-economic and demographic factors (e.g. Dill and Voros, 2007; Akar, Fischer and Namgung, 2012); weather and climate (e.g. Nankervis, 1999 and Hanson and Hanson, 1977); work culture (Heinen, Maat and Van Wee, 2013) and facilities at work (Stinson and Bhat, 2004). A detailed overview of literatures on bicycle use can be found in Heinen, Van Wee and Maat (2010). The above studies, however, have regarded mode choice in a cross sectional way as an outcome of a set of explanatory variables, and have not considered changes in the mode choice as a result of changes in travel, work or household conditions. Dynamic analyses of transportation issues have taken place using panel data, but these have primarily studied the effects of socio-demographic characteristics on household car ownership (e.g. Goulias and Kitamura, 1992; Dargay and Hanly, 2007). No dynamic analyses regarding commute mode have been carried out in association with long-term life events.

A dynamic approach to commute mode change assumes that over the life course, people's commute mode decisions may change in response to demographic, residential, job related and vehicle ownership related issues. Such events bring changes in life, which may create a different context for an individual, leading to rethink their present behaviours (Van der Waerden, Borgers and Timmermans, 2003a; Lanzendorf, 2003; Dargay and Hanly, 2007; Oakil, et al. 2011a). A first mechanism is that a change in life circumstances directly impacts on the characteristics of the commute trip, such as travel time and cost. For example, a longer commute distance due to a job change may encourage acquiring a car and using it for the commute (Oakil, et al., 2011b). Also Van der Waerden, Borgers and Timmermans (2003a) found that different mobility events (such as relocation or work change) had effects on the decision to switch mode. In addition, mobility events, such as acquiring a driver's license (Van der Waerden, Borgers and Timmermans, 2003a) and acquiring an additional car (Oakil, et al., 2010a), were found to increase the range of choice options of the commuters and influence mode choice. It is noted that in the context of (commute) mode change in response to a job or residential relocation or a change in vehicle availability, the causality of the relationship is open for debate. While it is conceivable that, for instance, a job change is 'external' in the sense that it is driven by other considerations than the implications for the commute (such as career prospects), it is also possible (especially in the Dutch context) that people look for a job closer to their homes in order to reduce their commute distances or be able to use slow commute modes such as bicycle. Likewise, a residential relocation may be to varying degrees influenced by the implications for daily travel in general (Stanbridge and Lyons, 2006) or the daily commute in particular (Bina and Kockelman, 2006). The concept that residential or job location are (partly) determined by the preferences for daily travel has been termed self-selection in the transportation literature. Using either dedicated surveys

including attitudinal and preference items (Schwanen and Mokhtarian, 2005) or advanced econometric methods (Pinjari, et al., 2007), self-selection has been shown to be at least partly responsible for the correlation between land use patterns and travel behaviour, and is likely to be associated with more dynamic relationships between vehicle ownership, job and residential location on the one hand and commute mode change on the other hand.

A second mechanism in the impact of demographic changes on the commute mode change is related to a change in responsibilities and daily activity patterns. For instance, changes in a household composition such as childbirth or divorce may invoke a change in the need for transportation options. Childbirth may generate an extra demand for owning a car because one has to drop off and collect children from day care centres, schools, etc. Verhoeven, et al. (2005) found that life-cycle events influenced commute mode choice decisions, but in some cases with a time lag. Prillwitz, Harms and Lanzendorf (2007) reported that changes in the household composition were related to commute distance. Oakil, et al. (2010c) found that birth of the first child increased the probability of a switch toward car commuting. In some cases, changes in responsibilities and activity patterns are associated with residential relocations. For instance, a work related or a residential relocation may also affect work status of the partner, car ownership or have implications for children's school travel (e.g. Sharmeen, Arentze and Timmermans, 2013). Thus, a combination of interrelated responses may be triggered, one of which may be a commute mode shift.

Although commute mode choice has been studied in a dynamic fashion to some extent, analysis of cycling in a longitudinal perspective is scarce. Barnes, Thompson and Krizek (2006) analysed increases in the mode-share for bicycle and its dependence on bicycle facilities. They investigated the modal-share of bicycle by comparing bicycle facilities of different locations and at different times for the same location. In a qualitative analysis, Bonham and Wilson (2012) investigated women's stopping and returning to cycling through the life-course. They found that changes in women's cycling patterns were related to changes in housing, employment, health and family status.

Taken together, the existing literatures suggest that changes in job and residential location and changes in the household composition may have a significant impact on (commute) mode changes, and that analyses excluding such household events may be biased. However, insight into the effects of demographic events and relocations on cycling as a commute mode is largely lacking. Therefore, this paper sets out to explore this relationship based on a retrospective survey held in The Netherlands, in which respondents reported on both demographic events and commute mode for a 21 year period. In contrast to the existing studies in cycling, our study takes a dynamic approach in the sense that we do not explain current commute mode from an individual's given characteristics and circumstances, but explain the occurrence or absence of changes in the commute mode from the dynamics in household composition, work and residential location and vehicle accessibility.

The remainder of this paper is organized as follows. The analytical approach section describes a detail method of the analyses. In the data section, data collection, sample

description and descriptive statistics are explained. The result section reveals the important factors behind bicycle mode switching behaviour. A summary of results and a reflection on the analyses are discussed in the conclusion.

7.2 Analytical approach

Given the need to investigate mode change in the context of cycling based on a retrospective longitudinal data set, we have defined two events that may take place: i) *Modal Shift from bicycle*, which means that an individual changes his/her commute mode from bicycle to another mode like car, bus, train, motor or walking from one year to another and ii) *Modal Shift to bicycle*, which means that another commute mode is replaced by the bicycle from one year to another. Obviously, whether or not a modal shift from bicycle takes place, is only relevant in cases where one uses bicycle as a commute mode in a given year. Likewise, a shift to bicycle is only relevant in cases where one does not use bicycle as a commute mode in a given year. Note that the commute mode change is defined based on the most frequent commute mode identified by the respondent for a given year. Modal shift is in this study defined in a binary way, e.g., we do not distinguish between a shift from car use to cycling or bus use to cycling, but regard them both as a shift to cycling. Likewise, we treat a shift from cycling to car and from cycling to bus similarly as a shift away from cycling. This binomial formulation is necessary given that small numbers of modal shift from bicycle (4.5%) and to bicycle (1.8%) have occurred in the samples (also shown in table 2). This indicates that many respondents have never changed their commute mode to or from bicycle in the whole survey period for both of the analyses.

To analyse the occurrence of a shift toward bicycle (for non-bicycle users) or away from bicycle (for bicycle users), these variables are used as dependent variables in a multivariate model, in which both dynamic variables (demographic, residential and work related changes) and static variables (current personal and household characteristics) serve as explanatory variables. To this end binary logit models are estimated. However, the shifts in commute mode as well as dynamic variables are derived from a longitudinal retrospective survey (see section 3), in which respondents indicated commute mode and personal/household characteristics for a 21 years period, implying that multiple observations for the occurrence/non-occurrence of commute mode change are available for each individual. Since multiple observations per individual are used to estimate the binary logit models, intra-individual correlation is accounted for by using a panel model formulation (see section below for details).

It is possible that an individual changes his/her commute mode more than once over the survey period. In those cases, we have considered consecutive years of using a particular commute mode as a single observational unit and thus multiple observational units for an individual are possible, depending on multiple modal shifts. These observational units are considered when accounting for random effects rather than taking an individual as the unit of observation. To this end, Biogeme 1.8 has been used to estimate a Mixed Logit Model with

random effect correlation between the observational units. Random effects across the units are assumed to be independent and identically distributed.

As mentioned earlier, the dependent variable is a binary variable. So, a discrete choice model is specified with two choices. Choice 1 represents a modal shift (to or from bicycle) and the utility associated with this choice is a function of different explanatory variables including random effects. Choice 2 represents a constant commute mode (i.e. a modal shift to or from bicycle has not happened) and the utility associated with this choice is a constant, which measures initial resistance to the modal shift, and includes random effect across the units. The utility function is defined as follows

$$u_{1it} = \sum_{k=1}^{n} \beta_{1itk} x_{1itk} + \lambda_{1i} + \varepsilon_{1it} \qquad (7.1)$$

and

$$u_{2it} = \alpha_{2it} + \varepsilon_{2it} \qquad (7.2)$$

where,

u_{1it} = Utility of choice 1 (commuting mode changed to/from bicycle) at time t.

u_{2it} = Utility of choice 2 (no commuting mode changed to/from bicycle) at time t.

i = Index of each segment of consecutive years of using a particular commute mode.

t = Time of observation.

k = Index of explanatory variables.

x_{1itk} = Explanatory variables for choice 1 at time t.

ε_{1it} = Random effect for choice 1.

λ_{1i} = Random effect related to a group.

α_{2it} = Constant explaining choice 2.

ε_{2it} = Random effect for choice 2.

7.3 Data

Retrospective data collection

Longitudinal data is necessary to analyse commute mode shift over a part of the life course. In this regard, panel data are the optimal option. However, panel data including commute mode and all household events such as demographic, residential, professional and long-term mobility events were not available. Therefore, a retrospective questionnaire survey was carried out in the Utrecht region of the Netherlands. The data included both state and event variables for every calendar year ranging from January 1990 to July 2010. On the one hand, a state variable represents a household characteristic in a particular year, for example, a state of household composition is living with partner or being a couple with children. An event, on the other hand, is defined as a change in a household characteristic in a particular year, for example, a household is single but starts to live with partner in a given year. Thus, the

household events bring change to household composition (e.g. marriage), household work situation (e.g. taking retirement) and/or to household resources (e.g. an increase in income). In terms of residential and mobility aspects, it indicates a change in job, residence, car ownership and/or commute mode. Historical data was collected for the following aspects:

a) Income and work status of the respondent and his/her partner.
b) Household events such as start of cohabitation, childbirth, children leaving the family home, divorce and death of the partner.
c) Residential characteristics (i.e. the year one moved in, location, residential cost per month, number of rooms, age of the dwelling, garden and parking facility).
d) Work location of the respondent and his/her partner.
e) Number of cars per household and car availability, commute mode and commute time for both the respondent and his/her partner.

Commute mode is defined as the most frequently used mode in a given year. It is realised that retrospective data may suffer from problems in recalling and can therefore be biased. However, several studies (e.g., Verhoeven, et al., 2008; Beige and Axhausen, 2008) suggest that the retrospective surveys can be a useful tool and can provide reliable information about the past events, if these events are very important. Likely, the critical events asked for in this survey, such as residential relocation, car fleet changes and job changes will fall into this category and can be remembered with acceptable accuracy. To minimize memory bias, we have checked for consistency in the dataset between related events. For example, we have checked whether the year of a relocation due to cohabitation matched with the reported year of the start of cohabitation. Based on such consistency checks, we believe that the data provides a sufficiently accurate account of household dynamics for our purpose.

It is also argued that the more distant the event, the more fragmented and biased the memory (Schoenduwe, et al., 2009). To test this claim, in a previous study (Oakil, et al., 2011b) we performed a comparison among results from three different data segments – i) the first half of the dataset with data from 1990 to 1999; ii) the second half of the dataset with data from 2000 to 2010 and iii) the complete dataset from 1990 to 2010. We tested the relationship of car acquisition or disposal with different household events such as start of cohabitation, separation, childbirth, child's home-leaving, retirement, relocation and job change based on Fisher's exact test. We found very few differences in terms of relationship between the events for three different segments of the dataset. Moreover, our assumption is that people would not respond if they could not recall. Thus the compromise is losing data rather compromising the reliability. The important compromise in regard to data lose is the binomial formulation of the analyses for this study. We also understand that the household states are difficult to recall, for example, commute mode or commute time. In these cases, we have categorised the data with a bigger interval to reduce the uncertainty about the reliability of the variable, for instance, 30 minutes interval for the commute time and mostly used commute mode in a particular year. Thus we are not able to differentiate between partial use of car and public transport or of bicycle and public transport etc.

The survey was based on a pen and paper questionnaire. It covered inhabitants of urban areas (Utrecht), suburban areas (De Bilt, Zeist, Bunnik, Driebergen and Baarn) and villages (Groenekan, Odijk, Werkhoven, Bosch en Duin, Maarn, Doorn and Austerlitz) and was distributed among 1200 candidate individuals in total. In this way, we covered different spatial contexts such as urban, sub-urban and rural areas. The candidates were approached by a random walk procedure. Surveyors knocked on every 10^{th} door of the preselected streets in the above municipalities and left a questionnaire if the candidate was willing to answer the questionnaire and was at least 30 years of age. The age of 30 was chosen to ensure that a respondent has a sufficiently long history to report. If the door was not opened or the resident did not want to collaborate, the surveyors would try the neighbour, until someone collaborated. The only selection criterion of the streets was that these were physically scattered over the survey areas. A face to face distribution procedure was followed to increase the number of returned questionnaire by increasing the commitment from the candidates.

Sample Description

The unit of observation of the sample is observation-year per person, i.e. every observation represents information of an individual for a calendar year, in which an event can or cannot occur. This means that observation-years represent the occurrence or non-occurrence of a commute mode shift, and the associated household events and state variables during the 21 years survey period. Thus the total number of observation-year is 10038, as 478 questionnaires are returned out of 1200 distributed questionnaires.

Based on the objectives of the analyses as explained in section 7.2, the sample is split into two different samples for two different analyses - i) to analyse commute mode shift from bicycle, observation-years are restricted to those who commuted by a bicycle in a given year and ii) to analyse commute mode shift towards bicycle, observation-years are restricted to those who did not commute by a bicycle in a given year. As an individual can be a user and a non-user of bicycle within his/her survey period, observations for different years of one person may be part of different sub-samples. The sample sizes are further reduced after the consideration of - i) missing values due to non-response to important questions and ii) exclusion of retired or non-working years. Based on the above considerations, the sample size for the analysis of modal shift from bicycle is 1228 observation-years from 131 respondents. The sample size for the modal shift to bicycle is 2859 observation-years from 237 respondents.

Descriptive statistics of both samples are presented in Table 7.1, in which person-observation years are the unit of analysis. One should be cautious in interpreting these figures in the context of repeated observations per person. Except for education and gender, age, residential density, work-status, household status and car availability are specific to a particular calendar year as reported by the respondents.

Table 7.1: Descriptive statistics of socio-demographic and state variables in two samples

Variables	From bicycle		To bicycle	
	Frequency	%	Frequency	%
Age of the respondent				
Age <= 30 years	212	17.3	404	14.1
Age 31- 40 years	358	29.2	799	27.9
Age 41-50 years	410	33.4	952	33.3
Age > 50 years	248	20.2	704	24.6
The respondent is a Female*	81	61.8	120	50.6
Highest education achieved by the respondent				
Low education (<=MAVO/MULO)*	7	5.3	13	5.5
High education (= University) *	62	47.3	106	44.7
Household composition				
Couple	321	26.1	912	31.9
Couple/Single with children	660	53.7	1566	54.7
Work-status of the respondent				
Part-time working	601	48.9	1013	35.4
Full-time working	572	46.6	1787	62.5
Population density of the residential area				
Density <= 500 pop/km^2	145	11.8	456	15.9
Density = 501-2500 pop/km^2	400	32.6	1139	39.8
Density = 2501-5000 pop/km^2	288	23.5	530	18.5
Density = 5001-7500 pop/km^2	160	13.0	355	12.4
Density > 7500 pop/km^2	235	19.1	379	13.3
Presence of InterCity station in the residential area	18	1.5	18	0.6
Car availability to the respondent				
Full-time car availability	432	35.2	2180	76.3
Part-time car availability	495	40.3	444	15.5
Total number of respondents	131		237	
Total number of observation-years	1228		2859	

* Statistics are based on the number of respondents.

Table 7.1 shows the frequencies and the percentages based on total observation-years for both the 'to bicycle' and the 'from bicycle' samples. Since education and gender do not vary over time, we use the total number of respondents to indicate the sample distribution. Table 7.1 shows that the sample representation is not very different from the population of the Netherlands. For example, about 51% of the population is more than 40 years old in 2012, which is about 53% and 57% for respective sub-samples in our study. For gender representation, the sample of "to bicycle" is similar to the population in 2012. About 71% of the households in the Netherlands own at least one car, which is reflected in the high proportion of car availability in both samples. However, the samples overly represent highly educated people. The same holds for the high percentage of car availability

(35.2+40.3=75.5% and 76.3+15.5=91.8%). This means that we have to be careful when applying the results in the context of the Netherlands as a whole. It is also difficult to investigate the representation of the samples with respect to household and mobility events, as such data is non-existent. However, the frequency of these events is sufficient to investigate the impact of various events on commute mode change decisions. Table 7.2 depicts the modal shift occurrences in the samples.

Percentages in Table 7.2 are based on the total number of observation-years. For instance, if one modal shift occurs in a 20 years history of an individual then the percentage is 5%. From Table 7.2 one can observe that event occurrences are quite different for the two different samples. The modal shift from other modes to bicycle (1.8%) is considerably lower than from bicycle to other modes (4.5%). This indicates that people are switching from bicycles to other methods of commuting more often than taking up cycling. It also shows that modal shifts from bicycle towards car are more frequent (2.5%) than towards public transport (1.9%). No such difference is observed for the shift towards bicycle. Table 7.3 displays occurrences of various events including demographic, professional and mobility events.

Table 7.2: Modal shift occurrence

From Bicycle			**To Bicycle**		
	Frequency	%		Frequency	%
To car	31	2.5	From car	25	0.8
To public transport	23	1.9	From public transport	26	0.9
To scooter	1	0.1	From scooter	0	0.0
Total to all other	**55**	**4.5**	**Total from all other**	**51**	**1.8**
Total observation-years	1228	100	Total observation-years	2859	100

Table 7.3: Descriptive statistics about life-cycle and mobility events

Life-cycle and mobility events	**From bicycle**		**To bicycle**	
	Frequency	%	Frequency	%
Cohabitation	24	2.0	66	2,3
Birth of the first child	30	2.4	55	1,9
Last child left home	15	1.2	31	1,1
Separation/divorce	9	0.7	20	0.7
Residential relocation	110	9.0	250	8,7
Change in employment	144	11.7	316	11.1
Full-time to part-time job	24	2.0	37	1.3
Starting full-time work	25	2.0	45	1.6
Commute time reduced to 30 min or less bike time	52	4.2	50	1.7
Commute time increased to more than 30 min bike time	46	3.7	52	1.8
Total observation-years	**1228**	**100**	**2859**	**100**

7.4 Results

The binary mixed logit model of mode shift (equation 7.1) was estimated with demographic, professional and mobility events as explanatory variables. Demographic events include start of cohabitation, birth of the first child, the last child leaving the family home and separation/divorce. Mobility related events include residential relocation, change in employment, and changes in commute time. The model also includes a dummy variable indicating whether the commute time by bicycle increases over 30 minutes or decreases under 30 minutes. In this respect, it is assumed that commuting time is 3 times higher by bicycle when compared to driving or public transportation. This is a reasonable assumption when traveling within a particular city or locality, where traffic rules restrict speed. Moreover, professional events such as switching work status from full-time to part-time work and starting of full-time work are included. There are also bundles of state variables consisting of socio-demographic and spatial context. The state variables are age, gender, education and work status of the respondent, household composition, population density of the residential area, the presence of an intercity rail station in the residential area and car availability to the respondent. The estimation results are displayed in Table 7.4.

