Methodologies for Urban Transport Studies

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1. Introduction: The Role of Transport in Urban Research

Transport has been an integral precondition and outcome of urban development from the ancient city to modern times. Efficient transport systems are an important success factor for societal development; at the same time, transport causes various negative side effects such as greenhouse gas emissions, air pollution, noise or space consumption. Being mobile is an inherent human need; people want to move; they want to be outside and to participate in social life. The current pandemic situation impressively illustrates this aspect. Even in lockdown periods, the share of persons leaving home at least once a day hardly dropped, whereas substantial changes in travel behaviour occurred in all other dimensions such as the number of trips, mode choice, etc. (Hubrich/Weber/Wittwer/Gerike 2020; Molloy et al. 2021).

The task of (urban) transport planning is to provide access for persons and goods to reach the relevant destinations while at the same time minimising negative side effects of transport demand. Transport research supports this task by investigating transport patterns and their determinants for persons and goods leading to various relevant research streams in urban transport studies:

- Travel behaviour: Profound knowledge on travel behaviour and its determinants is key for successfully modelling and shaping future transport systems. Travel behaviour is mainly analysed based on survey data, including quantitative and qualitative approaches as well as innovative emerging data sources.
- Freight traffic and logistics: These parts of the transport systems are mostly analysed based on quantitative measures of freight flows, firm interactions and logistics chains.
- Transport supply: This is largely analysed based on infrastructure data from Geographic Information Systems (GIS) as well as on data from operators of public transport and further mobility services such as departure frequencies or times. Further relevant data sources include provider data such as the current location of available shared vehicles and transport network mapping.

- Aggregate transport demand: Transport demand *generated* in an area would typically be estimated by travel behaviour surveys. This needs to be distinguished from transport demand *occurring* in an area or on a road link (which may be generated elsewhere), which can be estimated by traffic counts on roads or in public transport. Traffic counts can help validate the results of travel behaviour surveys or parameterise transport simulation models, but also have a strong value on their own.
- Transport simulation modelling: Transport studies have a strong practical value for policy, and one of their benefits is that they provide transport forecasts that are needed to adequately design future transport supply according to policy goals. The development of simulation models has a strong tradition in transport research, and it has reached an extremely sophisticated level in which the 'modelling community' can be characterised as a 'cluster' in its own right. Still, there are strong links to other communities since the results of travel behaviour surveys and traffic counts enter the modelling efforts in various places.
- Traffic safety: There is an equally distinct community of researchers who focus on traffic safety. Again, this research is largely based on quantitative data, often taken from official national, regional or local statistics on traffic accidents that are linked to road network data and sociodemographic information about those involved in accidents.

Transport thus connects people and urban activities and can largely be seen as a derived demand, though in certain ways it tends to have an intrinsic value, specifically in terms of psychological buffering (e.g. between home and work, Ory/Mokhtarian 2005), active physical movement (e.g. strolling, cycling) and symbolic representation (Steg 2005).

Transport demand has grown massively over the past century when mobility has become an inherent dimension of societies (Urry 2000) and economic development has transformed from 'spaces of place' to 'spaces of flows' (Castells 1996; 1998) including immaterial and material flows.

Transport studies have evolved from traffic engineering and economics. Even in 'side disciplines' engaged with transport such as geography, transport was closely linked to economic issues until the 1970s when the study of people's movement emerged in social geography as part of a broader agenda of looking at individual behaviour in time and space, inspired by time geography and other related schools (Carlstein/Parkes/Thrift 1978).

This rootedness of transport studies in engineering and economics has largely shaped their dominating methodologies. These are to a large extent based on the understanding that human behaviour is driven by utility maximisation and, thus, economic reasoning. Yet, these traditional models of individual travel behaviour have failed to date to fully account for the variation in observed behaviour, as can be seen in low rates of variance explanation. Combined with the need to better understand travel behaviour to develop targeted concepts to achieve more sustainability, this has led to the inclusion of the observed individuals' subjective perspectives including their perceptions, attitudes, preferences, subjective well-being and transport rationales (Scheiner/Holz-Rau 2007; Van Acker et al. 2014; Naess 2015). Not least, this development was accompanied by the intrusion of various (formerly 'neighbouring') disciplines into transport studies, including geography, psychology, sociology and others that introduced novel methods, theories and, broadly speaking, ways of understanding transport.

The majority of related studies are still based on the positivist understanding that objective knowledge ('truth') can be extracted from massive empirical observations. This is linked to strong methodological debates on data reliability, validity and representativeness, and advanced statistical methods of analysis. On the other hand, it can clearly be observed that the engagement of formerly 'neighbouring' disciplines in transport has led to radically different methodological understandings.

