Changes in travel mode use after residential relocation: a contribution to mobility biographies

Joachim Scheiner* and Christian Holz-Rau

Joachim Scheiner & Christian Holz-Rau, TU Dortmund University of Technology, Faculty of Spatial Planning, Department of Transport Planning, 44227 Dortmund, Germany

* corresponding author
phone ++49-231-755-4822, fax ++49-231-755-2269, e-mail joachim.scheiner@tu-dortmund.de

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Published paper:

Holz-Rau, Christian / Scheiner, Joachim (2012): Changes in travel mode use after residential relocation: a contribution to mobility biographies. In: Transportation 40(2), S. 431-458.

DOI: 10.1007/s11116-012-9417-6

Please reference this paper as shown above.

Abstract:

In recent years, a growing body of research has been emerging that focuses on changes in travel behaviour over an individual's life course. It has been labelled the 'mobility biographies approach' and highlights changes in travelling induced by key events and experiences in an individual's life course. In this context residential relocation plays an important role. This paper examines changes in travel mode use after residential relocations using structural equation modelling. It draws on retrospectively recorded empirical data collected in the region of Cologne. The findings show that relocations and associated changes in the built environment induce significant changes in car ownership and travel mode use and thus may be regarded as key events in an individual's mobility biography. Changes in levels of satisfaction with attributes of the built environment have a significant impact in this context as well. The causal direction of the changes fulfils expectations: suburbanisation is followed by increases in car use and decreases in public transport use, bicycle use and walking. The opposite is true for relocations into the city. In addition, changes in household structure that tend to go along with relocation have significant effects. The findings provide further evidence for the built environment having a causal impact on mode use: modal changes temporally follow changes in the built environment and thus appear to be adjustments to the new spatial setting.

keywords: residential self-selection, mobility biography, travel mode use, residential location choice, travel behaviour

1 Introduction

In recent years a growing body of research has emerged that focuses on changes in travel mode choice, travel distances, car ownership and other measures of travel demand over the life course of an individual. This is an enormous step towards an improved understanding of travel demand, as transport studies have long focused mainly on cross-sectional studies, even though time geography recognised the usefulness of the life path concept for travel studies as early as the 1970s (Hägerstrand 1975).

The emerging life course approach in transport studies has been labelled the 'mobility biographies approach' (Lanzendorf 2003; Scheiner 2003; Scheiner 2007). It is embedded in a more general perspective of life course research (Mortimer and Shanahan 2006) that includes, for instance, migration behaviour, employment transitions, or the family cycle. The mobility biograph-

ies approach highlights changes in travelling as induced by key life course events (Van der Waerden et al. 2003), such as residential relocation, changes in employment, or changes in the family or household structure. Taking a more generalised perspective, it refers to experiences relevant for an individual's travel behaviour.

The relevance of studying mobility biographies lies not only in scientific reasoning. Given that there is evidence that travel behaviour changes are an outcome of changes in circumstances that occur throughout life, then this also suggests that travel routines may be broken. Hence it may be possible to use planning schemes to actively change travel behaviour (Prillwitz et al. 2006) – provided that such schemes are able to change the relevant circumstances. Furthermore, impact assessment largely depends on cause-impact relationships. However, it is often difficult, if not impossible, to conclusively determine cause and effect using cross-sectional approaches, as some of the hypothesised causes for travel behaviour may actually be effects. The problem of causality is less acute for panel studies, as the temporal order of events belongs to the widely acknowledged criteria for causality – the cause precedes the effect. For instance, if travel mode choice changes after residential relocation, this suggests that the location change is the cause and the change in travel mode is the effect (Handy et al. 2005).

This paper examines precisely this interrelation, drawing on retrospectively recorded empirical data collected in the region of Cologne. The findings are based on structural equation modelling (SEM), a technique designed to address complex interrelations between a large number of variables.

The paper is structured as follows. In the next section the research background is described, beginning with a brief overview of the general approach of mobility biographies, followed by a review of studies on the interrelation between travel mode choice and residential relocation. Subsequently, the data and the methodology of analysis are introduced, followed by a presentation of the results. The paper finishes with some conclusions and comments on future research.

2 Research background

2.1 Mobility biographies: a process-oriented approach to travel demand

Biographical (or life course) approaches first emerged in sociology and psychology in the 1960s (Elder 1994), spanning research areas as diverse as education, employment, the family cycle, social networks, personality traits, health, and crime (see contributions in Mortimer and Shanahan 2006). In the field of spatial mobility, biographical approaches have been used in studies on residential relocation and migration (Pryor 1979; Stovel and Bolan 2004). In such studies, relocation is examined on the basis of family changes and fertility (Kulu 2008), or employment transitions (Clark and Withers 1999).

In the transport field, the interdependencies between short-term travel decisions and mid to long-term biographical processes have been largely ignored for a long time. Knowledge about the development of travel behaviour throughout individual life courses is therefore at best fragmentary. The term 'biographical processes' is used to refer to events and experiences in the individual biography that are correlated with specific forms of travelling.

An early study on the dynamics of travel behaviour distinguished between three levels of dynamics (Clarke et al. 1982; see also other early references in this paper): first, short-term micro-dynamics, capturing people’s 24 h daily activity/travel choices (see for an overview on day-to-day variability of travel Pendyala 2003); second, macrodynamic modifiers, addressing behavioural responses to transitions and trigger events over a period of some years; third, macrodynamic processes over a lifespan which are related to aging, life-cycle stages and cohort membership. It seems clear that the importance of taking a life-course perspective for the study of travel was recognised decades ago.

Most recently, the importance of using a biographical approach to study travel behaviour has been emphasised and labelled as the 'mobility biography approach' (Lanzendorf 2003; Scheiner 2003; Axhausen et al. 2006; Scheiner 2007; for an application to tourism and long-distance travel see also Frändberg 2008).

One reason for the small number of studies is the lack of panel or retrospective data on the individual level, although since the late 1980s substantial efforts have been made to collect such

data, e.g. the Puget Sound Transportation Panel used by Krizek (2003), the Dutch Mobility Panel (see Kitamura 1989 and other papers in this special issue of Transportation) or the German Mobility Panel used by Ottmann (2007). Long-term retrospective data have been used by Pooley et al. (2005) and Axhausen et al. (2006). The relative scarcity of data should not come as a surprise, as the collection of such data involves high costs in terms of money, time and effort (Axhausen 2008).

With respect to recent studies in this context, it is necessary to distinguish between at least two lines of research. Both draw on the idea that daily human action is usually based on the 'principle of least effort' that manifests itself in the development of habits serving as 'recipes' (Esser 1993) or 'scripts' (Gärling and Axhausen 2003) for behaviour. Only if structural changes or learning processes make a recipe appear unsatisfactory, would individuals re-evaluate their behaviour and, perhaps, search for alternatives.

The first line of research studies behavioural changes triggered by temporary interventions which aim either to break habits and make choices more deliberate, or to change actual behaviour, or both. Studies are typically either based on awareness raising concepts, e.g. by making participants reflect their travel schedules or by providing information on alternatives to the car (Garvill et al. 2003; Kenyon and Lyons 2003), or on the provision of free public transport (PT) tickets to drivers (Fujii and Kitamura 2003), or both (Bamberg et al. 2003). However, one notable study examined a somewhat different form of intervention: the temporary closure of a major road in Japan. Fujii et al. (2001) found that this event raised awareness for alternatives to the car. In a follow-up survey Fujii and Gärling (2003) found that those who changed from driving to PT during the road closure continued one year later to use PT more frequently than those who did not swap.