The pseudo rho-square shown in Table 7.4 represents the goodness-of-fit compared to the constant only model. In general, this constant represents a base-line probability of not shifting one's commute mode. Thus the high values of rho-square (0.58 and 0.64 for modal shift from and to bicycle respectively) for both models mean significant improvement of the models and a significant association with different household and mobility events.

Various life-cycle events appear to have a significant impact on mode switching to and from bicycle. For example, the start of cohabitation has a significant negative effect on commute mode switch from bicycle. This means that a bicycle user is more likely to continue using his/her bicycle when s/he starts cohabitating. However, it is not clear from this analysis why the start of cohabitation discourages the shift from bicycle commuting. The birth of the first child positively influences the decision to switch commute mode from bicycle to other modes. This is understandable given the need to transport the child to and from a day care centre, which is easiest done by car. Changing work status is also significantly related to modal shift. People are less likely to change from bicycle commuting to another mode when they switch from a full-time to a part-time job, whereas starting full time work has no significant effect. Starting a part-time job usually implies a lower income which lowers the probability of choosing options that may require extra costs, such as car or public transpiration. But, no significant relation is found between changes in work status and modal shift towards cycling.

Long-term mobility decisions such as residential relocation and change of employment are found to be related with modal shifts. Change of employment significantly influences the modal shifts to and from bicycle. The change of employment may logically lead to a modal shift (in either direction), since the change may lead to a difference in travel distance or accessibility of the work location.

Table 7.4: Result of modal shifts from and to bicycle commuting

	From bicycle			To bicycle		
	Value	**t-test**		**Value**	**t-test**	
Choice 2: No bicycle modal shift occurred						
Constant	5.63	4.70	***	4.06	3.86	***
Choice 1: Bicycle modal shift occurred						
Random parameter related to each group	-0.01	-0.00		0.06	0.09	
	0.00	Fixed		0.00	Fixed	
Start of cohabitation	-2.41	-1.91	*	-1.64	-1.25	
Birth of the first child	1.59	1.79	*	1.31	1.11	
Separation/divorce	-0.69	-0.19		0.71	0.43	
Residential relocation	0.38	0.65		0.95	1.67	*
Change in employment	1.32	2.64	***	1.09	2.11	**
Starting full-time work	1.13	1.12		1.27	1.18	
Full-time to part-time work	-2.43	-1.99	**	-1.63	-0.87	
Commute time decreased to 30 min or less bicycle time	-	-	-	6.64	11.20	***
Commute time increased to more than 30 min bicycle time	6.41	9.46	***	-	-	-
Age of the respondent						
Age <= 30 years	1.19	1.76	*	0.54	0.77	
Age > 50 years	-0.01	-0.01		-0.68	-0.81	
Age = 31-50 (Base)						
Respondent is a female	0.28	0.44		-0.69	-1.20	
Highest education achieved by the respondent						
Low education (<=MAVO/MULO)	-1.89	-1.44		-0.83	-0.71	
High education (= University)	-0.38	-0.76		-0.95	-1.81	*
Medium education (Base)						
Household composition						
Couple	0.69	0.90		0.12	0.15	
Couple or Single with children	0.63	0.77		0.42	0.50	
Single (Base)						
Work-status of the respondent						
Full-time worker	-0.38	-0.62		-0.98	-1.62	
Part-time worker/Student (Base)						
Population density of the residential area						
Density <= 500 pop/km2	0.99	1.20		-1.25	-1.09	
Density = 501-2500 pop/km^2	0.03	0.04		-0.26	-0.37	
Density = 2501-5000 pop/km^2	-0.02	-0.03		-0.39	-0.51	
Density = 5001-7500 pop/km^2	0.30	0.38		0.30	0.39	
Density > 7500 pop/km^2 (Base)						
Presence of intercity station in the residential area	-0.37	-0.23		1.74	1.43	

Full-time car availability	0.35	0.74	-1.00	-1.96	**
Pseudo Rho-square (compared to constant)	**0.5826**		**0.6378**		
Total number of observations	1228		2859		

* Significant at 90%
** Significant at 95%
*** Significant at 99%

The effect of residential change on the modal shift to bicycle is not readily evident and the effect is also marginally significant. This likely indicates a need for a detailed analysis of the characteristics of the residential environment before and after the move. In addition, car availability to the respondent is also included in the analyses and it is found that full-time availability of a car negatively affects the decision to shift ones commute mode towards cycling.

The results suggest that a change in commute time is the most significant reason to shift one's commute mode. Logically, a decrease in commute time is associated with a shift towards cycling and an increase in commute time is associated with a higher probability of shifting to either driving or public transportation. A change in commute time is the most important variable in both models.

Age and education appear to have significant effects on modal shifts. The effect of age is analysed compared to the middle age group (31 to 50 years) to investigate whether being 30 years or younger and being over 50 years have a significant influence on the decision to shift commute mode. Age is only significant for shifting commute mode from bicycle. We have found that young people (aged 30 years or less) are more likely to stop using their bicycles as a means of commuting. People older than 50 years do not show significant effects for any modal shift decisions. At the early stage of life (under 30 years), the frequent changes in residential location (55%) or employment (42%) may have encouraged a shift from bicycle to car. In addition, career development at that age may be associated with obtaining a more diverse set of transportation options, such as company cars or more budget available to use a car. University education has a negative influence on the commute mode shift towards bicycle, meaning that highly educated people are less likely to shift and take bicycle as the commute mode. Income may play a role in this respect, but also the fact that highly educated workers have longer commutes. However, gender, work status and household composition do not have a significant impact.

Nonetheless, the analyses indicate that the probability of no-change behaviour is also high. The constant values for the modal shift from bicycle and to bicycle are 5.63 and 4.06 respectively. Both values are statistically significant and considerably higher than other significant variables in the respective analyses. This means that the probability of keeping the same dominant commute mode for a particular year is very high, which indicates that structural changes in behaviour do not take place easily. This may be an indication of the strength of habit, even in the presence of changing life circumstances. However, it is also

possible that conscious deliberation, either in the presence or absence of structural changes in life circumstances, leads to the conclusion that a mode shift is not beneficial.

7.5 Conclusion

The analyses suggest that household events are important factors to consider in the analysis of bicycle commute mode shift behaviour. Demographic, professional and mobility events are found to significantly influence the decision to start or end the use of bicycle for commuting. Although static socio-demographic, job and residential aspects have an impact on commute mode switching, also changes in these aspects significantly add to the explanation of commute mode switching to and from bicycle. In some cases, changes in household characteristics are significantly related to the modal shifts, but not the static variables. For example, household composition is not significant, but the events of changes in the household composition are significant (e.g. the birth of the first child and the start of cohabitation). Thus, the study brings forward the importance of the consideration of household events in association with residential relocation and job change issues when implementing policies aimed at promoting cycling as a commute mode. We have also found that taking a part-time job negatively influences a shift from bicycle to other commuting methods. This may be due to having less resource at one's disposal and more time to spare. But having a part-time job may also be a decision made for different reasons, such as having time to take care of children. Taken together, such findings suggest that dynamics in the commute mode are an outcome of a complex interplay of dynamics in the household and the work situations and the locational factors implied by them. While the current study has unravelled some of these relationships, it is recommended that future studies should focus in more detail on such dynamic relationships.

Despite clearly demonstrating the merit of a dynamic approach to understanding commute mode shifts, we are aware of potential limitations of the retrospective data. One limitation is a loss of detail regarding the variables that are difficult to recall from the past such as commute mode and time. In addition, whereas individuals may alternate between commute modes, for instance, depending on weather, season or household allocation patterns, we have asked them to specify a single dominant commute mode for a whole year. This generalisation of the commute mode leads to a binomial analysis, where an ordered or a multinomial analysis could have been possible in case of more detailed use of bicycle such as frequency of bicycle-use per week. Moreover, we have lost a significant amount of information due to missing values and inconsistent information. Apart from the need to use a binomial formulation, this has also led to the exclusion of certain temporal dependencies. We have only included events occurring in the same year of a commute mode shift (or the non-occurrence); while household events occurring earlier or later may also have an influence on the modal shift. Thus, lag and lead effects of the household events cannot be considered. We also acknowledge that the absence of detailed spatial attributes of the residential and the work

location (due to difficulty in recalling) makes it difficult to conclude about the effects of relocation and employment change.

However, given these limitations, the data have allowed us to analyse commute mode shift using two decades of year-to-year information from the same individual. Such data might be difficult to obtain from a panel data due to attrition. To improve the retrospective data collection in future studies of commute mode change, a first initiative would be to detail the data collection regarding demographic events and mobility behaviour. While the data collected in the current study have served to gain a general insight in the longer term dynamics in a variety of domains (housing, work status, vehicle ownership, commuting), it is conceivable to develop dedicated retrospective surveys focussing on the commute mode, which would include more details regarding weekly patterns of using multiple modes, seasonal effects and household interactions. Another option would be to include more details about the vehicle owned/acquired/disposed, in terms of the type of car (size, fuel type, entertainment and communication options etc.) or type of bicycle (sports, hybrid, number of gears, electric support) or additional information about the work characteristics necessitating or preventing certain commute modes (e.g. business meetings, carrying goods etc.). We feel that obtaining dynamics of such detailed factors that potentially drive commute mode decisions may greatly increase our understanding of how commute mode decisions come about, even if the degree of detail implies compromises with respect to the period of retrospection.

Chapter 8:
Residential, employment and car ownership decisions - An integrated model of dynamics

Abstract

It is increasingly realized that mobility decisions such as residential choice, job/employment choice and travel choice are highly interrelated not only in terms of causality but also in terms of time-dependency. The paper investigates the dynamics explicitly by looking into residential relocation, change in employment and change in car ownership level and the temporal relationship among these long-term mobility decisions and with household events like cohabitation, separation, childbirth, child's home leaving and retirement. A Bayesian Belief Network approach is followed to investigate the underlying causal structure and learning the parameters. Data used for the analysis are obtained from a retrospective survey in the Utrecht region of the Netherlands. The results suggest that very limited interdependencies among mobility decisions exist. The only relationship found is between is car acquisition and moving to a smaller dwelling. Time dependencies are also found in the analysis. The important findings, in this regard, are that birth of the first child has an advanced effect on moving to a larger dwelling and car acquisition; cohabitation has a lagged effect on employer change; cohabitation has also a concurrent effect on moving up, car acquisition and employer change; divorce or separation has only a concurrent effect on moving to a smaller dwelling and car disposal.

8.1 Introduction

It is increasingly realized that mobility decisions and choices such as residential choice, job/employment choice and travel choice need to be based on an integrated framework. The interaction between various longer term decisions such as car ownership, residential location and work location has been shown in various studies (Van Ommeren, Rietveld and Nijkamp, 1999; Pinjari, et al., 2007; Waddell, et al., 2007). However, in existing models, integration is limited to a limited number of dimensions. Some have modelled the interaction between residential choice and travel choices, to describe how self-selection processes impact on locational decisions (e.g. Pinjari, et al., 2007; Cao, Mokhtarian and Handy, 2008). Others have investigated how the decisions about work and residential location mutually influence each other (Waddell, et al., 2007). However, models accounting for the interaction between multiple mobility decisions are lacking.

Another limitation of existing frameworks is related to the common use of discrete choice frameworks to represent interactions (e.g. Pinjari, et al., 2007; Waddell, et al., 2007). A drawback of such discrete choice frameworks is the prior specification of the interdependency in the model structure, which is not derived from data of households' behaviour on these dimensions. By definition, this cannot account for all theoretical notions that may exist in the decision making process (Witlox, Borgers and Timmermans, 2004), specifically conditional relevance cannot be seen (Witlox, 2005). Finally, existing studies are static in nature, for instance, looking into neighbourhood effects and travel (Schwanen and Mokhtarian, 2005; Bina and Kockelman, 2006; Bhat and Guo, 2007); or the effect of work location on residential choices and commuting behaviour (Waddell, et al., 2007; van Ham and Hooimeijer, 2009) on a cross-sectional basis. However, an emerging body of studies of the dynamics in household and mobility decisions suggests that relationships between decisions on different dimensions may stretch across multiple years, and that lagged responses and anticipation of events play an important role in the timing of decisions such as relocation, car ownership and job change (e.g. Feijten and Mulder, 2002; Oakil, et al., 2011a). Thus, a proper description of long term mobility decisions requires a more integrative representation of multiple choice dimensions, flexibility in the patterns of interaction and a proper representation of the longer term dynamics of these interactions.

Development of such dynamic, flexible and integrated models can build on a body of theoretical and empirical studies. Recently, Oakil, et al. (2011b) proposed an integrative theoretical model of multiple mobility decisions. In this view, long-term mobility decisions are dynamic, time dependent and interrelated. People take such decisions not only based on their current state but considering anticipated changes as well. For instance, changes in residence, work status or car ownership require substantial investment of time and money and only take place infrequently. Moreover, changes in the household situation may trigger stresses as defined in Brown and Moore (1970) and Salvini and Miller (2005); and stress-triggered decisions require time to adapt, since the necessary investment of time and money cannot take place instantaneously. This implies a lagged response to such needs. It also implies path dependency in the sense that a recent change (for example, relocation or car acquisition) may set limits to new changes due to limitations in financial, temporal or mental resources. Apart from the dynamism, it is noted that limitations in time and money budgets imply a strong interdependency between longer term decisions (Ettema, et al., 2007; Ettema, Arentze and Timmermans, 2007). For instance, households/individuals have to trade-off between spending their income to the dwelling or to transportation options (cars); and/or between working more hours (resulting in a higher income) and having more free time etc. Accounting for path dependency and anticipation will be important in order to improve insight into the timing and sequence of households' decisions about housing, work situation and car ownership in relation to demographic events.

The above ideas are supported by empirical studies of various long term mobility dimensions. Duration analyses are performed to analyse dynamics in mobility decisions,

mostly vehicle holding duration (e.g., Gilbert, 1992; de Jong, 1996), but also in housing decisions (e.g. Mulder and Wagner, 2001). Focus of these researches was the timing of different housing or vehicle ownership change events. For example, the timing of the first time home-ownership was analysed in connection to family formation by Mulder and Wagner (2001). In a broader perspective, Beige and Axhausen (2008) analysed durations of long-term and mid-term mobility aspects. They found that the number of births as well as the size of the household and the accommodation reduced the both residential duration and mobility resource duration in an analysis of hazard ratios of the competing risks duration models. Changes in education and employment during the observed period had a negative influence on the propensity to move in their analysis. In an integrated way, Rashidi, Mohammadian and Koppelman (2011) proposed a duration model to jointly estimate vehicle transaction, husband and wife job relocation, and residential relocation. Although they jointly estimated job relocation and residential relocation timing decisions, they used vehicle transaction as conditional to job and residential decisions. They found that with decreasing household size, the household tried to adjust the household vehicle needs and with increasing household size, the household held back of moving to a new location. Hazard values of both husband and wife job relocations both showed negative influence on residential relocation.

Life course and life cycle analyses provide a better understanding of the underlying processes. For instance, Lanzendorf (2003) proposed a mobility biography approach based on work of Salomon (1983) to explain travel behaviour by changes in life course stages. Empirically, for example, van der Waerden, Borgers and Timmermans (2003) and Verhoeven, et al. (2005) suggested that critical events and life cycle events, such as getting a drivers' license or having children, may influence structural decisions about mode choice. Structural decisions in this sense refer to the decision of the travel mode to use regularly for recurring trips, such as the commute. Results of qualitative studies support the relevance of the lifecycle approach in this domain. For example, Stanbridge, Lyons and Farthing, (2004) and Stanbridge and Lyons (2006) found that travel considerations were part of the prompt for the relocation itself, that travel entered the process of searching for a new property; and most importantly that relocation forced or prompted reappraisal of travel options once post-relocation journey experiences were encountered. Similar evidence had been found by Prillwitz and Lanzendorf (2006) and Prillwitz, Harms and Lanzendorf (2006). In a recent paper, Beige and Axhausen (2012) found that key turning points in life, such as personal and familial events (e.g., births, deaths, marriage, separation) have significant impact on the mobility decisions, such as residential or work location and car ownership. The authors emphasized that such turning points had lasting effects that were important from a policy perspective. By a series of binary logit model estimations for residential relocation, education and employment changes and changes in mobility resource ownership, they explained the existence of strong interdependencies between the various turning points and long-term mobility decisions during the life course. Altogether these studies provide evidence for the role of stress as a trigger for mobility decisions.

These studies, however, have not looked into the temporal relationships between multiple long term mobility decisions, which have been identified in various studies (Ettema and Timmermans, 2006; Ettema, et al., 2007; Oakil, et al., 2011b). For example, Oakil, et al. (2011b) found that long-term decisions like car ownership change are taken in adaptation, as lagged effect, as well as in anticipation, as lead effect. They found that households tend to acquire a car before the birth of a child and after a change of employer. Also, there were events that had immediate effects like employer change, residential relocation and cohabitation.

In light of the above discussion, the contributions of this paper are threefold. First, it will look into interdependence among residential, job and car ownership decisions. Second, it will investigate dynamics regarding these decisions explicitly by looking into changes such as moving to a larger dwelling type (moving up), moving to a smaller dwelling type (moving down) and moving to a similar dwelling type (no-change move), employer change,car acquisition and car disposal. In this respect time dependency is also recognized, i.e. relations may go both forward (responding to a change in household, residential, work or mobility situation as lagged response) and/or backward (anticipating a planned or expected change on these dimensions as lead response). Third, it will use a flexible way of determining such dynamic influences, without a priori determining the causality and direction of the relationships. The analysis will investigate above mentioned issues simultaneously in an integrated model. In this regard, data collection, data type and type of method are very important and described in the next section of methodology. Following the methodology section, empirical findings are presented in data analysis and result section. Finally, a concluding remark has been made in terms of results, policy implications and further scope of the research.

8.2 Methodology

Analytical framework

The analytical model includes dynamics, time dependence and interrelationship among long-term mobility decisions in a single framework. The framework is designed to depict lagged, concurrent and lead effect of different potential factors utilising a two years' record of different household and mobility events for every household as shown in Figure 8.1.

In Figure 8.1, it is assumed that current household states and household events and next year household events may influence mobility events of the current (t0) and the next years (t1). This definition explains concurrent, lagged and lead influences. First, when a current year state and/or event will influence a current mobility event or a next year's event will influence a next year's mobility event, it will indicate that the relationship is concurrent or immediate. Second, when a current state and/or event will influence a next year's mobility event, it represents a lagged influence. For example, a cohabitation in the current year will have a concurrent effect when it influences a relocation decision in the current year, but the same cohabitation will show a lagged effect when it will influence a relocation decision of

the next year. Third, if a next year's event influences a current mobility event, then it will be a lead effect of an upcoming event. Finally, last year's and current mobility states, as shown in Figure 8.1, explain state dependency. For example, a household living in an apartment may have higher probability to relocate than a row house dweller.