Firstly, the positivist paradigm has been criticised as being overly empiricist and focused on correlations ('correlationism'), and thus for failing to address the urgent questions of cause-impact relationships that need to be answered in order to target appropriate mechanisms to impact travel demand (Naess 2015). When addressing causality issues, this type of research typically looks at criteria such as statistical association, non-spuriousness and, in recent years, time precedence of the cause, but not the causal mechanisms that are at play (Naess 2015). In other words, some necessary, but not sufficient criteria are addressed. In response to this limitation, Naess (2015) proposes a critical realist position following Bhaskar (2008) to understand causality in terms of tendencies and generative mechanisms. According to this position, the world exists independently of researchers' knowledge and interpretations of it. Thus, there is need to sharply distinguish between the empirical (i.e. what we experience, what we can observe), the actual (i.e. whether events occur in reality or not, irrespective of whether or not we experience them) and the real (which includes what we experience, and the events that actually occur, and the cause-impact relationships that produce the events). This line of thought has generated rich mixed-methods research in which qualitative interviews are used to establish 'causal mechanisms' in terms of peoples' 'transport rationales' that help understand why they act the way they do (Wolday et al. 2019).

Secondly, a perhaps more radical departure from mainstream transport studies doubts that there is such a thing as cause and impact in human action. Rather it argues that cause-impact relationships can be observed in nature, while human action is based on people's reasons for acting (Scheiner 2005). While this point could be seen as being in line with critical realism as outlined above, a more radical reconstructive-interpretative approach claims that someone's mobility can be understood as a social entity that does not necessarily follow linear temporal and cause-impact structures, and that reflects social reality as well as subjective experiences (Rau/Sattlegger 2017). Hence, research should investigate people's memories as oral history that shapes present action (i.e. mobility), rather than questioning the validity of recall data. This approach aims to discover latent, less conscious structures of meaning in mobility (Rau/Sattlegger 2017).

The considerations briefly outlined above target travel behaviour, and this is what a large proportion of transport studies focuses on. It should not be forgotten, however, that there are a number of other key dimensions in transport studies (see above), which each have their own methods that cannot be covered in a single book chapter. Readers are referred to other resources in this respect.

This chapter focuses on quantitative travel behaviour analysis as one core data basis for urban transport studies. We refer readers to Røe (2000) and Goetz et al. (2009) for the discussion of qualitative methods. The following section outlines survey methods and data for investigating travel behaviour. Section 3 gives an overview of emerging new data sources on travel behaviour that increasingly complement the traditional survey data. This is followed by an example of a travel survey analysis taken from a project which was completed a few years ago but can still be seen as typical for recent related research (Section 4). The final section discusses methods, results and limitations and sets the study in context with metropolitan research.

2. Survey Methods and Data on Travel Behaviour

2.1 Diary-Based Travel Surveys as Main Quantitative Data Basis in Transport Studies

Early systematic and large-scale studies in data collection on travel behaviour date back to the 1970s. These were mainly motivated by the emerging mass motorisation and the increasing necessity to limit the negative side effects of motorised transport (Hubrich 2017). Diary-based approaches proved particularly suitable and are to this day the main workhorse for surveying the complex issue of travel for persons and households; they deliver the detailed information on the characteristics of trips, persons and households that is necessary for understanding, modelling and finally purposefully shaping travel behaviour and transport demand. The most serious drawback is that they are typically limited to only one randomly selected day because of the high response burden. This means that individual day-to-day variation in travel cannot be captured.

Fig. 1 shows a typical example of a traditional paper-based travel diary. Each single trip is listed in one column including at least the following information: start and end time, start and end location, main trip purpose, used transport modes, estimated distance. Further variables such as accompanying persons can be added if suitable. All transport modes used are to be ticked for each trip, but no information about the order, distance or duration of the separate trip stages (defined as trip segments that are covered by one specific transport mode) can be inferred. The main mode for each trip is determined based on a hierarchy of modes.

Travel surveys are today a standard tool in transport planning from national to municipal levels. These surveys are available in most metropolitan areas, the TEMS – EPOMM Modal Split Tool (see http://tems.epomm.eu) provides an overview of the modal split (defined as the share of trips per transport modes) in urban areas in Europe and beyond – and thus also on travel surveys as the typical database for generating the modal split.

Travel surveys are also a core data source for research on travel behaviour but are here often complemented by supplementary external data, additional questions or more specific surveys addressing the individual research questions of the study at hand.