Studying behavioural changes is key to effective travel demand management as it may help clarify the triggers that make individuals re-evaluate their habits and possibly change their behaviour. In addition, such studies can help identify the population groups that are most resistant to change in order to effectively target others who are less resistant.

Structural interventions may well trigger behavioural changes and thus act as key events. The focus of the mobility biography approach, however, is not so much on the effects of policy measures or other incentives on travel, but on those of life course related processes and events.

The second line of research focuses on such key events (Van der Waerden et al. 2003; Lanzendorf 2003; Klöckner 2004; Harms 2007), highlighting the notion of temporally fixed life course transitions that trigger behavioural changes. Scheiner (2003) also focuses on the role of one such key event – i.e. residential relocation – but in his theoretical reasoning tends towards a 'softer' understanding of the temporal course of behavioural changes and speaks of 'biographical processes' or 'experiences'. Axhausen et al. (2006) use a similar approach with a clear focus on the spatial structure of social networks.

A clear distinction has to be made here between the availability of transport means and travel behaviour. Both these elements taken together are labelled 'travel demand' in this paper. The decision to purchase a certain means of transport may be regarded as a relatively stable pre-decision about its actual use, even though there are delays between purchase and use (Simma and Axhausen 2001). The availability of a transport mode is therefore essential for the development and stabilisation of routines in travel mode choice. The car is particularly relevant here: its high purchase costs make it a long-term investment where net benefit increases with frequency of use.

Some commentators treat gaining a driving license or the purchase or disposal of a car as key events that may affect mobility biographies. However, these key events should be regarded as parts of the mobility biography rather than as determinants, because they imply pre-decisions that can be interpreted as a form of 'self-commitment' with respect to travel mode choice (Simma and Axhausen 2001).

The other biographical events that have been identified as transport relevant (Lanzendorf 2003; Van der Waerden et al. 2003; Scheiner 2007) can be categorised into three life domains:

- household and family biography: leaving the parental home, formation of a household with a partner/founding a family, birth of children, divorce, children moving out (Goodwin 1989; Zwerts et al. 2007)

- employment biography: commencement of job training or university entry, entry into the labour market (Harms 2007), change of job or education, income changes (Dargay 2001; Dargay and Hanly 2007), retirement (Ottmann 2007)
- residential biography: residential move (see next section).

In addition to such key events, at least two other biographical processes may be considered. Firstly, there is ongoing debate in transport psychology and sociology about the effect of socialisation in childhood and adolescence on adult travel behaviour (Baslington 2007; Klöpper and Weber 2007). Travel behaviour may be partially shaped by learning processes through which behaviour is transferred from parents, school or other key institutions to children: this behaviour may then be continued in later life. Haustein et al. (2009) recently established some empirical evidence for this.

Secondly, the processes of learning and ageing may not always be induced by temporally fixed key events, but also by experience gathered over a longer period. For instance, in gerontology a distinction is made between the 'young old' and the 'old old' (Rosenbloom and Ståhl 2002), but becoming an 'old old' does not necessarily involve a distinct biographical key event (although it may be induced by a key event, such as an accident or the decease of the partner).

The rather complex circumstances that are often associated with household and family biography warrant further discussion. In transport studies, the household context has long been recognised as having an important influence on an individual's travel. However, reducing the family element of the biographical context of travel behaviour to the household makes the focus too narrow (Borell 2003). Increasing divorce rates mean that more and more children live as 'commuters' between their separated parents. Such children may well regard individuals from four households as members of their families (i.e. father, mother, the partners of both, and the two partners' children who also commute from/to their own mother and father), implying complex patterns of travelling in children's and parents' biographies.

Last, but not least, it has to be emphasised that the life domains noted above and, thus, key events and experiences must not be considered in isolation. For instance, residential relocations often correspond with events in employment and household biographies, such as household formation, children's births or workplace change (Dieleman and Mulder 2002). When examining the effects of changes in residential location on car purchase it is therefore necessary to closely consider related changes in the household context.

While controlling for household changes, the focus of this paper is on the significance of residential relocation as a biographical key event for travel mode changes. Most studies to date focus on a certain key event as a trigger for travel behaviour changes, rather than tracing individuals over long periods. In doing so, they lay out important pieces of ‘middle ground’ between cross-sectional approaches and a long-term biographical perspective.

The issue under investigation here has been highlighted in a number of studies in recent years. The following section gives an overview.

2.2 Residential relocation and travel mode choice

In recent years changes in travel behaviour resulting from residential relocation have become a focus of transport studies. Generally speaking, the travel consequences of a residential move lie in changes in access to opportunities due to the change of location. Such opportunities include activity places, such as the workplace, retail and leisure facilities, or relatives' places of residence, as well as travel opportunities (particularly PT) (Van der Waerden et al. 2003). These considerations suggest that there are two features of relocation type that are important for the examination of interrelations between housing relocation and travel.

Firstly, the combined spatial differentiation of migration origin and destination is of great importance, as a change in accessibility is as much influenced by neighbourhood/location attributes at the former place of residence as by those of the new place (Krizek 2000). For instance, there is no reason to assume that moving into an inner city neighbourhood leads to increased PT use, as long as the former place of residence was a neighbourhood of the same type.

Secondly, migration distance has to be considered, as it indicates the extent to which existing activity places can be maintained after the move. Long-distance migration might lead to more

long-distance travel to visit relatives (Axhausen et al. 2006; Frändberg 2008), whereas the former workplace is not likely to be maintained (in most cases a workplace change may arguably have triggered the long-distance migration).

Destination choice, activity spaces and related travel distances after residential moves have been examined in a number of studies (Holz-Rau 2000; Scheiner 2005b) that focus on spatial ties to the former place of residence after the move. This research shall not be reviewed in more detail here, as this paper is concerned with travel mode use. However, it should be noted that such spatial ties and associated changes in travel distances may have an impact on travel mode choice. Changing activity patterns after relocation may also affect mode choice.

Several studies have found that car availability and travel mode use change after residential moves. These findings are of importance for spatial planning, as they contribute to doubts about whether spatial differences in travel demand, as observed in cross-sectional analyses, may be interpreted as being caused by the spatial context. They may rather be an outcome of individuals selecting themselves into locations that match their individual location preferences and their available (or preferred) means of transport. There is now substantial evidence for such residential self-selection effects (see the recent special issue of Transport Reviews, Vol. 29(3)).

Bagley and Mokhtarian (2002) find that spatial effects are at most of limited importance for travel mode choice when lifestyle and attitudes towards transport modes and accessibility are controlled for. The results of Kitamura et al. (1997) and Handy et al. (2005) tend to concur, as does the study conducted by Cao et al. (2007a) on car ownership. According to these studies, the effects of attitudes and/or sociodemographics on travel mode choice and car ownership dominate over and above the effects of urban form.

Scheiner (2005a) finds in a German context that the number of cars per adult in suburbanising households *before* their move is distinctly higher than that of their neighbours who stay in the city ('stayers'), suggesting that households select themselves into certain neighbourhood types according to their car availability (similarly Bauer et al. 2005). Demographic differences between the groups are controlled for.

However, if spatial differences in travel demand were caused exclusively by such self-selection effects, one would not expect travel demand to change after residential relocation as such changes suggest adaption to the built environment while the self-selection hypothesis suggests that travel demand is rather an effect of preferences. Results available suggest, however, that transport mode habits may indeed be broken after relocations.