Thus, using mobility events from two years enables the analysis to depict lagged, concurrent and lead relationships among mobility decisions. However, this conceptualisation means that household events and states, and mobility states are exogenous and do not influence each other. However, mobility events of both years (t0 and t1) are dependent and endogenous.

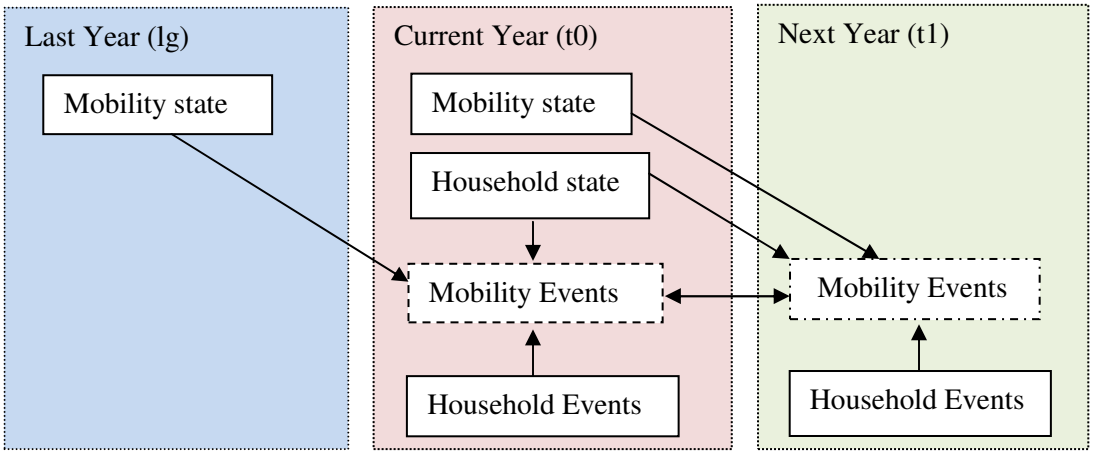


Figure 8.1: Analytical framework of data analysis

Method of data analysis

A formal mathematical framework is needed to test empirically whether the assumed relationships are supported by the data. Such a formal framework should accommodate a large set of variables from different timeframes and their mutual relationships without a prior definition of causality. It should be flexible to apply in a context of micro-simulation models to forecast future behaviours. In this regard, Bayesian Belief Network (BBN) is an attractive framework for the analysis. It does not require defining causal relationships a priori and it is capable of representing complex causal structures with direct and indirect effects occurring on different levels in a straightforward way. The calibration of BBNs on a data set takes place in a two-step process: 1) Structure learning - learning the structure of the network, and 2) Parameter learning - learning the Conditional Probability Tables (CPTs) at the nodes, given the structure. Two groups of algorithms have emerged: 1) scoring-based learning methods, and 2) constraints-based learning methods (see Cheng, et al., 2002). In this study, we will use a constraints-based method, which is based on the concept of mutual information and conditional independence test. It can efficiently depict causal relationships without any prior ordering of nodes. For a detailed explanation of the causality and learning structure, the readers are referred to the basic literature (e.g., Pearl, 1988, Spirtes, Glymour and Scheines, 1993, Heckerman, Geiger and Chickering, 1995).

In case of parameter learning, the estimation procedure determines observed conditional frequencies for each child node and its parent nodes in the data, if there are no missing values in the data. However, the conditional frequencies are not based on any significance test in the current system and also show equal probabilities when a particular case is unobserved in the data. So, a decision tree induction is introduced here to generate the conditional probability table. A decision tree provides a probability distribution of a decision node conditional on the attributes of leave nodes at the terminal nodes. This probability is used to fill the conditional probability table (CPT) in the BBN. The prediction is carried out based on the CPTs filled this way. Therefore, the child nodes found in the structural learning of BBN are used as decision nodes in tree induction and attributes used to split are from parent nodes of the particular child node as found in BBN structure learning. Chi-squared Automatic Interaction Detector (CHAID) algorithm is used for this purpose. CHAID uses a Chi-square measure to evaluate optional splits and stops splitting if no significantly different subgroups can be identified.

8.3 Data collection

Longitudinal data is necessary to analyse the complex relationships among long-term mobility decisions and life cycle events, especially for studying time dependences. In this regard, panel data are the best option. However, most of the available panel data is focused on single aspects, for example, either travel and household issues or residential change and household issues. This makes existing datasets difficult to use. So, a retrospective data collection has been carried out. The literature (e.g., Verhoeven, et al., 2008) indicates that retrospective surveys can provide reliable information about past events, if these events are memorable. Likely, the critical events asked for in this survey, such as residential relocation, car fleet changes and job changes will fall into this category and can be remembered with acceptable accuracy.

The survey was a traditional paper and pencil questionnaire survey. 1200 questionnaires were distributed among the candidate households based on expected return of 40%, i.e. about 500 questionnaires were expected to be returned. The questionnaire covered 21 years of history information of the households.

The survey was conducted in the Utrecht region in the Netherlands. The sampling strategy was to include municipalities (and streets within municipalities) that differ in terms of density, type of housing, accessibility to services etc., such as to obtain variations in spatial circumstances. In this regard, the survey included residences of urban areas (Utrecht), suburban areas (De Bilt, Zeist, Bunnik, Driebergen and Baarn) and villages (Groenekan, Odijk, Werkhoven, Bosch en Duin, Maarn, Doorn and Austerlitz).

It included both state and event variables for every calendar year starting from 1990 to 2010. Events are defined as a change in the state of household and mobility situation in a particular year. Household events include changes in household composition (e.g. marriage), household work situation (e.g. retirement) and/or in household resources (e.g. increase in

income). Mobility events included in the survey are changes in job, home, car ownership and/or also commuting mode. Historical data was collected for the following aspects:

a) Income and work status of the respondent and his/her partner.
b) Household events such as marriage, childbirth, children leaving the family home, divorce etc.
c) Residential characteristics (i.e. the year one moved in, location, residential cost per month, number of rooms, age of the dwelling , garden and parking facility).
d) Work location of the respondent and his/her partner.
e) Number of cars per household and car availability, commuting mode and commuting time for both the respondent and his/her partner.

In addition to the historical data, information on households' plan or target with respect to residential relocation, job change, car ownership, household formation and commuting behaviour were asked. In the final parts, the mobility situation of peers in the households' social network and households' perception of housing, job market and fuel prices were asked.

Sample Description

478 questionnaires were returned. As described earlier, each questionnaire includes 21 years history of the household. Eventually, the suitable sample size is 2279 person-years (Table 8.1) after the consideration of the following factors

i) The missing values due to no-response to important questions; and
ii) As mentioned earlier, the consideration of lead and lagged effects means an inclusion of 2 years information simultaneously in one case and thus to avoid double counting of the mobility events, alternating years are considered. To use data economically, odd calendar years are used as it yields more cases (2279) than even calendar years (2055).

Table 8.1 shows that the sample has an over-representation of dual working families (54.7%) and high income households (48.7%). It also shows that a high proportion of the sample owns at least one car and lives in semi-detached and detached houses. At the time of survey, 182 (38%) respondents have university education. This means that we have to be careful when applying the results in the context of the Netherlands as a whole. Table 8.2 provides statistics of the occurrence of demographic events, employer changes, vehicle transactions and residential relocations.

Table 8.2 provides a list of the variables used as mobility and household events. Residential relocation is considered in more detail by including direction of relocation in terms of dwelling type, i.e. whether a relocation leads to a bigger type of dwelling, smaller type or same type. Bigger to smaller is considered as Detached house to Room/shared house, based on the categorisation of the dwelling type shown in Table 8.1. Thus any relocation from apartment to row house; row house to detached house; or semi-detached house etc. will be considered as a relocation to a bigger dwelling type (Moving up) and any relocation in opposite direction will mean a relocation to a smaller dwelling type (Moving down).

Dwelling no-change relocation is also considered if a household moves to a similar dwelling type (Move no-change).

Table 8.1: Sample distribution over socio-economic characteristics and mobility states of the household

	Frequency	Percentage
Current Household State		
Age of the respondent		
i. <= 30 years	300	13.2
ii. 31-40 Years	535	23.5
iii. 41-50 Years	652	28.6
iv. 51-60 Years	462	20.3
v. > 60 years	330	14.5
Working status of the household		
i. Non-working	394	17.3
ii. Single working	643	28.2
iii. Dual working	1242	54.5
Gross household Income		
i. < = 3000 Euros/month	454	19.9
ii. 3001-5000 Euros/month	715	31.4
iii. > 5000 Euros/month	1110	48.7
Last Mobility State		
Dwelling type		
i. Detached house	328	14.4
ii. Semi-detached/corner house	753	33.0
iii. Row house	787	34.5
iv. Apartment	284	12.5
v. Room/Shared house	127	5.6
Number of car in the household		
i. No car	319	14.0
ii. One car	1266	55.6
iii. Two or more cars	694	30.5
Current Mobility State		
Dwelling type		
i. Detached house	337	14.8
ii. Semi-detached/corner house	779	34.2
iii. Row house	795	34.9
iv. Apartment	261	11.5
v. Room/Shared house	107	4.7
Number of car in the household		
i. No car	310	13.6
ii. One car	1260	55.3
iii. Two or more cars	709	31.1
Total Number of Observation	**2279**	**100.0**

In terms of job change, change in employer by either or both of the partners in the household is considered. It may not result in a change of location in a broader sense, i.e. changed employment may be in the same city. The analysis also accounts for increasing or decreasing the number of car/s in the household. Such direction of change is important in understanding the relationship with the direction of change in residential situation. As demographic and household events, start of cohabitation, separation, birth of the first child, home leaving of the last child and retirement of the respondent and/or the partner are included.

Table 8.2: Occurrence of household and mobility events

	Frequency	Percentage
Current Household Events		
Start of cohabitation	32	1.4
Separation/Divorce	13	0.6
Birth of the first child	29	1.3
Home leaving of the last child	26	1.1
Retirement of the respondent and/or his/her partner	47	2.1
Next year's Household Events		
Start of cohabitation	30	1.3
Separation/Divorce	6	0.3
Birth of the first child	42	1.8
Home leaving of the last child	33	1.4
Retirement of the respondent and/or his/her partner	56	2.5
Current Mobility Events		
Residential relocation to a bigger dwelling type	95	4.2
Residential relocation to a smaller dwelling type	16	0.7
Residential relocation to the same dwelling type	53	2.3
Employer change	270	11.8
Car acquisition	68	3.0
Car disposal	41	1.8
Next year's Mobility Events		
Residential relocation to a bigger dwelling type	78	3.8
Residential relocation to a smaller dwelling type	25	1.1
Residential relocation to the same dwelling type	47	2.1
Employer change	247	10.8
Car acquisition	77	3.4
Car disposal	30	1.3

In terms of event occurrence in the current and the next year, there are no big differences in the sample. Occurrences of separation and dwelling downgrade are notably different for the current year and the next year; and occurrences of these events are also very small. This indicates that people are more likely to move up than to move down. Occurrence of

residential relocation and employment change take place more frequently than changes in car ownership, similar to the findings of Beige and Axhausen (2012). Employer change is far more frequent than any other mobility aspect. It is an indication that employer change is more often independent of residential relocation and car ownership change, although not conclusive. In the next section, results of the BBN analysis are presented.

8.4 Results

As mentioned in the methodology section, there are two different parts of the analysis: structure learning and parameter learning in Bayesian Belief network. On the one hand, structure learning depicts the causal relationship among the mobility events and the household events. On the other hand, parameter learning shows the conditional probability of different events occurrences. Following sections illustrate the results.

Structure learning

Structure learning is carried out based on a constraint-based algorithm using the software BN powerconstructor, which follows a Three-Phase Dependency Analysis (TPDA) algorithm (Cheng, Bell and Liu, 1997; Cheng, et al., 2002). TPDA algorithm uses a heuristic search approach. According to Cheng, Bell and Liu (1997), TPDA follows a three-staged procedure: 1) drafting a network; 2) thickening the network, which adds edges to the draft; and 3) thinning the network, which removes unnecessary edges. The edges that result are undirected. In a final step, an algorithm is applied to direct the edges as far as possible by identifying so-called collider structures (Cheng, et al., 2002). Edges that remain undirected, if any, are presented to the user for making a decision (based on knowledge about the domain). However, domain knowledge can be imposed to fasten the learning and simplify the structure, which does not affect validity of the analysis (Cheng, Bell and Liu, 1997). In the Figure 8.2, domain knowledge regarding the causal relationship is illustrated, which explains the assumptions with respect to the analysis. The direction of the arrow in the Figure 8.2 represents a prior causal assumption, for example, age of the respondent can influence moving up but reverse is not possible. In addition, the dotted box is used to indicate that the variables within the box can influence each other in any direction.

Although both way directions are not possible in BBN, both way directions between the mobility events of the current year and the next year indicate that a causal link in either direction can be possible and will be investigated. Household events, dwelling type, number of car/s and age of the respondent, working status and income of the household can only influence mobility decisions as exogenous variables as described in section of analytical framework. In addition, the analysis lowers the default threshold, based on which mutual and conditional mutual information are investigated, for determining relationship between variables. The threshold is set to 0.4 times of the default value. This is done to capture the relationships that are weak. Due to small number of event occurrences in the sample, some relationships are weak. Thus the value of threshold affects the strength of the relationship and

lower threshold means weak relationships will also be revealed. The causal relationships found here are shown in the Figure 8.3.

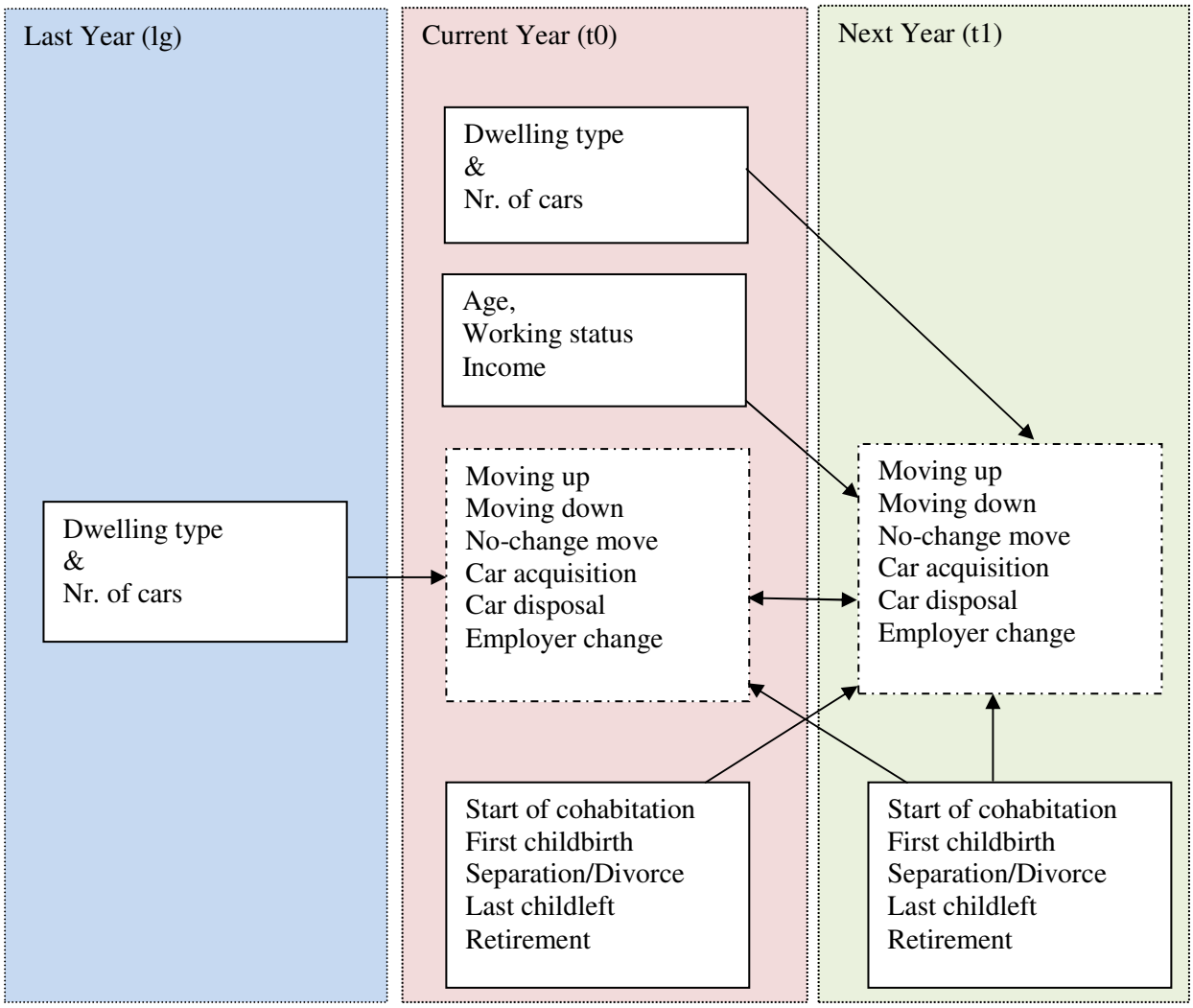
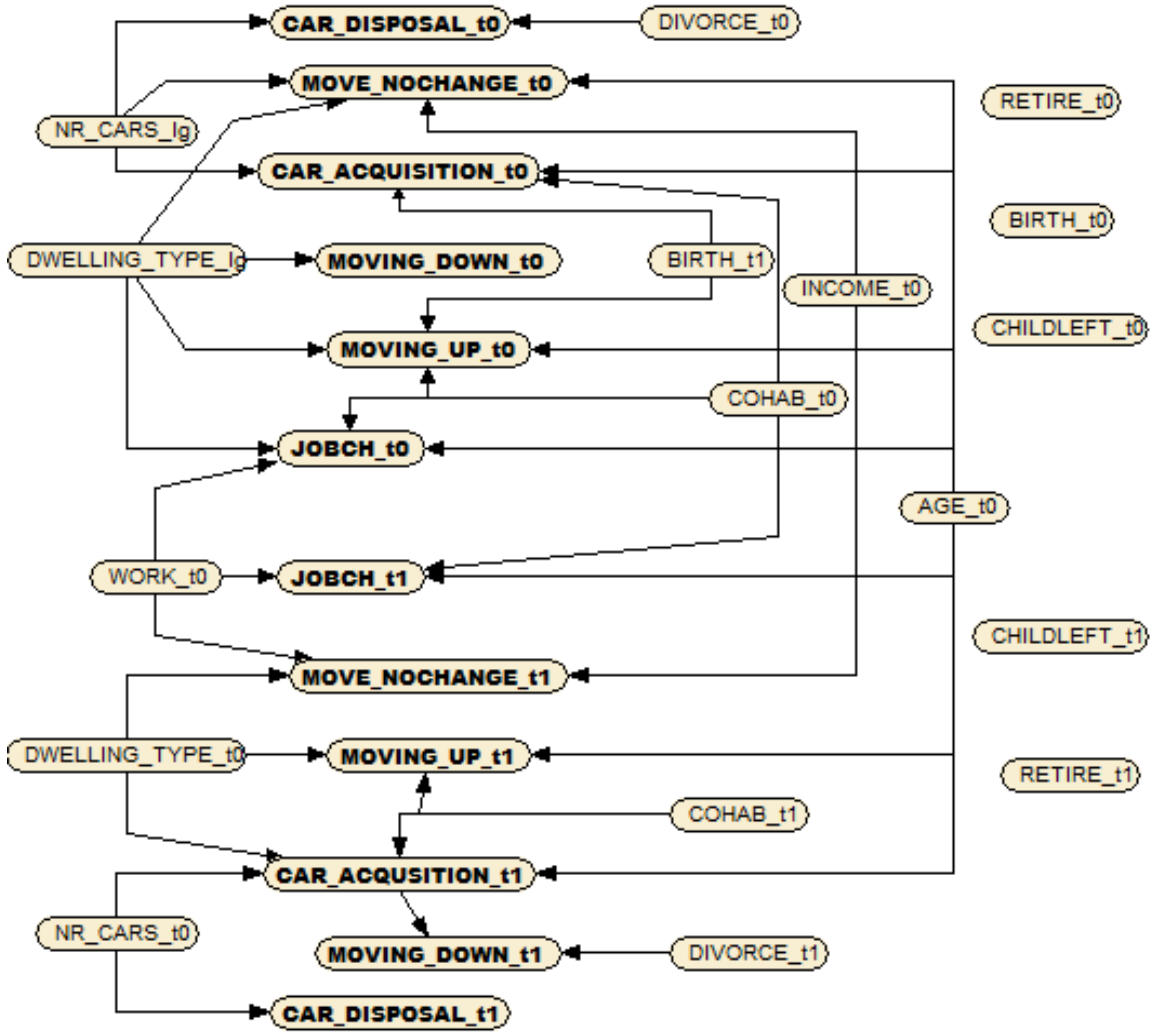