Travel does not only mean to move from A to B, it is also an activity which takes time and it might mean physical activity if walking or cycling is involved. Time use surveys are therefore also used in transport studies. These are far more standardised than travel surveys, based on the guidelines for Harmonised European Time Use Surveys (HETUS;

Fig. 1: Excerpt of travel diary (source: Austrian national travel survey 2013/14, translated from German, BMK 2013)

	First trip
When did your trip start?	___ : ___ o'clock (Hour, Minute)
What was the purpose of this trip? *Please report only one!*	To work ☐ Business/official ☐ Study/education ☐ Bring/fetch/accompany a person ☐ Shopping ☐ Errands ☐ Private visit ☐ Other leisure ☐ Home ☐ Other, please specify: ☐
Which transport modes did you use? *Please specify if you used multiple transport modes. Please specify also if you walked only a leg or walked the complete trip.*	Walking ☐ Bicycle ☐ Car as driver ☐ Car as passenger ☐ Motorcycle ☐ Citybus/regional bus ☐ Metro/tram ☐ City train/train ☐ Other, please specify: ☐
What was the destination? *Please note the address as acurate as possible. If it is not known, please write down as short description.*	Postal code/city: Address/description:
When did your trip end?	___ : ___ o'clock (Hour, Minute)
What was the distance?	appr. ___ km
Did you have further trips?	Yes ☐ No ☐

Fig. 2: Excerpt of time-use diary (source: Eurostat 2019)

Time	*What were you doing?* *Record your main activity for each 10-minute period from 07.00 to 10.00!* Only one main activity on each line! Distinguish between travel and the activity that is the reason for travelling.	*What else were you doing?* *Record the most important parallel activity.*	*Did you use a computer, smart device, internet, online tool, or similar technology or device for doing this?* Yes	*Where were you?* *Record the location or the mode of transport.* e.g. at home, at friends' home, at school, at workplace, in restaurant, in shop, on foot, on bicycle, in car, on motorbike, on bus, ...	*Were you alone or together with somebody you know? Mark "yes" by crossing* Alone (or with unknown persons)	With other household members: Partner	Parent	Children (up to 17 years)	Other household member	Other persons that you know
07:00-07:10	*Woke up the children*		☐	*At home*	☐	☐	☐	☒	☐	☐
07:10-07:20	*Had breakfast*	*Talked with my family*	☐		☐	☒	☐	☒	☐	☐
07:20-07:30	–"–	–"–	☐		☐	☒	☐	☒	☐	☐
07:30-07:40	*Cleared the table*	*Listened to the radio*	☒		☐	☒	☐	☐	☐	☐
07:40-07:50	*Helped the children dress*	*Talked with my children*	☐		☐	☐	☐	☒	☐	☐
07:50-08:00	*Went to the day care centre*	–"–	☐	*On foot*	☐	☐	☐	☒	☐	☐

https://ec.europa.eu/eurostat/web/microdata/time-use-survey). Fig. 2 gives an example of a time use diary based on HETUS standards. These questionnaires collect data on all activities carried out throughout one or more diary days and thus provide valuable background information on the activities carried out at the trip destination. At the same time, important information on trip characteristics is left out such as trip origin and destination. The focus of the questionnaire and also the field work on time use might lead to under-reporting of trips, for example when these are merged with related activities or not reported at all because of the pre-set time-intervals of usually 10 minutes.

Standards for data collection on physical activity are provided by the World Health Organisation (WHO) and increasingly used also in transport studies. The Global Physical Activity Questionnaire (GPAQ) is an established tool for physical activity surveillance, the questionnaires are provided at http://www.who.int/ncds/surveillance/steps/GPAQ/en (see Dons et al. (2015) for a research-based application and adaption of the GPAQ). Data from GPAQ-based surveys is a valuable resource for transport studies as it provides information not only on the duration of walking and cycling for transport in a typical week but also on other forms of physical activity, e.g., at work or for leisure purposes. Major limitations include the lack of spatial information as well as missing data on the detailed walking and cycling episodes and on trips with motorised modes.

Studies with more complex research questions and designs combine the different survey traditions in order to collect comprehensive data on human behaviour including travel, activities, physical activity and possibly also consumer expenditure (see, e.g., Aschauer et al. (2018a) for the Mobility-Activity-Expenditure-Diary (MAED) design). These studies are costly and associated with a high response burden but at the same time, they provide unique information and allow researchers to analyse various different aspects and determinants of travel behaviour jointly.

Travel surveys collect data on reported travel behaviour; these are also called revealed-preference studies. Studies on stated behaviour are another important source in transport research when people are asked about anticipated behaviour and travel choices in possible future scenarios and framework conditions.

2.2 An Alternative to Diaries: Frequent Activities

As outlined in the previous section, trip (or time use) diaries normally capture travel behaviour only for one single day. This means that they cannot be used to detect activity and travel patterns on the individual level, as these patterns may vary strongly from day to day and over time. E.g., a respondent who cycled to work on the diary day is not necessarily a frequent cyclist. Also, diary surveys need very large samples due to substantial variation between individuals, e.g. in distances travelled.