For instance, Handy et al. (2005) find that there are significant changes in travel mode choice as well as in travel distances by car after residential moves, even when location attitudes and travel mode attitudes are controlled for. They interpret this as evidence that the spatial context has a causal impact. This is confirmed for mode use in a study similar to the one reported in this paper (Cao et al. 2007b), while conclusions in a related study on changes in car ownership are more cautious (Cao et al. 2007a). Aditjandra et al. (2009) most recently report results from a similar study in England in which they found changes in mode use after relocation, particularly for walking and PT use, while changes in driving are less significant. Krizek (2003) confirms behavioural changes after relocations with regard to travel distances, while changes in mode use are smaller (a result that suggests self-selection effects).

Scheiner (2005a) finds that, in addition to the self-selection effects discussed above, the number of cars per adult in households increases after moves from the central city to the urban fringe and decreases whenever the relocation is in the opposite direction. In terms of travel mode to work this is confirmed by Dargay and Hanly (2007). In any case, leaving the city tends to narrow the margins for travel mode choice. Income elasticity of car travel is therefore lower in rural areas than in the city (Dargay 2002), because the decision in favour of a location far from a high-quality PT system more or less rules out reacting to changes in income or prices.

Stanbridge et al. (2004), in an interesting qualitative study, find that travel mode options are reconsidered to a considerable degree after residential moves, even if this does not result in actual changes in behaviour. They conclude that habits may be broken in a new context situation even if there is no behavioural change.

To sum up, the findings to date on residential self-selection and modal changes after relocation are mixed and – particularly for European contexts – rather limited. The following empirical study aims to shed additional light on the issue. Particularly, we aim to answer the following questions:

(1) Does the use of four different travel modes (car, PT, bicycle, walking) significantly change after residential relocation, and are these changes systematically associated with the direction of relocation?

(2) Does the number of cars in a household significantly change after relocations, and is this change systematically associated with the direction of relocation?

(3) Which impact do household composition and associated changes have on relocation as well as on car ownership and travel mode use?

(4) Do satisfaction levels with certain facilities in the neighbourhood play a significant role beyond the objective built environment in this context?

3 Methodology

3.1 Data used

The data used in this paper were collected in a standardised, cross-sectional door-to-door household survey with some retrospective elements. The survey was undertaken in 2002 and 2003 within the framework of the project StadtLeben (see www.vpl.tu-dortmund.de), and the area covered included ten study areas in the region of Cologne. 2,691 inhabitants took part in extensive face-to-face interviews about their travel behaviour, housing mobility, life situation, lifestyle, location preferences and residential satisfaction. The response rate was 27 percent of those asked. This appears to be a reasonable rate, given the high respondent burden (the average interview duration was 58 min; see Axhausen 2008 for an overview on response rates in mobility biography surveys).

Due to reasons of project flow some of the relevant variables were recorded using different questionnaires in some of the study areas. The analysis is therefore based on seven study areas only, all of which were surveyed in 2003. Excluding non-movers for whom no change information is available, the resulting net sample size is n=791. The working samples are half the size because the sample was split for validation (see below).

	Study areas*	Total sample (n=2,691)	Sample used (n=791)
Age 16 to 17 (%)	2.3	2.2	2.4
Age 18 to 39 (%)	39.5	34.3	50.5
Age 40 to 64 (%)	40.7	44.5	39.7
Age 65+ (%)	17.5	19.1	7.4
Female (%)	51.3	51.5	52.4
Foreigners (%)	15.7	4.8	4.3
Unemployed per inhabitant aged 16 years or older (%)	6.1	3.6	3.3

Table 1: Comparison between population in the study areas and sample

* All figures based on Cologne neighbourhoods (Stadtviertel) plus the municipalities of Kerpen and Overath
Source: Stadt Köln (2004), IT.NRW, StadtLeben data.

Assessing the representativeness of the sample is difficult due to the lack of small-scale socio-economic population data. In terms of age groups the sample well represents the population aged 16 and older in the neighbourhoods, with a certain bias towards the higher age groups (Table 1). In social terms, foreigners and unemployed are underproportionally represented, although the latter may be due to false responses. Underrepresentation of lower income groups is thus also likely, but this cannot be clearly determined, as micro-spatial figures of income distributions for

the areas are not available. In the partial sample we use in this paper, younger adults are overrepresented. This is clearly an effect of excluding non-movers. It is not possible to determine whether or not our sample is representative for movers. However, as we aim to find interrelations between travel mode use and other variables, rather than giving descriptive figures on travel mode use per se, we do not expect these structural differences between population and sample to substantially affect our results (Babbie 2003).

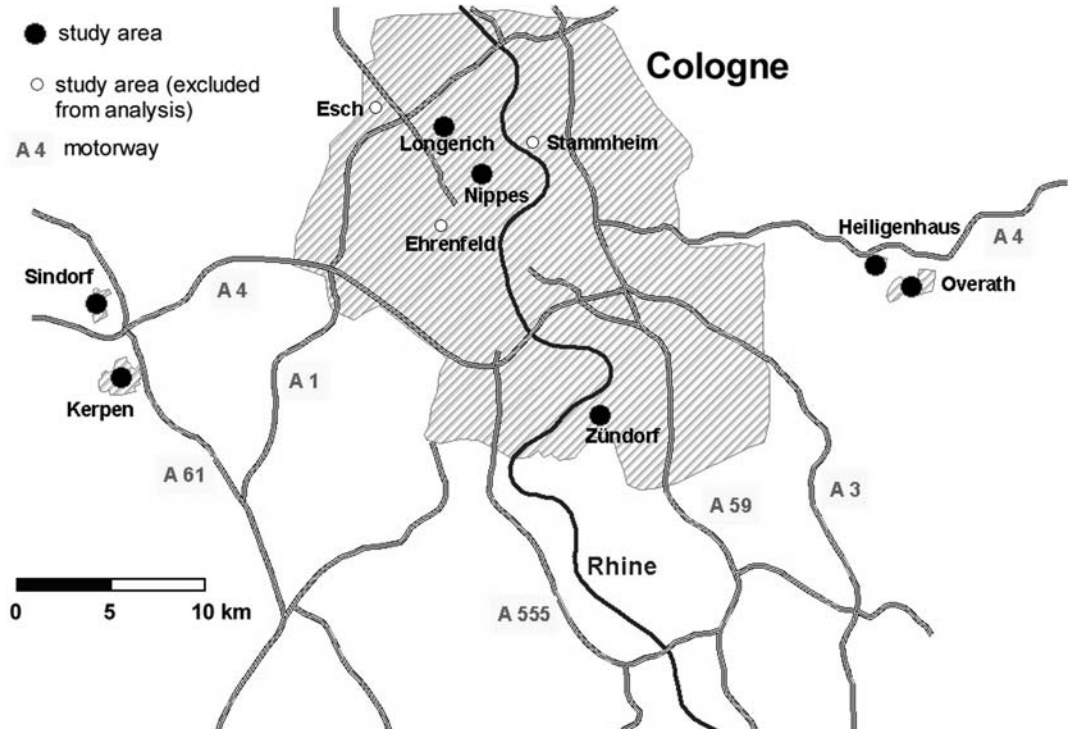

Fig. 1: Location of the study areas in the region of Cologne

Source: Authors' concept of project group StadtLeben

The five types of area are each represented by two study areas (Fig. 1): high density inner-city quarters of the nineteenth century ('Wilhelminian style': Ehrenfeld, Nippes); medium density neighbourhoods dating from the 1960s ('modern functionalism') with flats in three- or four-story row houses (Stammheim, Longerich); former villages located at the periphery of Cologne which since the 1950s have experienced ongoing expansion with single-family row houses or (semi-) detached single occupancy houses (Esch, Zündorf); small town centres in the suburban periphery of Cologne (Kerpen-Stadt, Overath-Stadt); and suburban neighbourhoods with detached single occupancy houses (Kerpen-Sindorf, Overath-Heiligenhaus). The four suburban neighbourhoods are all about 30 km away from Cologne.