Figure 8.2: Allowed directions of causal relationships in structural learning

In the Figure 8.3, structural relationship among long-term mobility decisions are shown. The direction of arrows indicates a causal relationship as found in the data. It is tried to put mobility decisions, which are defined as dependent variables and can influence one another, in the middle of the figure. The time of event occurrence is distinguished by using a different suffix. Variables used in this figure are presented in Table 8.1 and 8.2 and the identifications are expected to be self-representative. The relationship shows lagged, concurrent and lead effects from different household events. However, the mobility decisions are taken immediately in response to household events for most of the cases. In terms of time dependency, start of cohabitation and birth of the first child show effect on the mobility decisions of different timeframes. Start of cohabitation shows a lagged effect on employer change in the next year and birth of the first child of the next year shows lead effect on both car acquisition and moving up in the current year.

The analysis shows several plausible concurrent effects from different household events. Start of cohabitation has a concurrent impact on moving up, car acquisition and employer change. Results are similar for both of the time periods, i.e. the current year and the next year, except start of cohabitation of the next year does not influence employer change of the next year. Reasonably, divorce affects car disposal and moving down. This is also plausible given the need for one partner to change residence and such a forced change may lead to an immediate available house and thus downgrade of dwelling. Car disposal can be explained by less need for it, given that the household becomes smaller. But it can also be that the partner leaves the household of the respondent with his/her car. However, current divorce influences current car disposal and next year's divorce/separation influences next year's moving down. The analysis shows limited interdependency among residential relocation, car ownership change and employer change. However, car acquisition in the next year shows a concurrent effect on moving down in the next year. However, it is difficult to explain the reason.



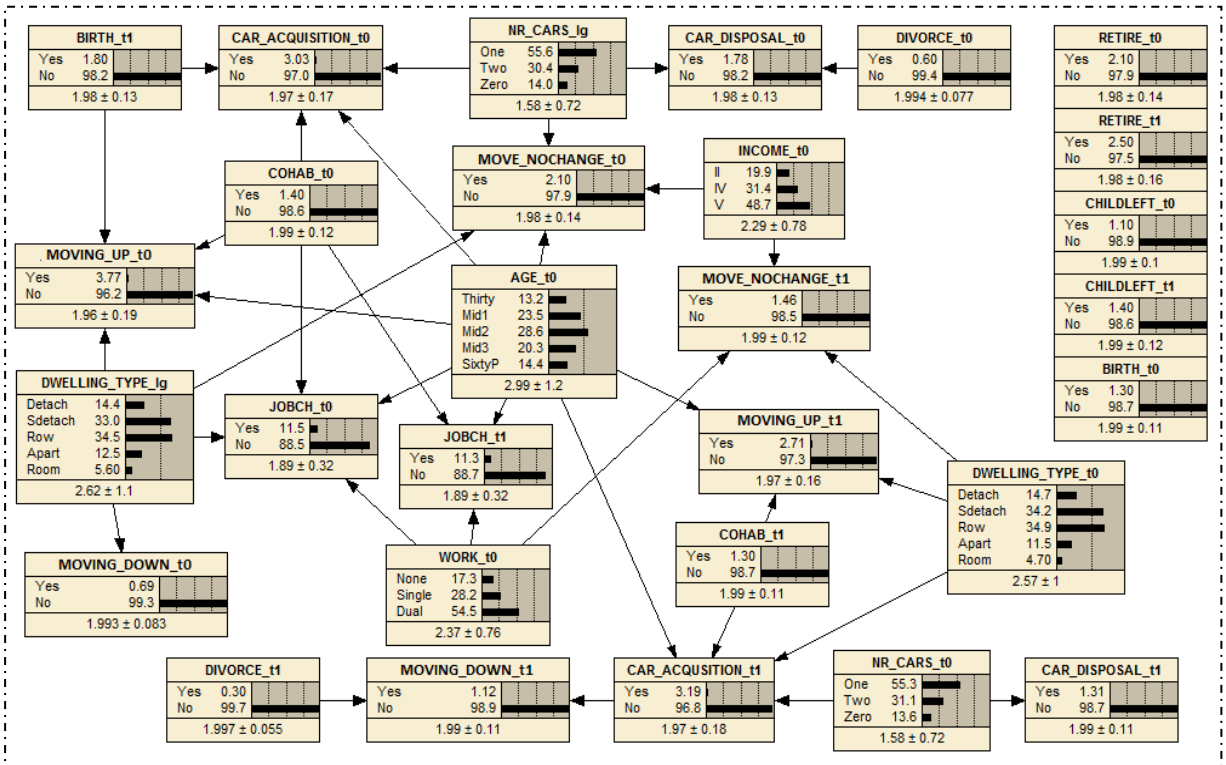
NB: lg = indicates state of last year; t0 = indicates events or states of the current year; and t1 = indicates events or states of the next year.

Figure 8.3: Structure of causal relationship among mobility decisions, household situation and events.

In addition, age of the respondent, working status of the household and household income play an important role in the mobility decisions. Mobility decisions also show state dependence in the sense that previous mobility status influences the decision. It is found that the number of cars available in the household before any decision influences the decision to acquire or dispose a car. Similarly, previous dwelling type influences the decision to upgrade or downgrade dwelling in the following year. The following section presents results from the parameter learning procedure.

Parameter learning

Netica 4.16 is used to compile the network learned from the structure learning. First, the conditional probability table (CPT) for each node is analysed by the decision tree induction based on the CHAID algorithm as described before. A splitting criterion is based on Pearson chi-square test and the significance level is fixed at 10%. The minimum number of cases required at the child node has to be 15. Second, the network is entered based on the structure learned in BN powerconstruct. Third, the CPT for every node in Netica is entered from the probability distribution of the decision tree induction. Finally, Netica is used to compile the network for the prediction based on the learned structure. In Figure 8.4, the predicted probability distribution of every node is shown.



NB: lg = indicates state of last year; t0 = indicates events or states of current year; and t1 = indicates events or states of next year.

Figure 8.4: Results of parameter learning in BBN

Figure 8.4 represents the overall prediction resulting from the analysis. In the following sections, impact of different influential variables on particular mobility decisions will be described. One of the strengths of the BBN analysis is that it can directly update the prediction if evidences are provided. Here, evidence means that a certain condition is known or given. So, providing evidence means updating the information. For example, providing evidence of "age < 30 years" means that the BBN updates information for the age node as "age < 30 years" is 100% probable and will update the prediction of all child nodes for which that age node is a parent node and by backward reasoning all parent nodes. In this way, it is possible to predict the impact of the state variables such as age, income and working status and of the events.

In addition, it is possible to depict a joint impact of two or more variables on a child node, i.e. providing evidence, for example, that "age < 30 years" and "an occurrence of cohabitation" simultaneously. To account for the joint effects, three possible states of evidence are considered for event variables – i) the influential event has occurred, ii) the influential event has not occurred and iii) without any evidence of the influential event occurrence, i.e. considering the sample probability of that influential event. This is helpful to investigate events' (e.g. cohabitation) impact for different household states (e.g. different income groups). Depending on these evidences, three predictions for the mobility events are possible and shown in a tabular format. The predictions show the probabilities of the occurrences of the mobility events. The changes in the prediction can be investigated by comparing the percentages. For example, if the probability given the occurrence of an influential event is higher than the probability without any evidence, then the influential event has a positive impact. Whether a particular variable has positive, negative or no effect can be shown including joint impact from two or more influential variables. The following figures (8.5, 8.6, 8.7 and 8.8) illustrate how the above mention method is operationalized.

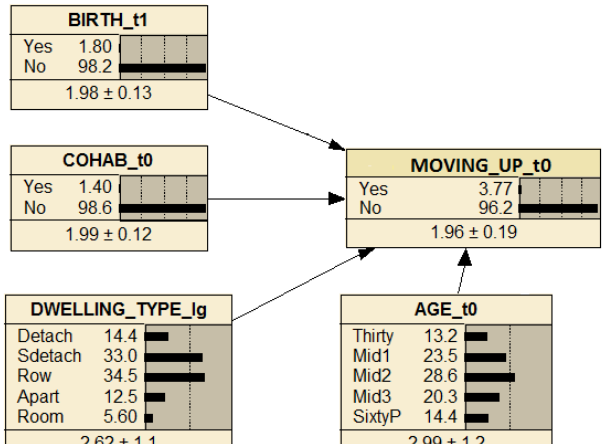


Figure 8.5: Without any evidence from influential variables

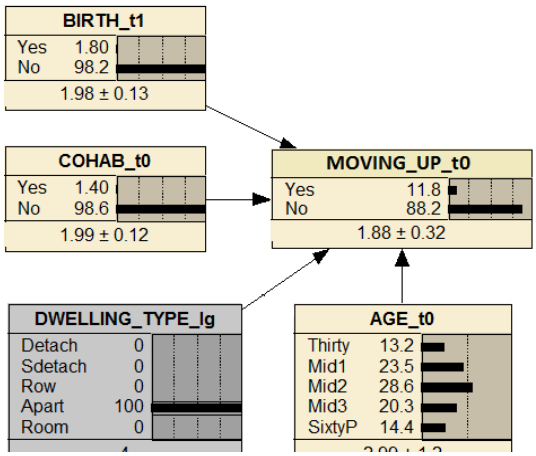


Figure 8.6: With the evidence for households living in apartments

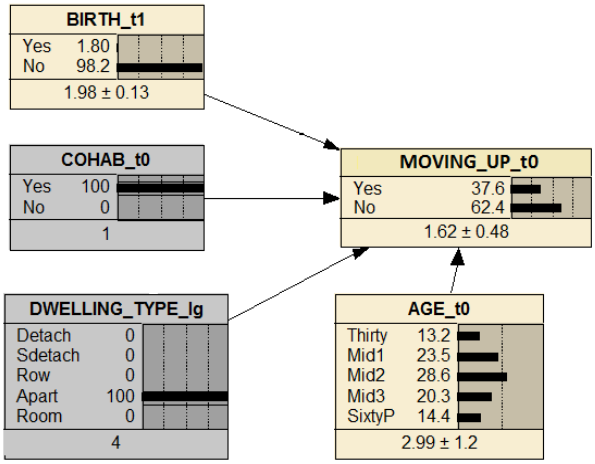


Figure 8.7: With joint evidence for households living in apartments and starting cohabitation

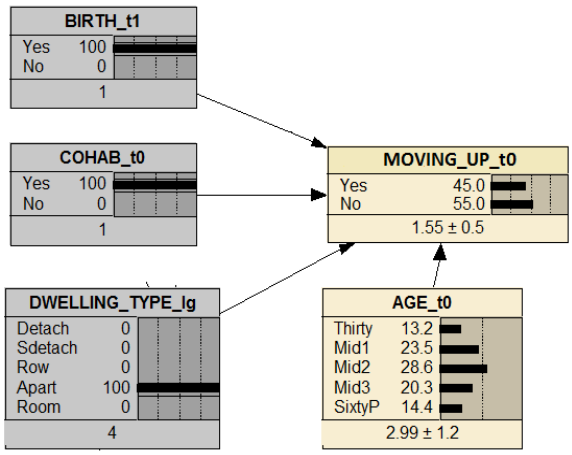


Figure 8.8: With joint evidence for households living in apartments, starting cohabitation and expecting the first child next year

In the above four figures, only influential variables that have effect on the decision to upgrade dwelling are considered. There may be other links to and from any of the variables shown in the figures. For simplicity, those links are not shown. Figure 8.5 shows that the probability to upgrade dwelling is 3.77% without any evidence. Figure 8.6 shows that the probability will raise to 11.8% if we know that households dwell in apartments, i.e. we have provided evidence that households live in apartment. In addition, Figure 8.7 shows that the probability will further increase (37.6%) when we know that households dwell in the apartments and they have experienced cohabitation in the same year of the relocation. This indicates a joint effect of the apartment dwelling and the event of cohabitation. Figure 8.8 illustrates the joint effect of apartment dwelling, cohabitation in the current year and birth of the first child in the next year. We have provided evidence for above three variables and the probability is updated to 45%. Using these probabilities, impacts of influential variables on different mobility decisions are described and presented in a tabular format in the following parts. Although it is possible to predict probabilities with evidence from more many variables, mostly combination of two variables is used for simplicity.

Probability of Upgrading the Dwelling

Following the above procedure, the impact of different influential variables, both state and events, on the decision to move up is investigated. Moving up in the current year and the next year are separately investigated. Table 8.3 represents moving up in the current year and Table 8.4 represents the same for the next year. In Table 8.3, the probability of moving up is predicted for households living in different dwelling types taking evidence from two household events occurrences, namely start of cohabitation in the same year of relocation and birth of the first child in the next year of relocation. The second column represents the

predicted probabilities of moving up for different dwelling types when we have no information update regarding household events, i.e. without evidence of any influential event. In the same manner, the third column represents the probabilities with the evidence of start of cohabitation in the same year of relocation and the fourth column shows the probabilities with the evidence of birth of the first child in the next year of relocation. In the fifth column, evidence from both household events is provided. This means that each cell of the final column shows the impact of three variables, i.e. dwelling type, cohabitation and birth of the first child. The predictions are shown as percentages in Table 8.3.

Table 8.3: The prediction (%) of moving up with evidences of dwelling type and household events (CURRENT year)

	Evidence of event				
Last Dwelling type	**Without evidence of events**	**Cohabitation (Current year)**	**Birth of the first child (Next year)**	**Both events**	**No Event**
Detached house	0	0	0	0	0
Semi-detached or Corner house	1.20	1.20	1.20	1.20	1.20
Row house	2.70	2.70	2.70	2.70	2,70
Apartment	**11.80**	**37.6**	**45.0**	**45.0**	10.8
Room or Shared house	17.30	17.30	17.30	17.30	17.30
Without evidence of dwelling type	3.77	7.00	7.92	7.92	3.65

NB: Underlined percentages are same as shown in figure 8.5, 8.6, 8.7 and 8.8.

Table 8.3 shows that both household events increase the probability of relocation to a bigger dwelling type. However, only apartment dwellers are significantly influenced by these events (as shown by the bold numbers in Table 8.3). Apartment dwellers are more likely to upgrade their dwelling in the same year of their starting of cohabitation with their partners (presented in bold numbers). The probability increases from 11.8% to 37.6%. But apartment dwellers become more inclined (11.8% to 45%) to move up in anticipation of birth of their first child. The increasing probability is understandable as extra space is required for an additional person in both cases. However, cohabitation can also mean moving in order to live with the partner. For other dwelling types, the probability of relocation remains the same. With the evidence of no event occurrence, apartment dwellers show less probability (10.8%) to move up compare to without evidence (11.8%). For other dwelling types, both events have no significant influence on the probability of moving up. Without the evidences of the household events, the probability of moving up is the highest for those who shared a dwelling (17.3%). The probability decreases with increasing size of the dwelling. This can be explained from the point of dwelling satisfaction, i.e. with a bigger dwelling, households are more satisfied and less inclined to move. Although, it is found that age of the respondent has influence on the moving up decision, it is not included in Table 8.3, because age of the

respondent shows no effect when household events are occurred. This means that the probability of moving up remains the same for all age categories given either or both of the household events. However, age of the respondent shows a significant influence for different dwelling types without evidence of the household events or with evidence that those events have not occurred.

Similar tables are prepared for moving up in the next year. Table 8.4 shows the impact of the household events for different types of dwellings. Similar to the result of the current year, age of the respondent does not have influence on the probability to move up in the next year given that the cohabitation has occurred and the probability remains always 20.8%. Table 8.4 shows the effect of cohabitation for different dwelling types for the next year.

Table 8.4 shows that apartment and shared house are the dwelling types, for which cohabitation has the highest influence on moving up for the next year data. The prediction increases to 66.7% from 13.6% for shared houses and from 7.96% for apartments. If there is no evidence that a household has experienced cohabitation or not, the probability of moving to a bigger dwelling type is higher for shared house (13.6%) and apartment (7.96%) dwellers. Other dwelling types also show an increase in the probability when there is evidence of cohabitation. The relationship between relocation and cohabitation is concurrent as these are both next year events. However, the higher probability (36.7%) for detached house is due to the absence of observation of the detached house and the moving up event. So, the probability represents the effect of cohabitation in general. This means that without any knowledge of dwelling type, cohabitation increases the probability of moving to a bigger dwelling type to 36.7%. In the last column of Table 8.4, the predictions show that the probabilities of moving up are lower if there is evidence that cohabitation has not occurred, in general and for all dwelling types. However, the changes are very marginal. For example, row house dweller has a probability of 2.07% to upgrade dwelling without any evidence, but it falls to 2.01% if an evidence of no cohabitation is provided.

