DISSERTATIONEN

Development of an innovative combined mobility-activity-expenditure survey and methodological comparisons with traditional disciplinary approaches

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Preface

The implementation of the mobility-activity-expenditure diary (MAED) survey described in this thesis as well as the analyses and publication of the results were carried out as part of the FWF (Austrian Science Fund) -funded project "Valuing (travel) time: Models and data for activity scheduling" (Project number: I 1491-G11).

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I would like to take this opportunity to thank those people who made it possible for me to complete my dissertation project and who supported me in its implementation.

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Finally, I would like to thank those people to whom I owe the most: my parents. They made it possible for me to reach this point in my education. My unconditional gratitude goes out to them for that, and for so much more that there is not enough space to cover here.

Abstract

This cumulative dissertation in the field of mobility behaviour research reports on research from the area of travel surveys. For current transport economic models, mobility research requires comprehensive and high-quality datasets. These datasets should consist of detailed information on trips, activities in-between the trips, and the spending behaviour of individuals. In response to this demand, a corresponding survey design is developed based on a mobility-activity-expenditure diary (MAED).

The present dissertation examines (i) to what extent the development and implementation of the MAED survey was successful in collecting required data of appropriate quality. Furthermore, on the basis of a comparative method study (ii) with an Austrian household travel survey (HTS) and (iii) with an Austrian time use survey (TUS), the methodological strengths and weaknesses of the different survey formats are evaluated by identifying non-reporting patterns.

The analyses showed that the MAED design is able to collect at a sufficient quality the data required for modelling relevant transport economic issues. It turned out that for both the HTS and the TUS, the underreporting of trips follows a systematic pattern. Thus, these two traditional survey methods are limited in collecting required combined trip and activity datasets with a sufficient quality. The results of the methodological study can help to optimise the survey methods of future HTSs and TUSs in order to obtain high-quality data.

Keywords: Travel behaviour, Time use, Travel survey methods, Data collection, Mobility-Activity-Expenditure-Diary

Kurzfassung

In der folgenden kumulativen Dissertation aus dem Bereich der Mobilitätsverhaltensforschung wird über Forschung zu einer innovativen Methode der Mobilitätserhebung berichtet. Die Mobilitätsforschung benötigt für aktuelle transportökonomische Modelle umfassende und qualitativ hochwertige Datensätze. Diese Datensätze sollten aus detaillierten Informationen zu Wegen, Aktivitäten zwischen den Wegen und dem Ausgabenverhalten von Personen bestehen. Als Reaktion auf diese Nachfrage wurde ein entsprechendes Erhebungsdesign – basierend auf einem Mobilität-Aktivitäten-Ausgaben-Tagebuch (MAED) – entwickelt.

Im Rahmen der vorliegenden Dissertation soll nun untersucht werden, (i) inwieweit die Entwicklung und Implementierung der MAED-Erhebung erfolgreich war, die benötigten Daten von entsprechender Qualität zu sammeln. Außerdem soll auf Grundlage einer komparativen Methodenstudie (ii) mit einer österreichischen Haushalts-Mobilitätserhebung (HTS) bzw. (iii) mit einer österreichischen Zeitverwendungserhebung (TUS) durch die Identifikation von Non-Reporting-Mustern evaluiert werden, welche methodischen Stärken und Schwächen die unterschiedlichen Erhebungsformate aufwiesen.

Die Analysen ergaben, dass das MAED-Design in der Lage war, die für die Modellierung transportökonomischer Fragestellungen benötigten Daten in hoher Qualität zu sammeln. Es zeigte sich, dass sowohl bei HTS als auch bei TUS das Unterberichten von Wegen nach einem systematischen Muster erfolgte. Damit sind diese beiden traditionellen Erhebungsmethoden nur bedingt in der Lage, die benötigten kombinierten Wege- und Aktivitäten-Datensätze in ausreichender Qualität zu sammeln. Die Ergebnisse der methodischen Analyse können dazu beitragen, die Erhebungsmethoden zukünftiger HTS und TUS zu optimieren, um qualitativ hochwertige Daten zu erhalten.

Schlagworte: Mobilitätsverhalten, Zeitverwendung, Mobilitätserhebungsmethoden, Datenerhebung, Mobilität-Aktivitäten-Ausgaben-Tagebuch

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Part I – Scope and Sequence

1 Introduction - Objective and definition of the research topic

1.1 Background and motivation

Transport research requires comprehensive and high-quality datasets – usually obtained from travel surveys or time use surveys – to investigate novel research questions that place mobility-related decisions and behaviour in a broader context. It has always been recognized that travel is a derived demand that is embedded in the overall framework of time and budget assignment. Nonetheless, this relationship was ignored for a long time, because modelling the complex trade-off processes between travel activities, non-travel activities, and budget assignment requires a large amount of information to be combined at the individual level. From this follows an increasing demand for integrated datasets including information on travel activities, non-travel activities, and expenditures.

In response to this demand, the core idea was to develop a new survey to collect a combined dataset that would meet the requirements of transport economic models. The research topic of this cumulative dissertation is not to set up transport economic models. The data obtained by the newly developed mobility-activity-expenditure diary (MAED) questionnaire was, due to its novelty, complexity, and completeness, suitable for an in-depth analysis within the framework of a methodological study. In the context of the present work, the MAED survey was subjected to a critical review. The aim was to find out whether the survey design was successful in its implementation and whether the different data types could be collected accurately. In order to determine the data quality, MAED served as a reference dataset for a comparative study with further datasets of travel- and non-travel-related activities.

1.2 Study aim

The first overall goal was the development and implementation of the MAED survey to obtain the integrated dataset of travel and non-travel activities as well as expenditures in order to meet the increased data needs for transport economic models (Research Article 1). The extent to which the diaries are capable of collecting the required data about trips and activities with high quality and response rates was examined.

Because MAED data was assumed to be of superior quality than data from traditional disciplinary approaches, methodological comparisons of MAED with datasets from other surveys (that are capable of collecting such integrated datasets) led to the two other overall goals: a comparison of MAED with a household travel survey (HTS) (Research Article 2) and a comparison of MAED with a time use survey (TUS) (Research Article 3). The datasets

are subjected to a comparative analysis in order to identify their methodological strengths and weaknesses and to assess the quality of all three survey formats and respective datasets. A particular focus was on the representation of trips (travel-related activities) and activities (non-travel-related activities in between trips) in these surveys, which were compared using different indicators.

1.3 Approach and research process

The common objective of the above-mentioned goals was to identify non-reporting effects in order to validate the information obtained from the three survey formats. It was assumed that there are connections between survey methodological variables and the mobility of the respondents through systematic underreporting of specific trips. The hypothesis was that the underreporting of trips in HTSs and in TUSs is based on a pattern that was induced by a poor design of the survey format that ultimately caused a systematic bias in the respective survey results (e.g. too few mobile persons, too low of a trip rate). The intended approach was to determine which trips specifically (or respectively, activities) were omitted from reporting in the respective format in order to uncover existing underreporting patterns and how these subsequently affected the various mobility indicators and ultimately the quality of the dataset. The methodological aspects of the respective datasets should allow a statement to be made as to the extent to which the respective format is suitable for the collection of combined datasets on trips and activities.[1] The analytical tools were descriptive statistics and dependency analyses.

The concept of a method study as a basis for this dissertation was defined in the context of the preparatory activities for the MAED survey of 2015, carried out by the Institute for Transport Studies at BOKU Vienna. The research process is shown in Figure 1. The dissertation project was based on empirical research: the compilation of a MAED dataset through the 2015 MAED survey and the subsequent data preparation, as well as the data preparation processes of the HTS and TUS datasets required for comparative analysis. In addition, data from the Austrian Register Census 2011 for the sample description and the Consumer Expenditure Survey 2009/10 were prepared for comparison with the MAED survey in Research Article 1. At the same time, comprehensive literature research was conducted on studies of item-non-reporting effects in travel surveys and time use surveys, as well as total non-response in the context of a speed-of-response analysis in Research Article 2. The results of the empirical analysis were disseminated in three research articles (see Section 4).

[1] A methodological comparison on the collection of expenditures was not part of the study as neither travel surveys nor time use surveys usually provide information on expenditures. Expenditure surveys, on the other hand, usually do not contain information on time use of any kind.

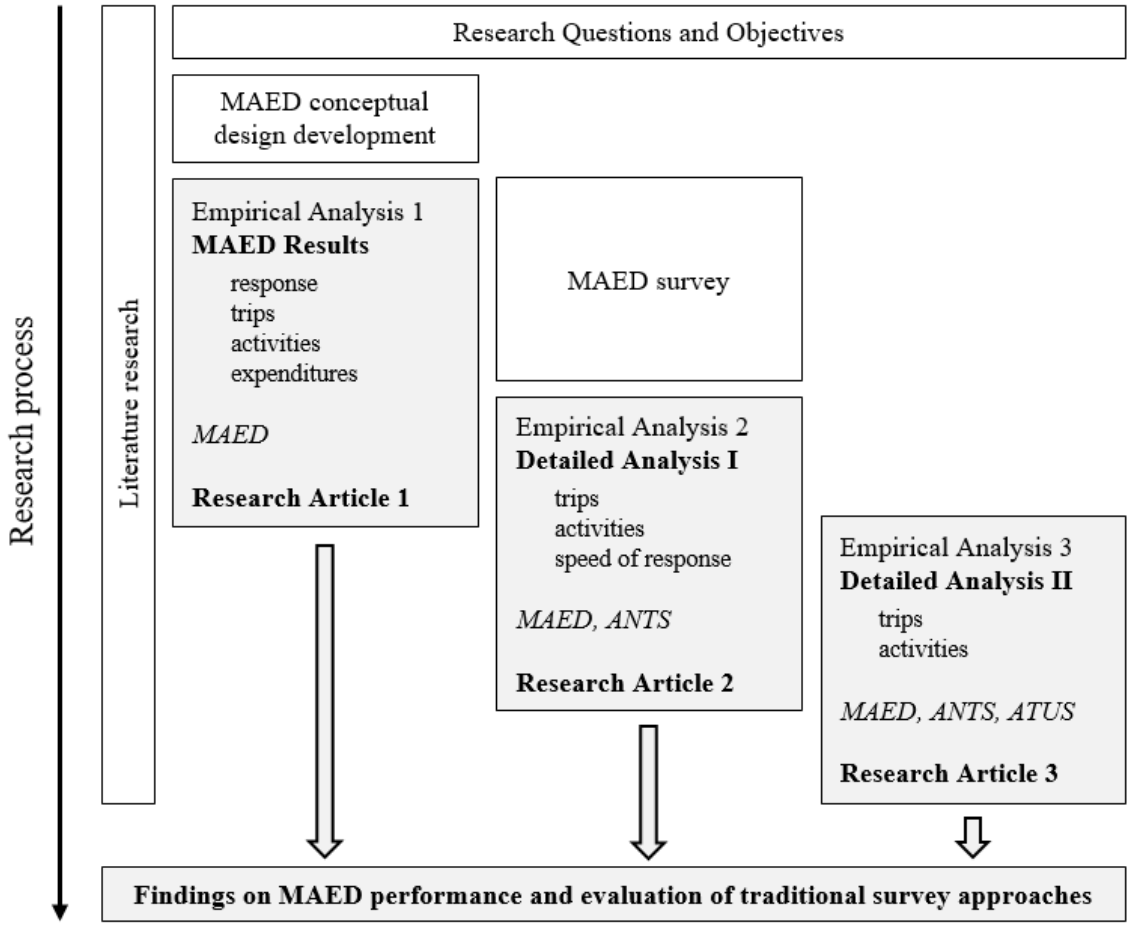

Figure 1: Research process

2 State of the art: the depiction of mobility behaviour through surveys

2.1 Need for transport and mobility-related data

Transport is a key economic sector. Sound knowledge of the transport situation of a country or a region is an indispensable prerequisite for developing solutions to transport problems and for making targeted investments in transport services and associated infrastructure. Road and rail infrastructure projects shape passenger transport in many respects. Decisions made in transport policy today have impacts on future transport demand. The information requirements for the design of services is considerable. Against the background of the demographic development of a population, specific indicators regarding transport[2] and mobility[3] form the basis for estimating the future demand for mobility and the long-term demand for transport services.

An important basis of transport decision-making is accurate and complete information on the demand side of travel behaviour and socio-demographic backgrounds. Knowledge about both transport-relevant and mobility-specific parameters is important. Transport indicators refer to objective measures (How much internal, origin/destination, and transit transport volume occurs in a given city, region, or cordon within a given time? How large is the transport volume of a given mode of transport?), mobility indicators of subjective values (The characteristics of a person or sample's travel behaviour: when does a person want to go from point A to point B, with which mode of transport, and for what purpose?). Knowledge about both types of indicators as a database should be available in order to enable transport modelling for a sustainable transport policy.

From the perspective of policy makers, there is a need for transport and mobility data at different levels. Depending on political responsibility and the type of transport planning instrument, there is a need at federal, state, and local levels for this information to be used as a basis for the planning of various transport facilities: (i) infrastructure such as motorways, roads, and cycle path networks; (ii) services such as local and long-distance public transport (PT); and (iii) the necessary legal framework. The corresponding authorities therefore have a need for reliable information on the current transport situation and people's mobility behaviour.

From an economic point of view, for example, the use of different means of transport by the population and companies are of interest. This data can serve as a basis for decisions on the development of new vehicles or PT and logistics concepts. For an integration of the

[2] System-related: transport is determined by the number of changes of location of an area.

[3] Subject-related: mobility – like transport - is determined by number of changes of location, but not of an area, but by (a) person(s) or any other specific sample

different modes of transport, the reasons for peoples' mobility decisions in everyday life must be known. Without this knowledge, transport forecasts and estimations of longer-term developments would not be possible.

In Austria, many of these databases on transport volume are collected by the Statistical Office (Statistics Austria - STAT) on behalf of the Federal Ministry of Transport, Innovation, and Technology (BMVIT). This data is collected at regular intervals for the transport modes of road, rail, water transport, and aviation for passengers and freight. The publication "Verkehr in Zahlen" (Herry et al. 2007) was first published by BMVIT in 2002. In this publication, a comprehensive description of the transport situation in Austria was available for the first time. The last edition was commissioned in 2011.

While transport indicators can be collected or measured for any area (e.g. by counting, transport flow analysis, measurements), mobility indicators have to be collected in a different way, typically by representative surveys of travellers (travel surveys), for which different methods and standards can be applied. A typical survey of mobility data is the Austrian-wide travel survey Österreich unterwegs, commissioned by the BMVIT. The Österreich unterwegs 2013/2014 (Tomschy et al. 2016) is the most recent overall depiction of the mobility behaviour of Austrian residents and households. In Germany, the Mobilität in Deutschland (MiD) and the Deutsches Mobilitätspanel (MoP) surveys are conducted in a similar way.

The collection of mobility data can be commissioned by different authorities. As mentioned above, this can be stipulated, for example, by a federal or state government in order to obtain a general overview and to be able to answer strategic questions on transport planning and development. On a more small-scale, regional level, travel surveys are commissioned and carried out in order to provide the basis for answering specific mobility-related questions. Examples of this approach are surveys of the mobility behaviour of the inhabitants of a region in order to determine the capacity requirements of a park and ride facility, or surveys for the determination of the mobility behaviour of the employees of a company in order to take targeted measures for the promotion of public transport or cycling within the framework of the company's internal mobility management.

2.2 Features of travel surveys

2.2.1 Survey design and process

Since the collection of mobile-related data is based on people reporting on their own behaviour, as opposed to the measurement of transport-related data, there is susceptibility to a different kind of errors. These are called non-reporting errors. The conception of a survey design that allows as few reporting errors as possible is therefore of the highest importance in order to capture a person's mobility behaviour as accurately as possible

Until 2011, there was no uniform standard for mobility surveys in Austria. In Germany, the KONTIV survey design ('New KONTIV-Design -NKD'; Socialdata 2009), which has been used since the 1970s (as an adapted survey design since 2002) in the MID survey, is used in nationwide HTS.

In order to ensure the comparability and high quality of travel surveys and to facilitate the merging of hitherto separately conducted surveys, the basis for a uniform quality and survey standard for travel surveys in Austria was created in 2011. As part of a conceptual study within the KOMOD project aiming at the preparation of a nationwide travel survey (Österreich Unterwegs 2013/2014), existing survey technologies and procedures as well as organisational models were analysed and compiled into a comprehensive survey concept. The result of the study was the *Handbuch für standardisierte Mobilitätserhebungen in Österreich* (*Handbook for standardised travel surveys in Austria*) (Fellendorf et al. 2011). Contractors of travel surveys, such as public authorities (federal states, cities, municipalities) and all institutions involved in travel surveys, thus have the opportunity to carry out surveys following a standardised guideline – the KOMOD standard.

2.2.2 Survey methods

In order to survey the mobility of a target population, several methodological approaches are available. Currently, retrospective surveys of travel behaviour represent the standard of survey designs. The following instruments, in which respondents are asked to describe their mobility behaviour in the form of a diary, are used:

- **CAPI – Computer-Assisted Personal Interview**: The mobility behaviour of a person is recorded in a face-to-face manner with an interviewer who, using a mobile input device (laptop, tablet), visits the person to be interviewed. Together with the survey participant, the interviewer runs through the questionnaire on the screen in order to collect the required information for the specified reporting period. A major advantage is that the data entered can be checked immediately for plausibility and completeness by suitable software.
- **CATI – Computer-Assisted Telephone Interview**: In a CATI survey, the mobility behaviour of a person is determined by means of a telephone interview. The respondent answers questions about trips taken during the reporting period. The interviewer simultaneously enters the answers into a database. Here, too, plausibility and completeness checks can be carried out immediately.
- **PAPI – Paper and Pencil Interview**: The paper and pencil interview – that is, the recording of data in a paper questionnaire (usually in the form of a paper trip diary) – is a frequently used method of travel data collection. The questionnaire is usually sent out by post and returned by the respondent in a reply envelope or handed over and collected personally by survey personnel. Data can only be entered and checked once the completed questionnaire has arrived back with the interviewer.

- **CAWI – Computer-Assisted Web Interview**: In a computer-assisted online survey, interviewees report on their mobility behaviour in a trip diary via an online web-based questionnaire. As in the cases of CAPI and CAWI, mechanisms can be employed that allow the surveyor to check the data for implausible or incomplete answers.

With the advent of the marketability of GPS and mobile phone technology, further possible forms of surveying mobility behaviour arose. These techniques allow mobility to be measured more or less directly, thus significantly reducing survey participants' response effort by automatically recording trips. However, the possibility of a proxy interview is no longer given.

- **GPS/GSM-based tracking**: Instead of having the test persons report trips manually, trips can be recorded via satellite. This requires a GPS/GSM-enabled device, which the respondent must carry with him or her for the duration of the survey period. Recent technological developments have resulted in a large number of devices and tracking tools. In general, these can be differentiated according to the type of trip recording. Active tracking requires participants to actively provide additional information (e.g. start/end of a trip, trip purpose). To this end, apps with attractive user interfaces for smartphones must be available in order to motivate the respondents accordingly. With passive tracking, the respondent only has to carry the device with him during the entire survey period (e.g. a data logger or smartphone) and occasionally charge it. Both versions, however, may require the user to manually check the recorded data and correct it if needed, as the technology is not yet fully developed to record all relevant information with sufficient reliability.

There is no standardised method for collecting mobility data across Europe in the context of national household travel surveys (NTSs). The travel surveys currently carried out throughout Europe differ according to their framework conditions and characteristics (sample size, survey frequency, reporting period duration, and definition of target population). The comparison of collected data across national travel surveys, and thus the analysis of mobility patterns, has been limited by the variety of methods used to collect data and by differences in the nature and format of data collected. Table 1 summarises the methodological approach and basic information used to collect NTS data from eight European countries.

Table 1: Basic survey information from eight European NTS (Own figure based on Ahern et al. 2013).

Country	Year of survey	Survey instrument	Sample size/units*	Frequency of data collection	Sampling approach
Belgium	2010	PAPI, CATI	8,532 Hh 15,821 Pe	No regular data collection	Random sample
Finland	2011	CATI, GPS	12,318 Pe	Every 6 years	Random sample
France	2008	GPS, CAPI	20,178 Hh 18,632 Pe	Every 10 years approx.	Stratified, multistage sampling
Germany	2008	PAPI, CATI, CAWI, GPS	25,922 Hh 60,713 Pe	Irregularly	Two stage random sampling with geographically stratification
Spain	2007	PAPI, CATI, CAPI	49,027 Hh 55,955 Pe	Irregularly	Selection of section and households in the Register Office
Sweden	2006	CATI	27,647 Pe	Irregularly	Randomly selected
Switzerland	2010	CATI	31,950 Hh 33,390 Pe	Every 5 years	Randomly over the year with equal probability
UK	2010	PAPI, CATI, CAPI	8,775 Hh 20,839 Pe	Annually	Random sample drawn from the Postcode Address

*Net sample of households (Hh) respectively persons (Pe).

2.2.3 Information content of mobility data

Mobility data obtained through a survey provides information about the mobility behaviour of a person, and subsequently of a household or population. It contains information about the key attributes of all trips – defined as out-of-home changes of location of the target person – within the period being reported. Trip characteristics commonly contain the following attributes:

- **Mode** (Means of transport): The mode chosen for a trip can be changed between trip stages. In general, a distinction is made between four main means of transport: walking, bicycling, PT, and motorized vehicles. There are different hierarchical methods for determining the main mode of a trip if several modes were used within one trip.
- **Trip distance**: Physical distance travelled (depending on the mode used) from the starting point (usually measured from the property boundary from which the person is leaving) to the desired destination.
- **Trip duration**: The duration of a trip includes travel times, waiting times, time spent searching for a parking space, and so on.
- **Start time**: The start time is the time at which a person leaves the last destination that they visited.

- **End time**: The end time is the time at which the person reaches the desired destination (in order to perform a desired activity, as described by the trip purpose).
- **Trip purpose**: The trip purpose describes the intended (main) activity at the destination. Trip purposes are primarily oriented to basic existential functions: dwelling, working (or otherwise business-related), education, shopping, leisure, errands, and other activities.

From the data collected from each person, qualitative basic mobility indicators can be derived, which can be used to describe the mobility of the population:

- **Share of mobile persons [%]**: The share of mobile persons is the share of persons that had at least one trip within their reporting period ("left the house").
- **Trip frequency of mobile person [trips/day]**: This measure describes the average number of trips of all persons per reporting day, usually depicted only for mobile persons.
- **Mode choice [%]**: Mode choice describes the share of trips for each mode ("modal split").
- **Average trip distance [km]**: Average trip distance can be specified per trip or per day.
- **Average trip duration [min]**: Average trip duration can be specified per trip or per day.
- **Distribution of trip purposes [%]**: This measure describes the share of trips according to trip purpose.

Table 2 gives an overview of mobility indicators from NTSs in eight European countries. Both the share of mobile persons in the reporting period, the trip frequency, and the characteristics of the trip attributes vary considerably between the countries.

Table 2: Key mobility indicators of eight European NTS (Own figure based on Christensen and Vázquez 2013).

Country	Share of mobile persons [%]	Trip frequency per mobile person	Distance of trips per day[km]	Duration of trips per day[km]
Belgium	72	3.24	32.8	74.6
Finland	83	3.49	52.3	80.5
France	85	3.64	45.9	78.4
Germany	90	3.89	43.4	96.0
Spain	89	3.61	47.9	68.9
Sweden	83	3.34	54.3	78.9
Switzerland	90	3.35	44.5	74.4
UK	78	3.62	42.5	85.5

Other components of a usual travel survey are questions regarding the mobility tools available to a person or household. These tools determine which options a person is

equipped with in order to meet his or her mobility demands. The tools can include the physical possession of means of transport (such as a personal car or bicycle) or licenses to use a mode (driver's license, discount or time card from a PT provider, membership in a car sharing or bike sharing company). In addition, important sociodemographic characteristics (gender, age, level of education, job status) are usually also surveyed.

2.3 Trends and indicators of mobility behaviour

The mobility behaviour of the Austrian population has changed somewhat in recent decades. The population has become increasingly mobile, but at the same time makes fewer trips. On average, the distances and durations of trips have become longer. Table 3 gives an overview of the state of the most important mobility indicators, comparing the Austrian NTS 1995 with the most recent survey Österreich unterwegs 2013/2014 (Tomschy et al. 2016).

Table 3: Development of the mobility behaviour of Austrians from 1995 to 2013/14[4]

	NTS 1995	**NTS 2013/2014**
Share of mobile persons [%]	82	85
Number of trips per mobile person per day	3.7	3.4
Distance of trips [km]		
Per trip	10	12
Per day	35	41
Duration of trips [min]		
Per trip	23	25
Per day	85	82
Mode choice [%]		
Walk	27	17
Bicycle	5	6
Car driver	40	46
Car passenger	11	11
Public Transport	17	18
Trip purpose [%]		
Work	32	31
Education	15	11
Shopping/ Errands	30	27
Pick-up/ Drop-off [5]	-	8
Leisure/ private visits	21	22
Other	3	0

The authors of the Österreich unterwegs 2013/2014 survey report point out, that it should be taken into account that the sociodemographic population structure of Austria has changed significantly in recent years. Therefore, some of the differences in the main mobility indicators are not due to changes in the mobility behaviour of individual groups of people, but to changes in the composition of the population. In addition, spatial structural conditions (e.g. urbanisation, urban sprawl, more shopping centres on the outskirts of cities) as well as personal mobility needs and available mobility tools (e.g. share of driving licence, car availability) have changed significantly. Reasons for changes in mobility behaviour are therefore manifold and difficult to determine.

What is certain, however, is that the large, multimodal transport offers that have developed in recent decades have led to a greater variety of options in mobility-related decisions, whereby more flexible and multimodal travel patterns can be observed (Kuhnimhof et al. 2006, 2012; Nobis 2007). Furthermore, the distinction between travel and non-travel

[4] The comparison refers exclusively to the autumn results for working day traffic of the 2013/2014 survey, since in 1995 only traffic in autumn and no weekends were recorded.

[5] The 1995 survey did not explicitly identify pick-up/ drop-off trips.

activities has become less definite. Nowadays, activities that used to involve travel (such as shopping or banking) can be done comfortably from home (Andreev et al. 2009, Eboli and Mazzulla 2013). In addition, the delivery service for many consumer segments of the daily life has been greatly expanded. This reduces travel demand and thus the frequency of trips.

The development of information and communications technology (ICT) and their application possibilities in the transport sector strongly contributes to why mobility behaviour should now be viewed from a different perspective than it used to be. Travel time, which is one of the main reasons for the choice of a certain transport mode (alongside other factors such as cost, comfort, and safety), has undergone a major change in its perception. Activities (leisure, work, shopping) can not only – as mentioned above – be done from home today, but it is now possible to combine them in an ICT-based form with travel. This means that travel time – in particular for PT – is assessed differently than it was a few years ago due to the possibility of using ICT on a trip. With the possibility of carrying out a secondary activity using ICT alongside the primary activity of travel, travel time in PT – in contrast to that of other means of transport – is perceived as more potentially usable and productive than before.

From the point of view of mobility behaviour research, trips and non-travel related activities are therefore much more interdependent than they were a few years ago. Accordingly, the inclusion of the non-travel-based time use between trips (henceforth referred to here as activities) is of significant relevance for modelling mobility behaviour in order to understand and predict mobility decisions in the broader context of activity scheduling.

2.4 Data requirements for advanced models of mobility behaviour

In order to measure and predict mobility behaviour, traffic forecasts are used to estimate the future demand for transport, as well as its ecological, economic, and social impacts. The basic measure of mobility behaviour is represented in the theory of individual utility maximisation, based on the formula below. In this formula, B describes the perceived benefit of staying in the origin location i or of a desired activity in the destination location j. The generalized transport user costs, C_{ij}, which are the subjective costs perceived by the transport user for a certain travel decision, become lower with a lower resistance to cover a given distance with the help of the chosen mode m. The resistance differs between the available means of transport and results in a different total utility U for an individual for each available mode.

$$U = \left(B_j - B_i - C_{ij|m}\right) > 0$$

Travel has always been embedded in the overall framework of activities, but this has been ignored for a long time. Recent advanced models account for this relationship. There is fundamental agreement in mobility behaviour research that mobility must be seen in a larger context: in the context of daily activity planning. Mobility and the decisions associated with it are thus seen as a form of time use that exists alongside the use of time for the completion

of other activities (activities that can be categorised into the basic existential functions). So-called trade-off processes take place between mobility and non-mobility related activities. In the sense of the personal maximisation of utility, people are willing to exchange time for activities that they regard as less beneficial in exchange for money, in order to spend more time on activities that they regard as more beneficial. These trade-off processes influence the decision-making behaviour of individuals in mobility matters. The generalized transport user costs C_{ij} are thus subject to a multitude of influencing factors, which can be determined by transport economic behaviour modelling. From the point of view of mobility behaviour research, the time use and the associated trade-off processes are becoming more and more relevant. Through the development of new forms of mobility (Mobility as a Service, automation, sharing concepts), emerging multimodal patterns, and the digitisation and introduction of new forms of communication through ICT lead to an ever-greater variety of options for the completion of everyday trips and activities (Mokhtarian et al. 2006).