As the two areas representing each type obviously differ, the areas are very varied with regard to location, transport infrastructure, central place facilities and sociodemographic structure (Table 2). Nonetheless it should be noted that spatially or socially 'extreme' areas were not purposely targeted. The overall aim was to find environments that may be typical also of other urban areas in Germany, rather than artificially overplaying physical or social differences between the areas.

It is important to note that the survey was designed to be cross-sectional with some retrospective elements. The latter elements are those used here and they are presented in the following section. Respondents who reported moving at least once since 1989 (i.e. within the 14 years prior to the survey) were asked for relocation patterns, changes in their household and changes in travel. Lifestyles and location preferences may have changed as well but there is no retrospective information available in this regard.

Despite these shortcomings, the data used is unique in Germany in so far as it allows connections to be drawn within a large variety of information on the individual level. To the best of our knowledge, the only similar data set in existence was collected in Northern California. This

survey also included location preference questions, and it also used retrospective questions, depending on recall. Preferences were only collected for the time of the survey (Cao et al. 2007b). As far as we are aware, there are to date no panel surveys in transport that include attitudinal questions for more than one point in time.

The present study contributes to existing research in three ways. First, it extends the theoretical framework of related studies to a broader biographical perspective. Second, it draws upon data collected in Europe, i.e. in a context for which there are few related studies, and that is very different from the U.S. in terms of transport as well as in terms of residential location behaviour. Third, it includes attitudes in terms of satisfaction levels with neighbourhood attributes.

	Nip-pes	Longe-rich	Zün-dorf	Kerpen Stadt	Sin-dorf	Overath Stadt	Heiligen haus	All areas
Travel time to Cologne centre (Neumarkt) by car [min]	8	15	21	24	27	25	25	21
Travel time to Cologne centre (Neumarkt) by PT [min]	10	22	36	51	33	42	49	35
Population density [1,000 inh/km²]	14.1	5.0	4.0	6.1	9.3	2.0	2.0	6.1
Distance to nearest supermarket [m]	184	425	389	424	435	444	2290	658
Groceries within 650 m straight line distance from residence [number]	74	11	10	21	17	15	5	22
Distance to nearest PT stop (rail) [m]	284	250	658	3,801	944	570	2,846	1,341
Mean household size [persons]	1.7	2.1	2.3	2.5	2.4	2.9	3.0	2,4
Mean age [years]	44	52	51	47	48	49	47	48
No car in household [%]	45%	21%	11%	10%	8%	6%	5%	15%
Household income > 3,000 Euro [%]	19%	27%	46%	27%	27%	51%	39%	33%
University degree [%]	38%	22%	22%	14%	13%	25%	20%	22%

Table 2: Description of sample – comparison between study areas

All values are mean values for respondents in the respective area, except where percentages are indicated.
Source: StadtLeben data.

Variables	Measured by...
Household context (state and change)	Number of adults and number of children in the household before the last relocation (baseline value); change in the number of children and in the number of adults in the household (individuals aged 16 and older count as adults in the data)
Car ownership (state and change)	Number of cars in the household before the last relocation; change in the number of cars since then
Relocation type	Derived from the difference in urbanity between the current and the previous place of residence
Built environment changes	Change in the quality of shopping facilities and services (used for non-motorised transport (NMT) models); change in the quality of the PT system (used for car and PT models) after the relocation
Changes in location attitudes	Change in level of satisfaction with shopping facilities and services after the relocation (used for NMT models); change in level of satisfaction with PT after the relocation (used for car and PT models)
Travel mode use changes	Estimated change after the last residential move in the frequency of use of four transport modes: the private car, PT, bicycle, and walking
Duration of residence	Duration of residence in the dwelling as well as in the neighbourhood in years (used only for control analyses)

Table 3: Overview of variables used

3.2 Variables

In the survey a number of retrospective questions were asked that are relevant here. The variables used are summarised in Table 3 and explained below, as appropriate.

All change variables except for changes in travel mode use are calculated as the difference between the respective score at the time of the survey v. prior to the last relocation. Changes in travel mode use were measured on a five-point scale ranging from 'much less frequently' to 'much more frequently' by asking the question: 'Did your travel mode use change after your last move, i.e. after moving into this flat/house? Please tell me whether you use the following travel modes less frequently, just as frequently as or more frequently than before the move.' Thereupon the four travel modes were given.

This may not represent the actual changes in great detail, but on the other hand we believe that the validity of a respondent's memory is likely to be higher for a generalised estimation of change than for specific details of behavioural changes. Thus, "to maximize recall *accuracy*, we consciously sacrificed measurement *precision*", as Cao et al. (2007b, p. 540, italic in original) put it for their similar data.

This measurement method does not allow the absolute level of use of a given mode before relocation to be determined. This is not fully satisfactory as any changes in behaviour tend to depend on the base level. An individual who already drives a lot before he/she moves to suburbia is likely to increase his/her driving less than one who does not drive much while living in the city. This negative interrelation between baseline level and change level has been confirmed in earlier studies (Krizek 2003; Prillwitz et al. 2006; Cao et al. 2007a).

The relocation type is captured by an ordinal-level variable combining the current as well as the previous place of residence, which was recorded in the survey in terms of the municipality where the respondent was last resident, plus - in the case of Cologne - the neighbourhood. The values this variable takes on describe the degree of change in urbanity and the direction of the move. Positive values indicate suburbanisation, negative values represent moves towards the city. The basic idea is that the spatial scope from urban to suburban represents a continuous spectrum rather than a discrete choice. Even for relocations within Cologne, the direction of the move is addressed by the variable[1]. It takes on eight values ranging from -3 (for relocations from suburban or rural areas to Cologne-Nippes) to +4 (relocation from inner-city neighbourhoods in Cologne to a suburban residential area).

The outcome of relocation is a change in an individual's spatial context. The built environment at the current place of residence is studied here with regard to two attributes selected in accordance with the travel modes in question. For the models of car and PT use, the built environment indicator is the quality of the PT system. As NMT depends more on proximity to facilities than on PT, the quality of shopping facilities and services in the neighbourhood is used. This is measured as the number of opportunities within a straight-line distance of up to 650 m around the place of residence, subcategorised into supermarkets, other grocery shops, other shops, medical services, and other services. All values are calculated separately for all respondents. The values for the subcategories strongly correlate with each other. They are therefore standardised and summarised on a mean scale (Cronbach's α=0.98).