An alternative is to collect information on 'typical' transport modes, trip distances and frequencies for a set of pre-defined activities such as going to work, shopping, attending cultural or sports events, or strolling (Rieser-Schüssler/Axhausen 2014).

This method, sometimes called 'frequent activities' approach, results in typical patterns on the individual level and can easily include rare activities (e.g. going to the opera), but comes at the expense of accuracy, as variation in modes used, distances covered, destinations visited or departure time within an activity class will not be captured. Further, this method requires a carefully defined set of activities. Generally speaking, the broader the categories, the more likely bias will occur. For instance, asking for several types of shopping goods (groceries, clothes etc.) allows respondents to report their behaviour more accurately than just asking for shopping trips in general.

In a reduced form, frequency questions are sometimes included in socioeconomic surveys such as the Mikrozensus or the SOEP (Socio-Economic Panel) in Germany, where information on the trip to work is recorded.

2.3 Evolving Survey Methods

Most travel surveys offer different channels for survey participation. Self-administered mail-back questionnaires and telephone interviews have dominated over many years. These are complemented by online questionnaires which are increasingly used by participants. Personal interviews are carried out in some countries and research projects (Aschauer et al. 2018a).

All these different survey methods are characterised by specific strengths and weaknesses (Hubrich 2017) but suffer generally from trip-underreporting particularly for short and irregular trips and for trips with short durations of the subsequent activity (Aschauer et al. 2018b).

Further challenges to the traditional survey methods are decreasing response rates particularly in register-based samples leading to the increasing use of convenience samples and commercial panels even for national travel surveys such as the Dutch Mobility Panel (Aschauer et al. 2018a).

Technology-based surveys using smartphones or dedicated GPS-devices are increasingly applied in transport studies with mainly non-representative convenience samples and are a promising avenue for future research (see, e.g., Harding 2019; Hubrich et al. 2020; Molloy et al. 2021). Smartphone-based surveys track respondents' trips and activities automatically with the aim to minimise respondent burden while at the same time achieving highest levels of detail and data quality. They allow collecting more comprehensive information than traditional trip diaries, e.g., not only on trips (defined as movements from an origin to a destination where an activity will be finally carried out) but also for trip stages. Smartphone-based surveys also allow to collect data for longer time periods than the traditional one-day diary. This is useful for daily mobility which involves substantial variation over time and particularly also for long-distance travel and rare events. These are not covered reliably in standard travel surveys.

Methods for sampling and surveying in transport studies are interdependent. For example, the combination of convenience sampling or commercial panels with smartphone-based tracking surveys allows for setting up surveys far more quickly than this could be done with traditional survey methods. Molloy et al. (2021) is an example for such a study collecting up-to-date data on travel behaviour in a longitudinal setting.

2.4 Cross-Sectional Versus Longitudinal Data

Travel surveys are with few exceptions cross-sectional surveys with the household being the usual sampling unit (Hubrich 2017). This means that fresh samples report their mobility in each new survey. Continuous surveys are carried out in some countries and studies. These are a special case of cross-sectional surveys that run throughout the year for one or more years.

Respondents in longitudinal panel surveys participate more than once in the same survey or a set of surveys. Longitudinal panels are usually administered with long time intervals between waves (e.g., one year). They often work with rotating samples incorporating a pre-defined refreshment in each new wave. Pseudo-panels are repeated cross-sectional surveys with similar or matched individuals with before-after-studies as the typical application.

Both cross-sectional and longitudinal survey designs have individual strengths and weaknesses. These are listed in Table 1. Many questions in research and practice can be answered based on the far more economical cross-sectional surveys, whereas only longitudinal designs capture the dynamics and processes of inter-individual and, in the case of panels, intra-individual change.

Tab. 1: Strengths and weaknesses of longitudinal panel survey versus cross-sectional survey methods (adapted from Gerike/Gosselin 2015)