A central strand of research in transport economics involves dealing with trade-off processes between transport decisions and individuals' patterns of time use and expenditure assignment. The focus of an individual's decision-making in mobility matters is thus on maximizing utility (e.g. maximizing leisure activities) and minimizing travel time, since the spending of travel time, though necessary, is regarded as less beneficial, or even perceived as a burden. Research questions evolving in the field of time use thus rely on data that goes beyond pure mobility-related information. They demand information that is based on a simultaneous collection of travel-related and non-travel-related data (hereinafter referred to as mobility or activity data). These integrated datasets provide an important basis for advanced behavioural models because travel behaviour can be modelled within the context of individuals' uses of time and the budgets available to them.

Time-use models can be used to quantify and evaluate trade-off processes. These models estimate the willingness to pay for a reduction in travel time, represented by the (subjective) value of travel time savings (VTTS), calculated as shown below (DeSerpa 1971). The VTTS is usually obtained from travel choice models and equals the value of leisure (VoL) – the opportunity cost regarding other activities (leisure or work) – minus the value of time assigned to travel (VTAT) – the value of a reduction of the travel activity by itself (Jara-Díaz and Guevara 2003).

$$VTTS_m = VoL - VTAT_m$$

Together with the $VTTS_m$, which denotes the mode-specific value of travel time saving calculated by a mode choice model and travel data, a time use model is needed to estimate the VoL with time use data. The $VTAT_m$ is the value of time assigned to travel, driven by mode-specific characteristics such as comfort and describing how productively in-vehicle time can be used for secondary activities (Jara-Diaz 2007). Ultimately, research in this area aims at investigating the importance of diminishing travel time compared to improving travel conditions. For a given VoL, the VTTS diminishes as the VTAT increases. That is, the higher

the perceived travel conditions are valued, the lower the willingness to pay to diminish travel time emerges (and vice versa). This can be considered from a policy point of view: if the VoL is the dominating component, one should favour investments in infrastructure that diminish travel time; if the absolute value of VTAT dominates, the conditions of travel should be improved.

Ideally, both travel and non-travel related data sources would be obtained from the same individual over the same period of time. Since both trips and activities have become more flexible and complex, as have the interdependencies between both, increasing interest in this kind of integrated mobility activity data is expected. Many researchers are working to better understand multiple trade-off processes and travel decisions and how these will change in the future. Prominent fields of research besides time use framework models (Jara-Díaz et al. 2008) include social interactions in multi-person households (Ho and Mulley 2015) and substitutive relationships between in-home and out-of-home activities (Srinivasan and Bhat 2005), which all have the potential to heavily affect future travel demands.

What do these developments mean for demand relating to the technology and design of travel surveys? The definition of travel as a form of time use implies that the collection of travel-related activities (i.e. trips) provides too little information for modelling mobility behaviour in the context of daily time scheduling. In any case, an applicable survey design must be able to provide information on both trips and activities. Currently, there are two main revealed preference (RP) -based survey designs that aim to capture travel time and other time use to create such an integrated database. Their general characteristics and their abilities to capture both types of data are described in the following section.

2.5 Formats and techniques for the collection of combined mobility and activity data

2.5.1 Overview and definitions

The following section explains characteristics and extents to which the currently available survey formats are used and are able to meet the requirements for integrated datasets (consisting of mobility and activity data from the same persons). Among the existing survey formats, two different types of surveys are most suitable for providing information on both trips and activities: HTS and TUS (Armoogum et al. 2014). Both are standard elements of data collection in the statistical systems of many countries around the world.

For a national HTS, a sample of the population is asked questions about their trips (often recorded in a diary) over a fixed period of time before the survey. Information about the activities at the destination of each trip can be derived from the trip purpose. From a conceptual point of view, however, the trips are only part of all possible daily activities. In other words, information on mobility can also be obtained from knowledge of peoples' daily

uses of time in the form of a TUS. Analyses of daily activities via TUSs also make it possible to link mobility behaviour with the use of time and other resources. The data on time use from TUSs is therefore an alternative source of information on mobility and activities. Both formats are able to collect both types of data, but in different qualities, as they are designed for different applications. Both survey formats thus have different strengths, weaknesses, and limits in their fields of application.

It should be mentioned that an important component in transport economics research is the consumer behaviour of persons and households. For a comprehensive approach to the above-mentioned fields of research, surveys on mobility and activities should therefore also provide information about the expenditures of private households to monitor general household living standards, well-being, and consumption patterns. Knowledge on expenditures is of great importance because the ratio between the utility of time over the utility of income (μ/λ) is a key indicator of the value of time. Estimating the utility of income (the denominator) requires knowledge about labour income and expenditures.

Survey formats that are able to obtain data on expenditures required for answering transport economic questions are not listed here. As this survey format represents a non-standardised process and provides additional rather than essential information on mobility and activities, it will not be discussed in detail below. Surveys on expenditures are national surveys that mainly focus on consumption and spending behaviour and generally do not include additional information on mobility and activities. In addition, different designs and standards exist depending on the country of origin, for example, Consumer Expenditure Surveys (CESs) in the USA or Household Budget Surveys (HBS) in EU member states. Neither HTSs nor TUSs usually provide information on expenditures, and furthermore, both usually have short observation periods of one or two days, which is not sufficient for considering the allocation pattern of expenditures as a representation of an individual's long-term equilibrium.

2.5.2 Survey formats with a focus on travel-related activities: travel surveys

Travel survey methods have undergone enormous changes in recent decades. Originally conceived as mainly face-to-face interviews in household or field surveys, these methods were soon applied as only one of many options in NTSs because of their lack of widespread applicability (Griffiths et al. 2000). Since the 1970s, when the first national and municipal travel surveys were implemented, methods for surveying travel behaviour have been continuously improved. Travel surveys are usually cross-sectional surveys with the household being the usual sampling unit and the survey duration being one diary day. Surveys that run over several days to uncover patterns in mobility behaviour are the exception. The German Mobility Panel (MOP) and the British National Travel Survey are examples of multi-day NTSs. Surveys that go beyond the usual reporting period of one or two days are mainly used in research projects to answer specific questions (Chalasani and Axhausen 2004). Further

examples are given in Stopher et al. (2008). Today, mixed-mode survey designs represent the state-of-the-art in travel surveys, as they use combinations of traditional and modern methods (see Section 2.2.2). The most recent Austrian NTS (Tomschy et al. 2016), which was conducted in 2013/14 based on the KOMOD-guidelines, offered PAPI, CAWI, and CATI-based opportunities to participate.

The use of GPS in HTSs has been tested since the end of the 1990s (Wolf 2006), but has not been able to establish itself as the only method of data collection. The inclusion of GPS/GSM-based survey technologies in NTSs is currently still in the pilot project phase to test how well these methods are suited to be part of a mixed mode survey design (Stopher and Greaves 2007). Technology-based surveys make use of the increased availability of location-enabled mobile devices and aim at improved accuracy of reported trips in terms of numbers, durations, and tours[6]. Although these methods have a demonstrably high information content and can significantly reduce the response burden for participants, there are, as with the other methods, problems of representativeness and of the unwillingness and inability of certain population groups to participate (unit non-response errors). Technology-based surveys are thus applied in research projects with mainly non-representative convenience samples (Kopp et al. 2015, Berger and Platzer 2015). Armoogum et al. (2014, see also Cottrill et al. 2013, Shen and Stopher 2014) gives an overview of pilot studies for the integration of GPS-loggers and smartphones into representative NTSs. There have been many discussions about whether GPS-enabled survey designs are able to overcome the sampling issues (Stopher et al. 2007) and survey fatigue challenges faced by multi-day diary surveys (Rizzo and Gregory 2016) that have come to mixed conclusions. The lack of representativeness of GPS-based travel surveys, together with the less than 100% recognition of the transport mode and trip purpose and the associated high level of necessary post-processing work by the survey participants are major limitations of this survey method so far.

In general, HTSs provide detailed information on travel activities, but activities are only roughly captured by the trip purposes. It is possible only to infer from the trip purposes of persons with at least two trips on the diary day the type of the subsequent non-travel activities involved. Trip diaries do not give any information about the activities before the first and after the last trip, and about persons with no trips on the diary day. Advantages of HTSs are their clear focus on the movement of travellers and related information, including transport modes, trip distances, the spatial context and locations of origins and destinations for each reported trip, the weather on the diary day, and the availability of mobility tools in general and on the diary day. On the downside, the linear increase of response burden with the number of reported trips encourages soft refusal – that is, deliberate non-reporting of trips in order to save effort (Gerike et al. 2013, 2015).

[6] A tour (sometimes referred to as a trip-chain) is defined as a series of trips that begin and end at an individual's home.

2.5.3 Survey formats with a focus on non-travel-related activities: time use surveys

The purpose of TUSs from the very beginning of their use has been to understand the lifestyles of people, including their social lives, based on their patterns of time use. Time use surveys were used specifically to depict those areas of peoples' lives for which no information was available from conventional data sources, such as national income statistics, labour and employment statistics, population statistics, and so on. From the point of view of research on social justice in the second half of the 20th century, an additional need was felt to measure the value of unpaid labour in order to estimate the contribution of unpaid work to human welfare (Hirway 2000). Thus, time use surveys can also be seen as a fundamental research instrument for bringing a gender perspective to planning activities.

Time use surveys provide detailed information about any activity throughout the entire day, which can include the type, location, and duration of each activity. Standards for time use surveys have been continuously developed. The state-of-art follows the methodological requirements of harmonized European time use surveys (HETUS) (Eurostat 2004, 2009; UNECE 2013). The Eurostat guidelines give recommendations on the sample design, diary days, survey forms, activity coding lists, interviewers, data coding, and estimators. Eurostat suggests that the member states use a self-administrated diary to record data in 10-minutes intervals. In 2008, revised guidelines were published. However, the time use data of European states are not yet fully comparable (UNECE 2010). National surveys are still mainly based on self-administered mail-back solutions, which are recommended by HETUS guidelines. In order to seize the potential for recruiting additional groups and for collecting new types of data, current research projects have been experimenting with online questionnaires and mobile devices (Sonck and Fernee 2013, Minnen et al. 2014).

Time use surveys usually consist of a diary format in which each line corresponds to one time-interval of a given period, preferably 10 minutes. For each of these intervals, respondents are asked to report the main activity (and sometimes the parallel executed secondary activity), the location, and additional persons with whom the activity was carried out. Therefore, travel-related activities are depicted just as any other non-travel activity type, but additional attributes, such as the mode, are asked for. However, the travel-related information obtained from TUSs is rarely sufficient for common travel demand models such as mode choice or route choice models, as factors such as trips distances are usually not asked for. The 10-minute interval provides only a rough grid for analysing short (temporally speaking) trips but gives a comprehensive overall picture of both travel activities and non-travel activities (Gerike et al. 2015). Open interval diaries exist, but they are more difficult to code and process.

With regard to the reporting period of a TUS, HETUS guidelines recommend that two diary days should be reported: one weekday and one weekend day. Recently, attempts have been made to apply time-use diaries, which cover a longer reporting period (Glorieux and Minnen 2009). The HETUS guidelines contain standards for activity classification and minimum lists

of activity categories for the case when open text fields instead of fixed activity categories are used (Eurostat 2009, UNECE 2013). The trip purpose as such can be identified according to the activities following the travel activity.

The most recent Austrian time use survey was conducted in 2008/09 by STAT and used a diary based on the HETUS guidelines (Ghassemi and Kronsteiner-Mann 2009). The self-administered survey is based on HETUS guidelines (Eurostat 2004, 2009, UNECE 2013). The survey material was personally delivered before the assigned diary day and collected afterwards by trained staff. The PAPI activity diary has one line per activity episode, including information about main and parallel activities with open text fields instead of pre-defined activity categories. The activities are reported for one day using 15-minute intervals.

2.5.4 Comparisons of travel and time use surveys

Both approaches have different strengths and weaknesses in capturing travel activities and non-travel activities comprehensively and reliably. The advantage of HTSs is its clear focus on capturing all travel-related information: their stages, trips, tours, and respective attributes, as well as the availability of mobility tools such as public transport season tickets, private cars, and car sharing memberships. Important information typically provided by HTSs but not by TUSs includes (i) spatial patterns, such as origin and destination, and (ii) detailed information on the chosen modes. However, HTSs do not record details of the activities between the two movements, but rather aggregate them into a general trip purpose, and secondary activities cannot be obtained. There is no information about in-home activities, which affects information on immobile people and those who spend a lot of time at home.

Time use surveys provide a more comprehensive assessment of travel in general, as there is no reason for soft refusal. Item non-response is more likely in travel diaries because it is an easy way for the respondent to reduce the response burden (Hubert et al. 2008, Van Wee et al. 2006). It is to be expected that respondents will report their activities including travel more accurately and completely compared to in HTSs. In general, TUSs provide a very thorough description of activities with their detailed classifications system and simultaneously record secondary activities as well as the presence of other persons. The design does bring the danger of misinterpretation of the respondent: activity sequences of trips without non-travel activities in-between can turn out to be sequences of trips and non-travel activities, in which both were merged into one activity episode (Gerike et al. 2015). In addition, TUSs usually do not satisfactorily cover the spatial aspects necessary for transport modelling. Time use surveys are rarely used in transport research because the prescribed interval impedes accurate data collection for short trips and because of missing information about locations, spatial context, and car availability. For example, the interval format can lead to underreporting of trips shorter than the prescribed interval.

Item non-response issues in HTSs and TUSs have been widely investigated, focusing on the number of missing trips and their characteristics (Hubert et al. 2008, Gerike et al. 2015) and

also, though less, on the frequency and duration of different types of activities. It should be noted that the literature also investigates the impacts of survey design on travel estimates based on the applied method (for comparisons within different HTS methods, see Ampt and Stopher 2005, Chlond et al. 2015; for comparisons between GPS-based and non-GPS-based HTSs, e.g. CATI and GPS-based travel surveys, see Bricka et al. 2012) and non-response issues (for non-response studies that are carried out subsequently to main HTS studies with the same sample, see Brög 2015, Brög and Meyburg 1980, Richardson 2003, Wittwer and Hubrich 2015), but these do not directly compare and evaluate characteristics of both HTSs and TUSs. Below, a detailed comparison of HTS and TUS travel estimates by various indicators is listed.

- **Share of mobile persons**: There are different findings in the literature on the extent of immobility in both survey formats. In Hubert et al. (2008), the number of immobile persons reported in HTS diaries was found to be twice as high as that reported in TUS diaries. It is assumed that the level of soft refusal in HTS diaries accounts for this difference. Gerike et al. (2013) found similar immobility rates for German HTSs and TUSs. They concluded that high-quality HTSs and TUSs yield similar immobility rates, and that the differences found, for example, in Hubert et al. (2008), result from differences in field work quality in addition to the methodological differences between TUSs and HTSs.
- **Trip frequency of mobile persons**: Findings in differences in the number of trips found by HTSs and TUSs are also not consistent. There are studies that show on average greater numbers of trips in TUSs compared to HTSs (e.g. Stopher 1992, Harvey 2003), but other studies find no such differences (Bose and Sharp 2005, Ironmonger and Norman 2006, Hubert et al. 2008, Nakamya et al. 2007). Gerike et al. (2015) compared NTSs and TUSs in Germany by including location changes without a trip recorded in the diary in their analysis. The authors found consistently higher numbers of trips per person and per day in the NTSs for all socio-demographic groups if location changes without trips were not considered for TUSs. However, they found that there were similar number of trips recorded in NTSs and TUSs if location changes without trips in TUSs are treated as trips. The TUS format often results in an odd number of trips per person and day (Gerike et al. 2015, Hubert et al. 2008, Stopher 1992). The reason for this effect might be that the travel diaries perform better in encouraging respondents to remember and reports trips both to a destination and back home compared to TUS diaries.
- **Trip purposes**: Differences in trip rates between TUSs and HTSs are higher for discretionary (leisure) trips compared to subsistence (work, education) and non-discretionary (e.g. shopping, errands) trips (Bose and Sharp 2005, Gerike et al. 2015, Richardson 2007, Stopher 1992).
- **Mode choice**: With regard to mode choice, Gerike et al. (2015) found significantly higher trip numbers in HTSs for walking, cycling, and public transport, but no

significant differences in numbers of car trips. Bose and Sharp (2005) found a close correspondence between TUSs and HTSs except for in walking. The authors attribute the difference in walking to the comparison methodology.

- **Trip duration**: The literature consistently reports higher average travel times in TUSs compared to HTSs (Gerike et al. 2015, Harvey 2003, Hubert et al. 2008, Richardson 2007, Vilhelmson 1997, Yennamani and Srinivasan 2008). For example, using Swedish TUS and HTS data, Vilhelmson (1997) calculated an average difference of 12 minutes travel time per person per day between the two surveys. For France, Belgium, and Great Britain, Hubert (2003, 2008) calculated differences in daily travel times of 10, 20, and 30 minutes respectively, with consistently higher daily travel times in TUSs compared to HTSs. Yennamani and Srinivasan (2008) found only slightly higher or similar daily travel times in HTSs, but variations between socio-demographic segments. The difference is largest for younger persons and smallest for males, low-income persons, and persons with lower levels of education. In general, researchers have found more heterogeneity in HTS compared to TUS data (see Hubert 2003 for similar findings). Hubert (2003) furthermore found that TUSs, HTSs, and a simulated HTS diverged less for employed persons and weekday data and more for persons with lower levels of education. They suggest that work trips are easier to conceptualise and report and are therefore equally well captured in both surveys. Gerike et al. (2015) compared the duration of individual trips in HTSs and TUSs. They showed that rounding effects resulting from the 10-minute intervals in the TUS are the main reason for the higher daily travel times in TUSs for German TUSs and HTSs. However, one needs to take into account that research also shows rounding effects for HTSs with 5-minute intervals for start and end times even though respondents are asked for exact times.
- **(Non-travel) Activities**: Gerike et al. (2015) computed the duration of non-travel activities both from HTSs (only for persons with at least two trips on the diary day) and from TUSs. The activity durations for HTS were calculated based on the trip purpose. Only activity durations for the time between the end of the first trip of the day and the start time of the last trip of the day were included in the analyses for both HTSs and TUSs. The results show a decent correspondence between the two surveys for subsistence activities. In the TUS, 35% of the time between the first and the last trip was spent on work activities, and 10% was spent on education (HTS: 36%, 9%). The share of shopping activity duration is fairly similar in both datasets. Differences in the other non-discretionary activity types result mainly from two factors: first, coding schemes differ between the two datasets. There are no care, voluntary, and personal care activities in HTSs, and there are no activities that describe accompanying trips in TUSs. Second, the activity in HTSs that follows each trip back home cannot be clearly assigned to any of the activity types. The share of leisure activities is 24% in TUSs, significantly higher than in HTSs, talking up 20% of the

time between the first and the last trip. These findings show that we can reliably infer subsistence activities from HTSs, but only for respondents with at least two trips and only for the time between the first and the last trip.

3 Research framework

3.1 Development of an integrated diary format and survey design (MAED)

A combined trip and activity dataset with a broad range of modelling applications places high demands on the corresponding survey format and method to be used for this purpose. The data collection formats described in the literature may, in general terms, meet these requirements only insufficiently: mobility, like many other activities (sleeping, eating, working), is subject to a daily and weekly rhythm. The instruments of conventional survey methods include diaries whose reporting periods are mostly limited to one or two reporting days in order not to strain the participants' response burden. This means that interactions and trade-off processes between mobility and activities cannot be depicted to a sufficiently timely extent, as week-based rhythm fluctuations are inadequately represented.

In order to fully understand the trade-off processes between travel and non-travel activities, more comprehensive information on the allocation of time to all kinds of activities as well as longer observation periods are needed, which cover not only the daily but also the weekly rhythms of individual time-use. This requires a survey format that reliably captures a high-quality dataset (with as low as possible item non-response) on mobility and the activities of persons in the same survey period in order to depict their equilibrium states.

These conditions were taken as an opportunity to initiate the development of an innovative questionnaire format. For this purpose, an approach was chosen that tried to combine the above-mentioned advantages of the two techniques used separately in their original form: travel surveys and time use surveys. The resulting information content should also include indispensable information on consumption behaviour for the short and long-term expenditures of the participating persons, which is usually collected in CESs. Elements from all three survey areas were combined in an integrated questionnaire format – the mobility-activity-expenditure diary (MAED) – to meet the stated requirements. The overall aim for developing a novel survey instrument was to obtain a dataset that includes all required components to model travel behaviour within the framework of consumers' home production according to the transport economic models described in Jara-Diaz et al. (2008).

In doing so, the stand-alone diaries of the three formats were simplified and re-arranged in order to achieve an integrated PAPI diary format with the following features.

- The overall diary structure resembles a conventional travel diary that is specialized in the exact collection of trips and their respective attributes; between each set of trips, all activities at the destination (i.e. all non-travel activities) are reported. This approach embeds travel firmly into the overall daily schedule.

- The activities are reported in open time intervals and pre-defined categories. The questionnaire did not ask for parallel activities (so-called secondary activities, which are frequently asked for in time use surveys).
- Questions on expenditures that occurred during trips or activities are placed within the respective sections of the diary to achieve an intuitive and self-explanatory scheme, with travel expenses in the trip section and expenses related to non-travel activities in the activity section.

The development process of the design included two field studies and a pre-test, based on which the design of the questionnaire was optimized. In each step of forming the final design, the levels of detail of the three approaches (mobility, time use, and expenditures) were modified in order to identify a design that best serves the purpose of this study.

The final structure of the diary (Figure 2) is structured in such a way that each trip is reported on the upper half of a separate page. The attributes of each trip are requested according to the KONTIV design. After specifying the address of the destination, all activities carried out at the destination are indicated line by line in the lower half. The activities are indicated until the test person leaves the location and begins a new trip, and thus has to switch to the top of a new page of the diary. A MAED questionnaire included 51 generic trip-activity pages to provide enough space for all of the trips and activities in a one-week survey period. A completely filled-out diary should consequently show a gapless, 168-hour succession of travel and non-travel activities. The survey was supplemented by a household questionnaire sheet in which the household's socio-demographic characteristics, mobility options, and long-term household expenditures were queried.

3.2 Carrying out the MAED survey

The main MAED survey was conducted in in spring and autumn of 2015. The sample was based on a random selection of Austrian households for 18 pre-defined strata arranged by region and level of urbanisation (urban, intermediate, and rural). In order to maximize the willingness to participate through direct personal motivation by phone calls, phone numbers of the sampled households were researched and added from the Austrian phone book. These were available in about 50% of the sample's addresses.

Numerous quality assurance and improvement measures were implemented in the process for the MAED main survey. Although the survey procedure followed the KONTIV design (Fellendorf et al., 2011, Socialdata 2009), minor modifications had to be made:

- Due to the expected high response effort, financial compensation in the form of a €40 incentive had to be introduced in order to minimize total (unit) non-response.
- Only employed persons were eligible to participate in the MAED survey because a wage rate was needed for modelling the above-mentioned trade-off-processes between time and money. Participants were identified through a screening phase.

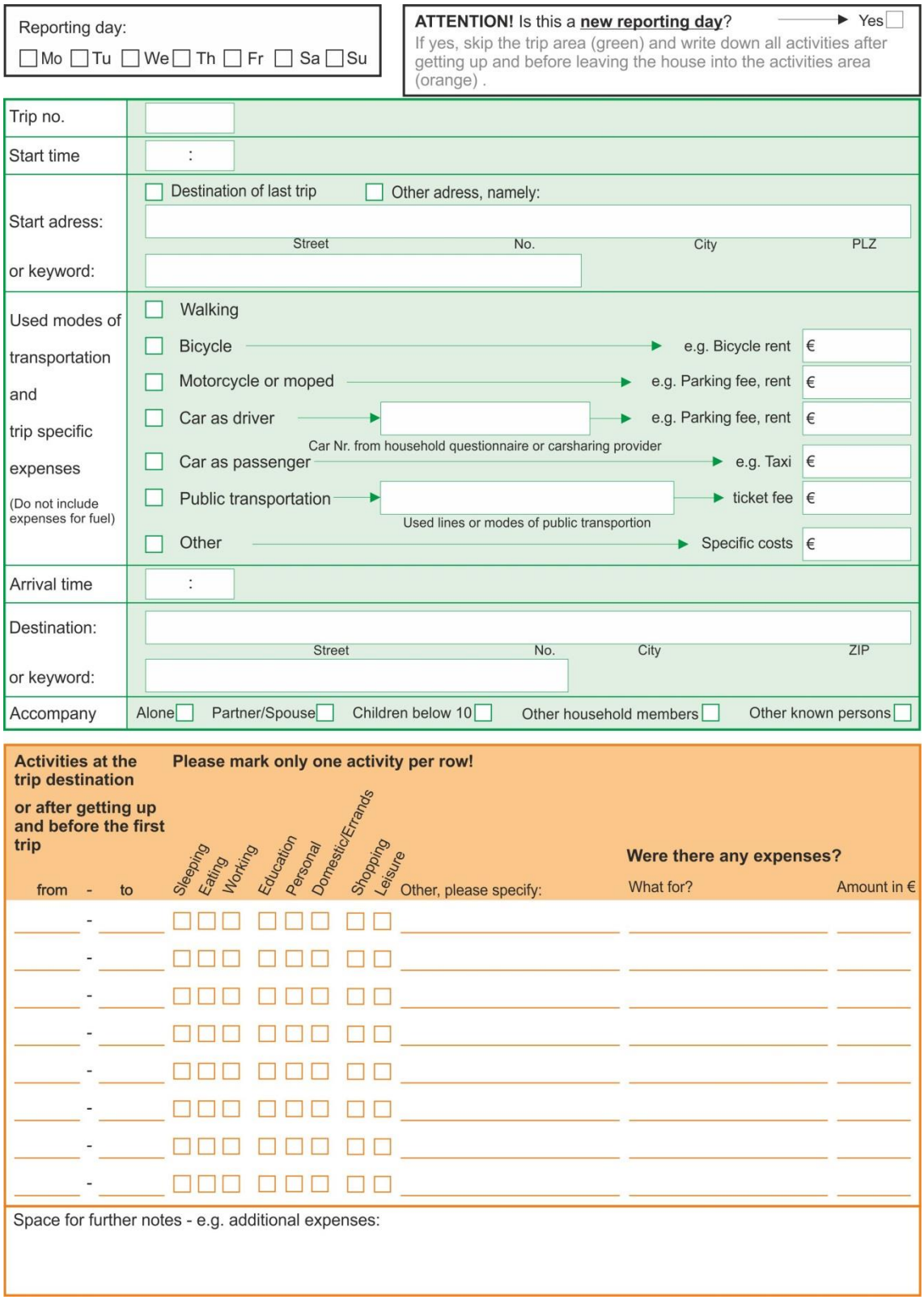

Figure 2: The final MAED design

The survey took place in spring and autumn in order to be able to depict the participating persons under as average conditions as possible, that is, in a situation unaffected by any kind of holidays. A total of eight survey waves took place in order to achieve a temporal and spatial dispersion in the targeted net sample. Over the duration of the survey, 12 persons

worked in the survey team. The generic survey procedure per respondent is shown in Figure 3. In a first step, an announcement postcard was sent to the sampled households. A distinction was then made according to the availability of a telephone number for the household:

1. Households with a telephone number received a motivational phone call two days later. In this phone call, employed persons were identified though a screening question about the employment status of all household members. Selected persons were asked whether they would like to receive the survey material.
2. Households without a telephone number were at first asked via an announcement postcard to provide their contact details with an enclosed postal reply card. In addition, they were informed of the restriction of the survey to employed persons. The households that replied received the survey material and were treated similarly to the households with an available telephone number from then on.

Given the large amount and high complexity of the information demanded in the survey, all households participating in the survey were contacted via phone during their scheduled reporting week to provide individual personal support. Returned questionnaires were registered and underwent data entry and plausibility checks within the next days. Missing or inaccurate data on the questionnaires was validated by another phone call. When data entry was completed, thank-you letters were sent out containing an incentive of €40 for every member of the household that had taken part in the survey.

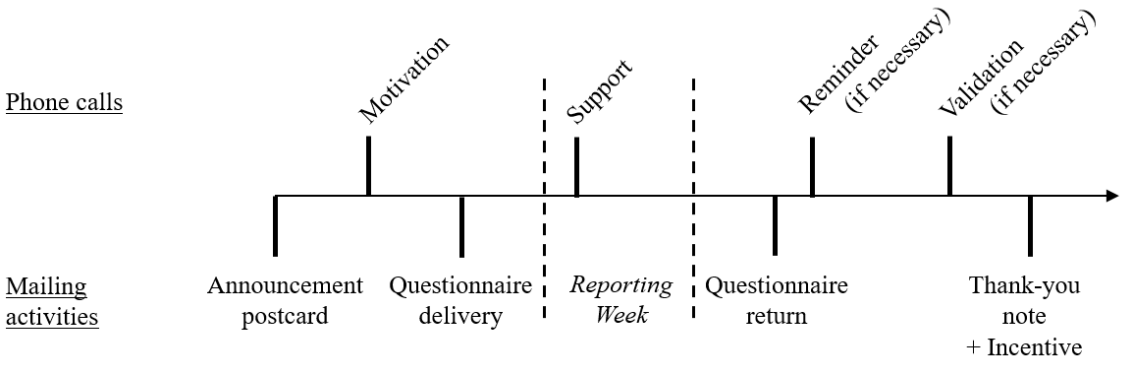

Figure 3: MAED survey procedure

After the data cleaning was finished in January 2016, a dataset was obtained consisting of 748 complete personal entries from 490 households that had participated. The overall response rate was 9.8%, or 11.9% with regard to the adjusted gross sample. The number of households that agreed to take part in the survey during the recruitment phase was 2.5 times higher when subjects were motivated by phone rather than by postal invitation.