The PT quality indicator includes, firstly, the variety of means of PT in the residential area, based on the predominant functions of the different means of PT (micro-scale coverage of an area (bus) v. large-scale access (local train or 'S-Bahn', regional train)). This scale ranges from 1 to 5 (for more details see Scheiner and Holz-Rau 2007, p. 500), and, secondly, the distance to the nearest railway station, no matter whether tube, S-Bahn or regional train. The distance is calculated

[1] Neighbourhoods within the medieval city walls were classified as inner-city. This represents a straight-line radius of about 2 km around Cologne cathedral. Neighbourhoods within the compact purlieus of the city – as visible on a figure ground plan – were classified as 'close to the inner-city' (approximately 5 km or less from the cathedral). Other Cologne neighbourhoods were classified as belonging to the edge of the city. Neighbourhoods outside Cologne but within the region (< 50 km from Cologne cathedral) were classified as suburban. Suburban sub-centres were categorised as 'less suburban' than suburban residential neighbourhoods. The resulting variable 'relocation type' thus represents a mix of change in distance from Cologne centre and central-place functional change.

separately for all respondents using geographical coordinates, while the variety is measured on an area basis (Cronbach's α=0.93).

Satisfaction with neighbourhood facilities and accessibility was measured using the question 'I will give you some characteristics of residential areas now. Please tell me how satisfied you – personally – are with the following attributes of your *last* [emphasised] residential area, i.e. the neighbourhood where you lived before you moved here'. Subsequently, the attributes were given. Answers were recorded on a five-point Likert-type scale ranging from 'not at all satisfied' to 'very satisfied'. Thereafter, the corresponding levels were measured for the current residence.

Satisfaction levels are measured in this paper using two elements. First, satisfaction levels with shopping facilities, services and leisure facilities for adults are merged into two mean scales for the current and the previous place of residence. The reliability levels are satisfactory (Cronbach's α=0.61 and α=0.72, respectively). Secondly, satisfaction levels with local public transport for the current and the previous place of residence are measured using two single items. The changes in satisfaction are calculated as the difference between the two, respectively.

The retrospective measurement of satisfaction levels presumably raises most doubt with respect to validity. It is the only variable used here that does not represent mere facts, but rather memories of a subjective attitude in the past that can hardly be recalled with the same precision as, say, the number of cars in the household. However, analyses of changes in residential satisfaction levels yield systematic and plausible results for the data used here (Scheiner 2006) as well as for similar data collected in the region of Dresden (Bauer et al. 2005).

Thoroughly reflecting on the variables used, more change variables would be desirable. This refers particularly to socio-economic variables such as income, education level, and the employment situation, for all of which there is no information on changes available. While this is clearly less than satisfactory, previous studies show that the number of cars in a household seems to respond more strongly to the number of potential drivers than to household income (see Bhat and Guo 2006 and Cao et al. 2007b for the U.S., Dargay 2002 for the U.K.). For simplification one might assume that socio-economic conditions before the relocation could be approximated by the situation at the time of the survey, and include the respective state variables in the analysis as a baseline. However, it is not reasonable to assume *changes* in travel mode use as an outcome of a certain *state* level at a *later* point in time, e.g. a certain income level.

To conclude the methodological reasoning, it should be noted that the analyses only refer to movers, while there is no control group (non-movers were included in the sample, but there is no change information available for them). There may be reasons for changes in travel mode use since the last relocation other than the relocation itself, such as a structural motorisation effect. However, in the questionnaire explicit reference was made to the context of the move. And what is more, the structural effect referred to involves a *general* increase in car use (and decrease in PT use) particularly for those whose last move took place long ago, while this paper studies interrelations with the *direction* of the move. Even for skewed distributions – e.g. a dominance of an increase in car use over a decrease for the other direction of relocation – such interrelations would suggest a causal interrelationship with the move.

Besides changes in structural conditions, the effects of the aging process may bias the results, as the definition of movers includes a rather long period of 14 years within which the last relocation may have taken place. Control analyses have been made that were limited to respondents who moved in the relatively short period of 5 years before the survey took place. The findings from these analyses confirm the findings presented here and support the validity of our results.

3.3 Methodology of structural equation modelling

The interrelations discussed above can be studied using structural equation modelling (SEM). This method is increasingly being used in transportation studies (Golob 2003), and it has been used for dynamic modelling (Cao et al. 2007b; Roorda and Ruiz 2008). SEM can be described as a combination of factor analysis and a generalised form of regression analysis. Compared to other multivariate techniques, SEM allows the investigation of multi-stage interrelations between variables. Unlike regression analysis or discriminant analysis, SEM is not limited to the analysis of explanatory (exogenous) variables on a single dependent (endogenous) variable. It can deal with several endogenous variables with interdependent relations with each other, as well as the inclusion of intervening variables. This feature is perfectly suited to the analysis of complex multi-

stage interdependencies and makes SEM superior to more 'classical' statistical techniques for the purpose of this study.

For non-normal data, Browne (1984) developed an asymptotically distribution-free (ADF) estimation procedure that can be applied to binary or ordinal-level variables. However, according to simulation studies, the maximum likelihood approach is robust against violations of distribution assumptions, at least for large samples (Golob 2003, p. 8). For non-normal continuous variables it is regarded as superior to the ADF procedure (Schermelleh-Engel et al. 2003, p. 27). In our case, kurtosis values are smaller than two for all variables used except for the two variables describing the state and change in number of adults in the household, which both have larger kurtosis values (state variable: 6.8, change variable: 5.3). The multivariate kurtosis values range between 21.8 (PT model) and 23.2 (walking model). The deviations from normality are significant, but moderate. Removing the two variables state and change in number of adults slightly improves model fit (e.g., RMSEA=0.010 instead of 0.103 in the car use model, RMSEA=0.087 instead of 0.096 in the walking model, see Table 4), but considerably corrupts the explained variances of endogeneous variables. In addition, removing these variables is clearly unsatisfactory from a theoretical point of view (see Ory and Mokhtarian, 2009, p. 37 for a well-balanced discussion of this issue).

According to Hoogland and Boomsma (1998) the ADF procedure performs better in the estimation of standard errors as long as the average kurtosis of the observed variables exceeds three, and n>400. Concerning necessary sample sizes, Hoogland and Boomsma suggest n>5*df, as otherwise the ML Chi square statistics tends to reject the model too often. For an average kurtosis >5.0 and ML estimation, the sample size should be n>10*df, and for the ADF procedure even n>20*df is recommended.

The available sample of n=791 seems appropriate for a robust application of the ML procedure, even if the sample is split into two halves (see below). The ADF procedure then reaches the limit of reliability, but seems still to be acceptable.

Due to poor model fit values in some first attempts with cross-sectional models and the violation of distributional assumptions, a rather rigorous approach was applied. First, the sample was randomly split into two halves. Then each model was estimated in four versions:

1. ML estimation of a theoretical model (no error covariances allowed) with the main sample
2. Empirical fitting of the model to the data by setting error covariances free step by step and checking the results for stability after each step
3. ADF estimation of the theoretical model
4. ML estimation of the theoretical model with the second sample for validation.

Each of the four model versions was compared to the others with respect to the strength and sign of the effects. The results turn out to be fairly stable and therefore appear quite trustworthy. Version 2 only serves to verify the coefficients in the theoretical model version when fitted to the data, while our substantial interest lies in the theoretical models. Empiristic models that allow for a multitude of error covariances tend to contain little information. Consequently, we favour relatively rigid hypothesis testing over best model fits. That is to say, our approach is confirmatory in nature and, thus, theoretically driven. For this reason we present version 1 model estimations in this paper. Other versions are not presented due to lack of space, but can be obtained from the authors on request. The analyses were undertaken using the program AMOS 5.0 to 7.0 (Analysis of Moment Structures). All parameters were estimated simultaneously.