Longitudinal panel survey	***Cross-sectional survey***
Strengths	
Allows for analyses of the effects of change in levels of causal factors	Allows for analyses of the effects of differences in levels of causal factors
Provide greater statistical reliability for a given sample size because of multiple observations of the same respondent	Lower response burden, limiting fatigue Larger sample sizes and possibility of higher response rates Representative samples are easier to achieve Data suitable for answering most of the relevant questions in transport research and practice, especially for survey periods of one week or longer
Can provide the basis for a quasi-experimental design for before-and-after evaluation of interventions	Continuous cross-sectional surveys and pseudo-panels can support limited control group strategies for before-and-after analysis of interventions
Data directly usable for observing the effects of unexpected events	Data from continuous cross-sectional surveys and pseudo-panels are directly usable for observing the aggregate effects of unexpected events
Panel ageing can be avoided and attrition reduced by rotating panels	Not subject to ageing or conditioning
Funding for further waves appears easier to obtain because of survey continuity	Funding for a target sample size can be easier to obtain because the per-respondent costs are lower and because of survey continuity for repeated and continuous surveys
Decreasing marginal costs from wave to wave thanks to increased competency and efficiency in survey work	Decreasing marginal costs thanks to increased competency and efficiency in survey work for continuous cross-sectional surveys
Weaknesses	
High response burden, possibility of low response rates, greater selection bias	Limited intra-personal variation but one-week survey periods sufficient for many analyses of intra-personal variation
Recruitment and maintenance of the panel sample is challenging because of high response burden	Limited opportunities to distinguish between inter-personal and intra-personal variation
Small and decreasing sample sizes (in second and following waves) Attritions, fatigue, panel ageing Conditioning (can be also a source of valuable data on learning) Privacy issues (easier to uncover the identity of individuals in panels; patterns of locational data may reveal addresses, etc.)	Questionable assumption of reversibility of effects: e.g. persons who have just sold their car assumed to behave the same as persons who never had a car
Difficulty to change the survey method without creating artefacts	Continuous and repeated surveys: difficulty to change the survey method without creating artefacts

3. Innovative Data Sources for Investigating Travel Behaviour

Various new data sources have emerged in the last years. They open new perspectives and opportunities for investigating travel behaviour and are increasingly used in research and also in practice. Examples for such data sources are smart card transactions in public transport, data from providers of innovative mobility services such as sharing companies, various types of smartphone data, online social media and mobile phone data. Most of this data is "passive data" that is collected without explicitly asking the users any questions (Rieser-Schüssler/Axhausen 2014).

Data from smart card transaction can be distinguished into data that is directly provided by the passengers (e.g., automatic fare collection, Wi-Fi or Bluetooth data from passengers in the system, trip planning logs) and data provided by the transport system (e.g., General Transit Feed Specification (GTFS), automated vehicle location, automatic passenger counting) (Chandresis et al. 2018).

Mobile phone data means passively collected location data from smartphone users (Bonnel et al. 2018). It allows researchers to construct origin-destination matrices including increasingly reliable distinctions between road and rail-based transport. It is mainly applied for investigating long-distance travel, as short-distance trips are hardly detected.

Data from social media is used for recruiting respondents in convenience samples (Hubrich/Weber/Wittwer/Gerike 2020) but also for analysing travel behaviour, e.g., by mapping locations reported in social networks such as Twitter or TripAdvisor. Social networks also open new opportunities for interacting with respondents, e.g., for giving feedback in travel surveys or for asking questions in real-time prompted by triggers such as specific travel situations.

Most of these new data sources are passively collected with the main advantages of large data volumes and high timeliness; the commonly continuous data stream usually provides real-time data. This leads to the need for new techniques in data storage, processing, analysis and visualisation but at the same time opens plenty of opportunities for new research questions and designs. On the other hand, such data do not permit to study individual travel behaviour, and they do not provide any information on social context (e.g., personal and household sociodemographic information, car ownership etc.).

4. Analysis Methods: Residential Preferences, Residential Choice and Travel Behaviour

4.1 Background and Methods

In the past decades, several debates have developed in transport studies that seek to understand how household residential choices are linked to travel behaviour, and how both residential choices and travel behaviour are linked to subjective preferences, attitudes, perceptions, and lifestyles (Scheiner/Holz-Rau 2007; Van Acker et al. 2014). Additionally, the links of all these concepts to people's life situations – as reflected in sociodemographic variables – are discussed intensively, and the debate as a whole is embedded in a long-established discussion on the effects of the built environment on travel behaviour. These debates have contributed substantially to a better understanding of travel behaviour and its links to societal change and housing needs, especially in metropolitan areas where the majority of related studies have been conducted.

There is no space in this section to adequately outline these rich debates comprehensively. Instead, readers are referred to the recent literature (Van Acker et al. 2016). It is important to note, however, that much of the discussion revolves around an adequate understanding of cause-impact relationships between the concepts mentioned above. As these concepts involve multiple angles and dimensions, various sophisticated statistical methods tend to be used to adequately capture associations (Mokhtarian/Cao 2008).

One of these methods is Structural Equation Modelling (SEM). SEM can be described as a combination of factor analysis and a generalised form of regression analysis. Contrary to other multivariate techniques, SEM allows the investigation of multi-stage interrelations between variables. Unlike regression 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 one other, as well as the inclusion of intervening variables that are endogenous to some but exogenous to other variables (see Scheiner/Holz-Rau, 2007, for more details). The factor analysis part of SEM consists of measurement models that measure latent (i.e. unmeasured) variables by manifest variables.