3.3 The MAED survey as a quality benchmark for existing survey designs

In the development of the MAED questionnaire and the corresponding survey format, the prerequisites were created in order to guarantee the generation of a dataset of high quality that was suitable as a basis for modelling for the transport economic questions mentioned above. Since the completion of the MAED survey, the prepared dataset has been used in several research approaches dealing with the valuation of time on work, leisure, and time assigned to travel. For more information on this branch of research, see Schmid et al. (forthcoming), Hössinger et al. (forthcoming), and Jokubauskaite et al. (forthcoming).

However, the MAED dataset offers a further advantage: since it should deliver a reliably high quality of data due to its numerous quality assurance measures, it can be assumed to represent a one-of-a-kind combined trip-activity dataset. Due to its completeness, it can be considered to be highly representative combined data on trips and activities, as it records these with high accuracy and minimises item non-response error through its design. This assumption of a high data quality is justified for three reasons:

1. The MAED survey includes support for the participants by phone during their week of reporting as well as extensive validation similar to the New KONTIV Design for HTSs (see Brög and Meyburg 1982, Brög et al. 1981, Brög and Meyburg 1980).
2. Trips are reported in the context of the daily schedule of respondents' activities, so respondents are better able to recall trips and cannot draw an advantage from soft refusal (Gerike et al. 2013, 2015).
3. Survey respondents received an incentive after successful participation and were thus motivated to fill out their diaries carefully and comprehensively.

On the basis of the assumption that MAED collects data that is as close as possible to reality, the dataset can be used as a reference dataset for the evaluation of data from existing national survey procedures. Traditional disciplinary approaches in the form of other survey formats that also provide trip and activity data as outputs (such as HTSs and TUSs) can be measured qualitatively and quantitatively by comparing them to MAED to enable in-depth non-response analyses. For transport planning, this opportunity can be considered of particular relevance for the following reason.

The MAED survey design does not show suitability for "everyday use" as a (national) household travel survey (as discussed in Section 5). In the future, transport planning and behavioural research will depend on data from existing survey formats that are regularly carried out with reasonable amounts of effort. In view of the above-mentioned transport economic relevance of combined datasets, the data collected from traditional approaches should provide as comprehensive a source of information as possible on trip and activity data for transport planners and policy makers, which is why it is important to be able to assess the quality of these traditional approaches. This methodological approach, which depicts the core elements of this thesis, can eventually contribute to the advancement of methods for imputing non-reported trips and activities into standard travel and time use surveys, and thus to enhancing the data basis used for transport modelling and planning.

4 Overview of the enclosed publications

4.1 Authorship Statements

The author submitting this dissertation is the first and main author of three selected research articles (see Part II – Selected Publications) that were published in professional peer-reviewed journals in the research field of transportation. The procedure was the same in all three cases: The results of each individual work of research were submitted at different times of the process as contributions to scientific conferences and confirmed for presentation. An invitation to submit a full paper followed each conference. The submitted articles were accepted in all three cases and published in the respective journals. Together, they form the core and formal requirements of this cumulative dissertation.

The author led the literature reviews, conceptual frameworks, and empirical analyses of all three articles. The co-authors added valuable contributions as they co-authored subchapter parts of each paper, added important references from the literature, proofread, discussed, and approved the submitted articles. They also supported the main author during the revision process of each submitted article.

4.2 Summary of Research Article 1

Aschauer et al. 2018a

The first article in this dissertation was written after a presentation of the first interim results of the MAED survey at the 14th International Conference on Travel Behaviour Research in July 2015, held in Windsor, UK (IATBR 2015). It was thus submitted based on preliminary data while the MAED survey was still ongoing. As part of the revision process, the article was updated with the final MAED data. The article was published in a special issue of *Transportation* on the IABTR 2015 in 2018.

The article starts with a brief theoretical outline of VTTS and the need to integrate travel decisions into the larger framework of time assignment and consumers' home production (Munizaga et al. 2008, Jara-Diaz et al. 2008)), as well as an overview of the models by Jara-Diaz (1998), which model travel decisions based on random utility theory. It is made clear that the data needed to estimate such models must necessarily include information on travel and non-travel-related activities as well as on the spending behaviour on goods consumption of the subjects over a period of time. The literature describes the current state of surveying practices for obtaining the required data. It examines formats that are theoretically capable of (separately) collecting such data (travel surveys, time use surveys, and consumer expenditure surveys) and their methodological characteristics. Subsequently, the development of the MAED questionnaire design is described, including the results of the pilot studies and the pre-tests that contributed to the adaptation of the design and the

planned survey process as well as the final MAED design. The following section contains a short field report that contains the survey procedure, the corresponding response rates, and the considerations regarding the incentive pay out date and amount.

The results section presents the quantitative results of the MAED survey. The sample characteristics of the MAED sample at the personal and household levels are compared with data from the Austrian national census, mobility and activity indicators with the ANTS respectively the ATUS data and data on expenditure with the latest Austrian CES. In general, it can be said that the MAED survey has the same representativeness problems (too many well-educated people, too few young people, etc.) that occur in other travel surveys. The comparison of the mobility data shows that trips have been captured well by the MAED survey. They show a higher share of mobile persons and a higher trip rate for mobile persons, which indicates that trips were recorded with a higher accuracy than that of the ANTS. The results of the comparison of the shares of different activity types show that the distribution of time use from both surveys is very similar. The distributions of the different expenditure categories between the MAED and the Austrian CES also show great similarities, but there are systematic fluctuations in some categories due to the (too short) survey duration of only one week and the lack of plausibility checks in the MAED expenditure survey in the household questionnaire.

In sum, the MAED dataset yielded a more accurate and consistent dataset for modelling travel behaviour within the framework of consumers' home production than any existing survey. It thus is an appropriate tool for researchers who are interested in an in-depth analysis of the trade-off processes between mobility decisions and time use.

4.3 Summary of Research Article 2

Aschauer et al. 2018b

The second article examines non-reporting effects in HTSs with the help of the MAED data, which serves as a comparative dataset. This article was submitted to the *European Journal of Transport and Infrastructure Research* in September 2016 following a presentation of the results at the 5th annual symposium of the European Association of Research in Transportation in Delft (hEART 2016) and published in 2018.

In this article, the MAED survey and the Austrian NTS 2013/14 are compared with each other and subjected to an in-depth investigation in order to examine non-reporting effects based on the methodological differences between the two surveys. The MAED survey is considered ground truth (based on the assumption explained in Section 3.3) in this comparison. For a correct comparison of the two data, the datasets were matched based on several personal characteristics of survey participants. The analysis covers the following three areas.

The identification of expected non-reporting effects in travel estimates in the ANTS

Since the MAED dataset was expected to be much more complete in terms of trips and activities due to its methodological advantages, a direct comparison of various travel estimates intended to uncover those trips that participants usually forget to report in HTSs, due to their methodological characteristics.

The results show that in the ANTS, underreporting of trips take place on two levels: (i) too many people reported no trips in the ANTS (immobility) (the share of mobile persons in the MAED was 92% vs. 89% in the ANTS) and (ii) mobile persons have too low a trip frequency in the ANTS (average trip frequency in the MAED: 3.81 vs. average trip frequency in the ANTS: 3.59). This means that certain trips were underreported in the ANTS. Common characteristics of unreported trips could be determined: short trips (< 5 km) in the afternoon-peak and medium-distance trips (5 - 20 km) in the morning-peak followed by short non-travel activity episodes (< 10 minutes) were the most commonly underreported.

Analysis of speed-of-response effects on travel estimates

Since both surveys provide detailed documentation of their fieldwork and the corresponding response variables of fieldwork are available, the so-called speed-of-response analysis of travel estimates (Brög and Meyburg 1981, Brög et al. 2009) was applied, which focuses on trip rates as fundamental indicators of travel behaviour. An attempt was made to relate the methodological differences in both surveys to mobility indicators in terms of their participants' response times.

The MAED survey showed no significant relationship between the trip rate and the overall response time, and furthermore, no evidence was found for self-selection. In contrast, the ANTS was found to have a decreasing effect of the response time on the trip rate: later respondents showed decreasing trip rates. The effect itself was weak but significant. Self-selection of a reporting day (a methodological weakness in HTSs) or actual different travel patterns remained possible reasons for this non-reporting effect.

Assessment of the completeness and accuracy of non-travel activities inferred from the trip purposes in the HTS

The MAED dataset has a more detailed record of activities compared to the ANTS, where this information can only be induced from trip purposes. This methodical advantage is used to check the quality of the ANTS information on the number and duration of activities.

The analysis showed that, if only persons who took least two trips on their reporting day are considered, there is a decent correspondence between activity durations in the MAED survey and the ANTS. A disadvantage of ANTS is the missing information on activities at home: home-based activities are not specified by type in ANTS. The analysis showed that ANTS could be used to gain reliable data on activities, however, the limitation is that no information is available for home-based activities, which accounted for 64% of the total time reported on and hold essential information for activity-based models.

The article concludes that the ANTS is well able to survey trips and activities at a high level of quality but recommends that future ANTSs should consider implementing data validation methods in the survey process to increase data quality and overall efficiency. In addition, the results of the analyses should be used to advance methods for the data processing of ANTSs: the data imputation must concentrate on correctly supplementing the proportion of mobile persons and typically underreported trips.

4.4 Summary of Research Article 3

Aschauer et al. 2018c

In the third article, the ATUS 2008/09 dataset was included in addition to the ANTS in order to compare it with the MAED dataset and to extend the analysis of non-reporting effects to another survey format. The results of the analyses comparing the three different survey formats were first presented at the 11th International Conference on Transport Survey Methods in September 2017 (ISCTSC 2017) in Estérel, Canada. They were then published in the form of this article in the conferences' *Transport Research Procedia* in 2018.

The overall aim of the article was to better understand the specific strengths and weaknesses of HTS and TUS formats in terms of quantifying travel and non-travel activities, as well as how reliably it is possible to infer trips and activities through different indicators from both survey types. Different specific underreporting effects for travel can be expected in both survey formats. The work was thus based on the research method of the second article, but with a stronger focus on the identification of underreporting effects in trips and activities (one of the second articles' three areas of research), in this case, for two survey formats.

Here, too, the data of the three surveys were matched based on personal characteristics in the course of data preparation. A special feature of the data preparation was the imputation of the trips in the ATUS dataset: the available binary location information of the data (home or not home) was used to impute missing (non-reported) trips where the location had changed without a trip being reported in-between. This led to two ATUS datasets being available for the comparison of the data: one without and one including imputed missing trips.

For travel related data, the ANTS showed the same underreporting characteristics as in the second article: short trips were underreported in the afternoon, mainly shopping trips as well as trips with short subsequent activity durations. The ATUS showed conflicting error results regarding travel estimates: without the imputed trips, it showed even stronger underreporting than the ANTS. With the imputed trips included, the indicators showed even higher values than those of the MAED dataset, both for the shares of mobile persons (MAED: 93%, ANTS: 90%, ATUS: 87%, ATUS with imputed trips: 96%) and for the trip rates of mobile persons (MAED: 3.73, ANTS: 3.44, ATUS: 2.96, ATUS with imputed trips: 3.92). This suggests that for the high values of travel estimates in the ATUS dataset including imputed

trips, either a) the ATUS dataset actually depicts the mobility behaviour of the participating persons better than the MAED (when the missing trips are imputed) or b) the question should be asked whether the binary location variable in the ATUS questionnaire is a reliable indicator of location changes to serve as a basis for trip imputation.

The quality of the ANTS and ATUS activity data differs significantly. Activity data from the ANTS contain: (i) no frequency of episodes and only the total duration of the main activity between any two trips, (ii) no information about the types of activities performed at home, and, thus, (iii) no information at all about immobile persons. If the ANTS is compared to the MAED and the ATUS at the same level of aggregation (main activity duration of persons with at least two trips), the results correspond well. The ATUS, on the other hand, like the MAED, gives a very detailed representation of the activity behaviour of individuals. They both describe the number and duration of in-home and out-of-home activities. ATUS gives a more detailed representation of the sequence of activities but fails to correctly depict trip-related activities without the support of imputation.

The article concludes with the recommendation to review the data quality of collected HTS and TUS data and to compare them with other datasets in order to prove the transferability of the insights gained for the particular sample of employed persons in the MAED data. However, the results so far can be used for ex-ante improvements of both of the analysed survey methods. The main goal should be to optimize the output of each survey design, as these designs will continue to be used in the application for which they were originally designed. Through the development of imputation methods based on the results of this study, additional ex-post quality assurance measures can be taken.

5 Summary and outlook

The main motivation of this cumulative dissertation was to report the implementation and methodological analysis of a newly developed travel and activity survey design called the mobility-activity-expenditure diary (MAED). It consists of three data collection formats that have been combined in order to obtain a dataset with the specific strengths of each format: (travel-related) data on mobility from travel surveys, (non-travel related) data on activities from time use surveys, and expenditure data from a consumer expenditure survey. The latter format is not part of the scope of this thesis. The MAED design was developed to obtain a dataset that includes all required components to model travel behaviour within the framework of consumers' home production (Jara-Diaz et al. 2008). The survey, which applied the MAED design for the first time, was conducted in 2015 and provided a dataset consisting of travel, activity, and expense data from 748 persons, all of which was collected simultaneously over a reporting period of seven consecutive days. The integrated MAED survey performed well and delivered all queried information at acceptable response rates.

Within this thesis, the MAED dataset has been used for a study of survey methods based on the high data quality achieved by the numerous quality assurance measures applied during the survey phase. The study aims at evaluating the data quality of the MAED dataset by comparing it with datasets from other survey formats that provided both travel and non-travel activity data: household travel surveys and time use surveys. At the same time, the study aimed at evaluating the applicability of the HTS and TUS datasets to transport economic models. The following can be summarised with regard to the three objectives of the work mentioned at the beginning of this thesis.

(1) Development and implementation of the MAED-survey to obtain the integrated dataset of travel and non-travel activities

The MAED survey was successful in collecting the required data. The subsequent analysis of survey design showed that MAED was able to produce a high-quality dataset. A comparison with the data from the last Austrian travel survey showed that trips had been captured well with a higher quality than in the ANTS of 2013/14. Compared to the latest ATUS of 2008/09, it could be determined that the information on activities between trips was collected well in disaggregated form. Only the quality of the collected expenditure data was not fully satisfying.

(2) Comparison of MAED with an HTS and (3) Comparison of MAED with a TUS

The Austrian NTS from 2013/14 and TUS from 2008/09 were compared with the MAED survey in order to investigate underreporting effects. The integrated questionnaire of the MAED was able to combine the strengths of both traditional forms due to its elaborate survey design. As trips had to be reported in the context of the daily schedule of respondents' activities in the MAED, underreporting was minimized. The MAED was able to demonstrate, due to its high reporting quality, that both traditional HTSs as well as TUSs

have problems collecting information about both trips and activities in sufficiently accurate forms. Both formats revealed patterns in trip underreporting. Non-reported trips had the following characteristics: trips in the afternoon, trips of short duration, trips followed by a subsequent activity of short duration, and trips with the purpose of shopping. Additionally, the ANTS contains only aggregated information about non-travel activities and provides no information at all about activities at home, which renders the data inappropriate for modelling the relationships between travel behaviour and activity scheduling. The TUS, on the other hand, accurately collects information on activities, but information about trips and their characteristics is recorded insufficiently: modes are not reliably reported, rounding leads to 15-minutes steps in trip durations, and many trips that fall between the time intervals are missing. The latter problem could be solved by the imputation of missing trips, which increases the travel estimates substantially, but only limited information can be inferred for these imputed trips. Both HTSs and TUSs therefore have only limited applicability for modelling of the relationship between travel behaviour and activity scheduling.

The transferability of the MAED method and survey process is, however, limited. On a large scale, national-level MAED surveys will hardly be a permanent alternative to traditional NTSs – the very complex survey design, high response burden, associated small net sample, and high monetary effort for the incentives will not allow use of the MAED survey design as a standard. That said, the findings of this methodological analysis can be applied to future HTSs and TUSs with the aim of recording trip and activity data as accurately as possible.

- Some of the methodological advances of the MAED survey can be applied ex-ante in the planning and fieldwork of surveys in order to minimize item non-response, optimize output, and increase overall efficiency. These include, for example, the introduction of data validation in HTSs or a reliable location variable (required for later imputation purposes) and more detailed questions about households' mobility tools in TUSs.
- Based on the imputation and correction mechanisms obtained from this study, ex-post quality assurance procedures can be applied. These include, for example, the correction of the proportion of mobile verses immobile persons as well as typically underreported trips for HTSs and the imputation of trips using the location variable in TUSs.

The MAED dataset offers further possibilities for additional analyses of the survey method due to its high completeness, its carefully recorded survey process, and numerous fieldwork variables. A detailed analysis of trips that were initially not reported in the questionnaire but stated in the validation phone call could provide further insights about item non-response in general (Aschauer et al., forthcoming). This could uncover further non-reporting patterns in conventional HTSs and thus help to develop further imputation rules for the HTS and subsequent data processing.

In a next step of method research, the form in which the results of this study are transferable should be investigated – for example, whether the results can also be transferred to other segments of the population or the entire population. In addition, it would be interesting to investigate whether the effects of underreporting can be identified even more clearly by combining MAED (or traditional formats) with modern survey tools such as smartphones or online questionnaires. Another aim of future research should be to test the combined trip and activity data of an HTS or TUS – improved by quality assurance measures and data correction mechanisms – for their applicability in mode choice and time use modelling. This would improve the data quality and make additional data sources available for transport economic models.

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7 List of figures

8 List of tables

9 List of abbreviations

BMVIT	Bundesministerium für Verkehr, Innovation und Technologie (Austrian Ministry for Transport, Innovation and Technology)
ANTS	Austrian national (household) travel survey
ATUS	Austrian time use survey
CAPI	Computer Assisted Peronal Interview
CATI	Computer Assisted Telephone Interview
CAWI	Computer Assisted Web Interview
CES	Consumer expenditure survey
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HBS	Household budget survey
HETUS	Harmonised European time use surveys
HTS	Household travel survey
ICT	Information and communications technology
KOMOD	Konzeptstudie Mobilitätsdaten Österreichs
KONTIV	Kontinuierliche Erhebung zum Verkehrsverhalten
MaaS	Mobility as a Service
MAED	Mobility-activity-expenditure diary
MiD	Mobilität in Deutschland (German NTS)
MOP	Deutsches Mobilitätspanel (German continuous HTS)
NKD	New KONTIV Design
NTS	National (household) travel survey
PAPI	Paper and Pencil Interview
PT	Public transport
RP	Revealed preference
SP	Stated preference
STAT	Statistics Austria (Austrian federal statistical office)
TUS	Time use survey
VoL	Value of leisure [€/h]
VTAT	Value of time assigned to travel [€/h]
VTTS	Value of travel time savings [€/h]

Part II – Selected Publications

Research Article 1

Aschauer, F., Rösel, I., Hössinger, R., Kreis, B., Gerike, R. (2018). **Time use, mobility and expenditure: An innovative survey design for understanding individuals' trade-off processes.** *Transportation*, (), 1-33.

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Time use, mobility and expenditure: an innovative survey design for understanding individuals' trade-off processes

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Abstract
A large amount of information is required to model the complex trade-off processes between travel activities, non-travel activities and budget assignment at the individual level. This paper describes the development of a new survey design, which incorporates components of travel surveys, time use surveys and consumer expenditure surveys in an integrated format, which is expected to deliver a richer data set allowing deeper insights into individuals' activity and consumption patterns. The survey procedure and the incentives paid, which were necessary to obtain acceptable response rates, are also described. Results from two pilot studies using a trip-based and an activity-based diary format are presented. The paper examines to which extent the diaries have been capable of collecting the required data with high quality and response rates. The innovative "Mobility–Activity–Expenditure-Diary" is introduced and results of the main survey using this design are presented. Travel behaviour and non-travel activities were reported at high quality. Expenditures would require longer observation periods (and preferably not only telephone but also personal support in the survey process) to reduce unsystematic variations and to better capture individuals' long term equilibrium.

Keywords Travel survey · Travel time · Time use · Time use survey · Consumer expenditure

Introduction

The value of travel time has always been subject to extensive debate in both academia and politics. As savings in travel time are often the major justification for infrastructure investments (BMVBW 2003), numerous studies deal with travel demand models which estimate the willingness to pay for a reduction of travel time, the subjective value of travel time savings (SVTTS). In most cases travelling is not a pleasure in itself, but a necessity to reach a location to engage in more pleasurable and useful activities.

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However, not only reductions in travel time, but also improvements of travelling comfort are crucial transport policy measures. In recent years the comfort of public transport vehicles has increased significantly. In-vehicle time has become more entertaining and convenient due to the use of mobile devices which allow us to use our time more productively. These developments let expect that the travel activity itself might be perceived more positively for public transport compared to the car (EC 2015).

These two aspects of travel time, the time loss due to the duration of travel and the valuation of travel as an activity itself are reflected in the two components of the SVTTS: (1) the willingness to substitute travel time for other activities (or value of time as a resource VOR), which is the marginal utility of an additional unit of leisure in the DeSerpa (1973) model and (2) the direct valuation of time assigned to travel (VoTAT), also called the value of time as a commodity (VOC). These two components are expected to vary in different ways, so they should both be known in order to fully understand the effect of transport projects (Jiang and Morikawa 2007). In order to shed light on the individual components, it is necessary to integrate travel decisions into the larger framework of time assignment and consumer's home production (Munizaga et al. 2008).

A main challenge of a joint time assignment and mode choice model with a microeconomic foundation is the merging of the two different types of models: Travel demand models are typically discrete choice models, e.g. mode choice, route choice or destination choice models, which model the indirect utility of travel decisions (Jara-Díaz 1998) based on random utility theory. Time and budget assignment models are continuous models, which model the direct utility of time use and budget allocation according to a Cobb–Douglas or an additive logarithmic utility function. The combination of discrete and continuous choice modelling approaches is a field of ongoing research (Jara-Diaz and Guevara 2003; Bhat 2008; Habib 2013).

Another challenge is the large amount of information required to model the complex trade-off processes between travel activities and non-travel activities. A prominent example of jointly estimating time assignment and travel decisions is the model developed by Jara-Diaz et al. (2008). Using a Lagrange optimization, they derive four equations (first order conditions) to be modelled in relation to each other:

$$\frac{\partial U}{\partial X_j} = \lambda P_j \quad \frac{\partial U}{\partial T_l} = \mu \quad \frac{\partial U}{\partial T_w} + \lambda w = \mu \quad \frac{\partial U}{\partial T_t^{MIN}} + \kappa_t = \mu$$

where U denotes the utility; X_j and P_j the amount and price of consumed good j; T_l, T_w and T_t^{MIN} the amount of time assigned to leisure, work, and travel; w the wage rate; λ, μ and κ_t the Lagrange multipliers representing the marginal utility of increasing available money, increasing available time, and reducing the minimum time constraint of travel, respectively. Besides the usual socio-demographic and socio-economic variables, the following information is required for estimating such a model:

- time assigned to travel activities;
- time assigned to non-travel activities, with the activities being subdivided into the categories of unconstrained activities (leisure) and constrained activities (such as personal care);
- budget assigned to goods consumption being subdivided into constrained and unconstrained goods.

Given that the objective is to model detailed trade-off processes between travel decisions, time use and budget assignment, it seems to be important to gain all necessary information from the same individual simultaneously. Moreover, data is required to be collected for an observation period of sufficient length to consider the allocation pattern as a representation of the individual's long term equilibrium. To the best of our knowledge, no dataset exists which meets all these requirements and there is no survey procedure available to collect these data at sufficient quality and quantity in a diary format. Some travel surveys cover long periods (e.g. Chalasani and Axhausen 2004), but information about non-travel-activities can only be roughly inferred from 'trip purposes' and no information about budget assignment is included. A possibility to retrieve all required information is the matching of data from independent time use and expenditure surveys (Jara-Diaz and Rosales-Salas 2015; Konduri et al. 2011), but this procedure yields only probabilistic rather than direct relationships between time and budget assignment. Castro et al. (2012) mentioned that the merits and appropriateness of such a synthetic data generation are debatable and further efforts on obtaining combined data on time-use and expenditure are desirable. In 2009, a new module on time use and consumption has been added to the Longitudinal Internet Studies for the Social Sciences (LISS) panel, administered by the CentERdata (Cherchye et al. 2012). Retrospective information on time use during the past 7 days preceding the interview and household consumption expenditure within the previous month (within the last year for large durables) is collected. Yet this data collection method does not yield information on travel modes of on the level of individual activity episodes and can lead to systematically biased mean values of time use (Browning and Gørtz 2006; Juster and Stafford 1991). Dharmowijoyo et al. (2015) deployed a panel time use and activity diary throughout a 3-week period to capture day-to-day variability and repetition patterns. However, the activity diary was sampled at 15-min intervals, hence short duration activities and trips are not recorded and information on goods consumption is not included.

The goal of this study is to develop a survey design that meets all requirements formulated above and at the same time ensures acceptable response burden and high data quality. Such a survey procedure should have an observation period of at least 1 week, since this period captures the rhythms of most activity types sufficiently and is a suitable compromise between response burden and data requirements (Jara-Diaz and Rosales-Salas 2015; Minnen et al. 2015; Senbil and Kitamura 2009; Zerubavel 1985). A combined data collection approach is meant to take advantage of three currently separate survey techniques:

- *travel surveys* including information about the characteristics and determinants of travel activities such as trip purpose, start and end time, duration, cost, transport modes, location of origin and destination;
- *time use surveys* giving complete information about travel and non-travel activities throughout the day including the types of main and parallel activities, location, start and end time of each activity episode;
- *consumer expenditure surveys* dealing with goods consumption and budget assignment in the short and long run.

We merge these three survey traditions into the innovative "Mobility–Activity–Expenditure-Diary" (MAED). This paper reports about the lessons learned from two pilot studies and the results of the following main survey, which uses the final MAED-design. With this research we hope to contribute to the advancement of methods for collecting data on travel behaviour in the context of individual's overall activity and consumption patterns.

The remainder of this paper is organised as follows: The state of practice for travel surveys, time use surveys and consumer expenditure surveys is presented in "Current state of survey practice" section. Findings from pilot studies which marked the path towards the final questionnaire design are discussed in "The Mobility–Activity–Expenditure-Diary (MAED) design" section. We first develop the general concept of the MAED based on the state of art and the goals of this study in "Approach to integrating the three survey traditions" section. We then explain the questionnaire designs for the pilot studies in "Findings from pilot studies" section and the final MAED design in "The final MAED design" section. "Survey procedure, response rates and incentives" section describes the survey procedure and the tested incentive schemes. Quantitative results of time use and expenditure patterns are presented and compared with data from national Austrian surveys in "Quantitative results of main survey" section. Conclusions and an outlook on further research are provided in the final section.

Current state of survey practice

Travel surveys: the trip-based approach

Methods for surveying travel behaviour have been continuously improved since the 1970s when the first national and municipal travel surveys were implemented. No standards for travel survey methods have yet been established, they vary from country to country (Armoogum et al. 2014). Travel surveys are with very few exceptions cross-sectional surveys with the household being the usual sampling unit and the survey duration being one diary day. The German Mobility Panel (GMP) (Chlond et al. 2015) and the research project Mobidrive are examples of multi-day surveys. Mobidrive succeeded to observe longitudinal travel patterns for a 6-week period using written diaries and intensive respondent support throughout the survey period (Chalasani and Axhausen 2004). The British National Travel Survey covers a period of a week (Taylor et al. 2013).

Most current travel surveys offer different channels for survey participation. Self-administered mail-back questionnaires and telephone interviews dominate. Online questionnaires are often provided but only used by small proportions of the participants. Personal interviews are carried out in some countries (see e.g. Centre for Studies on Networks, Transport, Town Planning and Public Building 2009).

Technology-based surveys are increasingly applied in research projects with mainly non-representative convenience samples (see e.g. Kopp et al. 2015). Armoogum et al. (2014, see also Cottrill et al. 2013; Shen and Stopher 2014) give an overview of pilot studies for the integration of GPS-loggers and smartphones into representative national travel surveys. Technology-based surveys make use of the increased availability of location-enabled mobile devices and aim at an improved accuracy of reported trips in terms of numbers, durations and routes in combination with a reduction of response burden. The lacking representativeness of technology-based travel surveys is a major limitation of this promising survey method so far.