4 Results

There are a number of heuristic indicators with which to assess the goodness-of-fit of structural equation models. For most such indicators decision rules that have been tested in methodological studies are available. Two of these indicators, along with the corresponding decision rule, are given in Table 4 for the theoretical models (version 1, see above) shown in Figs. 2, 3, 4 and 5 as well as for the respective best model version (i.e. those that have been empirically fitted to the data, version 2). The fit values of the theoretical models fail to meet a satisfactory level, but the values of the fitted models are all satisfactory to close.

	Goodness-of-fit indicator				df	
	RMSEA		Hoelter (p=0,05)			
Model	Version 1 (Figs. 2-5)	Version 2 (best)	Version 1 (Figs. 2-5)	Version 2 (best)	Version 1 (Figs. 2-5)	Version 2 (best)
Change in car use	0.103	0.026	115	481	22	14
Change in PT use	0.099	0.038	122	386	22	15
Change in bicycle use	0.097	0.046	130	338	22	18
Change in walking	0.096	0.038	131	400	22	17

Table 4: Goodness-of-fit and degrees of freedom for the models

The table gives values for two goodness-of-fit indicators as well as the degrees of freedom (df) for the model shown in the following figures and for the empirically fitted 'best' model version.
RMSEA (Root Mean Square Error of Approximation) measures discrepancy between the model implied and the true population covariance matrix, in relation to degrees of freedom. This ratio is related to sample size. In cases of close fit, RMSEA approaches zero. Values smaller than 0.05 indicate a close fit. Values larger than 0.1 are generally regarded as unacceptable. The Hoelter statistics specifies the sample size required (critical n) to reject the model at a given significance level. The larger the value, the better the fit. Values larger than 200 can be regarded as good.
Source: Authors' analysis. Data: Project StadtLeben.

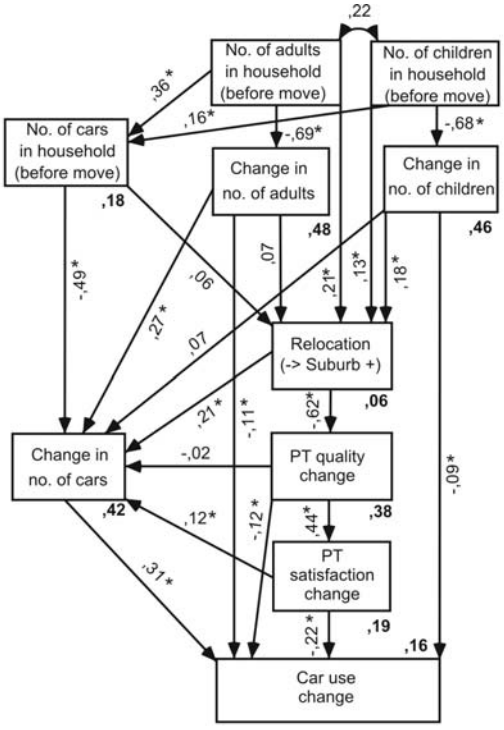

Fig. 2: Model of change in car use

Figs. 2, 3, 4 and 5 show standardised path coefficients and the proportions of explained variance of the endogenous variables (bold). Significant coefficients (p=0.05) are marked with an asterisk.
Source: Authors' analysis. Data: Project StadtLeben.

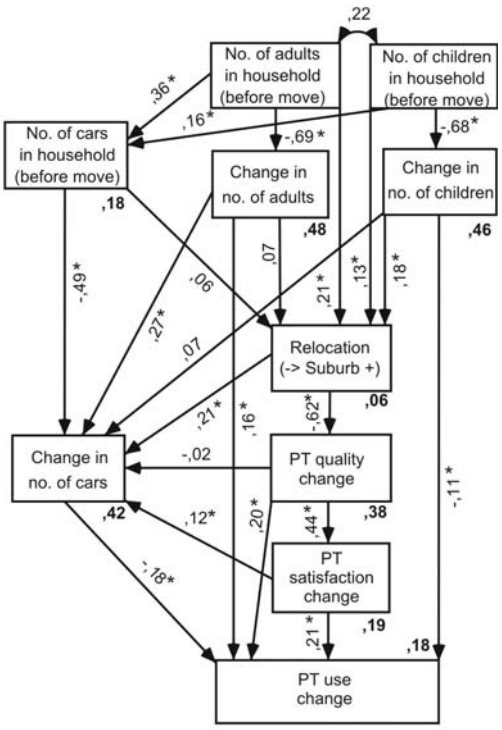

Fig. 3: Model of change in PT use

Source: Authors' analysis. Data: Project StadtLeben.

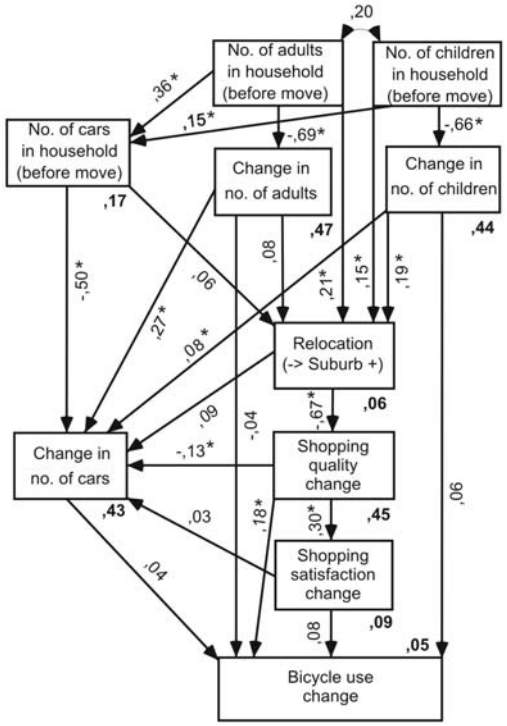

Fig. 4: Model of change in bicycle use

Source: Authors' analysis. Data: Project StadtLeben.

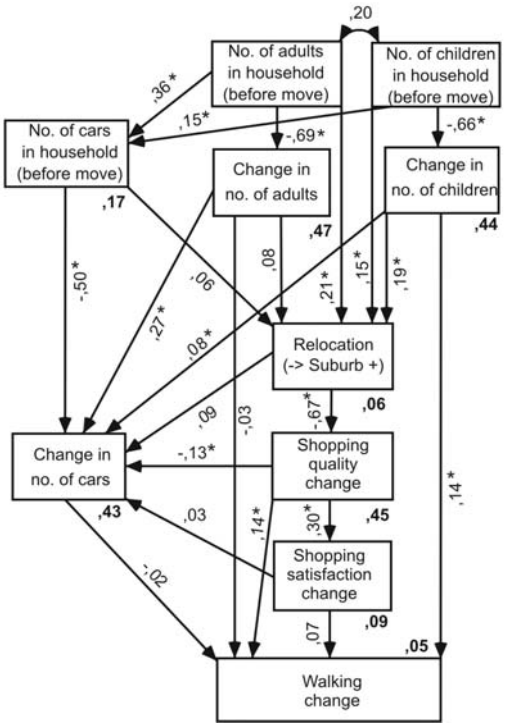

Fig. 5: Model of change in walking

Source: Authors' analysis. Data: Project StadtLeben.