There is much debate about the conditions under which the classical Maximum Likelihood (ML) approach can be regarded as superior to non-parametric procedures even when the normality assumption is violated (e.g., Hoogland and Boomsma, 1998). The available sample of about n=2,000 seems well appropriate for a robust application of the ML procedure, even if the sample is split into two halves (see below). The asymptotically distribution-free (ADF) procedure then reaches the limit of reliability but seems to still be acceptable. In the study presented here, a rather rigorous approach was applied. First, the sample was split into two halves by a random procedure. Then each model was estimated in four versions: (1) ML estimation of a theoretical model with the main sample; (2) empirical fitting of the model to the data; (3) ADF estimation of the theoretical model; (4) ML estimation of the theoretical model with the second sample for validation.

Version 2 served to verify the coefficients in the theoretical model version when fitted to the data, while our substantial interest lay in the theoretical models. Each of the four model versions was compared to the others with respect to the strength and sign of the effects. The results for each of the four versions turned out fairly stable and may clearly be interpreted in terms of the sign and strength of the effects. Hence, the results of Version 1 are presented here for two models.

The interpretations are based on direct as well as total effects. Total effects of one variable on another are calculated as the sum of direct and indirect effects, the latter being mediated by intervening variables. Taking total effects into account allows for a more thorough interpretation of interrelations. An example for the calculation can be found in the text below fig. 3. The analyses were undertaken with the programme AMOS 5.0 to 7.0 (Analysis of Moment Structures).

The data used in this chapter were collected in a standardised household survey within the framework of the project StadtLeben[1]. The survey was undertaken in ten study areas in the region of Cologne in 2002 and 2003. 2,691 inhabitants aged 16 and older were recruited based on random route procedure (representing a response rate of 27 percent) and took part in extensive face-to-face interviews.

The analysis is based on the seven (out of ten) study areas surveyed in 2003. The resulting net samples have a value of about n=2,000. The working samples have a size of about n=1,000 due to the split of the sample (see above). The areas range from high-density inner-city quarters of the 19th century to suburban neighbourhoods with detached single family houses at a distance of about 30 km from Cologne.

The theoretical structure of the models, as represented by the arrows in the figures below, are based on a number of assumptions and ideas.

1. Preferences towards certain residential environments (here: proximity to public transport [PT]) depend on the individual life situation, i.e. sociodemographic variables, and car availability.
2. Life situations can be described by a limited number of dimensions ('factors' captured by measurement models). Gender is represented in the models by a single variable, as it does not correlate sufficiently to other sociodemographic variables.
3. Actual residential location choice, represented here by the objectively measured PT quality in the residential neighbourhood, depends on life situation, car availability, and residential preferences.
4. Travel behaviour is a multi-dimensional construct composed of interrelated decisions such as trips made for certain purposes, mode choice, distances travelled, departure times chosen, routes chosen and more. This is represented here by mode use and trip distances covered.
5. Trip distances travelled depend on life situation, car availability, and residential preferences and actual residential location.
6. Modes used depend on the same variables plus distances travelled.

It is important to understand that the analysis takes place on the person level, not the trip level. Thus, trip distances are mean distances travelled for various trips of different purposes. Mode use is the percentage of the mode under study among all trips reported by a respondent. The trips are recorded using the 'frequent activities' approach, i.e. by asking for a broad range of pre-defined activities with 'typical' modes, frequencies and distances, rather than using a trip diary. This means that the trip records are not limited

1 StadtLeben – Integrated approach to lifestyles, residential milieux, space and time for a sustainable concept of mobility and cities (2001–2005). Project partners: RWTH Aachen, Institute for Urban and Transport Planning (coordination); FU Berlin, Institute of Geographical Sciences, Department of Urban Research; Ruhr-University of Bochum, Department of Cognition and Environmental Psychology; Dortmund University of Technology, Department of Transport Planning (see http://www.isb.rwth-aachen.de/stadtleben).

to a single random day, with all the limitations this implies. The downside is that the frequency estimates may be biased, and more 'unusual' modes and distances tend to be hidden.

4.2 Results

There are a number of heuristic indicators to assess the goodness-of-fit of structural equation models. One of these indicators is RMSEA. A rule-of-thumb decision rule is that model fit is adequate if RMSEA<0.05, and RMSEA>0.10 is unsatisfactory. In our case, RMSEA for the car use model is 0,127, and 0,112 for the PT model. However, the model versions 2 (fitted to the data) achieve RMSEA values of 0,035 and 0,043, respectively. 'Fitting' means that model restrictions (e.g., unpermitted associations between variables) are liberated so that the model fits the data better. This is at the expense of theory. As the results we present are virtually equal to those in the fitted versions, we see no reason to dismiss our theoretically justified models.