The survey procedure and the written questionnaire design of many travel surveys are based on the New KONTIV-Design (NKD) developed by Socialdata (2009). Households are contacted by mail and motivated via telephone calls. Incoming questionnaires are checked for completeness and additional phone calls are made for validation if necessary. Various reminders and a strict scheduling of all processes are important to achieve high response rates. The NKD-travel diaries list each single trip in one column (see Fig. 1) with

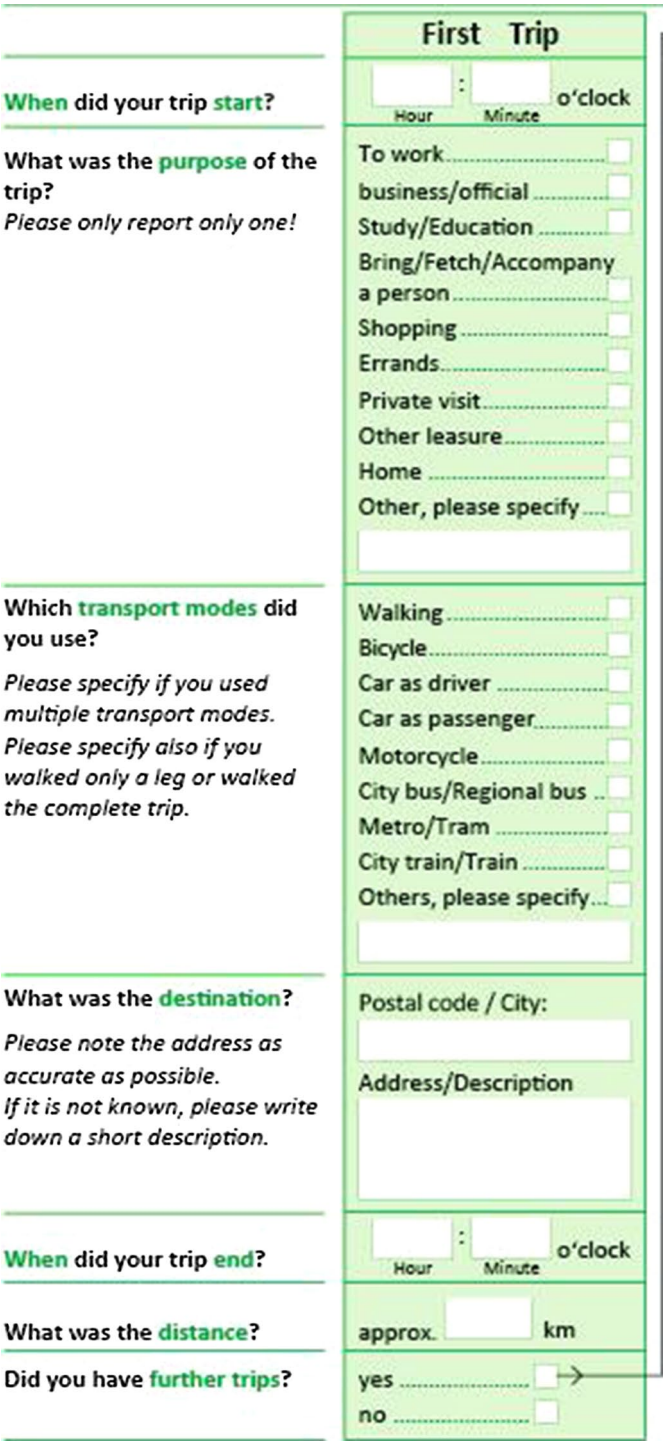
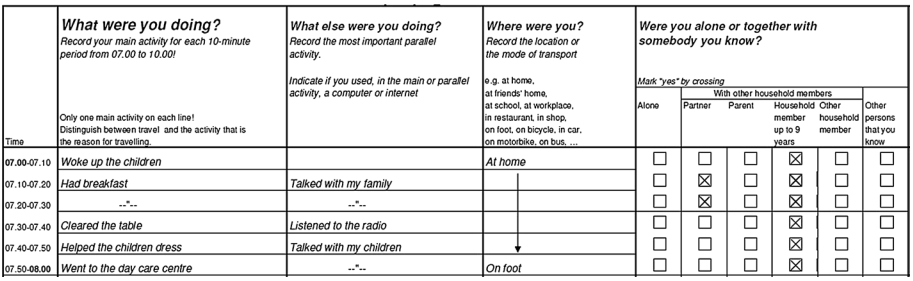


Fig. 1 Excerpt of travel diary (*source*: adapted from the Austrian national travel survey 2013/14)



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. Indicate if you used, in the main or parallel activity, a computer or internet	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	With other household members: Partner	Parent	Household member up to 9 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	☐	☐	☐	☒	☐	☐

Fig. 2 Excerpt of time-use diary (*source*: Eurostat 2009)

usually three to four trips on each page. At least the following data are collected for each trip: start and end time, start and end location, main trip purpose, used transport modes, estimated distance. Further variables such as accompanying persons can be included. Trip purposes are reported within pre-defined categories. The categories vary across different surveys, so far no standards exist. 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 can be inferred. Travel surveys based on the NKD-design work without incentives, but more burdensome surveys (e.g. with longer reporting periods) use small incentives. Participants in the GMP for instance are offered a lottery ticket. Response rates range from 50 to 80% with the exception of Germany with much lower response rates (Armoogum et al. 2014).

The most recent Austrian national travel survey (NTS) was conducted in 2013/14 based on the KOMOD-guidelines that were specifically developed for this survey (Fellendorf et al. 2011). The KOMOD-survey design heavily relies on the NKD-principles with some modifications, e.g. a 2-day diary instead of a 1-day diary. The data of the Austrian national travel survey will be used for comparison with our results in "Quantitative results of main survey" section.

Time use surveys: the activity-based approach

Time use surveys (TUS) provide detailed information about the type and location of any activity throughout the entire day. Standards for time use surveys have been continuously developed over almost 20 years resulting in several updates of the guidelines for Harmonised European Time Use Surveys (HETUS) (Eurostat 2004, 2009; UNECE 2013). The HETUS guidelines recommend self-administered mail-back diaries. Current research projects experiment with online questionnaires and mobile devices (e.g. Sonck and Fernee 2013), but national surveys are still mainly based on mail-back solutions. UNECE (2013) lists the use of technologies as one factor that has the potential for recruiting additional person groups and for collecting new types of data.

Each line in the mail-back written time use diary corresponds to one time-interval of preferably 10 min (see Fig. 2). For each of these intervals respondents are asked to report the main and the secondary activity, the location and additional persons with whom the activity was carried out. Travel is treated similarly to any other non-travel activity type; the question at which location the travel activities take place is to be answered with the transport mode e.g. "on bicycle", "by car".

Fixed interval diaries are recommended because of the reduced variation in the level of detail of the reported activities compared to open interval diaries and because open interval

data are more difficult to code and process. The time interval varies across different surveys, but most of them are based on 10-min intervals (UNECE 2013). The 10-min interval provides only a rough grid for analysing short trips, but gives a comprehensive overall picture of travel activities and non-travel activities (Gerike et al. 2015). The diary starts at 04:00 a.m. and covers 24 h with 3 h per page.

Attempts have been made to apply time-use diaries which cover a period of seven consecutive days (Glorieux and Minnen 2009), yet according to the HETUS guidelines two diary days should be reported, one weekday and one weekend day. Open text fields instead of fixed activity categories should be used in order to obtain the most comprehensive information possible about what the respondents actually did in each time interval. The HETUS guidelines contain standards for activity classification and minimum lists of activity categories (Eurostat 2009; UNECE 2013). Typical categories for locations are "home", "work place", "school", "other person's home", "restaurant", "hotel", and "holiday home". These are usually recorded without geocoding. HETUS time use surveys do not use incentives.

The latest Austrian time use survey was conducted in 2008/2009 by the federal governmental statistical agency Statistics Austria. The survey is based on the HETUS guidelines. The main and parallel activities are reported for 1 day using 15-min (30-min from 11:00 p.m. to 05:00 a.m.) intervals (Statistics Austria 2011). Data from this survey are used for comparison with the results from this study in "Quantitative results of main survey" section.

Comparison of trip-based and activity-based survey approaches

The trip-based and activity-based approaches have different strengths and weaknesses in capturing travel activities and non-travel activities comprehensively and reliably. Travel surveys provide detailed information about trips but only limited insights into non-travel activities. We can infer types of non-travel activities only from the trip purposes. We have no information about in-home activities; this concerns the time before the first and after the last trip and persons who report no trips at all on the diary day. Advantages of travel surveys are their clear focus on the movement of travellers and related information including open interval start and end times, locations of origin and destination, transport modes, trip distances, the spatial context, the weather on the diary day, and the availability of mobility tools (such as public transport season ticket, private car, car sharing membership) both in general and on the actual diary day.

Time use surveys are rarely used in transport research because the 10-min interval impedes accurate data collection for short trips and because of missing information about locations, the spatial context and car availability. The activity orientation is, however, superior to the trip-based approach in the sense of placing the travel activities in a context that matches the individual's way of thinking. Travel itself is in most cases a means to an end; it is the individual's daily activity schedule which creates the demand for travel. As a result, it is to be expected that respondents will report their activities including travel more accurately and completely compared to trip-based approaches. There is no reason to underreport travel by claiming not to have left home or by omitting individual trips (Gerike et al. 2013, 2015). The activity-based approach additionally allows collecting data on in-home activities and for immobile respondents.

HETUS time use surveys treat travel on the same level as any other activity with the disadvantage of losing detailed trip information compared to travel surveys. In addition, short trips of less than 10 min are not reported at all; subsequent activities at different locations

are often reported without a trip in-between. Gerike et al. (2015) found an average of 0.9 location changes without a trip in-between per diary day in the German time use survey of 2002. Respondents in time use surveys receive no instructions about whether to report each transport mode for every single trip stage. In the German time use survey of 2002 respondents tended to report only the main mode and intuitively omitted the short stages, e.g. going by foot. Activity sequences of trips without non-travel activities in-between turned out to be sequences of trips and non-travel activities, in which both of them were merged into one activity episode (Gerike et al. 2015).

Consumer expenditure surveys

Consumer expenditure surveys provide information about the consumption expenditure of private households to monitor general household living standards, well-being and consumption patterns (To and McBride 2013). These surveys are used to examine the economic and distributional impacts of policies and to revise the weighting of the basket goods in the Consumer Price Index.

No standards exist for consumer expenditure surveys. Their design therefore differs from country to country. Variations refer to the frequency of deployment and to the method of data collection. With few exceptions data collection comprises at least two instruments:

- *Expenditure diaries* Respondents report all their actual expenditures for goods and services in diaries, usually over a period of 14 days. Few diaries exist with diary periods of 7 days, 1 or 2 months. Diaries are filled out either for individual persons or for the entire household. Self-administered paper diaries or online diaries are used.
- *Retrospective interviews, questionnaires* In most countries respondents also report long-term and regular expenditures retrospectively for the last 1, 3, or 12 months. These expenses serve to correct the diary data for costs which do not occur in the diary period, and they ensure that also seasonal and one-time big-ticket items are included. This is indispensable for the calculation of the total consumer expenditures.

Monetary as well as non-monetary incentives are offered; some surveys encourage the use of online diaries through higher incentives than for the paper-based diary (To and McBride 2013).

The Austrian consumer expenditure survey is conducted as a household survey by Statistics Austria every 5 years. The most recent survey was carried out in 2014/15.[1] For 2 weeks all members of each participating household documented their personal expenses on goods and services either in a paper or online diary. Expenses had to be classified into three parts of the expenditure diary:

- *Part 1: Private garden or farming products for personal requirements.* All home-made agricultural products harvested and consumed within the 14-day period had to be recorded in the diary.
- *Part 2: All expenses made on food and drinks including pet food and visiting a restaurant or cafe*. A pre-defined categorization of food groups was used, so that all costs incurred could be stated by choosing the appropriate product and adding its amount and

[1] Results are so far only available for survey 2009/10.

Table 1 Austrian version of COICOP main divisions (Statistics Austria 2011)

COICOP main divisions	
01. Food and non-alcoholic beverages	07. Transport
02. Alcoholic beverages, tobacco and narcotics	08. Communication
03. Clothing and footwear	09. Recreation and culture
04. Housing, water, electricity, gas and other fuels	10. Education
05. Furnishings, household equipment and routine household maintenance	11. Restaurants and hotels
06. Health	12. Miscellaneous goods and services
	[13. Not for private consumption][a]

[a]Not included in total consumption

price. Product groups had a high level of detail (e.g. "wholemeal bread" and not just "bread").

- *Part 3: All other expenses.* For all other kinds of expenses two pages per day were provided offering one page with pre-defined categories of products (e.g. personal care, clothes, fuel) and an additional page with open text fields where respondents had to specify the purchased items.

At the end of the diary a page was provided to note expenses which tend to be forgotten by respondents (e.g. costs automatically debited from a bank account such as newspaper subscription, mobile phone bill).

In order to categorize the expenses made by the household members the *Classification of Individual Consumption Expenditures by Purpose* (COICOP) was used. This is a recommended classification scheme in Europe to group types of consumer expenditures (Statistics Austria 2011).

The Austrian version of the COICOP is shown in Table 1. It consists of 12 main divisions of expenditures, which are further broken down into six hierarchical levels of increasingly refined sub-aggregates. In addition to the 2-week diary, face-to-face interviews were conducted with the household members, a first one prior to the diary period and a second one afterwards. These interviews covered expenditures on major purchases (e.g. vehicles, vacation trips), running costs which are paid on a regular basis (e.g. rent, insurance) and sporadic costs (e.g. the annual pass for public transport) retrospectively for the last year. Questions which could not be answered in the first interview were clarified in the second along with inconsistencies such as double-reporting of expenses.

Survey participants were reimbursed with a 50 € voucher for completing the survey programme.

The Mobility–Activity–Expenditure-Diary (MAED) design

Approach to integrating the three survey traditions

The three survey traditions described above were combined in order to achieve the goal of collecting data about travel activities, non-travel activities and consumer expenditures from the same individuals for a 1-week period. One week seems to be a good compromise

between response burden and accurate representation of the individuals' long-term equilibrium, because intra-personal variation and routines that follow multi-day cycles can be observed for most activity types and expenditures (Jara-Diaz and Rosales-Salas 2015; Minnen et al. 2015; Senbil and Kitamura 2009; Zerubavel 1985). The challenge was to merge the three survey concepts in a way that keeps the response burden at an acceptable level and at the same time delivers all required information in high quality. For meeting this challenge, we removed everything that is not needed for the described model, merged the remaining contents to a clearly arranged questionnaire, and developed a survey procedure that ensures a high response rate for this questionnaire.

Our reference point to define the data requirements was the model developed by Jara-Diaz et al. (2008). In terms of activities this model requires a distinction between work, freely assigned activities (leisure), travel, and constrained activities for which a certain minimum duration is indispensable. In terms of expenses the model requires to differentiate between freely assigned and constrained goods. The detailed classification schemes of activities (HETUS) and expenditures (CIOCOP) are not required; they can be considerably simplified without limiting the options of modelling. The activity classification chosen for the integrated survey corresponds well with the transport literature that often aggregates trip purposes to subsistence (work, education), non-discretionary or maintenance (shopping, errands, accompanying, care, voluntary, personal care, other) and discretionary (leisure) trips (Gerike et al. 2015).

According to the above discussion both the trip-based and the activity-based approach have their strengths and weaknesses in capturing travel activities and non-travel activities. We thus considered both approaches in our pilot studies. Each survey instrument was modified in order to best serve the purpose of this study. The basic modifications and features are listed in Table 2.

The next section describes the tested questionnaire designs. "The final MAED design" section explains the final MAED design that was used in the main survey.

Findings from pilot studies

Several versions of questionnaires were tested in two pilot studies and a pre-test[2] before the MAED design was finalised and applied in the main survey, which ran from April 2015 to December 2015. In the two pilot studies variants of a travel diary (TD) being enhanced versions of the trip-based NKD and variants of an activity diary (AD) closely related to the activity-based HETUS-design were tested (see Table 3 for sample sizes and response rates). Consumer expenditures were included from the second pilot study on.

The main challenge of the *activity diary* (AD) was to make respondents report trips and activities in separate lines (time segments) of the diary. Apart from the basic modifications described in Table 2 the AD of pilot study 1 was very similar to standard HETUS time-use diaries. It comprised an open textfield for all activities other than those offered in categories and another textfield to record either the location of the non-travel activity or the modes of transport in case of a trip.

Pilot study 2 had two modifications: (1) The daily 04:00 a.m.–04:00 p.m. scheme was given up for starting the day with getting up. This avoids to artificially split up sleep time into two separate lines, which was overruled by several respondents (see

[2] The pre-test will not be further described, as it was very similar to the final MAED survey design.

Table 2 Features and modifications of the three survey traditions in our approaches

Activity-based approach

Open time-intervals, pre-defined activity classification All tested designs used pre-defined activity categories and open time intervals—contrary to the HETUS guidelines, which recommend open activity description and pre-defined time intervals. The main ideas behind the open time intervals were (1) to ensure that all trips are reported with correct start and end times, also short trips of less than 10 min; and (2) to reduce the response burden, because our scheme avoids multiple recording of long activity sequences (sleep, work etc.). The idea behind the pre-defined activity categories was to indicate the requested level of detail for the reported activities to the respondents. This should help to reduce unwanted variation in the level of detail, which is the main argument against open time-intervals in the HETUS guidelines

Accurate separation of travel activities and non-travel activities Literature shows that travel activities and non-travel activities tend to be mingled in activity-based questionnaires (Gerike et al. 2015). We thus tested different designs for motivating respondents to report travel-activities reliably and separately from non-travel activities

Addresses of visited locations We provided sufficient space to report the complete address for the start and end location of each trip in all versions of the questionnaires. Complete addresses are essential to georeference the locations visited which is a required prerequisite to obtain information on non-selected alternatives in the mode choice models or to add spatial attributes such as the distance to the next public transport stop. The importance of complete and correct locations was additionally emphasised in the instructions

Trip-based approach

NKD-design Our main idea was to stick as close as possible to the NKD design because it has proven to be successful in reporting travel-related information, but to expand the 'trip purpose' section in order to retrieve more detailed information about non-travel activities. We tested different approaches in the pilot studies to include non-travel activities between the trips, before the first and after the last trip, but also for diary days without any trip

Travel costs Questions about travel costs were included directly in the trip section of the diary from the second pilot study on (public transport ticket, parking ticket etc.)

Consumer expenditure

Reduced level of detail in expenditure categories Consumer expenditure diaries are very detailed with fine subdivisions of product groups. The model of Jara-Diaz et al. (2008) requires first and foremost a distinction between constrained and freely chosen goods; further distinctions may improve the model, but the number of cost categories that the model can deal with is strictly limited. Our classification of reported expenses was based on the main COICOP divisions with 12 categories shown in Table 1. In pilot study 2, pre-defined expenditure categories were tested against an open description of expenses with post hoc classification by the survey team

Travel costs as an exception According to our specific interest in travel, our final scheme includes more detailed questions on travel costs than usual travel diaries and expenditure diaries. Consumer expenditure surveys do not have special interest in travel; the COICOP division "Transport" is treated like any other product group

Table 4) and also criticized to cause extra work. (2) It provided a clearer distinction between travel and non-travel activities. The activity category "Trip/On the way" and the related information boxes were highlighted in blue to emphasize that only if the trip box is ticked information on transport modes and trip destination is required (see Fig. 3). Transport modes were offered in categories and the destination of the trip could be stated within the same line, so that the entire trip could be reported in one line, separately from non-travel activities. An additional help sheet with instructions on how to fill in the diary was enclosed which explicitly said not to mingle trips with non-travel activities and to always tick just one main activity within a line.

The *travel-based diary* (TD) was tested in two versions. Figure 4 shows the version of pilot study 1. The questionnaire design was very close to the NKD design: three trips

Table 3 Sample and response rates of the pilot studies on household level

	Pilot study 1			Pilot study 2		
Households in %	Overall (n = 300)	TD (n = 100)	AD (n = 200)	Overall (n = 145)	TD (n = 49)	AD (n = 96)
Recruitment phase						
Gross sample size	100	100	100	100	100	100
Not available[a]	35	35	35	29	30	29
Participation rejected	27	33	24	42	43	42
Participation agreed: households received questionnaires	38 (n = 114)	32 (n = 32)	41 (n = 82)	28 (n = 41)	27 (n = 13)	29 (n = 28)
Questionnaire phase						
Households returned questionnaires[b]	73	81	70	68	62	71
Net response of gross sample	28	26	29	19	16	21

[a]No phone number, not in target area, failed to contact, no communication possible

[b]Percentages based on households which received questionnaires

Table 4 Problems occurring for the diary schemes in pilot study 1 and pilot study 2

	Pilot study 1		Pilot study 2	
	AD ($n_{Diaries}=106$; $n_{Trips}=2669$)	TD ($n_{Diaries}=50$; $n_{Trips}=1329$)	AD ($n_{Diaries}=43$; $n_{Trips}=991$)	TD ($n_{Diaries}=20$; $n_{Trips}=487$)
Occurrences within diaries in %				
Mixture of trips and activities within one line	35	–	51	–
More than one activity category were chosen	21	–	53	10
04:00 a.m.–04:00 p.m. scheme disregarded	8	–	–	–
Inconsistent durations	–	8	–	–
Problems with activities from 04:00 until first trip	–	4	–	–
Return trips missing, legs instead of trips	–	2	2	–
Occurrences within trips in %				
Missing modes	4.2	1.7	0.2	0
	$\chi^2=17.04$ ($p<0.0001$)		G = 1.59 ($p=0.2062$)[b]	
Missing addresses	7.9	5.2 (n = 1664)[a]	12.7	4.9
	$\chi^2=10.3$ ($p=0.0013$)		$\chi^2=18.16$ ($p<0.0001$)	

[a]Including missing start addresses prior to the first trip of the survey week

[b]Log Likelihood ratio statistic (G) instead of Chi squared due to small counts

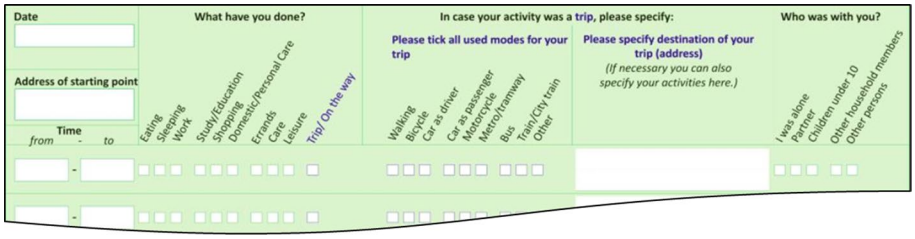


Fig. 3 Pilot study 2, activity diary (AD) based on HETUS expanded by travel mode and address

per page were displayed in columns with the usual travel information such as transport modes, location of the destination, start time, arrival time and trip length. Only the trip purpose section was modified to a list of pre-defined activity categories.

Each category had a text field to report the total duration spent for this kind of activity at the destination of the trip. Asking for the total duration instead of the start and end time of each activity episode was meant to reduce response burden, however at the expense of losing the information about frequency and duration of single activity episodes. Most respondents managed to report the duration of non-travel activities consistently with the start and end times of the trips, but complained about the burden resulting from this calculation. 8% of the respondents reported inconsistent durations for non-travel activities; 4% did not correctly report the durations of the activities between 04:00 a.m. and the first trip, 2% forgot to state return trips or split up trips into legs.

The TD design of pilot study 2 featured a list for chronological sequencing of activities adjacent to the column for the trip information in order to relieve respondents from cumbersome calculations. The activity section appeared very similar to the version used in the AD with pre-defined activity categories and an additional question on accompanying persons. The bottom of the trip column provided questions on selected transport expenses linked to the trip. This design caused only minor inconsistencies with small time gaps between the arrival time of a trip and the start time of the next activity, which could easily be corrected in the process of data entry.

A great proportion of the respondents who filled in an AD mingled travel and non-travel activities within one line. In the first pilot study 35% of the respondents reported travel and non-travel activities systematically in a wrong way: The whole sequence of trip, activity at the destination, and return trip was stated within one line (e.g. trip to the shop, shopping, and trip back home). It was assumed that this occurred because a trip is perceived as something directional resulting in a location. To state the transport mode instead of the trip destination seemed to have been misleading. In such cases it was impossible to code the activities properly, because neither the destinations, nor the transport modes and travel times could be identified. As a consequence, one-third of the questionnaires could not be used for further analyses. The attempt to solve this problem in pilot study 2 and to clarify the scheme was not successful, 51% of the respondents still made the same mistake.

When *comparing the activity diary with the travel diary*, the most serious disadvantage of the AD is that it caused a large number of respondents to tick more than one activity category in one line (21% in pilot study 1 and 53% in pilot study 2) despite the instruction to always choose just one main activity per time segment. In the TD of pilot study 2 only 10% of the respondents ticked more than one activity category, although parallel activities were allowed if the respondent could not decide for just one main activity. The lower part in Table 4 shows the analysis of missing modes and trips in both pilot studies. The TD data

Fig. 4 Pilot study 1, travel diary (TD)

exhibited significantly fewer missing addresses than the activity diary in both pilot studies. The same applies for missing modes in pilot study 1. With the improved design of the AD, missing modes were hardly a problem in pilot study 2.

Overall, the trip-based diaries performed better than the activity-based versions. The HETUS-based questionnaires is intuitive and simple, but trips are not well reported. If additional information on trips is included it becomes complicated and misleading. These findings are confirmed by other studies that also report missing or inconsistent trips for HETUS diaries (Gerike et al. 2015). Structuring the day by trips and asking for non-travel activities between those trips in a second step proved to be more self-explanatory. In addition, respondents who filled in the activity-based diary reported a longer duration for completing the diary (30–40 min compared to 20 min for the travel diary) and stated to be less willing to extend the reporting period in return for a higher incentive than those who filled in a travel diary. As a consequence, we used the trip-based design as a basis for further development of the MAED, which was subject to the pre-test and, after slight alterations, was used in the main survey (see Fig. 5).

The *expenditure diary* was included in pilot study 2 for the first time. The questions about expenses were provided on an extra sheet (separate from travel activities and non-travel activities) at the beginning of the diary (in the AD version) or at the end of each diary day (in the TD version). We tested two versions of expenditure questions: one with an open description of the expenses and one with pre-defined categories according to the COICOP main divisions.

The expenditure descriptions in the open design could be readily interpreted; most stated expenses could subsequently be assigned to a COICOP category. Around 11% of the expenses could not be assigned, but these were no missing values. They included statements such as ‘present’ or ‘pocket money’ for children. The advantage of the open design over the pre-defined categories is that even if it is not known what kind of goods these expenses were spent on (food, clothing, culture, restaurant etc.), the statements are still meaningful in terms of their assignment to committed and freely chosen expenses. The pre-defined categories bear a higher risk of misinterpretation. They may lead the respondents to choosing the wrong category without noticing the mistake. The share of expenses differed considerably for the categories ‘food’ and ‘restaurants and accommodation’ between the design with open categories and the design with pre-defined categories. The open descriptions enabled a clear identification of expenses associated with visits to a restaurant, which were assigned to ‘restaurants and accommodation’; respondents with a pre-defined cost sheet may have categorised such expenses as food. This supports the assumption that pre-defined cost categories can have different meanings for different individuals. So even though the effort to categorize openly reported expenses is high and interpretations depend on the coding person, the open design better suits our requirement to make a distinction between freely chosen and committed expenses.