Table 8.4: The prediction (%) of moving up with evidences of dwelling type and cohabitation (NEXT year)

	Evidence of event		
Dwelling type before relocation	**Without evidence of event**	**Cohabitation (Next year)**	**No cohabitation**
Detached house	0.48	36.7*	0.0
Semi-detached or Corner house	1.07	6.7	1.0
Row house	2.07	6.7	2.01
Apartment	7.96	66.7	7.18
Room or Shared house	13.6	66.7	12.9
Without evidence of dwelling type	2.71	20.8	2.47

*Shows the probability of moving up for cohabitation as Detached house has no-effect.

Probability of Acquiring a Car

Similar to the moving up analysis, car acquisition decisions are also influenced by various events and states. This section will show how these variables are affecting the probability of car acquisition. Table 8.5 explains the changes in the probability due to the occurrences of household events and for different car ownership levels. The results show that the probability of buying car/s in the current year increases immediately with the start of cohabitation (28.1%) and in anticipation of the birth of the first child in the household (17.6%), compare to the probability without any evidence of events (3.03%). In this case, number of cars has no effect on the decision. This means that probabilities do not vary over different levels of car ownership. However, if no household event has occurred or is expected, the probability of car acquisition in the current year decreases with an increase in the number of cars in the household. For instance, households without having a car are 4.30% likely to acquire car/s, whereas, it is 0.70% if they already own more than one car. Overall probability also decreases from 3.03% to 2.40% if the household events do not occur in the current or the next year. Decision to acquire a car in the next year is also described in the same manner. Table 8.6 shows the effect from cohabitation.

Table 8.5: The prediction (%) of car acquisition with evidences of household car ownership and household events (CURRENT year)

	Number of car/s in the household			
Household events	Without evidence of cars	None	One	More than one
Start of cohabitation (Current year)	28.1	28.1	28.1	28.1
Birth of the first child (Next year)	17.6	17.6	17.6	17.6
Both of the above events	28.1	28.1	28.1	28.1
Without evidence of events	3.03	4.87	3.47	1.38
No event (Cohabitation or birth of the first child) occurred	2.40	4.30	2.85	0.70

Table 8.6: The prediction (%) of car acquisition with evidences of household car ownership and cohabitation (NEXT year)

	Number of car/s in the household			
Household events	Without evidence of car	None	One	More than one
Start of cohabitation (Next year)	36.7	36.7	36.7	36.7
Without evidence	3.19	4.88	4.03	`0.96
No event (Cohabitation) occurred	**2.75**	**4.46**	**3.60**	**0.49**

Table 8.6 shows a very high positive effect of cohabitation on car acquisition for the next year. It is 36.7% compared to 3.19%, although without any evidence of car ownership levels. Similar to car acquisition in the current year, number of cars in the household does not affect

the decision given the event of cohabitation. But the probability of car acquisition (next year) decreases with an increase in the number of cars in the household, given that cohabitation has not occurred (bold numbers in Table 8.6) or no-evidence of the event. The probability declines from 4.46% for no-car household to 0.49% for more than one car household. However, dwelling type shows an additional impact on the decision, whereas dwelling type has no influence on the decision to buy a car in the current year. The change in the probability is very marginal, also given no-occurrence of cohabitation.

Probability of Changing Employer

As mentioned in the structure learning section, cohabitation has both concurrent and lagged effects on employer change. This section will depict how this event influences the probability of employer change given age of the respondent and working status of the household. Table 8.7 shows the predicted probability for employer change in the current year based on different evidences of household working status, start of cohabitation and age of the respondent.

Table 8.7: The prediction (%) of employer change with evidences of household working status, cohabitation and age of the respondent (CURRENT year)

Working status of the household	Start of cohabitation (Current year)	Age of the respondent					
		<= 30	31-40	41-50	51-60	> 60	Without evidence of age
None	Yes	15.1	11.9	10.3	7.97	7.07	10.4
	No	12.5	8.71	4.76	2.88	1.52	5.87
	Without evidence	12.6	8.75	4.84	2.95	1.60	5.93
Single	Yes	27.9	15.9	15.0	11.5	19.8	16.9
	No	25.3	12.7	9.41	6.41	14.3	12.4
	Without evidence	25.3	12.7	9.49	6.48	14.4	12.4
Dual	Yes	22.0	18.8	17.1	14.8	13.9	17.2
	No	19.4	15.5	11.6	9.71	8.35	12.7
	Without evidence	19.4	15.6	11.7	9.78	8.42	12.8
Without evidence of working status	Yes	22.5	16.8	15.3	12.7	14.4	15.9
	No	19.9	13.5	9.79	7.59	8.84	11.4
	Without evidence	19.9	13.6	9.87	7.67	8.92	11.5

Table 8.7 shows the probability of employer change combining evidences of three variables. In general, the probability decreases with the increase of age of the respondent with or without evidences of working status and/or cohabitation. This is understandable as people change employment more often at young age, when they search for an appropriate job, develop their career or face more uncertainty. For example, with the evidences of cohabitation and a non-working household, the probability of employer change is 15.1% if

the age of the respondent is less than and equal to 30 years, but it is 7.07% if the age of the respondent is greater than 60 years. However, change of employer for a non-working household means change of study location. In terms of working situation, the probability of changing employer gets higher if more people work in the household, except for the youngest and the oldest households. For example, the probability is 15.9% if the household is single working at the age between 31 and 40 years with the evidence of cohabitation, but it gets higher to 18.8% if the household is dual working for the same situation. However, it is difficult to explain why single working households are more likely to change employer at age greater than 60 years. Besides, dwelling type before the employer change is found to affect the employer change decision. It is found that people who live in smaller houses change their employer more often than bigger house dwellers. However, apartment dwellers are less likely to change employer than row house dwellers for the oldest age group (age > 60). The reason could be that the overall probability of that age group living in apartment is very low in the sample. However, dwelling type has no significant influence on employer change in the next year. Similarly, the probability of employer change in the next year is shown in Table 8.8.

Table 8.8: The prediction (%) of employer change with evidences of household working status, cohabitation and age of the respondent (NEXT year)

Working status of the household	**Start of cohabitation (Current year)**	**Age of the respondent**					
		<= 30	**31-40**	**41-50**	**51-60**	**> 60**	**Without evidence of age**
None	Yes	58.8	14.8	10.3	0.0	0.40	14.2
	No	21.9	14.8	10.3	0.0	0.40	9.37
	Without evidence	22.4	14.8	10.3	0.0	0.40	9.44
Single	Yes	58.8	14.8	10.3	4.10	0.0	15.0
	No	21.9	14.8	10.3	4.10	0.0	10.1
	Without evidence	22.4	14.8	10.3	4.10	0.0	10.2
Dual	Yes	58.8	14.8	10.3	7.60	10.0	17.2
	No	21.9	14.8	10.3	7.60	10.0	12.3
	Without evidence	22.4	14.8	10.3	7.60	10.0	12.4
Without evidence of working status	Yes	58.8	14.8	10.3	5.30	5.52	16.1
	No	21.9	14.8	10.3	5.30	5.52	11.2
	Without evidence	22.4	14.8	10.3	5.30	5.52	11.3

Table 8.8 shows a very limited effect on the probability of employer change in the next year. For example, cohabitation shows a lagged effect if the respondent is younger (Age <= 30 years). Also the probability does not vary over different working statuses. The influence of working status is only found for older age groups. It shows that the probability goes up when the household is a dual working household. For example, single working households older than 60 years have 0% chance of employer change, where it is 10% for dual working

households at the same age. For some associations, the number of event occurrences becomes very low in the sample. For example, non-working households can hardly be divided based on occurrence of cohabitation. This means that respondents older than 30 years are less likely to have a non-working household. It is even less likely to start cohabitation at that age bracket and still be a non-working household. This makes significance tests difficult and variations in the probability are not observed. In those cases, the probabilities are generalised. For example, age groups 31-40 and 41-50 show different probabilities (14.8% and 10.3% respectively) based on different age groups, but it is not possible to further breakdown based on cohabitation and/or working status.

Some relationships found in the structure learning are not seen in the parameter learning. Mostly, those relationships are found statistically insignificant in the CHAID decision tree induction. It is found in the structural learning that divorce has a concurrent influence on car disposal for the current year and for moving to a smaller dwelling type for the next year. However, during classification based on CHAID algorithm, divorce did not show significant associations with the aforementioned decisions. This is due to the small number of event occurrences.

8.5 Conclusion

The analysis put forward evidence about interdependence among mobility decisions and time dependencies among mobility and other household decisions. It is found that various household events have effects on mobility decisions and the effects can be concurrent, lagged and lead. The important findings, in this regard, are that birth of the first child has a lead effect on moving up and car acquisition and cohabitation have a lagged effect on employer change. This means that analyses of long-term mobility decisions based on cross-sectional data will be biased. For instance, analysis of relocation based on the current situation, even including previous situation, will not depict the effect from birth of the first child in the following year. Cohabitation has also a concurrent effect on moving up, car acquisition and employer change and divorce or separation has only a concurrent effect. The consideration of lagged, concurrent and lead effects also improves understanding of the timing of mobility decisions, which has further benefits in terms of prediction. However, there are household events such as home-leaving of the last child or retirement that have not shown a significant impact on mobility decisions.

In terms of interdependencies, mobility decisions regarding car ownership, residence and job are found to be limitedly interrelated when modelled simultaneously with other household decisions. For example, given start of cohabitation and birth of the first child in the following year, car acquisition and moving up decisions are independent. This means that policies aiming to affect car ownership by changing housing situation may not be fruitful as car ownership decisions are influenced by demographic changes rather than changes in residential situation. The only exception is the effect of car acquisition on moving down. However, to investigate the reason behind such decision requires more detailed data on

residential location, job scenarios and travel situation. This means that the scope of analysis is limited to investigation of mobility decisions and their interdependence over time. Conclusions about causal relationships can, however, not be drawn based on the analyses. Nonetheless, the information collected has proved to be useful in analysing the interdependence and time dependence among long-term mobility decisions. The study has built a framework based on Bayesian Belief Network, which explains long-term mobility decisions as an integrated process in household decision making. This framework can work as primary structure depending on which detailed and short-term decisions can be integrated, such as daily travel behaviour, residential and job location choice or type of vehicle ownership.

Chapter 9:
Summary and discussion

9.1 Summary

Life trajectory decisions such as residential, job and car ownership are highly interrelated and have direct implication for travel choices. Recent travel behaviour researches are focusing on long-term mobility choices in relation to life trajectories. Although these life trajectory decisions are interrelated, they may not be synchronised in time. This thesis contributes to the existing literature by looking interrelation among residential relocation, job switching, car acquisition and disposal, and commute mode switch across multiple timeframe. In contrast to previous studies, we have argued that relationships among these decisions may be complex and may not always indicate lagged response. We have argued that households not only show reactive behaviour but also pro-active behaviour. In addition, we have considered life events in detail, since the interrelationship and temporal dependence may vary based on the nature of events, for instance, lead effect of marriage on moving-up and concurrent effect of divorce with moving-down. In this respect, we have formulated three questions

i. *to what extent are changes in residence, job, car ownership and commute mode interrelated?*
ii. *to what extent are these life trajectory decisions associated with life events?*
iii. *what is the temporal ordering of these processes?*

To answer these questions, chapter 2 outlines a conceptual framework. Key elements of this framework are that long-term mobility decisions and life trajectory decisions are interrelated with complex mutual dependencies and that such relationships may stretch over longer periods. The timing and sequence of decisions regarding mobility resources, housing and work context is assumed to depend on the effort, time and money needed to implement a response to a changed context, the way in which aspirations develop and the extent to which events are deliberate decisions, and can therefore be foreseen, or happen unexpectedly, and imply follow up events. Therefore, a longitudinal life trajectory approach is required when analysing long-term mobility decisions. Building on this framework, the thesis contributes to the understanding of interrelated mobility decisions and the influence of life events through studies of various long-term mobility aspects. Specifically, it includes analyses of changes in car ownership level (chapter 4), residential relocation (chapter 5), and commute mode shift decisions for car commuters (chapter 6) and bicycle commuters (chapter 7).

Regarding the first research question, the analyses suggest that various relationships exist between long-term mobility decisions. Compared to previous studies, this study has investigated relationships between a more comprehensive set of long-term mobility decisions

and life events. In different chapters, relationships between residential relocation, change in car ownership level and commute mode shift are investigated, in terms of how they can be explained as a function of other mobility decisions, life events and socio-demographic variables. Although, the causality among these decisions may be contested, this study finds various interrelationships between mobility and life trajectory decisions. In car ownership analysis, both employer change and residential relocation are important. The study finds that employer change is positively associated with car disposal, whereas relocation is related to car acquisition. In residential relocation analysis, car acquisition, car disposal and employer change have a positive association with relocation. Although both car disposal and acquisition have a positive relation with relocation decision, the timing of the events is different compared to the results of car ownership analysis. In particular, a household is less likely to get rid of a car after residential relocation, but residential relocation decisions can be concurrent with car disposal decisions. Although an integrated approach considering residential relocation, job change, change in car availability and change in household size is followed for mode choice decisions in a previous study by Verhoeven (2010), this study explicitly shows that people's switch from their current commute mode to another, rather than their current mode use, is related to residential relocation, employer change, car availability and change in commute time. In this regard, the results indicate that change of employer is positively related with both ways of modal shift for bicycle and car commuting, and residential change works in favour of bicycle use in addition to the effect of commute time change.

In relation to the second question, we have considered that mobility decisions are not taken in isolation of life events such as cohabitation, divorce, child birth, home leaving of children and death of family members. In addition, and in contrast to earlier studies, we have also included work-status related events into the analysis of relocation, car ownership decisions and commute mode changes. These events include retirement and switching between full-time and part-time employment. The results indicate that work-status related events are important. Retirement shows a positive relation with car disposal. Switching from full-time to part-time employment encourages commute mode shift from car and discourages shift from bicycle. In terms of demographic events, we have included start of cohabitation, birth of a child, home-leaving of a child and separation of partners. A new insight is the found relationship of life trajectories and demographic events with commute mode shift decisions. Birth of the first child encourages a shifting towards car commuting and away from bicycle commuting. Start of cohabitation encourages bicycle commuting, whereas separation or divorce favours a shift both towards and away from car commuting. Such influences are not addressed in existing literatures. In addition, the results confirm the findings of previous studies in housing and transportation. For example, relocation as a result of start of cohabitation, birth of the first child and separation, car acquisition as a result of cohabitation, birth of any child and birth of the first child, and car disposal in relation with separation are important findings in our analyses.

Regarding the third research question, the study argues that the relationship between mobility decisions and life events can be concurrent, lagged and leading. Whereas previous studies have focused on concurrent (e.g. Prillwitz, Harms and Lanzendorf, 2006; Beige and Axhausen, 2012) and lagged effects (e.g. Beige and Axhausen, 2008; Verhoeven, 2010), we extend the relationship by incorporating lead effects in the relationship between mobility and life events. In the analyses we provide evidence of lead effects such as car acquisition in anticipation of birth of the first child and car disposal in anticipation of retirement and employer change. The findings also support lagged effects as seen in previous studies of residential relocation and mode choice. We find that separation and employer change have lagged effect on relocation and last year's relocation affects relocation in a given year negatively indicating path dependency. Also, we find lagged effects of separation and employer change on commute mode change both to and away from car. In addition, we find lagged effects on changing car ownership decisions such as lagged effect of relocation and separation on car disposal.

Finally, the study has aimed to put multiple mobility decisions and life trajectory decisions in a single analytical model to analyse their associations without defining any causality among decisions a priori. The interesting insight learnt from the analysis is that life trajectory decisions regarding car ownership, residence and employment are less likely to be related directly, rather different demographic events are found to trigger multiple decisions simultaneously such as cohabitation and anticipated birth of the first child lead to moving to a bigger dwelling and car acquisition simultaneously. Other results indicate similarity compared to our separate models of mobility decisions such as effects of cohabitation and birth of the first child on moving-up and car acquisition and effects of separation on car disposal and moving-down. The model further confirms the importance of the timing of related events. Concurrent, lagged and lead effects are seen in the same model with a probabilistic prediction of different decisions at different times. Important findings are lead effects of birth of the first child on car acquisition and moving to a bigger dwelling, and a lagged effect of cohabitation on employer change. The model is based on a Bayesian Belief Network. The advantage of this model over discrete choice models and structural equation models is its capability to determine mutual relationships among multiple mobility decisions from different timeframe without prior definition of causality. An additional advantage over structural equation models, is that the model infers the structural relationships, including direct and indirect effects, from discrete data.

9.2 Discussion

The thesis reports temporal dependencies among life trajectory decisions and travel decisions, in particular, commute mode based on events as they occurred in the histories of households. We have regarded events as an implemented decision reported by the households. Observing events does not allow to draw conclusions about causal relationships. However, building on theory, the relationship between events can be interpreted as the outcome of a response to

some external trigger or as a combination of events in response to a third event. For instance, as shown in the analyses of car ownership and residential relocation, divorce can be expected to imply a relocation and at the same time encourage car disposal. Similarly, employer change may encourage residential relocation as well as a change in car ownership level. Although we have defined dependencies considering residential relocation, car ownership change and modal shift as dependent on other mobility and life events in our separate models, we have revealed statistically significant associations among events. This is important given the requirement to understand complex household decisions, where multiple decisions are related to a particular mobility decision. In predictive modelling it may proof useful to focus on the relationship among events from different life trajectories and different timeframes rather than putting emphasis on causality. Analysis of timing of events indicates the order in which a decision may follow. Such sequence does not imply causality since we have assumed that stress may also arise from anticipation of changes and therefore, may invoke pro-active behaviour. We have found evidence of pro-active behaviour, at least when anticipated events are well predictable such as birth of the first child and retirement.

Although the data collected in this study is not representative for the Dutch or Utrecht populations and is subject to some limitations, the results have some policy implications. The main implication follows from the possibility to predict long-term mobility decisions from their life events. Start of cohabitation, birth of the first child and retirement are well planned household decisions and occur at a particular stage of the life-course. Although the trend of event occurrences may vary over decades, population statistics can provide accurate estimates of these events. Therefore, data of these events stored in detailed population and fiscal registers can provide a promising starting point for developing predictive models of long-term mobility events. Such models could describe combinations of long term mobility events in response to life events occurring in households, but also represent the impact of the residential and mobility situation on life events. Compared to existing predictive model systems in the context of population, housing and mobility, such a model system would have the advantage that decisions are modelled in parallel, allowing them to mutually influence each other and account for path dependency effects.

9.3 Direction for future research

This thesis contributes to a better understanding of households' decision making regarding their residential situation, vehicle ownership and commute mode, and the dependency of these decisions on life and career events. Nevertheless, some issues remain to be explored.