Now, we turn our attention to the effects found in the models. High social status is associated with markedly longer trips and higher shares of car use *as well as* PT (public transport) use (fig. 3, fig. 4). At the same time, individuals with high social status have lower NMT (non-mororized transport) shares (Scheiner 2010). The effects of social status on travel mode choice are a result of direct effects as well as indirect effects mediated by trip distances and residential location choice. Individuals with high social status tend to locate in central areas with good PT systems. These residential location decisions encourage PT use and counterbalance car use to a certain extent, but without fully offsetting the positive relationship between status and car use.

Women's shorter job trips account for a large part of this difference (models for trip purposes not presented here). Gender does not have much of an impact on travel mode choice. Thus, gender differences seem to be more a matter of activity spaces.

The life situation dimension 'family' is associated with a high mode share of the private car.

This association is mediated by higher car availability, less importance assigned to PT supply, and more remote residential locations in families, while there is no direct effect of 'family' on car use.

The availability of a car strongly increases trip distances and, obviously, car use, but decreases the use of PT. To some extent this is a result of the tendency for car-owners to locate in more peripheral places with lower PT quality, and to have lower preferences for PT.

With respect to the built environment, PT supply corresponds with relatively short trips, which is likely to be an effect of the generally higher urbanity found in neighbourhoods with a good PT system than of the PT system per se. The effect PT has on travel mode choice is even stronger than its effect on trip distances: living at a place with a good PT system leads to more PT use and less car use.

A high subjective preference for PT affects PT use more strongly than the objective quality of the system. Residential self-selection according to travel mode preferences is particularly pronounced in this case.

Last but not least, there is a clear and strong relationship between trip distance and travel mode choice: the longer the trips, the greater both car use and PT use. Firstly, mode choice depends on realised trip distances. These may be affected at best indirectly by urban policy concepts, e.g., by impacting on the monetary or generalised costs of travelling. Secondly, the *necessary* distances to potential destinations – i.e. to opportunities – may be affected directly by land-use planning. It should be encouraging for policy makers and planners that land-use does indeed seem to have a strong independent impact on travel behaviour, irrespective of people's attitudes and social background.

Fig. 3: Model of trip distances and car share – all trip purposes. This and the following figures show the estimated standardised path coefficients and the proportion of explained variance of the endogenous variables, the latter being indicated next to the variable boxes. Significant coefficients (p=0.05) are marked with an asterisk. The rectangles are observed variables, the ovals are latent constructs. The total effect a variable has on another variable is calculated as the sum of direct and indirect effects. For instance, the total effect of 'importance of PT' on 'car trips' equals -0.07 + 0.25-0.20 + 0.25*-0.11*0,20+0,02*0,20 = -0.12.*