The final MAED design

A sample page of the final MAED design is shown in Fig. 5. It is simpler and more self-explanatory than the pilot versions: Each trip is reported on a separate page and each page is divided into two boxes: the upper box contains the travel section based on the conventional NKD; the lower box contains the activity section based on our simplified activity

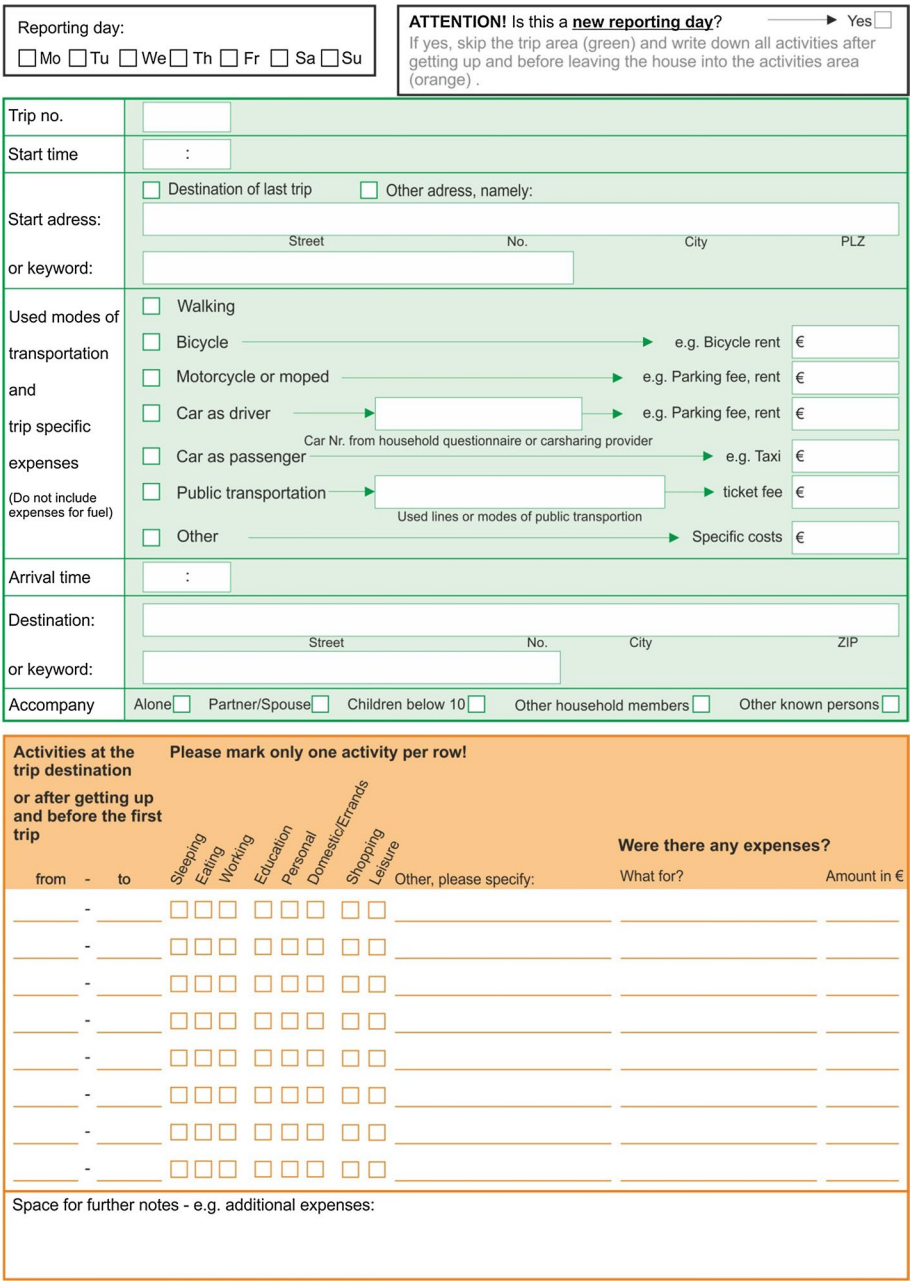


Fig. 5 The final MAED design used in the main survey

diary design developed during the pilot studies. Each activity being performed at the destination of the trip is reported line by line.

A diary day starts with getting up in the morning and ends with getting up on the next morning. This diurnal division is more intuitive than the 04:00–04:00 scheme of time-use diaries, which in most cases artificially divides the sleeping period into two blocks before and after 4:00 am. A new diary day starts on a new page, but in this case the trip section is skipped and all in-home activities after getting up and before the first trip are reported in the activity section. Thanks to this approach, the MAED features a continuous scheme of uniform pages for the entire week. It is not necessary to provide a pre-defined number of pages for each single day, but only enough pages for the whole week. This reduces the total number of required pages by half. The final MAED includes 51 diary pages for seven consecutive days. The number of pages corresponds to the maximum number of trips reported by participants in the pilot studies including a buffer.

The *trip section* includes the following information for each trip: start and end time, address of start and end location, the transport modes used and accompanying persons. Frequently visited locations (points of interest) can be noted on an extra page at the beginning of the diary with the corresponding address and a keyword (e.g. home, work), so that only the keyword must be stated in the address field of the trip section. The trip section also includes additional information, which is not part of the conventional NKD: (1) in case of car use the reference number of the car which is specified in a household questionnaire; (2) in case of public transport use the line numbers; (3) occasional travel costs (car rental, parking fee, bus ticket etc.) for all modes except walking.

The *activity section* corresponds to the simplified scheme derived from the HETUS diary. Non-travel activities are to be listed chronologically line by line and specified according to pre-defined categories. Activities that do not match a pre-defined category are to be specified in an open text field.

Questions on expenditures are included in different parts of the questionnaire. Daily expenses that occur during the observation period are stated directly in the diary pages. The joint statement of activities and expenses is intended to help to remember either of them: stating an activity may bring an expense to mind and vice versa. Travel-related costs are included in the trip section as described above. Expenses related to non-travel activities are stated along with the corresponding activity in the activity section. Following the findings of pilot study 2 that open descriptions are better to interpret and to classify in line with the model requirements than pre-defined cost categories, the diary page provides an open text field to describe the expense (e.g. groceries, cinema ticket, clothes) and another field for the amount. Expenses which cannot be linked to a reported activity (e.g. pocket money for children) can be stated at the bottom of the diary.

Infrequent long-term and regularly recurring payments, which do usually not arise on a weekly basis, are asked in the household questionnaire alongside with socio-demographic variables and available mobility tools (public transport season ticket, private cars, car sharing membership etc.). This scheme is closely related to the consumer expenditure surveys, which acquire additional information about long-term costs retrospectively for 1 year.

The household questionnaire of the MAED covers three segments for expenditures: “rent and housing costs”, “mobility costs” and “other long-term household expenditures”. Expenditures have to be stated for given time intervals (per month, half-year, year) depending on the type of good or service. This is assumed to be more convenient than summing up a monthly paid rent to the annual amount or recalling all actual costs incurred within the last 12 months. Mobility costs include season tickets for public transport, purchases of new vehicles (price and year of latest purchase or leasing rate), and monthly parking fees at home or at work. Pre-defined expenditure categories are applied here that follow the

COICOP classification to avoid the risk of respondents forgetting about important categories. Open text fields are provided only for other long-term payments not included in the pre-defined categories.

Due to the fact that the Jara-Diaz model heavily relies on the wage rate (see Jara-Diaz et al. 2008), the population of the MAED survey are households with at least one employed person. Only employed persons were to fill in the diaries, an additional cost sheet was provided for non-employed household members to account for money transfers within a household. In open textfields they could list all their expenses made during the diary week.

Survey procedure, response rates and incentives

A major challenge of the MAED survey is the high response burden caused by the large amount of information, the complexity of information, and the long observation period. In order to achieve high response rates and data quality it is necessary (1) to motivate the respondents at the beginning and again at crucial stages of the survey, (2) to provide individual support during the reporting period—written instructions are important but not sufficient, and (3) to offer an incentive in return for the high effort. In terms of information channels we used only self-administered mail-back questionnaires with telephone announcement and support. We decided against online questionnaires for several reasons:

- People tend to use the same channel for their answer through which they have been contacted (BRAWISIMO 2015). If they receive a written announcement they prefer a written questionnaire.
- There is some evidence that online questionnaires are filled out with less care and have more missing data, e.g. a high number of missing return trips in travel diaries (Kadan 2015).
- The survey served as a first feasibility test of the MAED design. The implementation and administration of an additional web-based questionnaire would have been too expensive. In prospective surveys it is yet desirable to offer both a written and online channel to increase response rates.

The *MAED survey procedure* is based on the NKD (Socialdata 2009). In answer to the higher complexity of information and the higher response burden we integrated additional phone calls. Figure 6 gives an overview of the survey procedure used in the main MAED survey.

The addresses of survey participants were gained from a random selection of Austrian households according to 18 pre-defined strata, which were arranged by region and settlement structure. For around 50% of sampled households a telephone number could be found. The availability of a telephone number makes a difference for the recruitment process, because announcement calls yield much higher participation rates than announcement letters:

- Households with available telephone number (V1) were sent an announcement post card, which notified them that they will be called within the next few days; they were not asked to reply to the announcement.

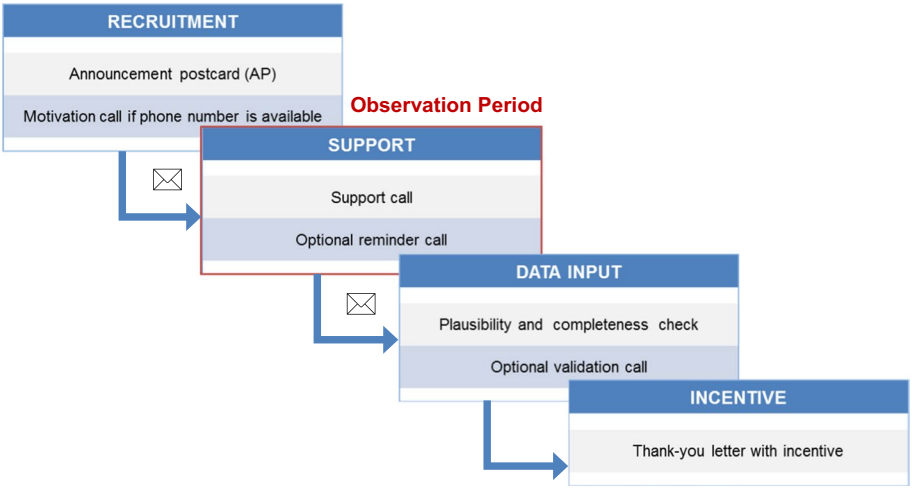


Fig. 6 Survey procedure of the MAED survey

- Households without available telephone number (V2) were sent a folding card, which informed them of the survey and the incentive in case of participation. They were asked to reply either by returning the folding card or via SMS or e-mail. Responding households were further asked to state the number of employed household members and a telephone number.

Households with telephone number were called for motivation 3 days after the announcement postcard was sent. They were informed about the study and the incentives, and were asked to participate in the survey. Households which agreed to participate were sent a questionnaire package with a pre-defined reporting period. On the first diary day households were called again. This call served two purposes: (1) as second motivation and reminder to start with the diary—if they had not started already; (2) to give the participants some key information how to fill out the diary correctly. Interviewees were trained to explain those parts of the questionnaires that were most important or tended to cause difficulties, e.g., how to code frequently visited locations or how detailed activities should be reported. Respondents could also ask questions. Households that returned the questionnaire in due time received no further call. Otherwise they received a reminder call every week until the questionnaire had been sent back or the household refused to participate.

Households without an available telephone number could only take part if they actively replied to the announcement letter. The answer (folding card, SMS or e-mail) should include the number of required diaries and a telephone number. From that point on the household was treated as described above: sending the questionnaire, phone call on the first diary day etc.

The returned questionnaires were first checked for completeness of documents and then entered into a database. This step included a validation with checks for plausibility and missing values on an automatic and manual basis. In case of missing or implausible answers respondents were called again; open questions were discussed and solved step by step together with the respondent to ensure high data quality.

Table 5 Sample and response rates of the main MAED survey

	Main MAED survey		
Households in %	Overall (n = 4997)	V1 (tel) (n = 1942)	V2 (no tel) (n = 3055)
Recruitment phase			
Gross sample size	100	100	100
Not available[a]		39	88
Participation rejected		33	1
Participation agreed: Households received MAEDs	17 (n = 865)	28 (n = 535)	11 (n = 330)
Questionnaire phase			
Households returned MAEDs[b]	63	62	64
Net response of gross sample	11	17	7
Usable net response of gross sample after validation of MAEDs	10 (n = 490)	15 (n = 299)	6 (n = 191)

[a]Announcement undeliverable or not returned, no communication possible, non-employed household

[b]Percentages based on households which received MAEDs

Table 5 shows the sampling of the main survey. The response rate of telephone households (V1) is at a similar level as in the pilot studies, which results from two balancing effects: On the one hand we had an additional selection criterion 'non-employed households', what causes a lower rate; on the other hand we had by definition no 'unavailable households' in this group, because households of group V1 were shifted to group V2 (households without telephone number) if the phone number was not valid or if contact attempts failed. A comparison of response rates of both groups shows that households motivated by telephone (V1) responded almost three times more often than those without known telephone number (V2) which had to reply actively to the announcement letter.

The *incentives* were an integral part of the survey procedure. In the main study we offered 40 Euros for each completed diary. The incentive was paid after the diary is returned, checked and validated. This ensured the respondents' interest to stay in contact with us until the data are finally validated and error corrected. In the pilot studies we tested different schemes:

- The amount varied between 30 and 60 Euros. 60 Euros were too much; the response rates and data quality did not increase accordingly. 30 Euros were sufficient for the simpler diary without expenditures in pilot study 1. The expenditures caused a considerable extra effort so that 40 Euros seemed to be the best compromise.
- We also tested a payment in advance. The motivating effect was indeed stronger than the after-payment of the same amount. Nonetheless we decided on the after-payment to the credit of a higher data quality: respondents were better motivated to answer our validation calls before they received the payment.

Quantitative results of main survey

An import question is whether our combined and condensed scheme measures the same values as the conventional surveys on time use, travel and consumer expenditure do. The combination of the three survey traditions is expected to affect the level of detail only, but not the distribution of main indicators.

In this section, we match our results with official figures of Statistics Austria as a benchmark. The latter had to be adjusted to fit the prerequisite of a population restricted to households with at least one employed person and the requirements in terms of model specifications described in "Approach to integrating the three survey traditions" section. Tables 6 and 7 present the values of some key socio-demographic characteristics of the MAED survey in comparison with the Austrian national travel, time use and consumer expenditure survey. These surveys are used in "Mobility", "Time use" and "Consumer expenditures" sections for comparative analyses. In view of the MAED survey's representativeness for the Austrian population of employed persons/households the Austrian national census (*Registerzählung 2011*) administered by the federal statistical agency of Austria (STAT, Bundesanstalt Statistik Österreich) is used as reference. Table 6 shows that women are slightly overrepresented in the MAED survey sample and the age distribution is left-skewed with younger employed persons being underrepresented, especially those aged 20–29. While the ratio of employed and self-employed persons corresponds well to the population the numbers on the highest educational degree attained indicate that more highly-educated people took part in the MAED survey. Graduates of universities, for example, are represented 2.5

Table 6 Personal characteristics (employed persons) of the MAED survey compared with national surveys[a]

	MAED survey	Statistics Austria National Census 2013	NTS 2013	Austrian Time Use Survey 2008/09
Households	490	2,006,004	10,490	3060
Employed persons	748	4,019,408	17,013	4546
Gender				
Male	50.0	53.3	53	50.0
Female	50.0	46.7	47	50.0
Age				
15–19	2.3	5.0	0.9	3.5
20–29	6.8	19.5	13.6	17.1
30–39	18.7	22.6	19.1	26.8
40–49	35.7	29.1	31.7	30.1
50–59	31.9	20.0	31.2	19.1
60+	4.6	3.8	3.5	3.4
Employed	88.7	88.8	n.d.	89.1
Self-employed	11.3	11.2	n.d.	10.9
Compulsory education	2.7	17.8	5.9	11.7
Apprenticeship, vocational school	36.0	50.9	48.3	60.2
High school	24.3	15.9	20.2	14.5
College, university	37.0	15.4	25.6	13.6

[a]Characteristics of the Austrian Consumer Expenditure Survey 09/10 were not available

Table 7 Household characteristics (households with at least one employed person) of the MAED survey compared with national surveys[a]

	MAED survey	Statistics Austria National Census 2013	NTS 2013	Austrian Time Use Survey 2008/09
Household size				
1 person	14.5	30.2	13.3	15.1
2 persons	29.4	23.1	30.0	27.0
3 persons	22.0	19.0	24.0	22.7
4 persons	27.1	18.2	22.6	24.6
> 4 persons	6.9	9.6	10.1	10.5
Urban	24.1	33.5	26.7	26.8
Intermediate	28.2	29.9	27.9	28.2
Thin	47.8	36.7	45.4	45.0
Target region				
Eastern Region	33.9	44.1	47.5	30.2
Upper Austria	23.1	16.9	5.6	15.0
Styria	18.2	13.8	21.9	10.4
Salzburg	6.9	6.4	4.7	15.7
Carinthia	5.1	6.2	4.2	9.0
Tyrol, Vorarlberg	12.9	12.7	16.0	19.7

[a]Characteristics of the Austrian Consumer Expenditure Survey 09/10 were not available

times more often than in the Austrian census. As far as mobility surveys are concerned, this is a well-known phenomenon (Gerike et al. 2015). The overrepresentation of university graduates is also due to the higher average age of participants, so they are more likely to have already completed their education.

The group of single-person households is underrepresented in the MAED (14.5%), employed single-person households add up to over 30% of Austrian households (see Table 7). The group of households with 4 members, in contrast, is overrepresented (MAED: 27.1%, Austrian national census: 18.2%). Regarding the level of urbanisation response rates were higher in rural areas. This explains to some extent the low number of single-person households, because they are found more often in urban areas. In small municipalities only every fourth household is a single-person household, whereas in cities this applies for almost every second household (Statistik Austria und Österreichischer Städtebund 2014).

The average monthly labour net income of fully employed persons cannot be directly compared due to Statistics Austria's missing objective definition of the term 'full-time job'. The monthly mean net income of fully employed persons (who classified themselves as such) is € 1836 in the Statistics Austria sample, whereas MAED respondents (who worked at least 37.5 h per week) reported € 2309 on average. This difference in income can mostly be explained by the higher level of education of MAED respondents (spearman correlation between educational level and monthly net income is 0.31, $p < 0.01$).

Table 8 Mobility indicators

	MAED survey n = 748 persons n = 18,203 trips	NTS 2013 n = 9436 persons n = 57,044 trips	χ^2	*p* value
Share of mobile persons				
Working day	0.97	0.91	162.1	$p < 0.0001$
Saturday	0.89	0.82	15.9	$p < 0.0001$
Sunday	0.71	0.69	1.82	$p = 0.257$
Number of trips per mobile person				
Working day	3.98	3.39	8.09	$p < 0.0001$
Saturday	3.74	3.40	1.78	$p = 0.074$
Sunday	2.85	3.15	− 1.43	$p = 0.154$
Distance of trips (*km*)				
Per trip	12.1	14.9	− 8.06	$p < 0.0001$
Per day	45.9	51.9	− 3.47	$p = 0.0005$
Duration of trips (*min*)				
Per trip	23.9	25.6	− 3.98	$p < 0.0001$
Per day	90.8	89.5	0.56	$p = 0.576$
Mode choice				
Public transport	10.9	11.9	7.36	$p = 0.007$
Car	69.5	70.1	0.44	$p = 0.507$
Bicycle	5.8	5.5	3.25	$p = 0.072$
Walk	13.8	12.5	4.61	$p = 0.032$

Mobility

The most recent Austrian national travel survey was conducted in 2013/14 based on the KOMOD-guidelines (Fellendorf et al. 2011). The KOMOD-survey design relies on the NKD-principles with some modifications, e.g. a 2-day instead of a single-day diary. The NTS offered three options to participate (PAPI, CATI, CAWI). As the survey was conducted over the period of 1 year, there is no seasonal distortion. A weighting procedure was performed on the data in order to represent the average daily mobility of the Austrian population. To ensure comparability with the MAED survey, the NTS data were filtered (1) for employed persons and (2) for survey data from the matching survey periods April to June and September to December.

Table 8 displays a comparison of the most important mobility figures of both surveys. Participants of the MAED survey reported a higher level of tripmaking (share of mobile persons per day) than participants of the NTS survey. Especially on working days the proportion of mobile persons is significantly larger. Also the mean number of trips per day and mobile person is higher (3.80 vs. 3.36). Allowing for the type of day (working day, Saturday, Sunday) the MAED results display typical trip rates (see Armoogum et al. 2014): the highest rate on working days (3.98), a slightly lower rate on Saturdays (3.74) and considerably fewer trips on Sundays (2.85).

The average trip distance of the MAED survey is 12.1 km compared to 15.1 km in the NTS. The higher number of diurnal trips of the MAED survey doesn't balance out the total mean daily trip distance per person, which is still 6.0 km longer in the

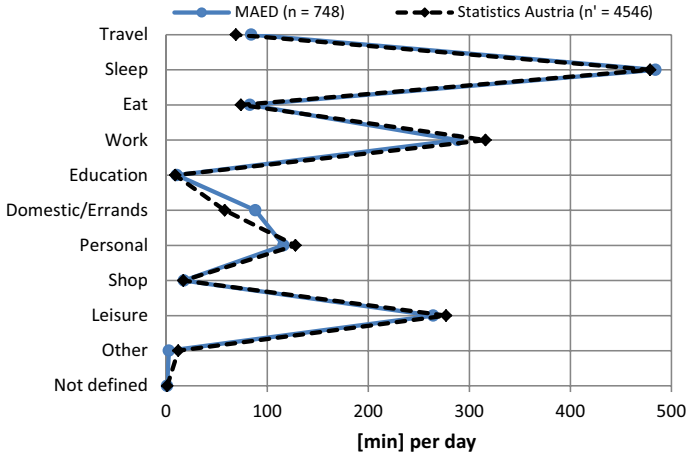


Fig. 7 Distribution of time assignment (employed persons) in the main MAED survey compared to the Austrian Time Use Survey 2008/09

NTS. Similarly, the average trip duration in the MAED survey is lower by 1.5 min, but exceeds the total daily trip duration by 0.6 min because of the higher trip rate. These differences may to some extent result from different methods of data collection: NTS trip distances and durations were estimated by the respondents, while we extracted this information from the Austrian traffic information system (VAO) based on geo-coded departure and arrival locations.

The differences in the shares of mode choices between the two surveys are negligible. The share of walking trips is slightly higher in the MAED survey, while NTS has higher shares of public transport. Because of the specific sample of employed persons only and higher response rates in rural areas, the share of car usage is relatively high in the MAED.

The results suggest that trips have been captured well by the MAED survey. The higher share of mobile persons and the higher trip rate of mobile persons indicate that trips were recorded with higher accuracy than in the Austrian NTS (see Table 8). By having to state all non-travel activities subsequently to the travel activities and all expenses linked to these activities, respondents seem to be less likely to forget about trips during the day or to omit short trips deliberately.

Time use

Figure 7 shows a comparison of the mean time assignment per day in the MAED with the figures of the Austrian Time Use Survey filtered for the subset of employed persons (see Tables 6 and 7 for sample characteristics).

The results of the MAED fit the time distribution of Statistics Austria very well apart from minor differences which can be explained by coding artefacts. With a differentiation of 426 categories the activity classification of Statistic Austria is much finer and had to be matched with the 10 categories of the MAED. All activities in the MAED which were marked ‘Other’ were coded a posteriori if a further specification of the activity was given or they were classified as ‘Not defined’ if no description was available. In line with home production theory a distinction was made between household production activities such

as cooking, cleaning and childcare, which could potentially be outsourced to someone else against payment (e.g. cleaning aid, babysitter) and personal activities which are either bound to the specific person (e.g. being sick at home, visiting a hairdresser) or are usually not transferred to someone else. The former activities were grouped into the category 'Domestic/Errands', the latter into 'Personal'. The surplus of 'Domestic/Errands' activities in the MAED may be due to the fact that survey participants were not always able to make a distinction between personal and domestic activities. The slight surplus of 'work' in the data of Statistics Austria can be explained by the survey's distributions of working days which add up to 76% of all reporting days whereas in the MAED survey the share of working days amounts to only 71%.

Consumer expenditures

Integrating information on consumer expenditures into the MAED posed a major challenge. Whereas time use is restricted to match exactly 168 h every week, expenses vary considerably; buying patterns in a randomly selected week can be quite distinct from the individual's long-term equilibrium. Moreover, the buying rhythms of goods and services underlay strong variations and cover several orders of magnitude. The questions on expenditures were thus included in different parts of the questionnaire as stated in "The final MAED design" section: the diary (D) focussed on frequently purchased items, the household section (H) on long-term expenditures.

A major issue in this context are exceptional large purchases during the reporting week. Such expenses were allocated to longer time periods according to operating life expectancies. On the other hand, the diary includes some zero spendings for essential consumption categories, for which zero expenses cannot be assumed in the long-term equilibrium, in particular in the categories 'Food', 'Clothing', 'Leisure', 'Travel', 'Services' and 'Insurance'. The zero spendings may partly result from the short observation period. We dealt with this problem of under-reporting by imputation, i.e. we replaced zero spendings in essential categories by average expenditures depending on income and household size classes.

Another issue is the overlap in coverage between expenses in the diary and the household questionnaire, because many expenditure categories were addressed in both sources (those labelled 'D, H' in Table 9). The overlap requires a procedure of determining the appropriate (more reliable) source or how to combine both sources in a manner that avoids double-counting. We applied two alternative methods:

- Method 1 is based on a source selection method described by Creech and Steinberg (2011) in the Consumer Expenditure Survey Anthology by the U.S. Bureau of Labor Statistics. The Consumer Expenditure Survey (CE) also consists of two instruments, a diary survey for all expenses incurred over a 2-week period and an interview survey that captures expenses for a recall period of 3 months or longer. In order to deal with the significant amount of overlap and to select an appropriate source, the Personal Consumption Expenditure (PCE) estimate produced by the Bureau of Economic Analysis (BEA) is used as reference for a comparison. A Mean Squared Error (MSE) is calculated by adding the variance of the CE data to the squared difference between the mean of the CE data and the PCE estimate. This is performed for both CE sources and the source with smaller MSE is chosen for each expenditure category. We adapted the method for a comparison with the Austrian Consumer Expenditure Survey estimates.

Table 9 Classification of committed and non committed expenditure categories

Category	Classification	Sources
Housing	Committed	H
Food	Committed	D
Accommodation and restaurants	Non-committed	D
Clothing	Non-committed	D, H
Furnishing, household equipment	Committed	D, H
Health	Committed	D, H
Travel	Committed	D, H
Electronics and communication	Non-committed	D, H
Leisure, recreation, culture	Non-committed	D, H
Education	Committed	D, H
Services	Committed	D, H
Financing	Committed	D, H
Insurance	Committed	D, H
Savings	Non-committed	H
Other	Non-committed	D, H

D diary, *H* household questionnaire

The expenses stated in the household questionnaire have consistently smaller variations than those in the diary, so that the decision was always in favour of the household source. However, the smaller variation does not necessarily indicate a higher reliability; it results from the fact that the household section comprises averaged estimates, whereas the diary comprises actual costs with higher variation but lower risk of biased perception.

- In Method 2 we did not select a particular source but calculated the weekly mean values (MV) of diary and household expenses for each overlapping category. This method has two advantages: (1) it reduces the number of zero spendings due to mutual completion; (2) it avoids inconsistencies, if the diary includes expenses during the reporting week, whereas the household section states no spendings for the same category.

The weekly expenses of the category 'Travel' were calculated in a different way, because travel costs are required at a trip- and mode-specific level for a mode choice model. Public transport costs accounted for PT reduction cards (H) and ticket costs (D); individual transport costs accounted for vehicle purchases (H), parking space rent (H), road toll stickers (H). A second reason for a different handling of travel expenses was that some of the running costs were not reported: trip costs depending on fuel type and vehicle consumption were estimated and imputed. All travel costs described above were summed up and allocated to a weekly basis. The category 'Savings' was calculated by subtracting the total expenses from the total income including labour and fixed income.

Table 9 shows a classification of expenditures into committed and non-committed goods. Expenses on goods associated with physical needs or maintenance activities are traditionally classified as committed (Jara-Díaz et al. 2013). People need to eat (Food), take care of their health and a dwelling place (Housing) with equipment (Furnishing, household equipment). Financing and insurance costs are committed as well as services, which are not related to leisure activities. Expenses on eduction and transportation are also regarded as committed (Jara-Díaz et al. 2013; Mokhtarian and Chen 2004).

Food consumed in a restaurant, accommodation costs on holiday trips, leisure and recreational goods are freely chosen expenses and therefore non-committed. Although 'Clothing' is at least partially essential we classified this category as non-committed as expenses added up to fairly high amounts which indicates that basic needs are exceeded. Electronics and communication devices are mainly used for entertainment and thus assigned to non-committed expenses. Savings and all other expenditures which were not further specified are regarded as non-committed.

Figure 8 shows the expenditure shares of both methods (MSE and MV) in comparison with the Austrian Consumer Expenditure Survey (CES) 2009/10 of Statistics Austria. The dataset of the CES required some processing prior to the comparison: (1) The CES dataset was filtered for employed households; (2) Rental equivalents of owner-occupied housing were removed, as no such values are included in the MAED data; (3) The sub-categories of the COICOP levels were slightly reorganized and recoded to match the MAED categories. This task served mainly to distinguish committed from non-committed expenses. Some inconsistencies remained, thus discrepancies in Fig. 8 can partly result from differences in coding.

Both preparation methods yield similar shares of expenditures by category, and the trends resemble the values of Statistics Austria. One reason for differences may be that the saving rate of private households diminished from 11.3 to 6.9% between 2009 and 2015. However, some expenditure shares display considerable deviations from the values of Statistics Austria, for which no specific explanation is available. We suspect the deviation to be the result of unsystematic fluctuations, which are caused by two factors: (1) the survey period of 1 week was too short to capture the long-term equilibrium with respect to frequently purchased items; and (2) the household questionnaire on long-term expenses was self-administered with telephone support, whereas traditional expenditure surveys include personal interviews where plausibility checks can be performed right away. This seems to be a necessary procedure to obtain more conclusive data.