First, we have conceptualized the long-term decisions addressed in this thesis as decisions at the household level. However, these decisions are also, to some extent, individual decisions. For instance, job change decisions depend to a considerable extent on individual aspirations and career orientations. Likewise, decisions about car ownership are at least partly based on the implications for the travel behaviour of individual household members. The bottom-line of this discussion is that households' decisions about longer term

mobility aspects are the outcome of negotiation processes between household members, in which the interests of the members may not be identical and need to be balanced. While negotiations between household members have been investigated with respect to daily travel behaviour (e.g. Zhang, Timmermans and Borgers, 2005, Miller and Roorda, 2003) and residential decisions (e.g. Timmermans, et al., 1992) interactions between households regarding a broader set of decision dimensions is lacking and is seen as a fruitful direction for further research.

Moreover, elaboration of the concept of stress is important to better understand the underlying causality of the relationships found in this thesis. An important aspect is how aspiration with respect to the residential, job and mobility situation develops over the life-course, potentially triggering changes in these domains. On the one hand, changes in individual and household characteristics, such as presence of children and income, may explain the aspirations or desired states. On the other hand, households' aspirations may differ based on their life style and preferences. For instance, households may trade-off income against available leisure time, with obvious implications for decisions regarding housing, car ownership and mobility. Likewise, preferences for urban versus rural residential locations, which are to a large extent independent of socio-demographic characteristics, may influence decisions regarding long-term mobility decisions. A key challenge will be to develop methods for tapping such preferences and relating them to longer term mobility decisions.

In addition, life style and preference may also depend on and vary over generations. Point in case is the recent trend that young adults show lower car ownership levels, but higher levels of air travel, possibly related to a preference for urban life styles. Collecting and analysing data about generational shifts in preferences and aspirations poses a great challenge. Finally, aspirations may be updated by interactions with a household's social network. Influence of the social network is recognised in travel behaviour analysis, but its impact on household long-term mobility decisions can also bring new insights.

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Appendices

Appendix 2.1: List of variables (WBO data used in chapter 2)

Variable Name	Description	Codes
age	Age (Maximum age taken) of the Head of Household (HH).	1 <= 20; 2 = 21-35; 3 = 36-50; 4 = 51-65 & 5 > 65
education	Education (Consider similar for both partners) of the respondent.	1 = None; 2 = Lagere school; 3 = LBO; 4 = MAVO/MULO; 5 = VMBO; 6 = HAVO; 7 = MBO; 8 = VWO/Atheneum/Gymnasium; 9 = HBO; 10 = University education & 11 = Other
household_type	Household Composition in 2002.	1=Single; 2=Couple without kids; 3=Couple with kids; 4=Single parent with kids & 5 = Others
number_children	Number of kids in the household	1 = 0; 2 = 1; 3 = 2 and 4 = 3+
household_workstatus	Work status of the household in 2002.	1 = Dual worker HH; 2 = Single worker HH & 3 = Non-working HH
household_income	Net monthly income of the household in 2002.	1 <= 1500; 2 = 1501-2500; 3 = 2501-3500 & 4 = 3500+
residentialarea_type	Residential area type in 2002.	1=urban centre; 2=outside centres; 3=sub-urban; 4=village & 5 = rural living
home_ownership	Does the HH own dwelling in 2002?	1 = yes & 2 = no}
dwelling_type	What is the dwelling type in 2002?	1=detached; 2=semi-detached; 3=corner dwelling; 4=row dwelling; 5=none of these & 6 = apartment
room_numbers	Number of rooms of the dwelling in 2002.	1 = 1; 2 = 2 ; 3 = 3; 4 = 4 and 5 = 4+
auto_ownership	Car ownership pattern in 2002.	1 = one; 2 = more than one & 3 = none
household_commute	Commute situation of the household in 2002.	1 = both commute; 2 = one partner commutes & 3 = no-one commutes
changehistory_householdtype	History of household composition change	1=change in 2001-02; 2=change in 2000 & 3 = no change from 2000
changehistory_residen	Residential relocation history.	1=change in 2001-02; 2=change in

		2000 and 3 = no change after 2000
satisfaction_dwelling:	Satisfaction with dwelling in 2002.	1=very satisfied; 2=satisfied; 3=neither satisfied nor dissatisfied; 4=dissatisfied & 5=very dissatisfied
satisfaction_neighbourhood	Satisfaction with neighbourhood in 2002.	same as previous variable
relocation_dwelling	Relocation decision within next 2 years to a particular dwelling.	1=detached; 2=semi-detached; 3=corner dwelling; 4=row dwelling; 5=no preference & 6=no move
relocation_residentialarea	Relocation decision within next 2 years to a particular residential area.	Same as 2002 and 6 = no move

Appendix 3.1: Questionnaire used for paper based survey.

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Onderzoek individuele keuzes ten aanzien van woning en autobezit

(de verstrekte informatie wordt enkel gebruikt voor onderzoeksdoeleinden)

Deel 1: Algemene informatie over uw huishouden

1. Wat is uw adres? (Als u kans wilt maken op een van de 25 geschenkbonnen van 25 euro die verloot worden, vult u dan hiernaast ook uw naam en huisnummer in)	Straatnaam of postcode
2. Wat is uw geboorteplaats?	
3. (Als u niet in Nederland geboren bent) Sinds wanneer woont u in Nederland?	

4. Vul alstublieft het geboortejaar, geslacht, positie in het huishouden in relatie tot u zelf, opleidingsniveau en huidige werk/studie locatie in voor elk van de leden van uw huishouden. Begin met de gegevens voor uzelf.

	Geboortejaar	Geslacht	Opleidingsniveau	Werkstatus	Locatie werk of studie
Persoon 1 (u zelf)	Jaar ……	i. Man ii. Vrouw	i. Geen ii. Lagere school iii. LBO iv. MAVO, MULO v. VMBO vi. HAVO vii. MBO viii. VWO, Atheneum, Gymnasium ix. HBO x. Universitair xi. Anders ……	i. Student ii. Werkzoekend iii. Part-time werkend iv. Full-time werkend v. Gepensioneerd/geen baan	……

Vervolg van deze tabel op de volgende pagina

	Geboortejaar	Geslacht	Positie in het huishouden	Opleidingsniveau	Werkstatus	Locatie werk of studie
Persoon 2	Jaar ……			i. Geen ii. Lagere school iii. LBO iv. MAVO, MULO v. VMBO vi. HAVO vii. MBO viii. VWO, Atheneum, Gymnasium ix. HBO x. Universitair xi. Anders ……		……
			i. Respondent ii. Partner iii. Kind iv. Ouder v. Broer/zus of anders		i. Student ii. Werkzoekend iii. Part-time werkend iv. Full-time werkend v. Gepensioneerd/geen baan	
		i. Man ii. Vrouw				

	Geboortejaar	Geslacht	Positie in het huishouden	Opleidingsniveau	Werkstatus	Locatie werk of studie
Persoon 3	Jaar ……			i. Geen ii. Lagere school iii. LBO iv. MAVO, MULO v. VMBO vi. HAVO vii. MBO viii. VWO, Atheneum, Gymnasium ix. HBO x. Universitair xi. Anders ……		……
			i. Respondent ii. Partner iii. Kind iv. Ouder v. Broer/zus of anders		i. Student ii. Werkzoekend iii. Part-time werkend iv. Full-time werkend v. Gepensioneerd/geen baan	
		i. Man ii. Vrouw				

Vervolg van deze tabel op de volgende pagina

	Geboortejaar	Geslacht	Positie in het huishouden	Opleidingsniveau	Werkstatus	Locatie werk of studie
Persoon 4	Jaar ……			i. Geen ii. Lagere school iii. LBO iv. MAVO, MULO v. VMBO vi. HAVO vii. MBO viii. VWO, Atheneum, Gymnasium ix. HBO x. Universitair xi. Anders ……		……
			i. Respondent ii. Partner iii. Kind iv. Ouder v. Broer/zus of anders		i. Student ii. Werkzoekend iii. Part-time werkend iv. Full-time werkend v. Gepensioneerd/geen baan	
		i. Man ii. Vrouw				

	Geboortejaar	Geslacht	Positie in het huishouden	Opleidingsniveau	Werkstatus	Locatie werk of studie
Persoon 5	Jaar ……			i. Geen ii. Lagere school iii. LBO iv. MAVO, MULO v. VMBO vi. HAVO vii. MBO viii. VWO, Atheneum, Gymnasium ix. HBO x. Universitair xi. Anders ……		……
			i. Respondent ii. Partner iii. Kind iv. Ouder v. Broer/zus of anders		i. Student ii. Werkzoekend iii. Part-time werkend iv. Full-time werkend v. Gepensioneerd/geen baan	
		i. Man ii. Vrouw				

Vervolg van deze tabel op de volgende pagina

	Geboortejaar	Geslacht	Positie in het huishouden	Opleidingsniveau	Werkstatus	Locatie werk of studie
Persoon 6	Jaar ……			i. Geen ii. Lagere school iii. LBO iv. MAVO, MULO v. VMBO vi. HAVO vii. MBO viii. VWO, Atheneum, Gymnasium ix. HBO x. Universitair xi. Anders ……		……
			i. Respondent ii. Partner iii. Kind iv. Ouder v. Broer/zus of anders		i. Student ii. Werkzoekend iii. Part-time werkend iv. Full-time werkend v. Gepensioneerd/geen baan	
		i. Man ii. Vrouw				

5. Verwacht u of bent u van plan uw huidige woning binnen 2 jaar te verlaten?	i. Ja	ii. Nee

6. **Indien u op de vorige vraag ja heeft geantwoord**, geef dan aan waarom u de woning wilt verlaten (meerdere antwoorden mogelijk)

Huishouden	**Huidige woning**	**Huidige buurt**	**Werk en studie**	**Sociaal netwerk**
i. Trouwen/samenwonen	i. Het huis is te klein	i. Slecht onderhoud	i. Verandering van werk/studie locatie	i. Dichtbij vriend(en)
ii. Scheiden/uit elkaar	ii. Het huis is te groot	ii. Onveilig gevoel in de buurt	ii. Start van een full-time baan	ii. Dichtbij familie
iii. Om zelfstandig te gaan wonen	iii. Voorkeur voor huur in plaats van koop	iii. Overlast door stank, lawaai of stof	iii. Overgaan op part-time werk	iii. Dichtbij vriend(en) van kind(eren)
iv. Geboorte kind	iv. Voorkeur voor een koophuis in plaats van huur	iv. Onvoldoende faciliteiten	iv. Met pensioen	
v. Inkomen toegenomen	v. Voorkeur voor een ander type woning	v. Anders (specificeer aub) ……	v. Werkzoekend na studie	iv. Anders (specificeer aub) ……..
vii Inkomen afgenomen	vi. Moeilijk aan de voorkeuren aan te passen		vi. Anders (specificeer aub) ……	
	vii. Geen centrale verwarming			
	viii. Slechte isolatie			
	ix. Trappen problematisch			
	x. Anders (specificeer aub) ……			

Deel 2: Informatie over uw levensloop (verleden, heden en toekomst)

1. Levensloopkalender

In dit gedeelte vragen we u informatie in te vullen over uw persoonlijke situatie en uw huishouden van 1990 tot 2010. Geeft u alstublieft het meest passende antwoord voor u aan op de kalender, waarin horizontaal de laatste 20 jaar van uw leven zijn weergegeven. Gelieve ook de startsituatie in 1990 voor elke vraag in te vullen.
NB: Gebruikt u alstublieft "×" of "✓"om jaren aan te geven. U kunt ook gebruikmaken van pijlen of lijnen om een langere periode aan te geven.

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Werkstatus																					
1. Vult u alstublieft in wat uw werksituatie was voor bovenstaande jaren																					
(1) Student																					
(2) Werkzoekend																					
(3) Part-time werkend																					
(4) Full-time werkend																					
(5) Gepensioneerd/geen baan																					
(6) Weet ik niet meer																					
2. **Indien van toepassing**, vult u alstublieft in wat de werkstatus van uw partner was voor bovenstaande jaren																					
(1) Student																					
(2) Werkzoekend																					
(3) Part-time werkend																					
(4) Full-time werkend																					
(5) Gepensioneerd/geen baan																					
(6) Weet ik niet meer																					
Inkomen																					
3. Geeft u alstublieft aan wat uw inkomen was (**bruto per maand**) voor bovenstaande jaren													NB: Gelieve bedragen vóór 2002 om te rekenen in euro's: 1 euro = Hfl 2,20.								
(1) Minder dan 1500 euro																					
(2) 1501-2500 euro																					
(3) 2501-3500 euro																					
(4) 3501-4500 euro																					
(5) Meer dan 4500 euro																					
(6) Weet ik niet meer																					

Vervolg van deze tabel op de volgende pagina

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
4. **Indien van toepassing**, geeft u alstublieft aan wat het inkomen van uw partner was (**bruto per maand**) voor bovenstaande jaren													NB: Gelieve bedragen vóór 2002 om te rekenen in euro's: 1 euro = Hfl 2,20.								
(1) Minder dan 1500 euro																					
(2) 1501-2500 euro																					
(3) 2501-3500 euro																					
(4) 3501-4500 euro																					
(5) Meer dan 4500 euro																					
(6) Weet ik niet meer																					

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Status van uw huishouden																					
5. Uit hoeveel personen bestond uw huishouden *inclusief uzelf*?																					
6. Geeft u alstublieft door middel van een '✖' of '✓' voor bovenstaande jaren aan wanneer een of meerdere van de volgende gebeurtenissen plaatsvonden																					
(1) U verlaat het ouderlijk huis																					
(2) Trouwen/gaan samenwonen																					
(3) Geboorte van kind(eren)																					
(4) Kind(eren) het huis uit																					
(5) Scheiding/uit elkaar																					
(6) Overlijden van een lid van het huishouden (geef alstublieft uw relatie met de persoon aan)																					
Indien er andere belangrijke familieomstandigheden hebben plaatsgevonden, geeft u deze dan aan in de onderstaande rijen en markeer ze op de kalender.																					
(7)																					
(8)																					
(9)																					
(10)																					

Vul alstublieft in hoe uw woonsituatie van 1990 tot heden is geweest, inclusief de laatste laatste verhuizing voor 1990 –
NB: Perioden van minder dan 6 maanden kunt u achterwege laten. Gelieve bij een meerkeuzemogelijkheid uw antwoord aan te geven door uw keuze te omcirkelen of met een "✖" of "✓".

	Huidige woonplaats	**Vorige woonplaats 1**	**Vorige woonplaats 2**	**Vorige woonplaats 3**	**Vorige woonplaats 4**	**Vorige woonplaats 5**
Woonsituatie						
7. Geef alstublieft uw woonlocatie aan (postcode of straatnaam en stad)	Straatnaam of postcode: …….. Woonplaats: ……	Straatnaam of postcode: …….. Woonplaats: ……	Straatnaam of postcode: …….. Woonplaats: ……	Straatnaam of postcode: …….. Woonplaats: ……	Straatnaam of postcode: …….. Woonplaats: ……	Straatnaam of postcode: …….. Woonplaats: ……
8. Wanner verhuisde u naar dit adres?	Jaar: …….	Jaar: …….	Jaar: …….	Jaar: …….	Jaar: …….	Jaar: …….
9. Type woning waar u in woonde	i. Vrijstaand	i. Vrijstaand	i. Vrijstaand	i. Vrijstaand	i. Vrijstaand	i. Vrijstaand
	ii. Half-vrijstaand	ii. Half-vrijstaand	ii. Half-vrijstaand	ii. Half-vrijstaand	ii. Half-vrijstaand	ii. Half-vrijstaand
	iii. Hoekhuis	iii. Hoekhuis	iii. Hoekhuis	iii. Hoekhuis	iii. Hoekhuis	iii. Hoekhuis
	iv. Rijtjeshuis	iv. Rijtjeshuis	iv. Rijtjeshuis	iv. Rijtjeshuis	iv. Rijtjeshuis	iv. Rijtjeshuis
	v. Appartement	v. Appartement	v. Appartement	v. Appartement	v. Appartement	v. Appartement
	vi. Kamer	vi. Kamer	vi. Kamer	vi. Kamer	vi. Kamer	vi. Kamer
	vii. Anders (specificeer) ……	vii. Anders (specificeer) ……	vii. Anders (specificeer) ……	vii. Anders (specificeer) ……	vii. Anders (specificeer) ……	vii. Anders (specificeer) ……
10. Was deze woning een huur- of koopwoning?	i. Huur	i. Huur	i. Huur	i. Huur	i. Huur	i. Huur
	ii. Koop	ii. Koop	ii. Koop	ii. Koop	ii. Koop	ii. Koop
	iii. Anders (specificeer aub) ……..	iii. Anders (specificeer aub) ……..	iii. Anders (specificeer aub) ……..	iii. Anders (specificeer aub) ……..	iii. Anders (specificeer aub) ……..	iii. Anders (specificeer aub) ……..
11. Wat was de huur of de hypotheeklasten (netto per maand)	…….. Euros	…….. Euros	…….. Euros	…….. Euros	…….. Euros	…….. Euros