Effect of... ...on:	No. of adults in household (before move)	No. of children in household (before move)	Change in no. of adults	Change in no. of children	No. of cars in house-hold (before move)	Reloc-ation type	PT quality change	PT satis-faction change	Change in no. of cars
Change in no. of adults	-0.689								
Change in no. of children		-0.675							
No. of cars in household (before move)	0.358	0.161							
Relocation type	0.180	0.022	0.071	0.179	0.060				
PT quality change	-0.111	-0.014	-0.044	-0.110	-0.037	-0.617			
PT satisfaction change	-0.049	-0.006	-0.019	-0.048	-0.016	-0.271	0.440		
Change in no. of cars	-0.325	-0.120	0.282	0.102	-0.476	0.193	0.029	0.121	
Car use change	0.002	0.029	-0.018	-0.038	-0.140	0.193	-0.206	-0.178	0.311

Table 5: Model of change in car use – total standardised effects

Source: Authors' analysis. Data: Project StadtLeben.

The variance explanation rates are in a reasonable range for individual data of travel behaviour, particularly taking into account the rather simplified measurement method for life situation that does not account for socio-economic variables. In the models for car and PT use, variance explanation exceeds that in the NMT models. This might be due to real or perceived frequencies of NMT use that may include mode shifts between trip purposes rather than changes in total ('here in the suburbs I do not walk to the shops any more, but on the other hand I go for a stroll more often').

Effect of... ...on:	No. of adults in household (before move)	No. of children in household (before move)	Change in no. of adults	Change in no. of children	No. of cars in household (before move)	Relocation type	PT quality change	PT satisfaction change	Change in no. of cars
Change in no. of adults	-0.689								
Change in no. of children		-0.675							
No. of cars in household (before move)	0.358	0.161							
Relocation type	0.180	0.022	0.071	0.179	0.060				
PT quality change	-0.111	-0.014	-0.044	-0.110	-0.037	-0.617			
PT satisfaction change	-0.049	-0.006	-0.019	-0.048	-0.016	-0.271	0.440		
Change in no. of cars	-0.325	-0.120	0.282	0.102	-0.476	0.193	0.029	0.121	
PT use change	-0.082	0.089	0.093	-0.157	0.076	-0.219	0.292	0.192	-0.183

Table 6: Model of change in PT use – total standardised effects

Source: Authors' analysis. Data: Project StadtLeben.

Effect of... ...on:	No. of adults in household (before move)	No. of children in household (before move)	Change in no. of adults	Change in no. of children	No. of cars in household (before move)	Relocation type	Shopping quality change	Shopping satisfaction change	Change in no. of cars
Change in no. of adults	-0.686								
Change in no. of children		-0.661							
No. of cars in household (before move)	0.356	0.153							
Relocation type	0.178	0.031	0.084	0.190	0.061				
Shopping quality change	-0.120	-0.021	-0.057	-0.128	-0.041	-0.674			
Shopping satisfaction change	-0.037	-0.006	-0.017	-0.039	-0.012	-0.205	0.304		
Change in no. of cars	-0.331	-0.125	0.282	0.114	-0.491	0.172	-0.123	0.033	
Bicycle use change	-0.013	-0.048	-0.036	0.037	-0.029	-0.129	0.198	0.083	0.042

Table 7: Model of change in bicycle use – total standardised effects

Source: Authors' analysis. Data: Project StadtLeben.

The strongest connections can be seen between the state variables and their respective change variables. These are negative in any case. Having a large number of cars in the household reduces the likelihood of purchasing further cars, and having a low number of cars reduces the likelihood of car disposal. Analogously, if the number of adults or children in the household is relatively large before relocation, the likelihood of a further increase is low. It has to be noted that the variation essentially ranges between one and two.

There is a very close interrelation between the built environment and the satisfaction level associated with it. Suburbanisation is accompanied by considerable reductions in PT and shopping quality, and this in turn leads to markedly decreasing satisfaction levels. For moves from suburbia to the city the contrary is found.

Effect of... ...on:	No. of adults in household (before move)	No. of children in household (before move)	Change in no. of adults	Change in no. of children	No. of cars in house-hold (before move)	Reloc-ation type	Shopp-ing quality change	Shopp-ing satisfact ion change	Change in no. of cars
Change in no. of adults	-0.686								
Change in no. of children		-0.661							
No. of cars in household (before move)	0.356	0.153							
Relocation type	0.178	0.031	0.084	0.190	0.061				
Shopping quality change	-0.120	-0.021	-0.057	-0.128	-0.041	-0.674			
Shopping satisfaction change	-0.037	-0.006	-0.017	-0.039	-0.012	-0.205	0.304		
Change in no. of cars	-0.331	-0.125	0.282	0.114	-0.491	0.172	-0.123	0.033	
Walking change	0.007	-0.091	-0.042	0.113	0.005	-0.112	0.163	0.069	-0.024

Table 8: Model of change in walking – total standardised effects

Source: Authors' analysis. Data: Project StadtLeben.

Concerning the determinants of relocation it is worth noting that an increase in household size tends to be associated with suburbanisation. This applies more to household growth by children than by adults, confirming the classical cliché of family suburbanisation. However, having adults join the household tends to induce suburbanisation as well, albeit not significantly. In most cases this is likely to reflect people living as singles in an urban environment and moving to the urban fringe as a couple or a family. However, there may also be cases in which children became adults in the time between the relocation and the survey.

Having a relatively large number of cars in the household may also contribute to suburbanisation, although the effects are not significant. Car ownership was shown to be a significant determinant of location choice by Scheiner (2005a) on the basis of the same data set. At the same time, suburbanisation leads to a further increase in the number of cars in the household. This mutual interrelation between car ownership and suburbanisation is also found, albeit the other way round, for moves into the city (see Scheiner 2005a).

The impact of relocations on change in number of cars differs according to the indicator used to describe changes in the built environment. When changes are measured by the PT quality indicator, the effect on car ownership is particularly evident with respect to the relocation variable itself, less so with respect to the spatial effect of the relocation. Hence, it seems to be the relocation that results in car ownership changes rather than the associated change in PT quality[2]. This may be attributed to spatial changes anticipated before the relocation. When households suburbanise they may anticipate the need for an additional car no matter whether PT quality actually declines with the move or not.

An unexpected association is found between changes in satisfaction levels and change in car ownership. The stronger the increase in satisfaction with PT, the *stronger* the increase in the number of cars. This implausible interrelation moderates and attenuates the strong effect relocation has on car ownership, but does not outweigh it. The effect is not found in the models that use shopping and service facilities instead of the PT system to describe the built environment and the satisfaction level associated with it (Figs. 4 and 5). This is because the effect of relocation is weaker in these models. At this point, it becomes particularly evident that the coefficients are estimated simultaneously and are thus interdependent. They should therefore only be interpreted in their joint context and with respect to the total effects given in Tables 5, 6, 7 and 8, the total

[2] Unsurprisingly, the change in PT quality turns out significant when the relocation variable is removed from the model. Anyway, this does not render the above interpretation inconsistent, as excluding the relocation variable means that PT quality change would be likely to capture some effect of spatial context change (i.e. of relocation).

effect a variable has on another variable being the sum of direct and indirect effects (in the case discussed here it makes no difference as the total effect satisfaction change has on car ownership change equals the direct effect).