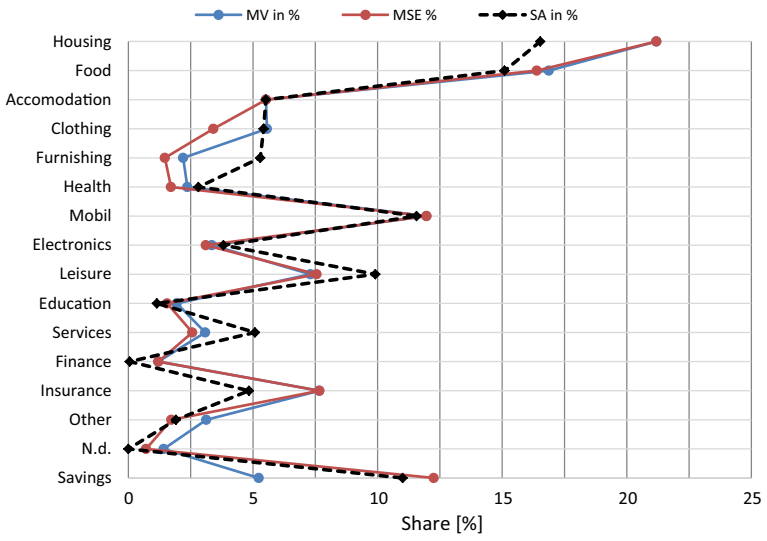


Fig. 8 Distribution of expenditure types by calculation methods in comparison with Statistics Austria 2009/2010

Conclusions and outlook for further research

Our motivation for developing a novel survey instrument was to obtain a dataset, which includes all required components to model travel behaviour within the framework of consumers' home production (Jara-Diaz et al. 2008). To this end we developed a questionnaire and survey design, which enables the collection of data about travel activities, non-travel activities and expenditures from the same individuals over a period of 1 week. The developed survey instrument is based on existing travel diaries, time use diaries, and consumer expenditure diaries. These stand-alone diaries were simplified and re-arranged in order to achieve an integrated MAED with the following features:

- The overall diary structure resembles a conventional travel diary, which structures the day by trips; non-travel activities are nested within the trips.
- Non-travel activities are reported in open time intervals and pre-defined activity categories, although the HETUS guidelines recommend pre-defined intervals and open activity descriptions. This alteration was necessary to keep the response burden at a reasonable level; for the same reason we omitted the parallel activity description, which is a serious downside of this simplification.
- Questions on expenditures are placed within different sections of the diary to achieve an intuitive and self-explanatory scheme: travel expenses in the trip section, expenses related to non-travel activities in the activity section, long-term expenses in the household questionnaire.

It has become evident that the integrated MAED survey performs well and delivers all queried information for travel and non-travel activities at acceptable response rates. Compared to conventional time use and expenditure surveys, it seems that the re-arrangements did not systematically affect the distribution of main activity categories; travel activities are reported more accurately than in conventional travel diaries. Individual telephone motivation and support of respondents as well as an incentive are required in return for the high response burden.

The quality of collected expenditure data is not fully satisfying. We were successful in including all required information in a condensed form into the MAED, however, conventional expenditure surveys put more effort into data collection by means of personal interviews and longer observation periods. This would also be desirable for the MAED to reduce unsystematic variation and to obtain better representations of individuals' long term equilibrium. A technology-based version of the MAED could be a reasonable way to introduce automated data processing and balance checks in view of income and expenditures.

Despite this moderate weakness there is no doubt that the MAED survey yields a more accurate and consistent dataset for modelling travel behaviour within the framework of consumers' home production than any existing survey (or the probabilistic merge of different surveys) may yield. We expect an increasing interest in this kind of integrated data, since both travel and non-travel activities have become more flexible and complex, as do the interdependencies between both. Many researchers work on a better understanding the multiple trade-off processes and travel decisions and how they will change in the future. Prominent fields of research are social interactions in multi-person households (Ho and Mulley 2015) and substitutive relationships between in-home and out-of-home activities (Srinivasan and Bhat 2005), which have the potential to heavily affect future travel

demand. The research questions evolving in these fields inevitably rely on integrated data that can be obtained through a MAED survey.

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Research Article 2

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Implications of survey methods on travel and non-travel activities: A comparison of the Austrian national travel survey and an innovative mobility-activity-expenditure diary (MAED)

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This paper contributes to the research on non-reporting effects in mixed-method household travel surveys (HTS) in two ways: Firstly, we compare travel activities reported in the established Austrian National HTS (ANTS) with an innovative survey approach, the so-called "Mobility-Activity-Expenditure Diary" (MAED), and secondly we extend the analysis to (i) additional travel estimates and to (ii) non-travel activities. The analysis addresses three main goals: (i) identification of non-reporting effects in the HTS for travel estimates, (ii) analysis of speed-of-response effects on travel estimates, (iii) assessment of the completeness and accuracy of non-travel activities inferred from the trip purposes in the HTS. Underreporting in HTS occurs both on person level and on the trip level, and mainly for peak-hour trips with either short distances or short durations of the subsequent non-travel activity. No significant underreporting was found on the tour level. Speed-of-response effects are small in both surveys but significant for the ANTS. The duration of non-travel activities per activity type corresponds well in the MAED-survey and in the ANTS but the information in the MAED-survey is much richer. The results can be used threefold: (i) to develop correction factors that account for systematic biases in HTS, (ii) to identify omitted items (trip frequency, duration, distance etc.) if HTS data are used without correction factors, and (iii) to demonstrate the importance of high quality field work and validation.

Keywords: *data collection, response burden, speed of response, time use, travel survey methods, mobility-activity-expenditure diary.*

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1. Introduction

Household travel surveys (HTS) are an important data source for transport planning and research. Established HTS are mixed-method approaches that combine paper-and-pencil questionnaires (PAPI), telephone interviews (CATI), web-based questionnaires (CAWI) and personal interviews (Armoogum et al. 2014). Innovative tracking methods with dedicated GPS-devices or smartphones are not yet fully established in survey practice (e. g. for national travel surveys, NTS) but are widely used in research. Reporting quality and non-reporting effects in HTS can significantly influence the quality and usability of the resulting data and thus have been analysed in various studies based on:

i. follow-up validation directly within the HTS, including speed-of-response analyses (Brög and Meyburg 1980, Richardson 2003) and non-response studies (Brög and Meyburg 1980, Richardson 2003, Wittwer and Hubrich 2015),

ii. comparisons of different HTS methods (Armoogum et al. 2014, Madre et al. 2007) and validation with external data sources such as traffic counts (Ashley et al. 2009),

iii. comparisons of HTS and time use surveys (TUS) (Gerike et al. 2015, Armoogum et al. 2008), and

iv. comparisons of HTS with GPS-based innovative survey approaches (Rasouli and Timmermanns 2014, Safi et al. 2017).

Differences have been identified in the proportion of mobile persons, in the number of trips per person day (trip rate), and in the trip characteristics. Validation studies and comparisons of different survey designs directly within the HTS show significant effects of (a) sophisticated and high quality survey designs for all steps from the sampling procedure to data processing, (b) response rates and (c) the speed-of-response. Brög and Meyburg (1980, see also Brög et al. 1982, Brög and Meyburg 1981, Brög 2009, Socialdata 2009) aim to establish a "ground truth" from a PAPI survey with the help of extensive validation of the received questionnaires within their New KONTIV Design (NKD).

Comparisons between TUS and HTS conclude that TUS data generate higher travel estimates (Stopher 1992, Harvey 2003, Hubert et al. 2008). The underlying hypothesis is that activity-based diaries are more intuitive as they put travel in the context of the daily schedule, so that respondents are better able to recall trips and less susceptible to soft refusal. However, these findings only hold if "location changes between two time intervals in the diary without a reported trip in-between" are added to the actually reported trips (Gerike et al. 2015). Comparisons of GPS surveys with HTS reveal a similar pattern (Jin et al. 2014, Rasouli and Timmermanns 2014, Safi et al. 2017). Trip numbers are on average higher in GPS surveys compared to traditional HTS, particularly for discretionary trips.

This paper aims at contributing to this line of research on reporting quality and non-reporting effects in HTS (i) by adding a comparison of travel activities reported in HTS with an innovative survey approach, the so-called "Mobility-Activity-Expenditure Diary" (MAED), and (ii) by extending the analysis to (iia) additional travel estimates that to our best knowledge have not been considered before and to (iib) non-travel activities (called 'activities' in this paper).

We compare the Austrian national travel survey (ANTS) from 2013/14 (BMVIT 2015), a traditional mixed-method HTS, with the innovative hybrid travel/time use MAED-survey. The latter is a self-administered mail-back survey based on the NKD. The travel section is similar to the established HTS, but the MAED adds detailed questions about all activities between any two trips and about all committed expenditures. We consider the MAED dataset as "ground truth" in the comparison, which contains (almost) all trips and activities with high accuracy. This assumption seems justified for three reasons: (i) MAED respondents received an incentive after

successful participation and were thus well motivated to fill out the diary carefully, (ii) trips are reported in the context of the daily schedule, so that respondents are better able to recall trips and cannot draw an advantage from claiming not to have made a trip, and (iii) the MAED-survey includes the same extensive validation as the NKD (developed from Brög and Meyburg 1980).

The following three goals are set for the comparison of the MAED-survey and the ANTS in this paper:

- Identification of non-reporting effects in the travel estimates of HTS: In addition to the usual travel estimates reported in the literature as described above and in section 2, our comparison accounts for additional indicators in order to deepen the understanding of the non-reporting effects. These are in particular (i) tours (defined as a series of trips that begin and end at an individual's home); (ii) temporal pattern of trips in order to understand whether non-reporting is related to the start time of a tour or a trip; and (iii) the duration of the subsequent activity after each trip as possible determinant of non-reported trips.
- Analysis of speed-of-response effects on travel estimates: A particular strength of our database is that detailed field work variables are available for both surveys. They characterise the survey process and are used for analysing the so-called "speed-of-response" effect for the travel estimates. The literature reports ceteris paribus systematic differences in trip rates for respondents who directly answer after the first mailing (early respondents) and respondents who only answer after the last reminder activities (late respondents) (Brög 2009, Richardson 2003). These comparisons of travel estimates for early and late respondents serve two purposes: (i) to estimate the hypothetical travel estimates at 100 percent response rate (Brög 2009) or (ii) to identify biases in travel estimates resulting from speed-of-response effects (Richardson 2003; see also Axhausen and Weis (2010) for a response-burden/self-selection explanation). The latter is elaborated in this paper.
- Assessment of the completeness and accuracy of non-travel activities inferred from the trip purposes in the HTS: Based on methods developed in Gerike et al. (2015), the number and duration of activities are computed for the ANTS and compared with the activities reported in the MAED-survey.

This paper aims at investigating differences between the MAED-survey (considered as "ground truth") and the ANTS (a traditional HTS) for key travel estimates and non-travel activities in order to better understand non-reporting effects in HTS. The results can be used threefold: (i) to identify what information is lost (trip frequency, duration, distance etc.) if HTS data are used without any correction, (ii) to develop correction factors that account for systematic biases in HTS, and (iii) to demonstrate the importance of high quality field work and validation.

The remainder of this paper is organised as follows: In the next section, we review the literature on comparisons of different survey designs and on the speed-of-response effects on travel estimates. The literature review includes all types of comparisons i) to iv) as described above, but the focus is on the comparison of TUS and HTS (iii) because the literature in this field is rich and the MAED-survey is a hybrid between TUS and HTS. We describe the data used in this paper and the methods for data processing and data analysis in section three. The results of the analysis are presented in section four. The final section five discusses the results and gives an outlook for further research.

2. Literature Review

2.1 Non-reporting effects in travel estimates

Hubert et al. (2008) found the number of immobile persons (persons who stay at home on the reporting day) reported in HTS to be twice as high as that reported in TUS for the three countries UK, France and Belgium. The authors assume that the level of soft refusal in HTS diaries accounts for this difference when respondents deliberately do not report any trip in order to reduce their response burden. Madre et al. (2007) compare the share of immobile persons in different HTS. They find greatly varying shares between otherwise similar survey types with soft-refusal given as an important reason for these differences. The quality of the field work and the survey protocol are identified as main determinants of soft-refusal besides the survey method. These findings are supported by Gerike et al. (2013) who find similar immobility rates for the German TUS and HTS and conclude that high quality TUS and HTS yield similar immobility rates and that the differences found e.g. in Hubert et al. (2008) might result from field work quality in addition to the methodological differences between TUS and HTS.

The findings in all comparisons of i. to iv. (as classified in section 1) show consistent underreporting effects in HTS for the number of trips (Armoogum et al. 2014, Brög and Meyburg 1980, Gerike et al. 2015, Rasouli and Timmermanns 2014). Mainly short and irregular trips are underreported in HTS resulting in higher differences in trip rates for discretionary ('leisure') trips compared to subsistence ('work', 'education') and non-discretionary (e.g. 'shopping', 'errands') trips (Bose and Sharp 2005, Gerike et al. 2015, Richardson 2007). The TUS format results in more odd number of trips per person and day (Gerike et al. 2015, Hubert et al. 2008, Stopher 1992). The reason for this effect might be that the travel diaries perform better in supporting respondents to remember and reports trips to the destination and back home compared to TUS diaries. No studies have been found that analyse the influence of duration of the subsequent non-travel activity on trip-underreporting. Gerike et al. (2015) analysed differences in the start time of the first trip and the last trip as one possible further indicator for soft refusal when e.g. last trips on a diary day are systematically underreported in order to reduce response burden. Based on a comparison of the German TUS and HTS, the authors find no significant differences in the start time of the first trip in contrast to the start time of the last trip which was significantly later in TUS compared to HTS. Daily travel times and distances are more consistent in the literature across survey methods; underreporting seems to be mainly an issue of trip rates (Armoogum et al. 2014, Hubert et al. 2008, Schüssler 2010).

Primerano et al. (2008, see also Ho and Mulley, 2013) give an overview of definitions for trip chains (in this paper referred to as tours) as sequences of trips that are linked to each other. The literature reports several variables that impact people's propensity to chain trips, including social circumstances, the spatial environment, and the transport system (Scheiner 2014). No consistent findings exist for the relation between trip chaining and mode choice (De Witte et al. 2013). Typical tours consist of one main activity such as work and additional short activities such as shopping, errands, accompanying or leisure on the way to the main activity or back home (Primerano et al. 2008). We found no literature about comparisons of the number of tours per person and day and their characteristics between different survey types.

2.2 Speed-of-response analysis of travel estimates

The speed-of-response analysis (Brög and Meyburg 1981, Brög 2009) of travel estimates focuses on trip rates as fundamental indicator of travel behaviour. The correct number of trips per person is the core basis for any subsequent analysis of travel behaviour. Speed-of-response studies for HTS mainly find less trips for late respondents compared to early respondents (Richardson 2003). The following reasons for the lower trip rates of late respondents are discussed in the literature (Wermuth 1985, Richardson 2003):

a. Different socio-demographic groups: Early and late respondents might belong to different socio-demographic groups with different travel patterns. Respondents with no or few trips might think that their response is of less value and answer late. Respondents with many trips on the other hand might be less likely to spend their time filling out questionnaires. They might also answer late even though they are interested in the topic of travel.

b. Different travel patterns: Early and late respondents might belong to the same socio-demographic groups but might have different travel patterns, e.g. when the late respondents travel less.

c. Self-selection of diary day: In travel surveys, a specific reporting date is assigned to each respondent. A new reporting date is assigned when the original reporting day has elapsed. People might select a diary day with no or few trips in order to minimize their response burden. In doing so, they can answer truthfully without any non-reporting but still they report too few trips.

d. Item-non-response: Participants might leave out selected trips in their diary because the task of filling out the diary is considered being too time-consuming (intentional non-reporting) or the survey's design makes the task of answering truthfully difficult for them (unintentional non-reporting).

The speed-of-response technique has been used to analyse and correct shortcomings of survey outcomes with a low response rate (Brög and Meyburg 1980, Brög et. al 2009). Richardson (2003) applies the speed-of-response technique and finds decreasing trip rates from early to late respondents but not differences in the socio-economic characteristics of early and late respondents (effect (a) from above). The author finds only slight differences in the number of non-reported trips between early and late respondents (see Brög 2009 for similar findings) and concludes that item-non-response (effect d) from above) should not be the reason for the lower trip rates of late respondents. The author suggests the following explanations for the lower response rates of late respondents: lower actual trip rates (effect b) from above) and self-selection of the diary day (effect c) from above); a preference is expressed for the self-selection mechanism.

2.3 Non-travel activities

Gerike et al. (2015) compute the duration of non-travel activities from both HTS (only for persons with at least two trips on the diary day) and TUS. The type of activity in the HTS between trips is deducted from the trip purpose. Only activities carried out between the end of the first trip of the day and the start of the last trip of the day are included in the analysis for both surveys. The results show a good correspondence between the two surveys for subsistence activities. 35 % of the time between the first and the last trip of the day in TUS are spent on 'work' activities and 10 % on 'education' (HTS 36 %, 9 %). The percentage of time spent on 'shopping' activities is similar in both datasets (5 %). Differences in the other non-discretionary activity types mainly result from two effects: Firstly, coding schemes differ between the two datasets. There are no trip purposes describing 'care for others', 'voluntary' or 'personal care for oneself' in HTS, and there are no activities of the type 'accompanying' in TUS. Secondly, the 'home' activity in HTS that follows each trip back home cannot be clearly assigned to any of the activity types. The share of 'leisure' activities in TUS (24 %) is significantly higher than in HTS (20 %) in the time between the first and the last trip. These findings show that we can reliably infer from HTS on subsistence activities, but only for respondents with more than two trips per day and only for the time between the first and the last trip.

2.4 Summary of the literature review and research gaps

Corresponding to the three goals defined above for this paper, we derive the following research gaps from the literature review:

- Goal 1, identification of non-reporting effects in the travel estimates of HTS: There is a need to further analyse non-reporting effects in HTS, in particular to better understand the effects of the temporal distribution of trips and of subsequent activities on non-reporting effects in HTS. In addition, non-reporting analysis on tour level is required for a better understanding of the non-reporting effects identified so far in the literature.
- Goal 2, analysis of speed-of-response effects on travel estimates and goal 3, assessment of the completeness and accuracy of non-travel activities inferred from the trip purposes in the HTS: Only few studies have been carried out so far in these two fields with partially inconclusive and contradictory results.

3. Data sources and methodology

3.1 Survey description

This section describes the surveys that have been analysed for this paper. A detailed summary of both surveys' characteristics can be found in Appendix A.

Mobility Activity Expenditure Diary (MAED)

The MAED-survey was conducted in spring and autumn of 2015 as a self-administered mail-back survey with a one-week reporting period and detailed questions about all trips as well as all activities for each diary day. The questionnaire contains a travel diary part based on the NKD with an expanded 'trip purpose' section in order to retrieve detailed information about activities (see Rösel et al. 2015 for a detailed description of the diary). This 'activity section' corresponds to a simplified scheme derived from a widely used time use diary format, the HETUS (Eurostat 2004, 2009).

The addresses of survey participants were a random selection of Austrian households for 18 pre-defined strata. These were arranged by region and level of urbanisation (urban, intermediate, rural). A telephone number could be identified for around 50 % of sampled households. Only employed persons were eligible to take part in the MAED-survey as a wage rate was needed for modelling the trade-off-processes between time and money using the transport economic models described in Jara-Diaz et al. (2008).

Figure 1 gives an overview of the survey procedure. The announcement postcard was sent to all sampled households followed by a first phone call to the households with telephone number. Households without telephone number were asked to provide their contact details via return of the announcement postcard. If these households answered and provided their contact details, they received the survey material and were treated similarly to the households with a listed telephone number from then on. The first phone call to households with available phone number served two purposes: Only employed persons were selected with the help of a screening question about the employment status of all household members. They were directly asked whether the survey material could be sent to them. The material was sent to them after they had agreed to take part in the survey. After having received the survey material, respondents were called for motivation and support at least once. Respondents sent the survey material back to the survey team after completing the survey for their reported week. Comprehensive plausibility checks followed immediately, similar to the procedure in the NKD (Brög 2009, Socialdata 2009). Respondents were called back in order to correct implausibilities and to complete missing items. Each participant with complete questionnaires received an incentive of €40 (voucher) after their data had been validated and no more calls for retrieving missing data were necessary.

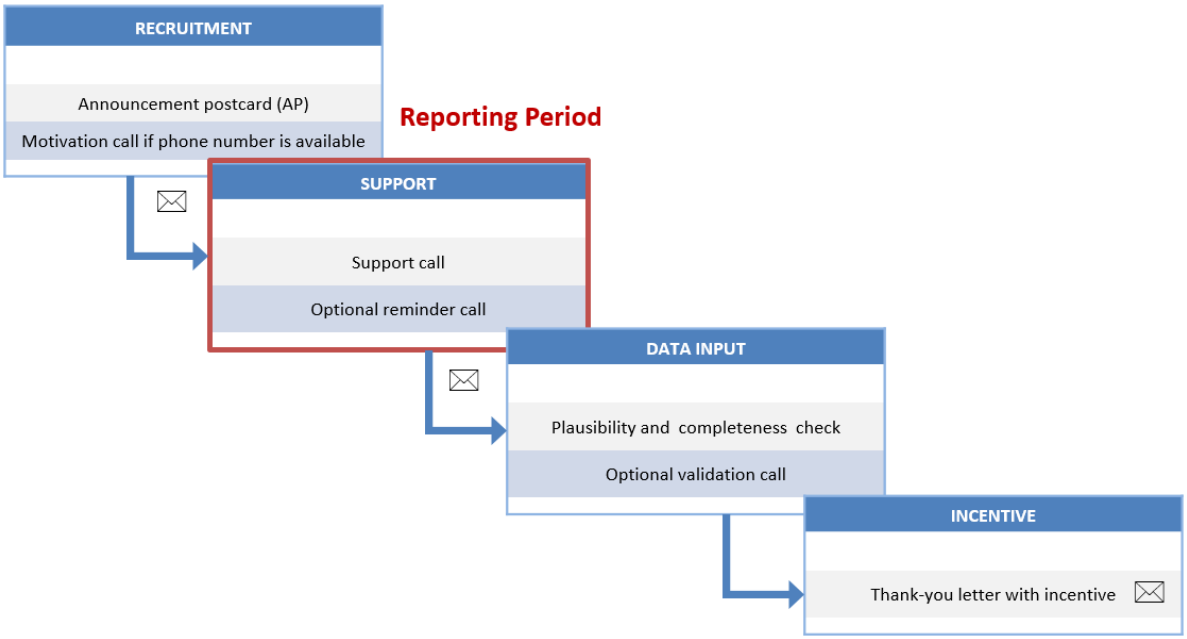

Figure 1. Survey procedure of the MAED-survey

Austrian National Travel Survey (ANTS)

The ANTS was carried out from October 2013 to November 2014 on behalf of the Austrian Ministry for Transport, Innovation and Technology. The survey method followed the guidelines of the KOMOD-Handbook (Fellendorf et al. 2011) with three options for participation (PAPI, CATI, CAWI). The survey material was based on the New KONTIV-design (Socialdata 2009) with the major modification of two consecutive reporting days. Contrary to the MAED-survey, households of the ANTS received the questionnaire unsolicitedly shortly after the announcement postcard, followed by motivational telephone calls. Up to four reminder postcards including new reporting dates were sent to the households who had not responded yet. Postal household addresses were sampled from the Austrian civil register and telephone numbers were added similarly to the MAED-survey.

3.2 Data processing

Appendix A gives an overview about key characteristics of the MAED-survey and the ANTS (original and matched sample). For data processing, respondents from the ANTS were selected for further analysis as follows in order to ensure comparability with the MAED-survey: Firstly, only employed persons who had their reporting days from April to June or from October to December (field work-periods of the MAED-survey) and only with their first reporting day were selected. Secondly, both datasets were matched at the level of person reporting days in order to take advantage of the weekly diary of the MAED-survey. For each person reporting day in the MAED data we selected one person in the filtered ANTS which exactly matched the following categorical variables: level of urbanisation, type of weekday, gender, age, education, availability of a car and of a public transport season ticket. We purposefully included PAPI, CAWI and CATI respondents from the ANTS into the matching procedure in order to acknowledge the final goal of this paper: the better understanding of non-reporting effects in established mixed-method HTS. The sample description and key travel estimates for the ANTS by survey method (separately for PAPI, CAWI and CATI) as listed in Appendix B show the differences between the survey methods within the ANTS.

We define immobile persons as those who did not report a single trip for their reporting day. Trip data in both surveys was curtailed by setting a boundary for trip distance to 100 kilometres. Trips that continued over midnight were included in the dataset with the end time set to midnight.

Response variables (also called field work variables) were computed for both surveys as the basis for the speed-of-response analyses. Two types of variables were computed:

i. five variables which describe the household's response duration in different phases of each survey and

ii. three variables describing frequencies of attempted telephone calls

For creating response variables equally applicable to both survey designs, the ANTS response data was additionally filtered for households that took part via PAPI-method (75 % of all households) in the survey. Figure 2 gives an overview of the variables describing the household's response (see Appendix C for a detailed summary of all variables).

The methods used for computing the type and duration of non-travel activities in the ANTS and in the MAED-survey are described in Appendix D. An activity coding scheme was developed that translated activity types from the MAED-survey and trip purposes from the ANTS into a common activity types. A list of the original activity types is provided in Appendix E

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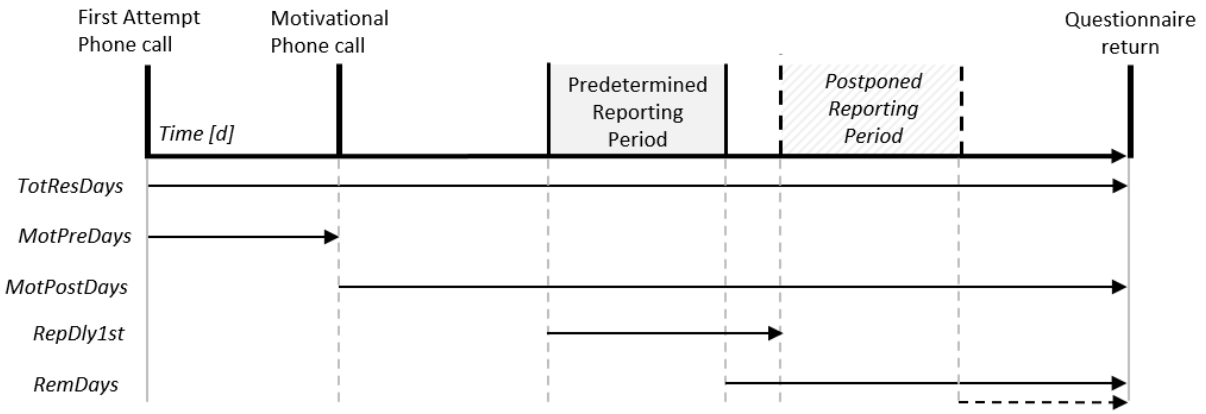


Figure 2. Response variables describing response durations in different phases of both surveys.

3.3 Sample description

Table 1 gives an overview of the matched sample's characteristics. Data from the Austrian National census as collected by Statistik Austria (*'Registerzählung 2011'*) is listed in addition to the matched MAED/ANTS-sample in order to compare socio-demographic characteristics of the matched sample used for this paper with those of the overall Austrian population of employed persons, according to the ILO-definition (ILO 1993). For comparing sample characteristics at household level, the Statistik Austria sample was reduced to households with an employed reference person[6]. The original weighted and filtered ANTS sample is included in Table 1 in order to identify possible differences to the matched MAED/ANTS-sample respectively to Statistik Austria.

The matched MAED and ANTS samples correspond very well by definition as most of the variables listed in Table 1 have been used for matching in the data processing step. Compared to

[6] The household's reference person according to Statistics Austria is defined as the oldest person of the nuclear family (for single-family households) or as the oldest person, that represents the middle generation of that family (for two- or multi-family households).

the official statistics from Statistik Austria, females are slightly overrepresented in the matched MAED/ANTS-sample. The groups of young and low-educated persons are underrepresented in the matched MAED/ANTS-sample. These are typical pattern known also from other household travel surveys (Armoogum et al. 2014) and visible also in the original weighted ANTS-data in Table 1. The MAED/ANTS-sample contains fewer single-person households and fewer households in urban areas compared to the official statistics. Lower response rates in urban areas compared to rural areas are one reason for this phenomenon. Both persons and households of the matched sample show the typical high availability of mobility tools, e.g. vehicles, season tickets or car club memberships, for employed persons. The high proportion of MAED/ANTS-participants from rural areas also causes the higher rate of car ownership.