Vervolg van deze tabel op de volgende pagina

	Huidige woonplaats		Vorige woonplaats 1		Vorige woonplaats 2		Vorige woonplaats 3		Vorige woonplaats 4		Vorige woonplaats 5	
12. Bouwjaar woning	i.	Voor 1900	i.	Voor 1900	i.	Voor 1900	i.	Voor 1900	i.	Voor 1900	i.	Voor 1900
	ii.	1900-1930	ii.	1900-1930	ii.	1900-1930	ii.	1900-1930	ii.	1900-1930	ii.	1900-1930
	iii.	1930-1960	iii.	1930-1960	iii.	1930-1960	iii.	1930-1960	iii.	1930-1960	iii.	1930-1960
	iv.	1960-1990	iv.	1960-1990	iv.	1960-1990	iv.	1960-1990	iv.	1960-1990	iv.	1960-1990
	v.	Na 1990	v.	Na 1990	v.	Na 1990	v.	Na 1990	v.	Na 1990	v.	Na 1990
13. Aantal slaapkamers	.....		.....		.....		.....		.....		.....	
14. Welke buitenruimte had deze woning?	i.	Voortuin en achtertuin	i.	Voortuin en achtertuin	i.	Voortuin en achtertuin	i.	Voortuin en achtertuin	i.	Voortuin en achtertuin	i.	Voortuin en achtertuin
	ii.	Achtertuin	ii.	Achtertuin	ii.	Achtertuin	ii.	Achtertuin	ii.	Achtertuin	ii.	Achtertuin
	iii.	Geen tuin	iii.	Geen tuin	iii.	Geen tuin	iii.	Geen tuin	iii.	Geen tuin	iii.	Geen tuin
	iv.	Balkon/dakterras	iv.	Balkon/dakterras	iv.	Balkon/dakterras	iv.	Balkon/dakterras	iv.	Balkon/dakterras	iv.	Balkon/dakterras
	v.	Geen	v.	Geen	v.	Geen	v.	Geen	v.	Geen	v.	Geen
15. Welke parkeerfaciliteiten waren aanwezig?	i.	Eigen garage	i.	Eigen garage	i.	Eigen garage	i.	Eigen garage	i.	Eigen garage	i.	Eigen garage
	ii.	Eigen parkeerplaats	ii.	Eigen parkeerplaats	ii.	Eigen parkeerplaats	ii.	Eigen parkeerplaats	ii.	Eigen parkeerplaats	ii.	Eigen parkeerplaats
	iii.	Parkeren op straat	iii.	Parkeren op straat	iii.	Parkeren op straat	iii.	Parkeren op straat	iii.	Parkeren op straat	iii.	Parkeren op straat
	iv.	Anders (specificeer aub)	iv.	Anders (specificeer aub)	iv.	Anders (specificeer aub)	iv.	Anders (specificeer aub)	iv.	Anders (specificeer aub)	iv.	Anders (specificeer aub) .....
Welk van de volgende redenen speelden een rol bij de verhuizing uit de voorgaande woning? (meerdere antwoorden mogelijk)												
16. Persoonlijke redenen:	Niet van toepassing		i.	Trouwen of samenwonen	i.	Trouwen of samenwonen	i.	Trouwen of samenwonen	i.	Trouwen of samenwonen	i.	Trouwen of samenwonen
			ii.	Scheiding of uit elkaar	ii.	Scheiding of uit elkaar	ii.	Scheiding of uit elkaar	ii.	Scheiding of uit elkaar	ii.	Scheiding of uit elkaar
			iii.	Om zelfstandig te gaan wonen	iii.	Om zelfstandig te gaan wonen	iii.	Om zelfstandig te gaan wonen	iii.	Om zelfstandig te gaan wonen	iii.	Om zelfstandig te gaan wonen
			iv.	Geboorte kind	iv.	Geboorte kind	iv.	Geboorte kind	iv.	Geboorte kind	iv.	Geboorte kind
			v.	Anders (specificeer aub)	v.	Anders (specificeer aub)	v.	Anders (specificeer aub)	v.	Anders (specificeer aub)	v.	Anders (specificeer aub) .....
17. Vverandering in inkomen:	Niet van toepassing		i.	Inkomen gestegen	i.	Inkomen gestegen	i.	Inkomen gestegen	i.	Inkomen gestegen	i.	Inkomen gestegen
			ii.	Inkomen gedaald	ii.	Inkomen gedaald	ii.	Inkomen gedaald	ii.	Inkomen gedaald	ii.	Inkomen gedaald

Vervolg van deze tabel op de volgende pagina

18. Verandering woonvoorkeuren en woonbehoeftes	Niet van toepassing	i.	Voorkeur voor een kleiner huis	i.	Voorkeur voor een kleiner huis	i.	Voorkeur voor een kleiner huis	i.	Voorkeur voor een kleiner huis	i.	Voorkeur voor een kleiner huis
		ii	Voorkeur voor een groter huis	ii.	Voorkeur voor een groter huis	ii.	Voorkeur voor een groter huis	ii.	Voorkeur voor een groter huis	ii.	Voorkeur voor een groter huis
		iii.	Voorkeur voor een ander type woning	iii.	Voorkeur voor een ander type woning	iii.	Voorkeur voor een ander type woning	iii.	Voorkeur voor een ander type woning	iii.	Voorkeur voor een ander type woning
		iv.	De trappen zijn een probleem	iv.	De trappen zijn een probleem	iv.	De trappen zijn een probleem	iv.	De trappen zijn een probleem	iv.	De trappen zijn een probleem
		v.	Moeilijk aan te passen	v.	Moeilijk aan te passen	v.	Moeilijk aan te passen	v.	Moeilijk aan te passen	v.	Moeilijk aan te passen
		vi.	Eenzaamheid	vi.	Eenzaamheid	vi.	Eenzaamheid	vi.	Eenzaamheid	vi.	Eenzaamheid
		vii.	Geen centrale verwarming	vii.	Geen centrale verwarming	vii.	Geen centrale verwarming	vii.	Geen centrale verwarming	vii.	Geen centrale verwarming
		viii.	Slechte isolatie	viii.	Slechte isolatie	viii.	Slechte isolatie	viii.	Slechte isolatie	viii.	Slechte isolatie
		ix.	Anders (specificeer aub) ……	ix.	Anders (specificeer aub) ……	ix.	Anders (specificeer aub) ……	ix.	Anders (specificeer aub) ……	ix.	Anders (specificeer aub) ……
19. Voorkeur voor andere eigenaarsvorm:	Niet van toepassing	i.	Voorkeur voor huur	i.	Voorkeur voor huur	i.	Voorkeur voor huur	i.	Voorkeur voor huur	i.	Voorkeur voor huur
		ii.	Voorkeur voor koop	ii.	Voorkeur voor koop	ii.	Voorkeur voor koop	ii.	Voorkeur voor koop	ii.	Voorkeur voor koop
20. Ontevredenheid met de wijk:	Niet van toepassing	i.	Slecht onderhouden	i.	Slecht onderhouden	i.	Slecht onderhouden	i.	Slecht onderhouden	i.	Slecht onderhouden
		ii.	Onveilig gevoel in de buurt	ii.	Onveilig gevoel in de buurt	ii.	Onveilig gevoel in de buurt	ii.	Onveilig gevoel in de buurt	ii.	Onveilig gevoel in de buurt
		iii.	Overlast door stank, lawaai of stof	iii.	Overlast door stank, lawaai of stof	iii.	Overlast door stank, lawaai of stof	iii.	Overlast door stank, lawaai of stof	iii.	Overlast door stank, lawaai of stof
		iv.	Onvoldoende faciliteiten	iv.	Onvoldoende faciliteiten	iv.	Onvoldoende faciliteiten	iv.	Onvoldoende faciliteiten	iv.	Onvoldoende faciliteiten
		v.	Anders (specificeer aub) ……	v.	Anders (specificeer aub) ……	v.	Anders (specificeer aub) ……	v.	Anders (specificeer aub) ……	v.	Anders (specificeer aub) ……

Vervolg van deze tabel op de volgende pagina

	Huidige woonplaats	Vorige woonplaats 1		Vorige woonplaats 2		Vorige woonplaats 3		Vorige woonplaats 4		Vorige woonplaats 5	
21. Verandering werksituatie	Niet van toepassing	i.	Verandering in locatie voor werk/studie	i.	Verandering in locatie voor werk/studie	i.	Verandering in locatie voor werk/studie	i.	Verandering in locatie voor werk/studie	i.	Verandering in locatie voor werk/studie
		ii.	Voltijd aanstelling gekregen	ii.	Voltijd aanstelling gekregen	ii.	Voltijd aanstelling gekregen	ii.	Voltijd aanstelling gekregen	ii.	Voltijd aanstelling gekregen
		iii.	Verandering naar part-time werk	iii.	Verandering naar part-time werk	iii.	Verandering naar part-time werk	iii.	Verandering naar part-time werk	iii.	Verandering naar part-time werk
		iv.	Met pensioen	iv.	Met pensioen	iv.	Met pensioen	iv.	Met pensioen	iv.	Met pensioen
		v.	Op zoek naar werk na de studie	v.	Op zoek naar werk na de studie	v.	Op zoek naar werk na de studie	v.	Op zoek naar werk na de studie	v.	Op zoek naar werk na de studie
		vi.	Werd werkloos	vi.	Werd werkloos	vi.	Werd werkloos	vi.	Werd werkloos	vi.	Werd werkloos
		vii.	Anders (specificeer aub) ……	vii.	Anders (specificeer aub) ……	vii.	Anders (specificeer aub) ……	vii.	Anders (specificeer aub) ……	vii.	Anders (specificeer aub) ……
22. Was de bereikbaarheid van de woning per openbaar vervoer een reden om de woning te verlaten?	Niet van toepassing	i.	Ja	i.	Ja	i.	Ja	i.	Ja	i.	Ja
		ii.	Nee	ii.	Nee	ii.	Nee	ii.	Nee	ii.	Nee
23. Was het sociale netwerk een reden om de woning te verlaten?	Niet van toepassing	i.	Wil dichter bij een vriend(in) wonen	i.	Wil dichter bij een vriend(in) wonen	i.	Wil dichter bij een vriend(in) wonen	i.	Wil dichter bij een vriend(in) wonen	i.	Wil dichter bij een vriend(in) wonen
		ii.	Wil dichter bij familie wonen	ii.	Wil dichter bij familie wonen	ii.	Wil dichter bij familie wonen	ii.	Wil dichter bij familie wonen	ii.	Wil dichter bij familie wonen
		iii.	Wil dichterbij vriend(in) van kind(eren) wonen	iii.	Wil dichterbij vriend(in) van kind(eren) wonen	iii.	Wil dichterbij vriend(in) van kind(eren) wonen	iii.	Wil dichterbij vriend(in) van kind(eren) wonen	iii.	Wil dichterbij vriend(in) van kind(eren) wonen
		iv.	Anders (specificeer aub) ……	iv.	Anders (specificeer aub) ……	iv.	Anders (specificeer aub) ……	iv.	Anders (specificeer aub) ……	iv.	Anders (specificeer aub) ……

Noemt u alstublieft de locatie van werk of studie van uzelf en uw partner van 1990 tot heden en de laatste verandering voor 1990 –
NB: Beschouw uw studielocatie alstublieft als werklocatie.

	Huidige werkplek	**Vorige werkplek 1**	**Vorige werkplek 2**	**Vorige werkplek 3**	**Vorige werkplek 4**	**Vorige werkplek 5**
Uw werksituatie						
24. Geeft u alstublieft uw werk/studielocatie aan.	……..	……..	……..	……..	……..	……..
25. Wanneer startte u de bovengenoemde baan of studie?	Jaar: ……..	Jaar: ……..	Jaar: ……..	Jaar: ……..	Jaar: ……..	Jaar: ……..
De werksituatie van uw partner (indien van toepassing)						
26. Geeft u alstublieft de werk/studielocatie van uw partner aan.	……..	……..	……..	……..	……..	……..
27. Wanneer startte uw partner de bovengenoemde baan of studie?	Jaar: ……..	Jaar: ……..	Jaar: ……..	Jaar: ……..	Jaar: ……..	Jaar: ……..

Hieronder vragen wij u om de situatie met betrekking tot woon- werkplek en het bezit van vervoermiddelen in de afgelopen 20 jaar weer te geven. Gelieve ook de startsituatie in 1990 te vermelden.
NB: Noem de situatie in 1990 en vermeld daarna alleen veranderingen, of geef door middel van pijlen of lijnen een langere periode aan.

	1990	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Vervoer en transport																					
28. Aantal beschikbare auto's in uw huishouden.																					
	1990 of eerder	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
29. **Indien van toepassing**, noemt u alstublieft wanneer er binnen uw huishouden rijbewijzen werden behaald.																					
(1) Wanneer haalde u uw rijbewijs?																					
(2) Wanneer haalde uw partner zijn/haar rijbewijs?																					
(3) Wanneer haalde een van uw kinderen zijn/haar rijbewijs?																					
(4) Wanneer haalde een ander gezinslid zijn/haar rijbewijs (geen partner/kinderen)?																					

Vervolg van deze tabel op de volgende pagina

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
30. Geeft u alstublieft aan welke vervoersmogelijkheden voor u beschikbaar zijn																					
(1) Full-time beschikbaarheid van een eigen auto																					
(2) Full-time beschikbaarheid van een auto van de zaak																					
(3) Beschikbaarheid van een eigen auto in overleg met andere gezinsleden																					
(4) Beschikbaarheid van een openbaar vervoersabonnement																					
31. **Indien van toepassing**, geef alstublieft de vervoersmogelijkheden van uw partner aan																					
(1) Full-time beschikbaarheid van een eigen auto																					
(2) Full-time beschikbaarheid van een auto van de zaak																					
(3) Beschikbaarheid van een eigen auto in overleg met andere gezinsleden																					
(4) Beschikbaarheid van openbaar vervoersabonnement																					
32. Geef alstublieft aan hoeveel tijd (in minuten) u gemiddeld besteedt aan woon-werkverkeer met het vervoermiddel dat u het vaakst neemt (indien van toepassing)																					
(1) Door u																					
(2) Door uw partner																					
33. Geef alstublieft aan welk vervoermiddel (eigen auto, bus, trein, motor of fiets) gebruikt wordt voor woon-werkverkeer (indien van toepassing).																					
(1) Door u																					
(2) Door uw partner																					

2. Carrièreperspectief of toekomstdoel:

Dit gedeelte bestaat uit vragen die gaan over uw (en uw partner's) toekomstdoelen of carrièreperspectief. Deze plannen kunnen betrekking hebben op uw werksituatie, woonsituatie of uw gezinssituatie.

Geeft u alstublieft aan of u de onderstaande doelstellingen wilt bereiken (door dit in de eerste kolom met "✖" of "✓" te markeren. Wij vragen u ook om aan te geven:

- wanneer u deze doelstellingen denkt te bereiken

- hoe zeker u bent deze doelstelling te bereiken

NB: U hoeft alleen gewenste veranderingen ten opzichte van de bestaande situatie aan te geven.

Werkgerelateerde doelstellingen	**Dit is een doelstelling**	**Wanneer denkt u dit doel te bereiken?**						**Zekerheid 1 = niet heel zeker 2 = enigszins zeker 3 = zeer zeker**
		In 2010	**In 2011**	**binnen 3-5 jaar**	**binnen 5-10 jaar**	**na 10 jaar**	**Weet ik niet**	
Heeft u tot doel om								
34. uw studie af te maken								
35. een studie of opleiding op hoger niveau te beginnen								
36. een part-time baan te vinden								
37. een voltijd baan te vinden								
38. met pensioen te gaan of te stoppen met werken								
39. uw inkomen te verhogen (salarisverhoging of meer zaken doen)								
40. Veranderen van werklocatie								
Heeft uw partner tot doel om (indien van toepassing)								
41. zijn/haar studie af te maken								
42. een studie of opleiding op hoger niveau te beginnen								
43. een part-time baan te vinden								
44. een voltijd baan te vinden								
45. met pensioen te gaan of te stoppen met werken								
46. uw inkomen te verhogen (salarisverhoging of meer zaken doen)								
47. Veranderen van werklocatie								

Vervolg van deze tabel op de volgende pagina

Reis en transport doelstellingen	Dit is een doelstelling	Wanneer denkt u dit doel te bereiken?						Zekerheid 1 = niet heel zeker 2 = enigszins zeker 3 = zeer zeker
		In 2010	In 2011	binnen 3-5 jaar	binnen 5-10 jaar	na 10 jaar	Weet ik niet	
Bent u van plan om…								
48. een rijbewijs te halen								
49. full-time te beschikken over een auto								
50. te beschikken over een auto die met meerdere gezinsleden gedeeld wordt								
51. een abonnement op het OV aan te schaffen								
52. De reistijd van uw woon-werkverkeer te verminderen								
i. met 10 min								
ii. met 10-20 min								
iii. met 20-30 min								
iv. met meer dan 30 min								
53. Uw woon-werkvervoersmiddel te veranderen in								
i. Auto								
ii. Openbaar vervoer								
iii. Auto + openbaar vervoer								
iv. Fiets + openbaar vervoer								
v. Fiets								
vi. Anders								
Is uw partner van plan om… (indien van toepassing)								
54. een rijbewijs te halen								
55. te beschikken over een full-time auto								
56. te beschikken over een auto die met meerdere gezinsleden gedeeld wordt								
57. een abonnement op het OV aan te schaffen								

Vervolg van deze tabel op de volgende pagina

Reis en transport doelstellingen	Dit is een doelstelling	Wanneer denkt u dit doel te bereiken?						Zekerheid 1 = niet heel zeker 2 = enigszins zeker 3 = zeer zeker
		In 2010	In 2011	binnen 3-5 jaar	binnen 5-10 jaar	na 10 jaar	Weet ik niet	
58. de reistijd voor woon-werkverkeer te verminderen								
i. met 10 min								
ii. met 10-20 min								
iii. met 20-30 min								
iv. met meer dan 30 min								
59. Veranderen van het vervoersmiddel voor uw woon-werkverkeer naar								
i. Auto								
ii. Openbaar vervoer								
iii. Auto + openbaar vervoer								
iv. Fiets + openbaar vervoer								
v. Fiets								
vi. Anders								

Persoonlijke doelstellingen	Geen doelstelling	Wanneer denkt u dit doel te bereiken?						Zekerheid 1 = niet heel zeker 2 = enigszins zeker 3 = zeer zeker
		In 2010	In 2011	binnen 3-5 jaar	binnen 5-10 jaar	na 10 jaar	Weet ik niet	
Bent u van plan om…								
60. te trouwen of samen te gaan wonen								
61. kinderen te krijgen								
62. andere dingen te doen/verkrijgen (vult u deze zelf in)								
i.								
ii.								
iii.								
iv.								
v.								

Vervolg van deze tabel op de volgende pagina

Woonsituatie	Geen doelstelling	Wanneer denkt u dit te bereiken?						Zekerheid 1 = niet heel zeker 2 = enigszins zeker 3 = zeer zeker
		In 2010	In 2011	binnen 3-5 jaar	binnen 5-10 jaar	na 10 jaar	Weet ik niet	
Bent u van plan…								
63. een andere woning te zoeken								
64. uw woningtype te veranderen naar								
i. Vrijstaand								
ii. Half-vrijstaand								
iii. Hoekhuis								
iv. Rijtjeshuis								
v. Appartement								
vi. Gedeeld huis								
65. Veranderen van huis eigendomstype naar								
i. Huur								
ii. Koop								
iii. Anders								
66. geen tuin meer te hebben								
67. een grotere tuin te krijgen								
68. een eigen garage te bewerkstelligen								
69. een groter huis te zoeken								
70. een kleiner huis te zoeken								
71. een auto te kopen voor het gezin								

Deel 3: Sociaal netwerk en marktverwachting

1. Sociaal netwerk

De volgende vragen gaan over mensen die dichtbij u staan. Hiermee worden de mensen bedoeld met wie u of uw partner belangrijke zaken bespreken, waarmee u of uw partner regelmatig contact hebben, of de mensen die er voor u zijn als u hulp nodig heeft en die niet tot uw familie behoren.

Geeft u alstublieft enige persoonlijke, woon-, werk- en vervoersgerelateerde informatie over de 4 person(en) (geen familie) die voor u het belangrijkste zijn..
NB: Het is niet noodzakelijk om hier een nauwkeurig antwoord te geven; een schatting is voldoende.