In the models that include shopping and service facilities, the change in built environment that results from relocation has a stronger effect on car ownership than the relocation itself. Changes in satisfaction level have hardly any effect. Neither of these observations is surprising. If satisfaction level impacted on car ownership it would imply that cars were purchased as an effect of dissatisfaction with shopping facilities, or that cars were sold as an effect of high levels of satisfaction with shopping facilities. Decisions on car purchasing are, however, more related to job trips and longer trips and therefore to the PT system than to the comparatively short shopping trips. This raises the question as to why the *objective* quality of shopping facilities in the neighbourhood has an impact on car ownership. The likely reason is that the quality of shopping facilities works as a general indicator of urbanity, and this general level of urbanity in the neighbourhood affects car ownership decisions.

Besides being associated with the built environment and related satisfaction levels, changes in car ownership are closely connected with changes in household structure. Both the birth of children and an increase in the number of adults – whether induced by household formation by couples, or by children growing up – are associated with an increase in the number of cars. It appears plausible that the effect of an additional adult outweighs the effect of an additional child. Nonetheless, the need for a car after family foundation has also been proven in the literature (Zwerts et al. 2007). This may be connected to an increased need for goods transport and coordination, and the tight time budget of parents.

As far as travel mode use is concerned, the direct effect of relocation on mode use has been excluded from the modelling. We assume that it is not the act of relocating itself but associated changes in the spatial environment that affect mode use (as opposed to car ownership, which may be affected in advance due to anticipation of changes in the environment; see above). The results do indeed indicate a significant impact. The directions of changes confirm expectations. Suburbanisation leads to an increase in car use at the expense of PT, the bicycle, and walking; and vice versa. The changes are stronger for the car and PT than for bicycling and walking. This finding strongly supports the notion of the built environment having a causal impact. If residential self-selection of the population according to their travel attitudes were the only driver of travel mode use, no changes following relocation would be expected.

Besides relocation effects, travel mode use is affected by changes in the household. The birth of a child is associated with less PT use and more walking. It is interesting that the direct effect of childbearing on car use is negative as well. However, this negative effect is almost completely offset by indirect effects mediated by car ownership and relocation (Table 5). According to this, having a child *as such* tends to be associated with less, rather than more, driving. This is partly superimposed by increases in car ownership and/or suburbanisation, both being associated with childbearing and positively affecting car use.

When interpreting these results, additional gender-related findings should be addressed. An increase in walking following the birth of a child is observed only for women (separate model estimations for men and women not documented here; sample sizes are n=414 for women, n=377 for men without splitting the sample). Hence, the increase in walking as well as the slight decrease in car use following childbearing are likely to be effects of an increase in neighbourhood-oriented trips by women with babies or infants, e.g. strolls with babies, walks to the playground, or escort trips to the nursery school.

An increase in the number of adult household members also has a positive impact on PT use. This is attenuated, although not outweighed by increasing car ownership. The PT increase is likely to be an effect of there being more shared cars among couples than singles. At the same time, the direct effect of an increasing number of adults on car use is negative as well, but this is completely outweighed by car ownership increases.

The car turns out to be a powerful moderator between life situation and mode use. As expected, the increase in car ownership leads to a steep increase in car use and a steep reduction in PT use. Hence, the car is a strong pre-decision on travel mode use. At least this is true for medium to long-distance trips: car ownership increases have virtually no effect on non-motorised trips. This

may be due to respondents' false estimations of changes in their non-motorised trips following car purchase. The data used here support findings in a U.S. study suggesting that after-relocation increases in walking are often remembered overproportionally, regardless of the type of relocation (Handy et al. 2005). However, another plausible interpretation is that while car owners may hardly use PT, they are perfectly prepared to walk or bike, as long as the destination is close enough (Scheiner 2009).

5 Outlook

In this paper, changes in travel mode use after residential relocations have been examined using structural equation modelling. The findings show, firstly, that sociodemographic changes in the household that tend to go along with relocation can be seen to have significant effects on travel mode use. Secondly, changes in the built environment associated with relocations also induce considerable changes in travel mode use and thus may be regarded as key events in an individual's mobility biography. This finding provides further evidence for the built environment having a causal impact on mode use, as modal changes temporally follow changes in the built environment and thus appear to be adjustments to the new spatial setting. This suggests that travel mode use is sensitive to the physical context in which people live and is thus not only a result of residential self-selection. However, whether and to what extent the changes found are partially affected by residential self-selection over and above the effects of built environment changes cannot be exactly determined here. Cross-sectional analyses of the same data set indicate self-selection effects, as they reveal travel and accessibility preferences as having significant effects (Scheiner and Holz-Rau 2007).

In terms of relevance to transport policy, adaptions of travel mode use to the built environment encourage the view that land-use does indeed seem to have a significant and strong impact on travel behaviour. According to our results, changes in the built environment range among the strongest impact factors for travel mode use changes. This not only has consequences for physical urban planning, but also reveals the advisability of providing information for location-seeking households on the consequences of certain residential location decisions for their travel and associated costs. Put into the wider context of mobility biographies, life course research on travel behaviour can contribute to the further identification of the effects of changes in life circumstances on travel, and can help to distinguish between changes that may be affected by planning and those that may not.

However, this paper has certain limitations and leaves a number of open questions that may be the subject of future research.

First, there is the temporal perspective of the adjustment in travel behaviour following on changes in external circumstances. The findings of Dargay (2001) suggest considerable delay in the adjustment of car ownership after income changes. Similar delays may exist with respect to behavioural changes after relocation. This raises the question as to which point in time is best for ex-post surveys for evaluation.

Second, a growing number of studies focus on the effects of residential self-selection on mode choice and, more generally, travel behaviour. This often involves including attitudes and preferences towards travel, accessibility, and the built environment over and above objective measures of the built environment as determinants of travelling. To the best of our knowledge, however, there are to date no panel data available in the transport field that include changes in preferences that may accompany changes in residential location. Cao et al. (2007b) address this problem in a study similar to that reported here by approximating travel preferences before relocation by travel preferences at the time of the survey (i.e. after the relocation). Although this may be one way of coping with the existing lack of data, it does not answer the question as to what came first after the relocation: the 'new' built environment or the (possibly) new preferences. Even if travel preferences did indeed shape travel behaviour to a considerable degree, this would not necessarily be evidence for self-selection, in case the preferences themselves were changed after relocation in order to adapt to the new spatial setting.

Third, although the data used here contain a large variety of individual information, they have some notable shortcomings in that they do not include information on changes in income, employment status, or lifestyle that may be associated with the relocation.

Last but not least, it should be kept in mind that the changes in travel mode use are represented in these data only on a rather generalised level. This suggests that conclusions should not be drawn too quickly, as the self-reported changes may overestimate the real changes. Further, the possibilities of changes in activity spaces or in activity patterns after relocations have not been addressed in this paper. Activity-based approaches may more accurately capture such interrelations (Waddell 2001). There is clearly a need for further research in this field as well as in the fairly new and wider field of mobility biographies. For other biographical processes such as changes in the household and family structure or changes in the employment process this is even more the case than for residential location changes.

Acknowledgements: The research in this paper was funded by the German Research Foundation (DFG) as part of the project 'Wohnstandortwahl, Raum und Verkehr im Kontext von Lebensstil und Lebenslage' (Choice of residential location, built environment and transport in the context of lifestyle and life situation, 2006-2008), and by the German Federal Ministry of Education and Research (BMBF) as part of the project 'Integrated residential location information as a contribution to reduce land consumption'. The authors also wish to thank four anonymous reviewers for their constructive and encouraging comments.

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