Table 1. Sample characteristics of matched MAED and ANTS data, filtered ANTS data and Austrian National Census

	MAED 2015 matched	ANTS 2013/14 matched	ANTS 2013/14 filtered, weighted	Stat. Austria 2011
n households	485	3,741	5,829	-
n persons	738	4,830	9,436	-
n person reporting days	4,830	4,830	9,436	-
Gender*				
Male	49.4	49.4	53.1	53.3
Female	50.6	50.6	46.9	46.7
Age*				
15-19	1.9	0.5	0.7	5.0
20-29	6.5	8.7	13.6	19.5
30-39	19.0	18.6	19.1	22.6
40-49	37.0	34.9	31.3	29.1
50-59	31.4	33.6	31.8	20.0
60+	4.2	3.8	3.5	3.8
Highest level of education*				
Compulsory school	2.5	3.9	4.8	17.8
Apprenticeship, college	37.6	36.2	48.2	50.9
Matura	24.2	26.5	20.5	15.9
University, FH	35.6	33.5	25.9	15.4
Household size				
1 person	9.0	7.9	12.5	30.2
2 persons	28.1	29.1	30.0	23.1
3 persons	22.5	23.9	24.4	19.0
4 or more persons	40.4	39.1	33.1	27.7
Level of Urbanisation [7]*				
Urban	21.9	21.9	23.8	33.5
Intermediate	27.9	32.0	28.6	29.9
Thin	50.1	46.1	47.6	36.7
Personal mobility tools available */**				
Car	94.3	94.3	94.9	76
Public Transport pass (Season ticket, zone ticket	31.8	31.8	25.2	22***
Household's availability of vehicles **				
Bicycle	89.9	89.2	91.5	71
E-Bicycle	6.7	4.5	6.7	
Moped/Motorbike	23.7	25.5	25.2	
Car	95.5	93.9	95.4	89

* matching variable, ** not collected by Statistik Austria, but by the Austrian Ministry for Transport, Innovation and Technology, *** season tickets only

3.4 Analysis methods

Figure 3 shows the analytical framework used for this paper. The overall aim of this paper is to analyse non-reporting effects in HTS. These effects are distinguished into direct and indirect effects. Direct effects are analysed by comparing results in travel estimates in both surveys. Indirect effects consider the speed-of-response as mediating variable based on the hypothesis that the survey design influences the response duration of participants and that this survey duration

[7] Definition for the MAED-survey and Statistik Austria: According to the Degree of Urbanisation (DEGURBA) - classification by the European commission (Eurostat 2011); Definition for the ANTS: According to the Austrian Conference on Spatial Planning's (ÖROK) spatial types (ÖROK 2007). Both definitions are comparable for Austria.

in turn is related to the travel estimates. We analyse the differences between the travel estimates and activities in both surveys using descriptive statistics and t-tests.

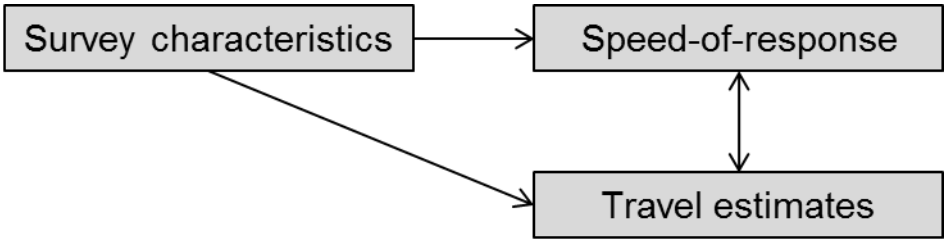


Figure 3. Analysis framework

The response variables described in section 3.2 and Appendix C are used for investigating the indirect effects. The variable "TotResDays" is used for analysing the overall differences in trip rates between early and late respondents as in Brög et al. (2009) and Richardson (2003). The overall effect of different trip rates as a function of the speed-of-response is decomposed into its several components as described in the literature (see section 2.2): Differences in the socio-demographic characteristics of early and late respondents are analysed in order to test reason a) (different socio-demographic groups). The variable "RepDly1st" is used to test reason c) (self-selection of travel day). Reason d) (item-non-response) is tested similarly to the estimation of the direct effects but looks now at differences in travel estimates for early and late respondents of each survey. Reason b) (different travel pattern) is discussed indirectly based on the insights gained on the reasons a), c), d). The role of a possible fatigue-effect in participants of the MAED-survey is analysed by means of a linear model with regard to the reporting day and the according type of weekday (Working day, Saturday, Sunday).

4. Results

4.1 Overview of standard travel estimates

Table 2 gives an overview of the core travel estimates of both surveys. The overall proportion of mobile persons is significantly higher in the MAED-survey with 91.8 % compared to ANTS with 89.0 %. The likely reason for this difference is soft refusal in the ANTS.

The overall number of tours per day does not differ significantly. 64.7 % of the person days have one tour in the MAED-survey (60.2 % in ANTS), 27.6 % have two tours in the MAED-survey (30.5 % in ANTS) and 7.7 % have more than two tours (9.3 % in ANTS). The trip rate is with 3.81 trips per person day significantly higher in the MAED-survey compared to ANTS (3.59). The trip rates in the MAED-data follow the typical pattern described in the literature (see e.g. Armoogum et al. 2014).

The average trip distance of 13.9 km is higher in the ANTS compared to the MAED-survey with 11.1 km, and also the average total daily distance travelled of 49.9 km is higher in the ANTS (MAED: 42.3 km). The duration of single trips and the daily travel time values follow the same pattern. Consequentially, the higher number of trips per person reporting day in the MAED-survey does not compensate for the survey's lower distance and duration per trip. The difference in average trip distance is even larger when analysing working days only (MAED: 10.4 km, ANTS 14.0 km), which is mainly due to the large difference in trip distances of commuting trips for respondents in intermediate communities (MAED: 12.3 km, ANTS 20.1 km). Differences in commuting distances in urban areas (MAED: 8.0 km, ANTS 10.2 km) and rural areas (MAED: 16.8 km, ANTS 21.1 km) are not as large. The higher share of persons in intermediate communities in the ANTS generates longer average trip distances over all area types and trip purposes even though differences for trip purposes other than commuting are not substantial.

The higher trip rates in the MAED-survey confirm the initial hypothesis that the MAED-survey succeeded in motivating participants to report their trips more completely. The lower trip distance and trip duration in the MAED-survey can be attributed to two effects: (i) differences in commuting distances as described above and (ii) underreporting of short trips in the ANTS resulting in a lower trip rate on the one hand and a higher average trip distance / duration on the other hand.

The modal split values of the MAED-data and the ANTS show typical distribution for samples of employed persons and correspond well even though the differences are found to be significant. This level of significance can be attributed to the large sample size for the trips.

Socio-demographic characteristics and key travel estimates are listed separately for the original, filtered (in case of ANTS) and matched datasets in Appendix F in order to provide detailed information about the influence of filtering and matching on these variables.

The general pattern of underreporting found so far is analysed in more detail in the following sections. Direct effects are analysed in section 4.2 (travel estimates) and section 4.4 (activities). Section 4.3 is dedicated to the indirect effects of the speed-of-response as introduced in section 3.4.

Table 2. Travel estimates for MAED and ANTS (matched sample)

	MAED 2015	**ANTS 2013/2014**	χ^2	p-value
n person reporting days	4,830	4,830		
n mobile person reporting days	4,434	4,298		
n trips	16,910	15,431		
Share of mobile persons				
Overall	**0.92**	**0.89**	22.40	< 0.001
Working day	0.97	0.93	80.2	< 0.001
Saturday	0.88	0.86	1.45	0.228
Sunday*	0.71	0.76	4.75	0.029
Number of trips per mobile person				
Overall	**3.81**	**3.59**	5.52	< 0.001
Working day	3.99	3.67	6.62	< 0.001
Saturday	3.74	3.63	1.07	0.287
Sunday*	2.84	3.12	-3.18	0.002
Number of tours per mobile person				
Overall	**1.47**	**1.44**	1.93	0.053
Working day	1.48	1.44	2.30	0.021
Saturday	1.56	1.53	0.62	0.536
Sunday*	1.34	1.38	-1.16	0.247
Distance of trips [km]				
Per trip	11.1	13.9	-13.32	< 0.001
Per day	42.3	49.9	-7.13	< 0.001
Duration of trips [min]				
Per trip	23.8	26.8	-8.18	< 0.001
Per day	90.8	96.3	-3.24	0.001
Mode choice				
Public Transport	9.3	11.5	42.40	< 0.001
Car	72.2	68.7	46.80	< 0.001
Bicycle	5.7	6.5	7.44	0.006
Walk	12.8	13.3	2.06	0.151

* including holidays and public holidays

4.2 Detailed analysis of item-non-response for tours and trips

Tours

The above analysis shows that the overall number of tours per day does not differ significantly between the MAED-survey and the ANTS. The proportion of tours with only one trip (e. g. strolling or walking the dog) is almost the same in both surveys (MAED-survey: 7.4 %, ANTS: 6.8 %). On the contrary, there are differences in the number of tours with two (56.5 % in MAED, 64.6 % in ANTS) or three trips (19.3 % in MAED, 14.2 % in ANTS). These might be an indication for item-non-response in the ANTS when e. g. short in-between trips on the way back home are not reported. The temporal distribution of tours might be another indication for soft refusal when e.g. late tours are underreported. The number of tours starting in the hours of the morning-peak (6 a.m. to 8 a.m.) and afternoon-peak (3 p.m. to 6 p.m.) is slightly higher in the MAED-survey

compared to the ANTS, and lower for the off-peak periods, but the differences are not significant. Soft refusal seems therefore not to be an issue for tours. Also late tours of the reporting day seem to be well-reported in both surveys.

Trip characteristics

The average number of trips per reporting day differs significantly between the MAED-survey (3.81 trips per day) and the ANTS (3.59 trips per day). The share of persons with two (30.3 % in MAED, 36.4 % in ANTS) and three trips (17.4 % in MAED, 12.7 % in ANTS) on their reporting day is significantly different in both surveys. The proportion of persons with four or more trips is almost the same in both surveys. The significantly lower trip rates in the ANTS show that the higher proportion of persons with two trips on their reporting day in the ANTS and with three trips in the MAED-survey results from missing trips within tours in the ANTS, rather than from missing trips back home in the MAED-survey as assumed e. g. by Hubert et al. (2008).

Similarly to the tours, the proportion of trips beginning in the peak-hours in the MAED-survey is higher compared to the ANTS. However, unlike for tours the difference for trips is significant.

The overall high number of trips in peak-hours is a direct result of the requirement for respondents in the matched sample to be employed. Underreporting in ANTS is highest in the afternoon-peak when people travel back home and do not report their trips on the way back from their main activity. The number of trips in the MAED-survey is 12.6 % higher compared to the ANTS in the afternoon-peak from 3 p.m. to 6 p.m. (7.9 % in the morning-peak from 6 a.m. to 8 a.m. and 3.4 % in off-peak hours). We analyse these underreporting-effects further in the following graphs for different trip characteristics.

Figure 4 presents the distribution of trips per trip distance from both surveys. The number of trips per person below or equal to 20 km distance is significantly higher in the MAED-survey (3.25) compared to the ANTS (2.90) in this distance class. No significant differences exist for the middle distance classes. The number of trips per person above 50 km is significantly lower in the MAED-survey (0.15) compared to the ANTS (0.22). This difference results from longer commuting trips in the ANTS as discussed above. Short trips are strongly underreported in the ANTS in the afternoon-peak, whereas underreported trips in the morning-peak have medium distances. A possible explanation for this effect might be that activities with short durations take place following these trips as shown in Figure 5. Trips with a subsequent activity of ten minutes or less in the morning-peak are strongly underreported in the ANTS (18.0 % less than in the MAED-survey). Figure 4 and Figure 5 together show that trips in the ANTS are substantially underreported if either the trip itself has a short distance or the activity subsequent to the trip has a short duration (see Stopher et al. 2007 for similar findings). The distribution of trips per trip duration shows similar pattern as described above for the trip distances.

Figure 6 shows that mainly car trips (including also motorbikes) are underreported in the ANTS. The high absolute difference of 0.29 car trips per person day results from the high modal share of car trips in both surveys (see Table 2) but also the relative difference is highest for car trips: Respondents in the MAED-survey have on average 7.5 % more car trips compared to ANTS. Differences in the trip rates are not significant for any of the other modes.

Figure 7 shows the number of trips per person and trip purpose. The number of trips per person with the purpose 'back home' is significantly higher in the MAED (1.43) compared to ANTS (1.33). Two effects interact here: The overall trip rate is higher and tours are longer in MAED compared to the ANTS. Longer tours with more trips per tour reduce the number of trips back home but this effect is more than compensated by the overall higher number of trips per person in the MAED-survey. The number of 'shopping' trips per person show the biggest difference, with 0.49 in the MAED-survey compared to 0.28 in the ANTS. This trip purpose is heavily affected by underreporting in the ANTS throughout the day, especially in the afternoon-peak.

Differences between the two surveys in the number of trips with the purpose 'errands' might be an artefact and disappear when the purposes 'errands' and 'other' are grouped together.

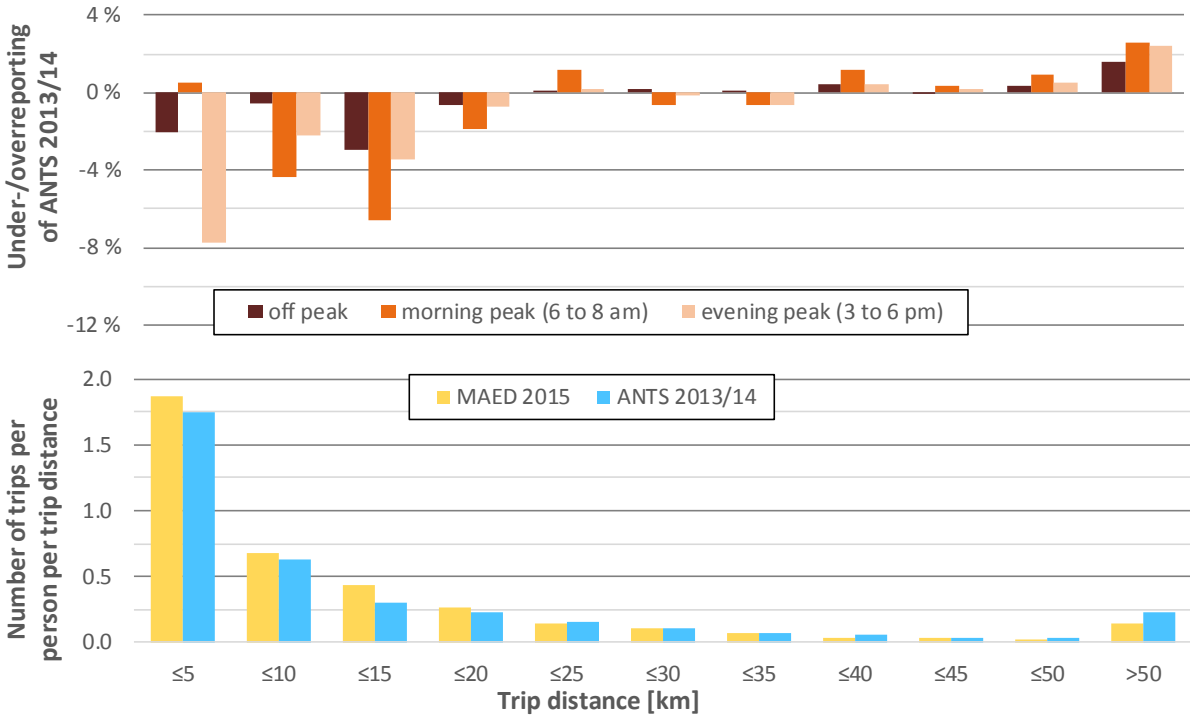


Figure 4. Distribution of trip distances of all trips per person per day (below) and respective under-/overreporting of ANTS 2013/14 (above).

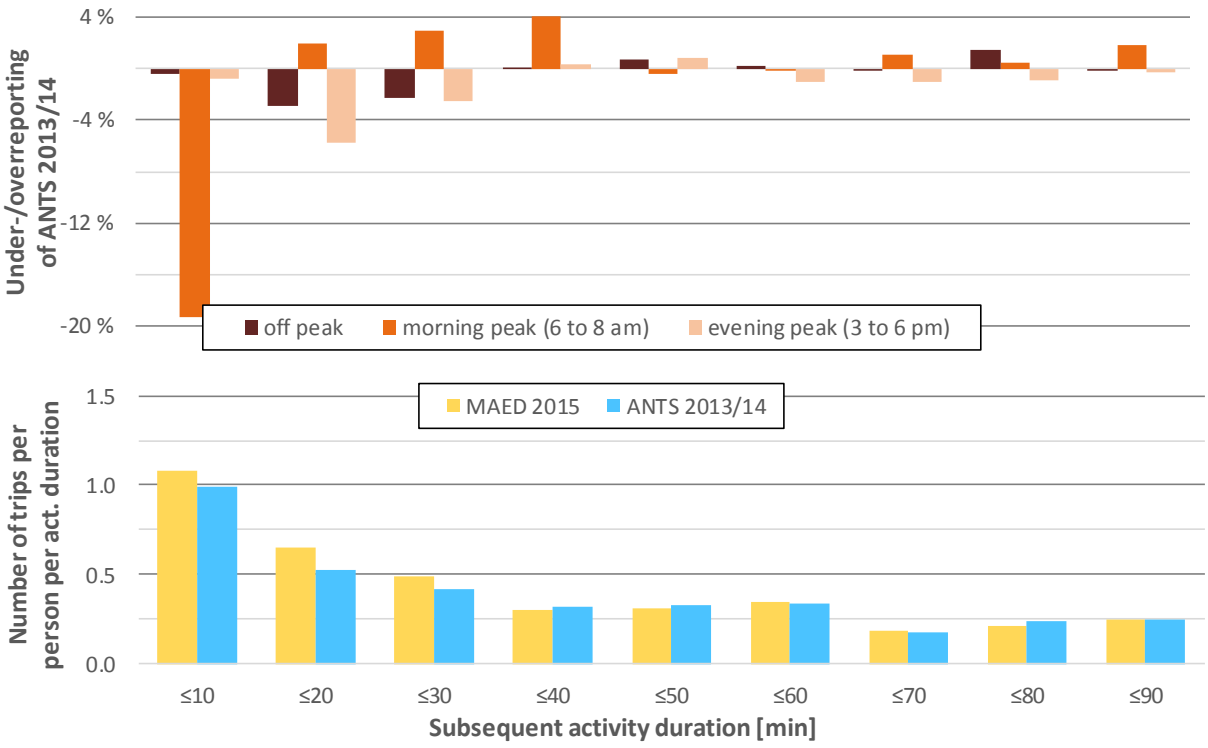


Figure 5. Distribution of trips with regard to their subsequent activity duration (up to 90 minutes; below), and respective under-/overreporting of ANTS 2013/14 (above). Only persons with at least two trips are included.

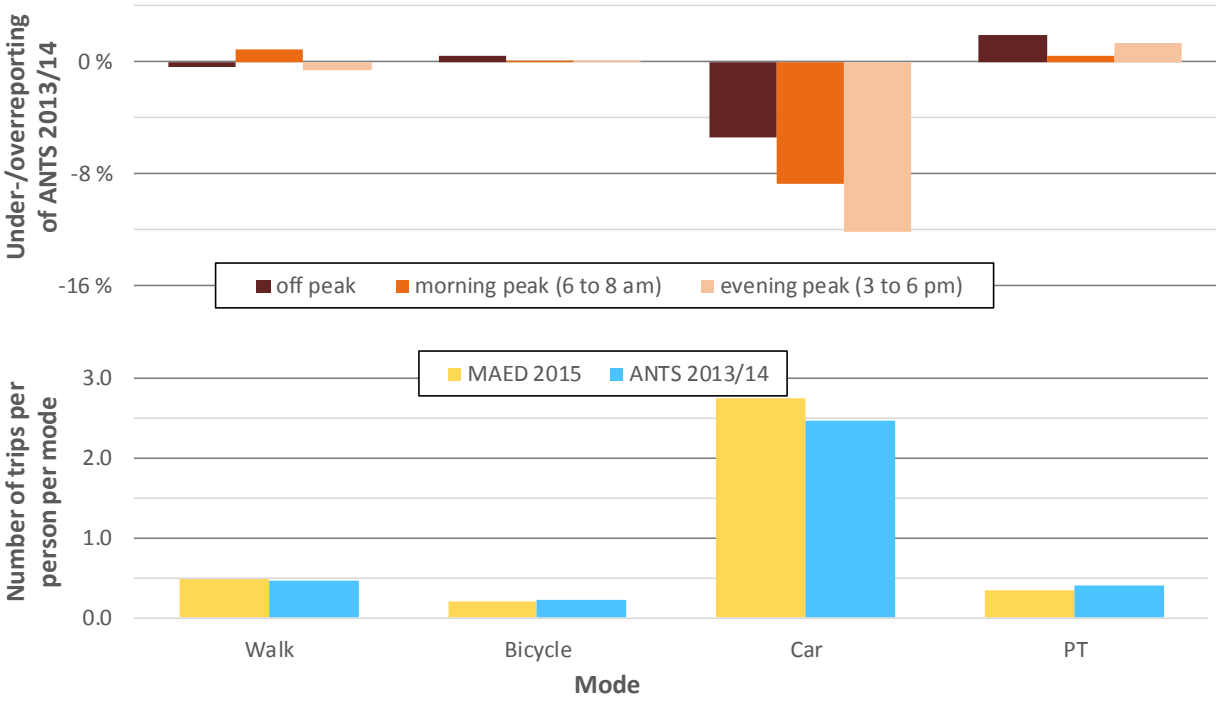


Figure 6. Distribution of modes of all trips per person per day (below) and respective under-/overreporting of ANTS 2013/14 (above).

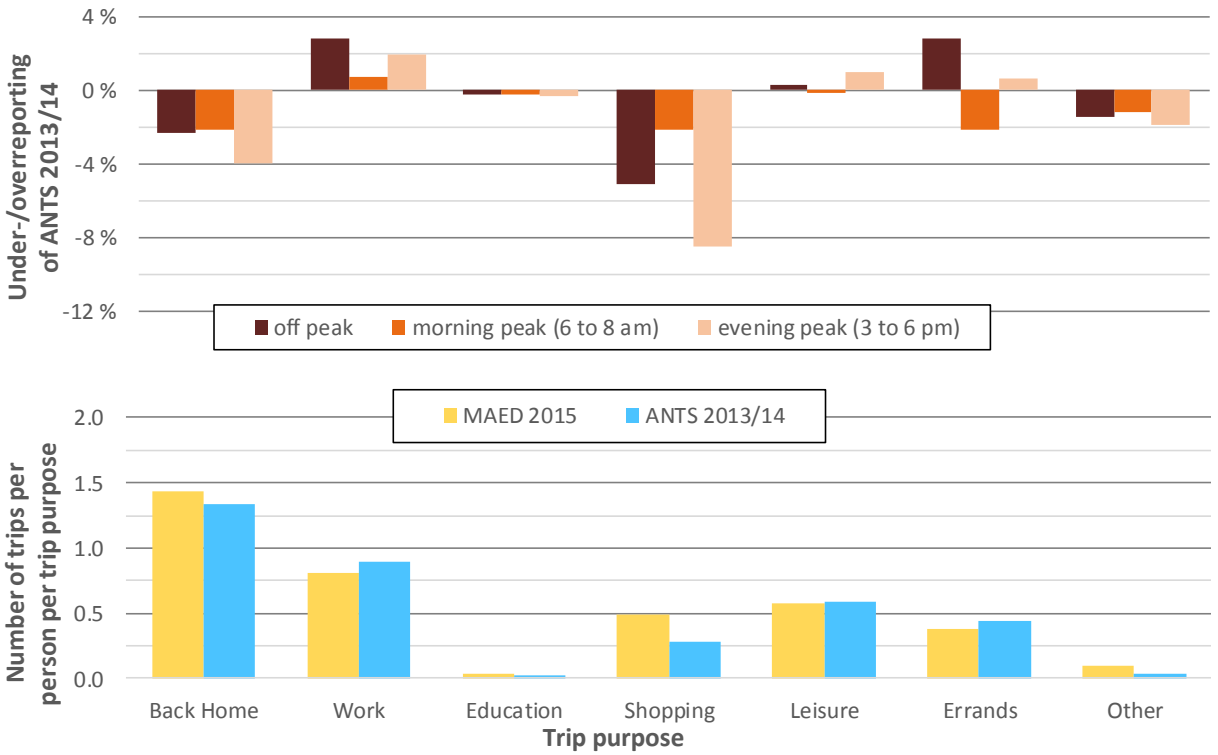


Figure 7. Distribution of trip purposes of all trips per person per day (below) and respective under-/overreporting of ANTS 2013/14 (above).

4.3 Speed-of-response analysis

Correlations between the field work variables were tested in order to investigate the indirect effects of the survey methods on the speed-of-response and the trip rate (see Table 3). A significant correlation was found between the overall response time ("TotResDays") and the trip rate for the ANTS but not for the MAED. Different from "TotResDays", the variable "MotPostDays" excludes the time needed until the motivational phone call. It is significant for the MAED but not for the ANTS. This shows that the effect of a decreasing trip rate with an increasing response time exists in both surveys but the effect size is very low and in the MAED-survey hardly significant as visualised in Figure 8. This figure shows the trip rate and the share of mobile persons for each decile of respondents in the order of their speed of response. Almost no difference between the deciles exist for the share of mobile persons. The difference for the trip rates is very small though significant for the ANTS. We applied a linear model for the ANTS to estimate trip rates for different total response time, measured by the variable "TotResDays". The estimated trip rate would increase from 3.59 to 3.63 trips per day if all respondents answered within 15 days at the latest.

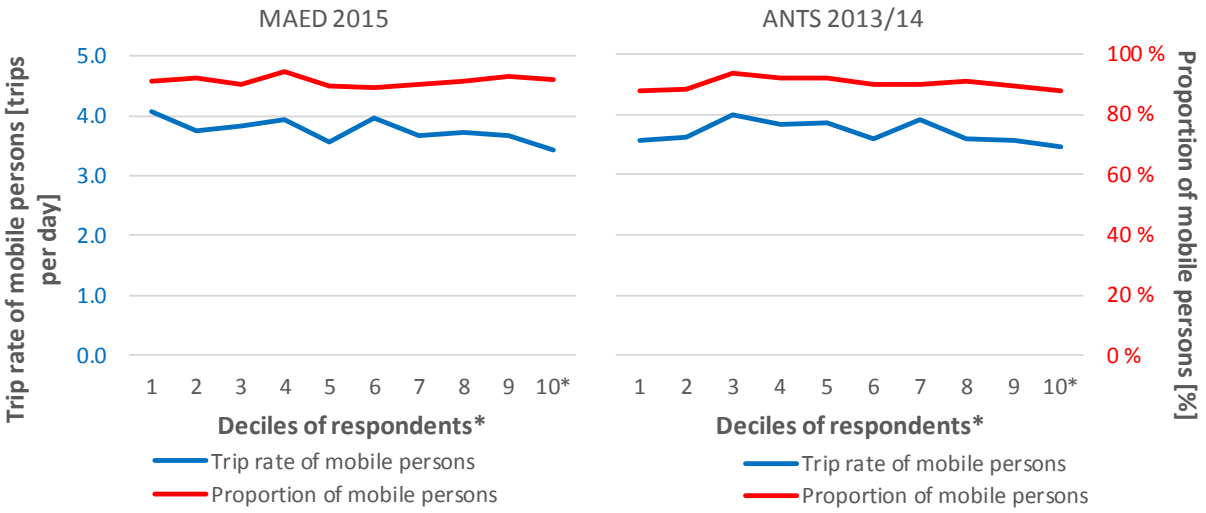
The variable "RemDays" as the number of days from day after last reporting day to the arrival of the questionnaire is significant for the MAED-survey, but effect size is again very low. This effect may not be a response effect strictly speaking, but rather it might be related to the survey incentive of € 40 when conscientious people fill out the questionnaires more accurately (and thus report more trips) and send their questionnaire back quicker compared to respondents who care less about the incentive. The linear model applied to estimate trip frequency if all respondents sent back their questionnaire within five days at the latest shows that the survey's overall trip rate of mobile persons would go up from 3.81 to 3.89 trips per day.

No significant correlations are found between trip rates and the frequencies of attempted phone calls ("TotCallAttFrq", "TotCallDays", "TotCallFrq") nor the duration from the first phone call attempt to the actual first contact in either of the surveys ("MotPreDays"). There is no correlation between the trip rate and the efforts to reach the respondent on the phone for the first time. We also found no significant correlations when analysing the impact of response effects by field variables on the share of mobile persons for both surveys (see Appendix G).

Table 3. Impact of response effect on trip rate

	MAED 2015				**ANTS 2013/2014**			
	ρ	*p-value*	$\bar{x}$	*SD*	*ρ*	*p-value*	$\bar{x}$	*SD*
TotResDays	-0.075	0.101	27.44	13.04	-0.073*	0.002	13.39	10.82
MotPreDays	-0.023	0.621	4.45	6.63	-0.015	0.623	4.66	3.65
MotPostDays	-0.096*	0.033	20.76	8.96	-0.050	0.108	8.10	8.33
RepDly1st	-0.018	0.689	2.23	5.15	-0.088**	0.000	0.96	3.98
RemDays	-0.116*	0.011	6.91	6.25	-0.039	0.100	9.08	8.54
TotCallAttFrq	-0.049	0.283	5.87	4.68	-0.023	0.341	5.68	4.75
TotCallDays	-0.056	0.217	4.66	3.41	-0.019	0.435	4.18	2.86
TotCallFrq	0.006	0.897	2.57	1.32	-0.033	0.174	1.40	1.21

* significant at the 5 % level, ** significant at the 1 % level



* Respondents are classified into deciles depending on their speed-of-response. "1" on the x-axis stands for the 10 % fastest respondents, "10" stands for the 10 % slowest respondents etc.