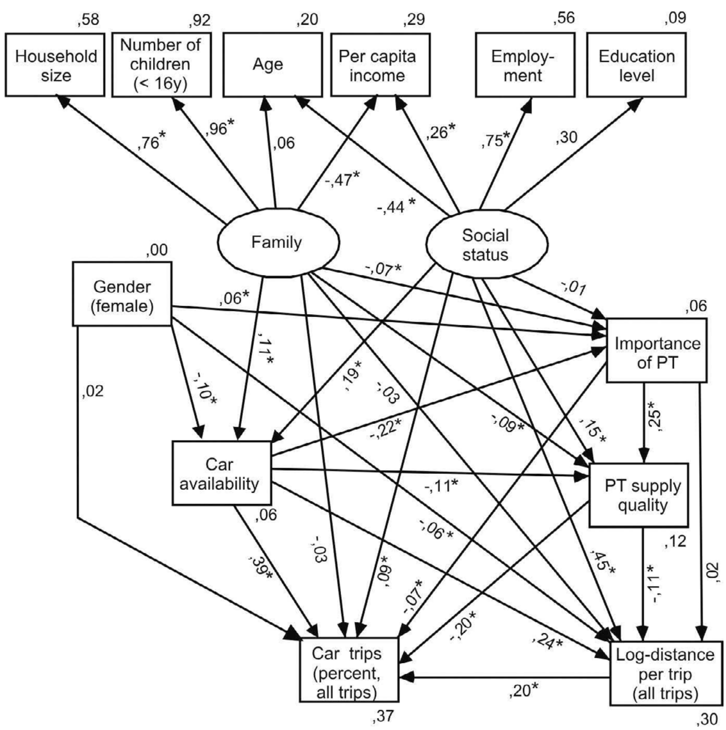
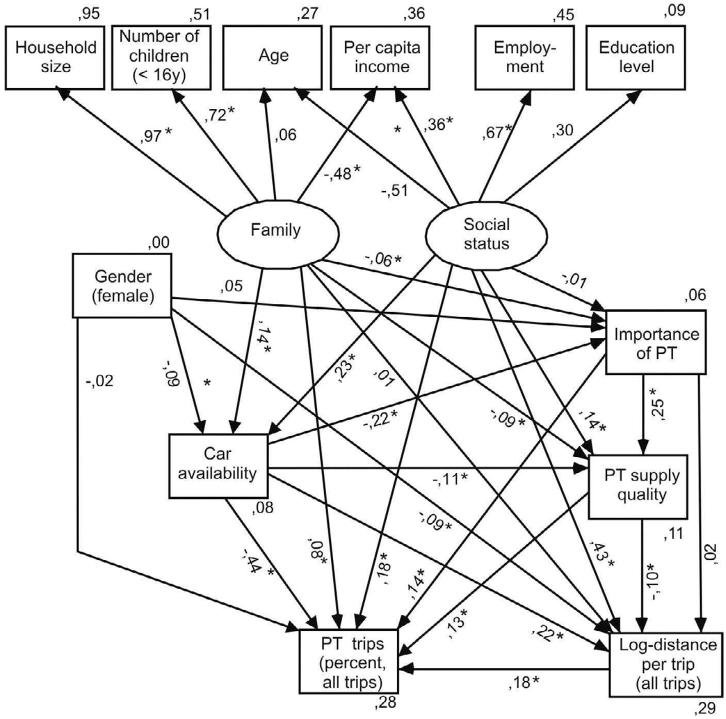


Fig. 4: Model of trip distances and PT share – all trip purposes



5. Conclusions for Metropolitan Research

Transport analysis is an integral part of urban and metropolitan research. Transport is not just physical movement, but reflects economic and social spatial exchange in metropolitan areas and beyond. This is mirrored in the fact that the various activities performed in daily life are an integral part of travel behaviour analysis. Travel behaviour analysis thus serves to better understand what people do, where they go, how they interact with other people, and in which ways and to which extent they are engaged in societal and economic metropolitan life.

The Covid-19 pandemic was accompanied by much substitution of physical transport by virtual communication and activities (e.g., work or shopping), and this amplified trends of substitution and complement that have been observed for decades, as expressed in terms such as the 'city of flows' (Castells 1996; 1998). Still, physical co-presence in time and space and the trips associated with this remain of key importance for economic, social, cultural and psychological well-being.

Our example study shows interdependencies between urban structure, individual life situations and preferences, and transport in terms of trip distances and mode choices. It represents a glimpse at the spatial interrelations in a metropolitan area shaped by social and economic as well as spatial circumstances people live in.

In terms of methods for data analysis, there is a need to clearly reflect the levels on which transport analysis is typically done. The analysis presented here is on the person level. This implies that the link between distance and travel mode is not studied on the trip level but on the level of a person's average trip distances and relative dominance of certain modes. Also, the individual household context of a person is only insufficiently considered by controlling for household income and household type. Actual travel interactions between household members were not included. In recent years there has been much research effort on inter-person interactions in travel, either within households or beyond (Ho/Mulley 2015; Scheiner 2020), and these interactions are clearly a fruitful field for metropolitan studies. Also, multiple dimensions of the urban environment remained unconsidered, such as density and land-use at sites other than the residence, e.g., at the workplace. Finally, although respondents' subjective preferences have been captured by standardised scales, this only poorly reflects their own perspectives and reasonings, but rather the researchers' theoretical assumptions about statistical associations.

In terms of data on travel behaviour, we have found a long tradition going back to the 1970s. Methods for data collection in travel surveys have evolved over time from mostly paper-and-pencil surveys to mixed-mode approaches including increasing shares of online interviews and smartphone-based tracking of respondents' behaviour. Early data is less rich and comprehensive than the more recent one but still, the harmonisation of historical datasets from different time periods up to today holds a great potential for research on travel behaviour.

Various emerging new data sources open completely new perspectives and opportunities for understanding travel behaviour mainly because of their scope and timeliness. They lead to the need to develop new methods for data processing, analysis and visualisation. Privacy issues are a major concern and also the transparency and reliability of the often commercial data.

What is more, recent qualitative research in transportation (Rau/Sattlegger 2017) provides promising avenues for future research that has hardly been touched upon in this chapter.

An important task is to combine the different data sources for each planning task or transport study anew in a way that the respective research questions can be answered comprehensively. New data sources and techniques of analysis also open new opportunities for advancing transport models.

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