	Persoon 1	**Persoon 2**	**Persoon 3**	**Persoon 4**
1. Wat is uw relatie met deze persoon (bijv. vriend/kennis/collega)?	……..	……..	……..	……..
2. Geeft u alstublieft een schatting van de leeftijd van deze persoon	……..	……..	……..	……..
3. Geef aan wat zijn/haar werksituatie is	i. Student	i. Student	i. Student	i. Student
	ii. Werkzoekend	ii. Werkzoekend	ii. Werkzoekend	ii. Werkzoekend
	iii. Part-time werkend	iii. Part-time werkend	iii. Part-time werkend	iii. Part-time werkend
	iv. Full-time werkend	iv. Full-time werkend	iv. Full-time werkend	iv. Full-time werkend
	v. Gepensioneerd	v. Gepensioneerd	v. Gepensioneerd	v. Gepensioneerd
4. Geef aan waar hij/zij werkt of studeert (zo precies mogelijk)				
5. Geef alstublieft een indicatie van zijn/haar inkomen (bruto per maand)	i. Minder dan 1500 euro	i. Minder dan 1500 euro	i. Minder dan 1500 euro	i. Minder dan 1500 euro
	ii. 1501-2500 euro	ii. 1501-2500 euro	ii. 1501-2500 euro	ii. 1501-2500 euro
	iii. 2501-3500 euro	iii. 2501-3500 euro	iii. 2501-3500 euro	iii. 2501-3500 euro
	iv. Meer dan 3500 euro	iv. Meer dan 3500 euro	iv. Meer dan 3500 euro	iv. Meer dan 3500 euro
Woonsituatie van uw kennis/vriend(in)				
6. Woonlocatie van de persoon (zo precies mogelijk)	……..	……..	……..	……..
7. In welk jaar is deze persoon hier naartoe verhuisd?	……..	……..	……..	……..

Vervolg van deze tabel op de volgende pagina

	Persoon 1		Persoon 2		Persoon 3		Persoon 4	
8. Woning type van deze persoon	i.	Vrijstaand	i.	Vrijstaand	i.	Vrijstaand	i.	Vrijstaand
	ii.	Half-vrijstaand	ii.	Half-vrijstaand	ii.	Half-vrijstaand	ii.	Half-vrijstaand
	iii.	Hoekhuis	iii.	Hoekhuis	iii.	Hoekhuis	iii.	Hoekhuis
	iv.	Rijtjeshuis	iv.	Rijtjeshuis	iv.	Rijtjeshuis	iv.	Rijtjeshuis
	v.	Appartement	v.	Appartement	v.	Appartement	v.	Appartement
	vi.	Anders, specificeer aub ……..	vi.	Anders, specificeer aub ……..	vi.	Anders, specificeer aub ……..	vi.	Anders, specificeer aub ……..
9. Heeft deze persoon een huur- of koopwoning?	i.	Huurwoning	i.	Huurwoning	i.	Huurwoning	i.	Huurwoning
	ii.	Koopwoning	ii.	Koopwoning	ii.	Koopwoning	ii.	Koopwoning
10. Bouwjaar woning vriend	……...		…….		…….		…….	
11. Aantal kamers woning vriend	……...		…….		…….		…….	
12. Aanwezigheid tuin	i.	Voor- en achtertuin	i.	Voor- en achtertuin	i.	Voor- en achtertuin	i.	Voor- en achtertuin
	ii.	Achtertuin	ii.	Achtertuin	ii.	Achtertuin	ii.	Achtertuin
	iii.	Geen tuin	iii.	Geen tuin	iii.	Geen tuin	iii.	Geen tuin
Reizen en transport van deze kennis/vriend(in)								
13. Heeft hij/zij een rijbewijs?	i.	Ja	i.	Ja	i.	Ja	i.	Ja
	ii.	Nee	ii.	Nee	ii.	Nee	ii.	Nee
14. Heeft hij/zij een auto binnen zijn/haar huishouden?	i.	Een	i.	Een	i.	Een	i.	Een
	ii.	Meer dan een	ii.	Meer dan een	ii.	Meer dan een	ii.	Meer dan een
	iii.	Geen	iii.	Geen	iii.	Geen	iii.	Geen
15. Wat is zijn/haar reistijd voor woon-werkverkeer?	……...		…….		…….		…….	
16. Welk vervoersmiddel gebruikt hij/zij het meest?	i.	Auto	i.	Auto	i.	Auto	i.	Auto
	ii.	Openbaar vervoer/fiets	ii.	Openbaar vervoer/fiets	ii.	Openbaar vervoer/fiets	ii.	Openbaar vervoer/fiets

Vervolg van deze tabel op de volgende pagina

2. Marktverwachting

In dit gedeelte wordt u een aantal vragen gesteld over uw verwachtingen ten aanzien van de woning- en arbeidsmarkt en vervoer.

Geef alstublieft uw mening over de huizenmarkt, arbeidsmarkt en vervoer.
NB: Kies het antwoord dat het beste uw mening weergeeft

17. Verwacht u dat de komende 3 jaar meer woningen in de sociale sector beschikbaar zullen komen?	i.	Ja, in uw huidige omgeving
	ii.	Ja, in een andere omgeving die vergelijkbaar is met uw huidige omgeving
	iii.	Geen verandering
	iv.	Weet ik niet/geen mening
18. Wat verwacht u ten aanzien van de prijzen van koopwoningen in de komende 3 jaar?	i.	Deze zullen significant stijgen
	ii.	Deze zullen licht stijgen
	iii.	Deze zullen gelijk blijven
	iv.	Deze zullen licht dalen
	v.	Deze zullen significant dalen
	vi.	Weet ik niet/geen mening
19. Denkt u dat er in de komende 3 jaar meer of minder banen beschikbaar zullen zijn die voor u interessant zijn?	i.	Meer banen
	ii.	Minder banen
	iii.	Geen verandering
	iv.	Weet ik niet/geen mening
20. Denkt u dat de kosten van autogebruik in de komende 3 jaar zullen stijgen?	i.	Sterke stijging
	ii.	Geringe stijging
	iii.	Geen verandering
	iv.	Weet ik niet/geen mening
21. Denkt u dat de reistijd met de auto in de komende 3 jaar zal toenemen als gevolg van toenemende congestie?	i.	Sterke toename
	ii.	Geringe toename
	iii.	Geen verandering
	iv.	Weet ik niet/geen mening

Dank u vriendelijk voor uw medewerking

Samenvatting:
De tijdafhankelijkheid van levensgebeurtenissen en mobiliteitskeuzen

Verhuizing, verandering van baan en verandering in autobezit zijn huishoudensbeslissingen die een structurele impact op het dagelijks reisgedrag hebben. De beslissingen kunnen onafhankelijk van elkaar genomen worden, maar ook samenhangend in de tijd. Zulk afhankelijkheden kunnen echter in verschillende temporele volgordes van gebeurtenissen resulteren. Huishoudens kunnen besluiten om te verhuizen in reactie op een verandering van baan, maar ze kunnen ook verhuizen vooruitlopend op een verandering van baan. Het negeren van dergelijke samenhangen tussen huishoudensbeslissingen met lange termijn effecten kan leiden tot minder nauwkeurige voorspellingen van activiteiten- en verplaatsingspatronen en verkeersprognoses. Om beter rekening te houden met interacties tussen huishoudensbeslissingen, worden in dit proefschrift drie onderzoeksvragen beantwoord:

i. in hoeverre hangen verandering van woonplaats, werk, autobezit en vervoerswijze onderling samen?
ii. in hoeverre hangen deze veranderingen samen met levensgebeurtenissen?
iii. wat is de temporele ordening van deze gebeurtenissen?

Om deze vragen te beantwoorden wordt eerst een conceptueel model geschetst. Belangrijke kenmerken van dit conceptueel model zijn dat structurele mobiliteitsbeslissingen (over wonen, werken voertuigbezit en vervoerwijze) onderling samenhangen, dat ze samenhangen met levensgebeurtenissen en dat onderlinge afhankelijkheid zich over lange periodes kan uitstrekken. De timing en volgorde van beslissingen over mobiliteitsmiddelen, wonen en werken is afhankelijk van de inspanning, tijd en geld die nodig zijn voor een reactie op een veranderde context, de ontwikkelen van aspiraties in het huidhouden en of er sprake is van bewuste beslissingen of onverwachte gebeurtenissen waarop gereageerd moet worden. De nadruk op onderlinge afhankelijkheden die zich over langere perioden uitstrekken maakt en longitudinale benadering noodzakelijk. Voortbouwend op het conceptueel model, is een vragenlijst ontwikkeld om over een periode van meerdere jaren gegevens te verzamelen met betrekking tot mobiliteitsaspecten zoals de woonsituatie, autobezit, werklocatie en vervoerswijzen; demografische aspecten, zoals huishoudengrootte, en gebeurtenissen zoals gaan samenwonen, geboorte van een kind, gezinsverlating en scheiding; professionele aspecten zoals het aantal werkuren, en sociaal-economische aspecten zoals leeftijd en inkomen.

Omdat panel data die al deze aspecten omvat niet bestaat, is gekozen voor een retrospectieve data verzameling voor de periode 1990-2010 in de regio Utrecht, Nederland. Op basis van de verzamelde gegevens, zijn in deze studie verschillende analyses uitgevoerd om de dynamiek en onderlinge samenhang van langdurige mobiliteitsbeslissingen te onderzoeken. Met behulp van mixed Logit analyses, onderzoekt de studie veranderingen in autobezit, woonrelocatie en vervoerswijze in het woon-werk verkeer. Het doel is om de relaties tussen mobiliteitbeslissingen onderling en met demografische gebeurtenissen te identificeren, en te onderzoeken hoe deze verbanden leiden tot een temporele ordening van gebeurtenissen. Een laatste analyse is gericht op het ontwikkelen van een geïntegreerd model dat de onderlinge relaties tussen verhuizing, verandering van baan en verandering in autobezit beschrijft en koppelt aan demografische en professionele levensgebeurtenissen.

Uit het autobezit model blijkt dat demografische gebeurtenissen zoals geboorte van een kind en het begin van samenwonen relatief vaak samengaan met de aanschaf van een extra auto auto-acquisitie, en scheiding relatief vaker leidt tot het wegdoen van een aan auto. Ook een gebeurtenis als pensionering beïnvloedt het autobezit. Verder is verandering van werkgever gerelateerd aan het wegdoen van een auto en is verhuizing gerelateerd aan de aanschaf van een extra auto. Verhuizing en scheiding/echtscheiding laten een uitgesteld effect zien op beslissingen over aanschaf of wegdoen van een auto. Op geboorte van het eerste kind wordt daarentegen geanticipeerd door aanschaf van een extra auto, en op pensionering en verandering van werkgever wordt geanticipeerd door het wegdoen van een auto.

Met betrekking tot verhuizing wordt aangenomen dat dit een padafhankelijkproces is dat verweven is met andere huishoudelijke beslissingen. Hoewel padafhankelijkheid in verhuizingen in eerdere studies is onderzocht in relatie tot eerdere verhuizing en verandering van baan, is het nog niet onderzocht in de context van levensgebeurtenissen in huishoudens. In het binaire logit model dat verhuizing beschrijft is gevonden dat huishoudens minder geneigd zijn om te verhuizen als ze vorig jaar verhuisden, maar het effect is zwak als gecontroleerd wordt voor demografische, professionele en andere mobiliteitsbeslissingen. Beginnen met samenwonen en scheiding zijn de belangrijkste demografische gebeurtenissen die invloed hebben op verhuizing. Het verlaten van het ouderlijk huis door het laatste kind en de geboorte van het eerste kind blijken ook te leiden tot een hogere kans op verhuizing. Huishoudens met meer dan een auto hebben meer kans om te verhuizen in vergelijking met huishoudens met een of geen auto. Daarnaast is er een sterk positief effect van aanschaf of wegdoen van een auto op de verhuiskans. Hierbij heeft het wegdoen van een auto een groter effect dan de aanschaf van een auto. Dit kan betekenen dat het wegdoen van een auto sterk gekoppeld is aan een verhuizing naar plaatsen met een betere bereikbaarheid met andere vervoerwijzen (zoals binnensteden), wat kan leiden tot minder autogebruik. Verder vergroten echtscheiding en het veranderen van werkgever de kans op verhuizen, maar met een vertraagd effect.

In de studie is verder gekeken naar het effect van lange termijn beslissingen van huishoudens met betrekking tot verhuizing, werk en gezinssituatie op de vervoerswijze in het

woon-werkverkeer. Een reden om hier naar te kijken is dat dergelijke gebeurtenissen in huishoudens een aangrijppunt kunnen zijn voor gerichte interventies, leidend tot gedragsverandering. In dit verband is in deze studie gekeken naar veranderingen in de hoofdvervoerwijze van en naar het werk (modal shift) tussen waargenomen jaren, en niet naar de vervoerwijze keuze in een bepaald jaar. In twee afzonderlijke analyses, is de modal shift voor autogebruikers en fietsers onderzocht. Diverse huishoudensgebeurtenissen hebben een significante relatie met modal shift. Geboorte van het eerste kind vergroot de kans op een overstap van andere vervoerwijzen naar de auto, en op een overstap van fietsten naar andere vervoerwijzen. Een fietser heeft minder kans om te stoppen met het gebruik van de fiets als hij/zij gaat samenwonen of trouwen. Scheiding toont een positief maar vertraagd effect op modal shift, zowel van als naar de auto. Veranderen van werkgever is positief gerelateerd aan modal shift van en naar de fiets en van en naar de auto. Dit kan verklaard worden uit het feit dat verandering van werkgever kan leiden tot een verandering van reisafstand of bereikbaarheid van de werklocatie. Het positieve effect van verhuizen op een modal shift naar de fiets is minder gemakkelijk te zien. Een gedetailleerde analyse van de kenmerken van de woonomgeving voor en na de verhuizing kan hier meer inzicht bieden. Vertraagde effecten van scheiding en verandering van werkgever worden gevonden voor de modal shift van en naar de auto. Daarnaast is gebleken dat de overschakeling van voltijds naar deeltijdwerk de kans op een modal shift naar de fiets vergroot. Een dergelijke verandering impliceert meestal een lager inkomen, waardoor de kans op het gebruik van een goedkoop vervoermiddel als de fiets groter wordt.

Ten slotte zijn in de studie meerdere mobiliteitsbeslissingen en huishoudensgebeurtenissen geintegreerd in een analytisch model. Het model is gebaseerd op Bayesian Belief Networks. Het voordeel van dit model ten opzichte van discrete keuze modellen en modellen op basis van structurele vergelijkingen is de mogelijkheid om onderlinge relaties tussen gebeurtenissen op verschillende tijdstippen te bepalen zonder a priori de richting van causaliteiten vast te leggen. Een extra voordeel ten opzichte van modellen op basis van structurele vergelijkingen is dat het model beter relaties tussen discrete variabelen kan beschrijven. Een interessant inzicht uit het model is dat beslissingen over autobezit, woonlocatie en werk niet direct van elkaar afhankelijk zijn, maar dat ze tegelijkertijd onafhankelijk van elkaar genomen worden in reactie op veranderingen in de gezinssamenstelling. Zo is gevonden dat het gaan samenwonen en de verwachte geboorte van het eerste kind tegelijkertijd leiden tot het verhuizen naar een grotere woning en aanschf van een (extra) auto. Andere uitkomsten van het model bevestigen de resultaten van de eerdere binaire logit modellen. Zo kan het gaan samenwonen en de geboorte van het eerste kind leiden tot het verhuizen naar een grotere woning en aanschaf van een auto, en is scheiding gerelateerd aan het wegdoen van een auto en verhuizen naar een kleinere woning. Het model bevestigt verder het belang van de timing van gerelateerde gebeurtenissen. Gelijktijdige, vertraagde en anticiperende effecten worden gevonden in het Bayesian Belief Network model. Belangrijke bevindingen zijn een anticiperend effect van de geboorte van het eerste

kind op de auto overname en verhuizen naar een grotere woning, en een vertraagd effect van het gaan samenwonen op verandering van werkgever.

Dit proefschrift beschrijft temporele afhankelijkheden tussen huishoudensgebeurtenissen an mobiliteitsbeslissingen. Gebeurtenissen zijn hierbij beschouwd als een geïmplementeerde beslissing zoals door huishouden gerapporteerd in de enquête. Het observeren van gebeurtenissen maakt het niet mogelijk om conclusies over causale verbanden te trekken. Echter, op basis van de theorie, kan de relatie tussen gebeurtenissen worden geïnterpreteerd als het resultaat van een reactie of anticipatie op een externe trigger of als een combinatie van gebeurtenissen in reactie op een derde gebeurtenis. Hoewel we geen harde conclusies over causaliteit kunnen trekken is het van belang statistisch significante verbanden tussen huishoudensgebeurtenissen en mobiliteitsbeslissingen vast te stellen. Dergelijke statische verbanden kunnen de basis vormen voor voorspellende modellen, waarmee de kans op bepaalde gebeurtenissen (bijvoorbeeld verhuizing, aanschaf van een auto of vervoerwijze) voorspeld kan worden, zonder dat harde conclusies over causaliteit nodig zijn. Tevens kan de volgorde van gebeurtenissen in huishoudens voorspeld en beschreven worden, waarbij wel onderscheid gemaakt kan worden tussen reactief, gelijktijdig en anticiperend gedrag.

Hoewel de verzamelde gegevens in dit onderzoek niet representatief zijn voor de Nederlandse of de Utrechtse bevolking en bepaalde beperkingen kent, hebben de resultaten een aantal beleidsimplicaties. De belangrijkste implicatie volgt uit de mogelijkheid om mobiliteitsbeslissingen te voorspellen uit huishoudensgebeurtenissen. Begin van samenwonen, geboorte van het eerste kind en pensionering zijn veelal geplande gebeurtenissen en gebeuren in een bepaald stadium van de levensloop. Hoewel de timing van dergelijke gebeurtenissen kan variëren gedurende decennia, kunnen op basis van bevolkingsstatistieken nauwkeurige schattingen van deze gebeurtenissen gemaakt worden. Daarom vormen gegevens over dergelijke gebeurtenissen opgeslagen in gedetailleerde bevolkings- en fiscale registers een veelbelovend uitgangspunt voor het ontwikkelen van voorspellende modellen van de mobiliteitsbeslissingen van huishoudens. Dergelijke modellen kunnen combinaties van mobiliteitsbeslissingen beschrijven als reactie op gebeurtenissen in het leven van huishoudens, maar beschrijven ook het effect van de woon- en mobiliteitssituatie op demografische en loopbaangebeurtenissen. Vergeleken met bestaande modelsystemen voor demografische ontwikkeling, woningmarkten en mobiliteit, zou een dergelijk modelsysteem het voordeel hebben dat beslissingen tegelijkertijd worden gemodelleerd, waardoor ze elkaar wederzijds beïnvloeden en effecten van padafhankelijkheid kunnen voorspellen.

Curriculum Vitae

Abu Toasin Md Oakil was born in Rajshahi, Bangladesh, on November 22, 1980. He completed his Undergraduate and Master's degree in Urban and Regional Planning from Bangladesh University of Engineering and Technology (BUET). He won Prime Minister's Gold Medal, the national award of Bangladesh, for academic excellence at undergraduate level. He worked as a Lecturer of Urban and Regional Planning in the same institution for three years. Later he moved to UK to pursue another master's degree in Regional and Urban Planning studies at the London School of Economics and Political Science (LSE). After completion of the programme, he joined Utrecht University for his Ph.D. programme, where he worked on travel behaviour and long-term mobility decisions analyses. He has a keen interest in quantitative analysis, travel behaviour and society, and active travel and health.