Figure 8. Trip rate and proportion of mobile persons (means) as a function of the speed-of-response.

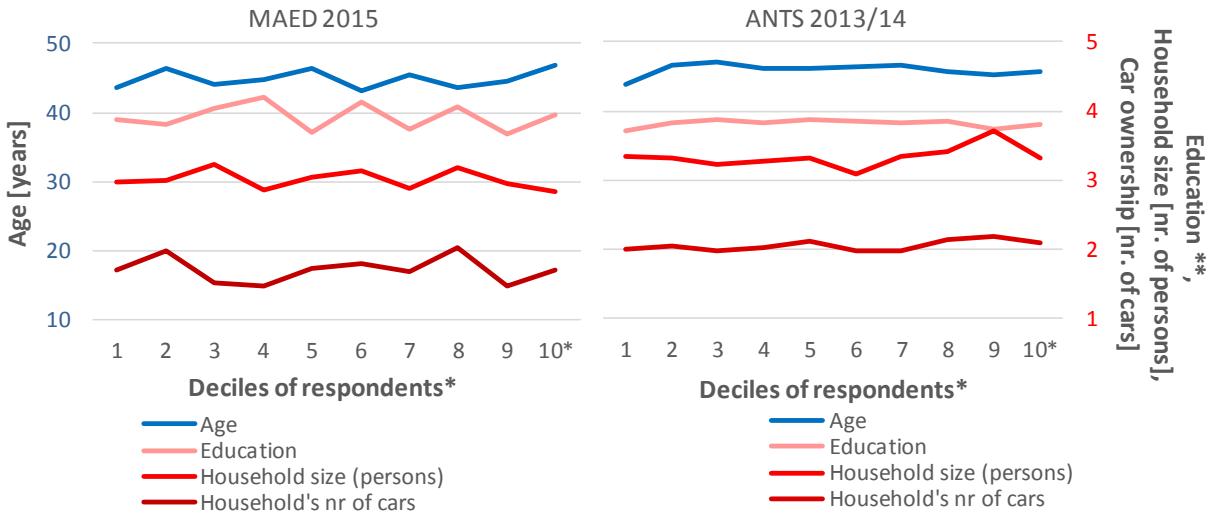
Fatigue as a possible reason for a decreasing trip rate within the MAED-participants' reporting week was not found. The linear model applied showed that the trip rate is hardly affected by the reporting day (β_o = -0.003, p = 0.85). In the following we examine possible reasons for the decreasing trip rate based on the finding from the literature review described in section 2.2:

a. Different socio-demographic groups: Figure 9 shows the socio-demographic characteristics for each decile of respondents along its speed-of-response. No significant differences were identified; socio-demographic characteristics are stable across all deciles.

c. Self-selection of travel day: The variable "RepDly1st" is used for testing the effect of self-selection. It is significant for the ANTS but not for the MAED-survey. Respondents who postpone their reporting day in the ANTS state significantly less trips compared to respondents who directly report their travel for the predetermined reporting day. The model applied to estimate the trip rate of ANTS if all respondents reported on first scheduled reporting day shows that the overall trip rate would increase from 3.59 to 3.63.

d. Item-non-response was analysed in section 4.2 without considering the speed-of-response. The analyses were repeated with the different deciles of respondents differentiated by their speed-of-response. No differences were found between the early and the late respondents who both show the underreporting effects found in section 4.2 without significant differences.

From the above analyses we conclude that differences exist neither in the socio-demographic characteristics of early and late respondents (effect a) in section 2.2) nor in their item-non-response pattern (effect d)). The reason for the overall decreasing trip rate found in variable "TotResDays" for the ANTS should therefore either be the self-selection of the travel day (effect c)) and/or different travel pattern (effect b)). The self-selection effect is significant for the ANTS and definitely contributes to the decreasing trips rates for late respondents. In addition, there might be the effect b) of different travel pattern but this needs further investigation and cannot be clearly disentangled based on the available information.



* Respondents are classified into deciles depending on their speed-of-response. "1" on the x-axis stands for the 10 % fastest respondents, "10" stands for the 10 % slowest respondents etc., ** Education scale:1=no educational degree; 5=university degree.

Figure 9. Socio-demographic characteristics (means) as a function of the speed-of-response.

4.4 Analysis of activities

Table 4 compares the activity duration per type in both surveys. The main activity type for the MAED-survey is computed as described in section 3.2 and compared with the activity types that were derived from the trip purposes in the ANTS. Only persons with at least two trips are included in Table 4 in order to have at least one activity episode other than home in the ANTS for each person included. These are 89.3 % of all respondents in the MAED-survey and 85.5 % in the ANTS. Activity durations for all persons are provided in Appendix H.

No significant differences exist for the activity types 'home' and 'work'. Daily travel time is higher in the ANTS compared to the MAED-survey as discussed above. The overall activity duration for 'education' is low for both survey but slightly higher in MAED, since the sample contains few part-time working students. Activity duration for the type 'shopping' is only slightly higher in the MAED-survey compared to the ANTS even though the number of 'shopping' trips is much higher as was shown in section 4.2. This supports the hypothesis that mainly activity episodes of short duration are underreported in the ANTS. Overall the differences in the activity types 'errands', 'shopping', 'leisure' and 'other' are difficult to interpret and might result partly from different definitions of the activity types in the two surveys. The overall activity duration for all these activity types is exactly the same for the MAED-survey and the ANTS (120 minutes).

The last column in Table 4 shows the ratio of the number of activities per detailed activity type over the number of activities per main activity type between two trips in the MAED-survey (called activity frequency thereafter). Each activity episode in the ANTS can by definition only have one type (generated based on the trip purpose of the preceding trip) whereas for the MAED-survey, information about each detailed activity episode is available throughout the reporting day. We use this detailed information to gain a better understanding of how much information is missing in HTS on activities carried out other than the main trip purpose. The analysis in Table 4 shows that the activity ratio is almost 1.00 for the activity types 'shopping' and 'errands'. This means that 'shopping'/'errands' activities are rarely mixed with activities of other types in between two trips and that the trip purposes 'shopping'/'errands' in the ANTS allow to comprehensively classify the subsequent activity episode before the next trip. Higher values for the activity frequency are found for the other activity types.

Table 4. Activity duration in the MAED-survey and the ANTS (matched sample, persons with two or more trips)

Activity category	Mean activity duration MAED [min]*	Mean activity duration ANTS [min]	*t-value*	*p-value*	**Activity ratio MAED ****
Home	925.7	926.2	-0.09	0.932	4.39
Travel	91.0	96.6	-3.27	0.001	1.00
Work	295.2	292.7	0.45	0.652	1.57
Education	7.3	4.6	2.68	0.007	1.59
Errands	14.2	24.6	-7.18	<0.001	1.07
Shopping	18.4	14.0	4.59	<0.001	1.06
Leisure	80.6	72.3	2.57	0.010	1.20
Other	6.3	9.0	-2.41	0.016	1.12

* Main activity type, ** Number of detailed activities per main activity type in MAED

Table 5 cross-tabulates the main and the detailed activity types for the MAED-survey. The columns in Table 5 list the duration for each detailed activity type that is contained in the main activity type of this row. The sum of each row corresponds to the duration for this activity type listed in Table 5. Table 5 shows that the time at home is mainly used for 'sleeping' and 'leisure', as was found in Gerike et al. (2015). The activity type 'errands' with a duration of 181.3 minutes (only at home) consists of personal care, domestic work, taking care of children, banking etc. 'Work' and 'education' activities as main activity types are partly combined with 'leisure' activities. Overall the mean number of 1.63 for the activity ratio across all activity types seems to be low but no literature was found to check the plausibility of this result.

Table 5. Activity duration per detailed and main activity type (matched sample, persons with two or more trips)

Main activity	Sleep	Travel	Work	Education	Errands	Shopping	Leisure	Other	**Mean activity duration MAED [min]****
Home	473.2		24.6	3.3	181.3	0.8	241.2	1.1	925.7
Travel		91.0							91.0
Work	0.4		285.1	0.1	0.8	0.4	8.5		295.2
Education			0.0*	6.7	0.0*	0.0*	0.5		7.3
Errands	0.0*		0.2		13.3	0.1	0.5	0.1	14.2
Shopping			0.0*		0.1	17.6	0.6		18.4
Leisure	0.4		0.5		1.0	0.4	78.2	0.0*	80.6
Other	0.0*		0.1		2.2	0.0*	1.7	2.3	6.3

* <0.05 min, ** Main activity type

5. Discussion and conclusion

This paper analyses non-reporting effects in the ANTS as an example for a standard mixed method HTS in comparison with the MAED-survey as an innovative hybrid survey design with elements from TUS and HTS. The MAED-survey is considered as "ground truth" in this comparison. The analysis addresses three main goals with the following conclusions:

- Identification of non-reporting effects in HTS for travel estimates: Standard mixed method HTS capture the number and temporal distribution of trip chains (called tours in this paper) well. Underreporting as a result of item-non-response occurs on two levels: (i) on the person level in terms of a too low rate of mobile persons, and (ii) on the level of trips. The overvalued share of immobile persons in HTS may be considered by calculating travel estimates only for mobile persons; it might be corrected by increasing the share of mobile persons by approximately 3.5 %. A better option would however be to call immobile persons back during validation and ask them insistently if they had any trips on the diary day. The trip estimates for mobile persons in HTS need to be corrected with special attention to short trips (< 5 km) in the afternoon-peak and medium-distance trips (5 − 20 km) in the morning-peak when these are followed by short non-travel activity episodes (< 10 minutes). The transport mode of the non-reported trips is determined by the transport mode chosen for the whole tour. The main reason for the higher number of persons with odd number of trips in the MAED-survey was found to be the underreporting of trips within tours of three or more trips in the ANTS, especially in the afternoon-peak. Differences in the length of tours in the MAED-survey and the ANTS are higher on working days compared to Saturdays, because short shopping or errand trips in combination with e. g. work trips are mainly carried out on working days, whereas Saturdays have the highest number of tours but a small number of trips per tour. Plausibility checks and data processing for HTS should therefore not only be done on the trip level but also on the tour level.
- Analysis of speed-of-response effects on travel estimates: These play only a minor role for the aforementioned non-reporting effects. The MAED-survey shows no significant relationship between the trip rate and the overall response time. There was no evidence found for self-selection in the MAED-survey. For the ANTS we found a decreasing effect of the response time on the trip rate similar to most other studies. The effect size is very low but highly significant. No differences in the socio-demographic characteristics of early and late respondents and their item-non-response were found, so that self-selection of a reporting day or actual different travel patterns remain as possible reasons for the overall decreasing trip rates of late respondents in the ANTS. Given that the speed-of-response effect on the trip rate is small and dependent on the survey procedure, the question must be raised whether the decreasing trend should be extrapolated to a 100 % response rate or whether the speed-of-response should be assumed to have no effect on the trip rate. This question can only be answered by non-response studies as done e.g. by Richardson (2003). From our findings we conclude that the analysis of HTS data can be done without considering speed-of-response effects.
- Assessment of the completeness and accuracy of non-travel activities inferred from the trip purposes in the HTS: Home-based activities account for 64 % of the total time but are not specified by their type in HTS. From the MAED-survey we know that the main activity types that people perform at home are 'sleeping', 'personal care', 'domestic work' and 'leisure'. This is a mixture of mandatory and freely chosen activities that need to be distinguished in most analyses. If we consider only persons with at least two trips on their reporting day, we find a good correspondence of activity durations in the MAED survey and the ANTS. Despite some minor deviations that should be analysed further, we conclude that we can reliably infer from HTS-data not only travel estimates but also main activities.

Overall, the MAED-survey proved effective as a basis for analysing non-reporting effects in HTS. The MAED-survey is, however, far too costly for being a prototype for future HTS. Standard HTS do not need to collect data on all non-travel activities nor on expenditures. They can and should keep their scope; they need to focus on trips and their determinants but more sophisticated

validation methods such as the ones applied in the MAED-survey can help improving data quality for HTS and could probably increase the overall efficiency of the HTS. The insights gained from this paper can be used to advance methods for data processing of HTS in terms of correcting the share of mobile persons and in terms of trip imputation. Corrections are necessary on the trip level, whereas trip-chains (tours) should be used as a means for imputing trips correctly into the respondents' overall daily schedule. The developed method for analysing the different aspects of the speed-of-response effect proved effective. We were able to disentangle the different aspects and to identify the reasons behind the overall decreasing trip rates of late respondents in the ANTS. Future studies could extend the speed-of-response analysis by applying this method to other person groups beyond employed persons, which were analysed in this paper. The analysis of non-travel activities showed that HTS can be used to gain reliable data for activity-based models e. g. for generating daily schedules, however, with the limitation that no information is available for home-based activities. A detailed analysis of trips that were initially not reported in the questionnaire but stated in the validation phone call could provide further insights about item-non-response in general and as a function of the speed-of-response. Further findings on non-reporting effects can be expected from comparing the HTS with innovative survey methods such as GPS-based travel surveys.

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Appendix

Appendix A. Survey descriptions of MAED 2015 and ANTS 2013/2014 (original and matched sub sample used for this paper)

Survey	**MAED 2015**	**ANTS 2013/2014**	**MAED 2015**	**ANTS 2013/2014**
Dataset	**Original**	**Original**	**Matched sub-sample in this paper**	
Survey method	PAPI (postal)	PAPI (postal), CAWI, CATI	As Original	
Survey design	trip-based section (KONTIV) activity based section (HETUS) consumer expenditure section	KONTIV	As Original	
Questionnaires	Household Person Trip-Activity Diary Expenditures	Household Person Trip Diary	As Original	
Incentives	EUR 40 (voucher)	-	As Original	
Spatial information	Geocoded addresses	Geocoded addresses	As Original	
Survey Area	Austria Six target areas, each with rural, intermediate and urban communities	Austria All communities	As Original	
Response Rate	11.9 %	26.2 %		
			Applied filter in data processing for comparability	
Target population	Employed persons based on ILO definition (ILO 1993)	Household members > 6 years	As Original	Employed persons
Survey Period	04-06/2015, 09-12/2015	10/2013 – 11/2014	As Original	12/2013, 04-06/2014, 09-11/2014
Reporting Date	Seven consecutive days	Two consecutive days	As Original	First of the two reporting days (fatigue effect)
			Matching criteria	
			level of urbanisation, type of weekday, gender, age, education, availability of car and public transport season ticket	
Sample size	748 persons of 490 households	38,220 persons of 17,070 households	738 persons of 485 households	4,830 persons of 3,741 households
Data size	5,236 reporting days 18,203 trips	76,440 reporting days 196,604 trips	4,830 reporting days 16,910 trips	4,830 reporting days 15,431 trips

* only PAPI with available telephone number for the speed-of-response analysis

Appendix B. Sample characteristics and key travel estimates for the ANTS by survey participation method

		ANTS 2013/14 original, weighted							
Participation method		**all**		**CAWI**		**PAPI**		**CATI**	
n households	[% households]	5,829	[100]	1,125	[19]	4,279	[73]	425	[7]
n persons	[% persons]	9,436	[100]	1,700	[18]	7,134	[76]	602	[6]
n trips	[% trips]	29,622	[100]	4,664	[16]	23,279	[79]	1,679	[6]
Gender									
Male		53.1		55.8		52.5		52.2	
Female		46.9		44.2		47.5		47.8	
Age									
6-34		23.1		26.9		22.6		17.9	
35-54		60.6		61.2		60.3		63.3	
55+		16.3		11.9		17.1		18.8	
Highest level of education									
Not specified		0.6		2.9		0.0		1.2	
Compulsory school		4.8		4.3		4.8		6.3	
Apprenticeship, college		48.2		37.7		50.7		48.1	
Matura		20.5		23.2		20.0		18.8	
University, FH		25.9		31.8		24.5		25.5	
Household size									
1 person		12.5		20.6		10.3		13.6	
2 persons		30.0		29.2		30.2		30.1	
3 persons		24.4		20.6		25.4		24.2	
4 or more persons		33.1		29.5		34.2		32.0	
Level of Urbanisation									
Urban		23.8		29.4		22.9		17.9	
Intermediate		28.6		30.5		28.2		28.0	
Thin		47.6		40.1		48.9		54.1	
Share of mobile persons									
Overall*		**0.88**		**0.84**		**0.90**		**0.87**	
Working day		0.92		0.88		0.93		0.93	
Saturday		0.84		0.81		0.86		0.78	
Sunday**		0.74		0.67		0.76		0.71	
Number of trips per mobile person									
Overall*		**3.36**		**2.99**		**3.47**		**2.87**	
Working day		3.39		3.19		3.46		3.03	
Saturday		3.49		2.97		3.65		2.63	
Sunday**		3.15		2.71		3.26		2.58	
Number of tours per mobile person									
Overall		**1.40**		**1.28**		**1.44**		**1.24**	
Working day		1.38		1.31		1.40		1.34	
Saturday		1.42		1.24		1.48		1.15	
Sunday**		1.41		1.29		1.29		1.21	
Distance of trips [km]									
Per trip		13.4		16.2		13.1		9.4	
Per day		45.0		48.0		44.9		35.8	
Duration of trips [min]									
Per trip		20.2		18.7		20.5		19.9	
Per day		67.9		55.3		70.3		76.3	
Mode choice									
Public Transport		12.1		12.7		12.2		8.6	
Car		69.9		67.6		70.7		64.3	
Bicycle		5.8		6.9		5.7		2.8	
Walk		12.2		12.8		11.5		24.3	

* (i)Overall share of mobile persons and (ii) overall number of trips per mobile person as core travel estimates where tested across participation methods by ANOVA, both highly significant (p-value < 0.001) ** including holidays and public holidays

Appendix C. Response Variables

Variable type [unit]	Variable Name	Label Remark	Boundary for outliers min	mix
Response duration [days]	TotResDays	*TotalResponseDays:* number of days from 1st attempted call to arrival of completed questionnaire The variable "TotResDays" can be seen as the main overall response variable: it measures the response duration from the first phone call attempt until the completed questionnaires were received by the survey team. It includes all parts of the survey beginning from the time needed to get a person on the phone for the first phone call and eventually to motivate the household for taking part in the survey, to the time needed for completing the questionnaires as well as possible postponements of the survey period, to possible delays in sending the completed questionnaires back to the survey team. The validation period is not considered as the timeline for the validation was only determined by the survey team and the respondents had no influence on its duration.	0	70
	MotPreDays	*Motivation(Agreement)PreDays:* number of days from 1st attempted call to motivation call (willingness to participate) The variable "MotPreDays" measures the number of days between the first attempted phone call (with the intention of asking whether the announcement letter was well received and whether the household accepts receiving the questionnaires) and the so-called motivational phone call (when the household agrees to take part in the survey). The duration of "MotPreDays" is influenced by the number of phone call attempts before the respondent was actually talked to for the first time both for the first phone call and for the motivational phone call.	0	30
	MotPostDays	*Motivation(Agreement)PostDays*: number of days from motivation call to arrival of questionnaire The variable "MotPostDays" measures the time between the motivational phone call and the receipt of the completed questionnaires by the survey team. Different from "TotResDays", "MotPostDays" does not include the time needed to get a person on the phone for the first call and for the motivational call. Persons who are hard to reach on the phone might have a longer "TotResDays" but the same "MotPostDays".	0	50
	RepDly1st	*ReplyDelay1st:* number of days from 1st scheduled reporting day to actual 1st reporting day The variable "RepDly1st" stands for the time between the (first) predetermined and the actual reporting period and measures how often respecively for how long the reporting period was postponed.	0	20
	RemDays	*ReminderDays:* number of days from day after last reporting day to arrival of questionnaire The variable "RemDays" measures the time between the day after the last day of the actual reporting period until the completed questionnaires were received by the survey team.	0	30
Telephone calls [frequ.]	TotCallAttFrq	*TotalCallAttemptedFrequency:* number of all calls attempted	0	25
	TotCallDays	*TotalCallDays:* number of days with calls attempted	0	15
	TotCallFrq	*TotalCallFrequency:* number of all calls in which conversation with the participant has occurred	0	7

Appendix D. Methods for computing the duration and type of non-travel activities in ANTS and in the MAED-survey

Activity duration was computed for the ANTS based on the trip purposes as follows:

- The whole reporting day was assigned to "home" for the immobile persons who did not report any trip on the reporting day.
- The time from midnight (0:00) to the start of the first trip and the time from the end time of the last trip to midnight (24:00) was assigned to "home".
- The time between the start time and the end time of each trip was assigned to "travel".
- The time between the end time of each trip and the start of the subsequent trip was assigned to the trip purpose of preceding trip.

The detailed activity episodes in the MAED-survey were transformed into „main activities" in order to harmonise the level of detail with the ANTS. The transformation was guided by the following question: What activity type would be obtained, if the respondents of the MAED-survey filled in a conventional travel diary? In order to resemble this situation, we used the following procedure:

- The time between the start time and the end time of each trip was assigned to "travel".
- The time between the end time of each trip and the start time of the subsequent trip was assigned:
  - To "home" if the arrival location of preceding trip (location of the activity) was the home address,
  - To the activity category with the longest duration for all other arrival locations.

Appendix E. Matched classification of activities from MAED (HETUS-based categories) and ANTS (trip purposes) to the common activity classification

Matched activity type	**MAED 2015** Original activity type	**ANTS 2013/14** Original trip purpose
Home	All activity types with location "home" or after the last trip	Back home
Travel	Travel	Travel
Work	Work*	to Work Business
Education	Education*	School / Education
Shopping	Shopping*	Shopping
Leisure	Leisure* Eating*	Leisure Private Visit
Errands	Domestic/housekeeping* Personal, errands*	Private errand Pick-up/drop-off Accompaniment
Other	Other*	Other

* with location ≠ "home"

Appendix F. Sample characteristics and key travel estimates for both the MAED and ANTS original (MAED) respectively filtered (ANTS) and matched datasets.

	MAED 2015 original	MAED 2015 matched	ANTS 2013/14 filtered, weighted	ANTS 2013/14 matched
n households	490	485	5,829	3,741
n persons	748	738	9,436	4,830
n person reporting days	5,236	4,830	9,436	4,830
n trips	18,203	16,910	29,622	15,431
Gender				
Male	50.0	49.4	53.1	49.4
Female	50.0	50.6	46.9	50.6
Age				
15-19	2.3	1.9	0.7	0.5
20-29	6.8	6.5	13.6	8.7
30-39	18.7	19.0	19.1	18.6
40-49	35.7	37.0	31.3	34.9
50-59	31.9	31.4	31.8	33.6
60+	4.6	4.2	3.5	3.8
Highest level of education				
Compulsory school	2.7	2.5	4.8	3.9
Apprenticeship, college	36.0	37.6	48.2	36.2
Matura	24.3	24.2	20.5	26.5
University, FH	37.0	35.6	25.9	33.5
Household size				
1 person	14.5	9.0	12.5	7.9
2 persons	29.4	28.1	30.0	29.1
3 persons	22.0	22.5	24.4	23.9
4 or more persons	34.1	40.4	33.1	39.1
Share of mobile persons				
Overall	**0.92**	**0.92**	**0.88**	**0.89**
Working day	0.97	0.97	0.92	0.93
Saturday	0.88	0.88	0.84	0.86
Sunday*	0.71	0.71	0.74	0.76
Number of trips per mobile person				
Overall	**3.80**	**3.81**	**3.36**	**3.59**
Working day	3.97	3.99	3.39	3.67
Saturday	3.74	3.74	3.49	3.63
Sunday*	2.84	2.84	3.15	3.12
Number of tours per mobile person				
Overall	**1.47**	**1.47**	**1.40**	**1.44**
Working day	1.47	1.48	1.38	1.44
Saturday	1.55	1.56	1.42	1.53
Sunday*	1.34	1.34	1.41	1.38
Distance of trips [km]				
Per trip	11.0	11.1	13.4	13.9
Per day	41.8	42.3	45.0	49.9
Duration of trips [min]				
Per trip	24.2	23.8	20.2	26.8
Per day	91.9	90.8	67.9	96.3
Mode choice				
Public Transport	10.9	9.3	12.1	11.5
Car	69.5	72.2	69.9	68.7
Bicycle	5.8	5.7	5.8	6.5
Walk	13.8	12.8	12.2	13.3

* including holidays and public holidays

Appendix G. Impact of response effect on share of mobile persons (mobility)

	MAED 2015				**ANTS 2013/2014**			
	ρ	*p-value*	$\bar{x}$	*SD*	*P*	*p-value*	$\bar{x}$	*SD*
TotResDays	0.013	0.778	27.44	13.04	0.005	0.821	13.39	10.82
MotPreDays	0.074	0.115	4.45	6.63	-0.042	0.175	4.66	3.65
MotPostDays	-0.053	0.240	20.76	8.96	-0.014	0.646	8.10	8.33
RepDly1st	0.010	0.826	2.23	5.15	-0.045	0.063	0.96	3.98
RemDays	-0.071	0.117	6.91	6.25	0.023	0.338	9.08	8.54
TotCallAttFrq	-0.002	0.965	5.87	4.68	0.029	0.228	5.68	4.75
TotCallDays	-0.007	0.874	4.66	3.41	0.035	0.143	4.18	2.86
TotCallFrq	-0.056	0.218	2.57	1.32	0.000	0.994	1.40	1.21

Appendix H. Activity duration in the MAED-survey and the ANTS (matched sample, including immobile persons)

Activity category	Mean activity duration MAED [min]*	Mean activity duration ANTS [min]	*t-value*	*p-value*	**Activity ratio MAED****
Home	969.6	978.4	-1.47	0.141	4.91
Travel	83.2	85.7	-1.55	0.121	1.00
Work	270.5	258.9	2.13	0.033	1.59
Education	7.0	4.0	3.22	0.001	1.64
Errands	13.2	22.1	-6.51	0.000	1.08
Shopping	16.5	13.2	3.38	0.001	1.06
Leisure	73.1	70.0	1.02	0.306	1.20
Other	5.8	7.7	-2.01	0.044	1.12

* Main activity type, ** Number of detailed activities per main activity type in MAED

Research Article 3

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Reporting quality of travel and non-travel activities: A comparison of three different survey formats

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Abstract

This paper reports a comparison of the Austrian National Household Travel Survey (HTS) and Time Use Survey (TUS) with a 3rd survey format – the "Mobility-Activity-Expenditure-Diary" – to better understand the specific strengths and weaknesses of HTS and TUS in terms of quantifying travel and non-travel activities and their specific underreporting effects. The main goal is to demonstrate how reliable we can infer from both survey types on travel and non-travel activities regarding different indicators.

Keywords: Data collection; Time use; Travel behaviour; Travel survey methods; Mobility-activity-expenditure diary

1. Introduction

There is an increasing interest in modelling travel decisions in the wider context of activity scheduling (Bhat et al. 2013) or consumers' home production. From this follows an increasing demand for integrated datasets including information both on travel and non-travel activities. Two survey formats exist that can deliver such data with opposing strengths and weaknesses: (i) Household Travel Surveys (HTS) provide detailed information on trips, but non-travel-activities (called activities in this paper) can only be roughly inferred from 'trip purposes'. (ii) Time Use Surveys (TUS) provide much information on activities but only limited transport related information. Important context variables for

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mobility behaviour such as car ownership are missing in TUS, and trip data can hardly be used for modelling travel behaviour e. g. because origins and destinations are not geocoded and no trip distances are provided.

Besides these differences in survey coverage, different specific underreporting effects for travel can be expected for HTS and TUS. Comparisons of different HTS show that mainly short and irregular trips are underreported (Aschauer et al. 2018). Comparisons between HTS and TUS find higher travel estimates for TUS (Stopher 1992, Harvey 2003, Hubert et al. 2008) and conclude that activity-based diaries are more intuitive also for reporting travel activities. However, trip numbers in TUS are only higher in those comparisons with HTS, if the so-called location changes without any reported trip in-between (indicating missing trips) are imputed as trips (Gerike et al. 2015). The attributes of these imputed trips are however unknown and cannot be imputed, e.g., the duration and the chosen travel mode. Underreporting of trips is thus an issue both for HTS and for TUS. Only few studies exist that compare activities both in HTS and TUS (Gerike et al. 2015).

This paper reports a comparison of the Austrian National HTS (ANTS) from 2013/14 (BMVIT 2015) and the Austrian National TUS (ATUS) from 2008 (Statistics Austria 2011). A third survey format is included: the "Mobility-Activity-Expenditure-Diary" (MAED-survey), which was developed to obtain a dataset with all required components to model travel behaviour in the framework of consumers' home production (Jara-Diaz et al. 2008) as it combines elements of HTS, TUS, and consumer expenditure surveys (CES) into an integrated format (Rösel et al. 2015). The MAED dataset represents a reference source, which is regarded close to "ground truth" in this paper and that contains (almost) all trips and activities with high accuracy. This assumption seems justified for three reasons: (i) similar to TUS, trips are reported in the context of the daily schedule, so that respondents are better able to recall trips and cannot draw an advantage from soft refusal, (ii) the MAED-survey includes extensive validation similar to the New KONTIV Design in HTS (Brög and Meyburg 1982, Brög et al. 1981, Brög and Meyburg 1980) and (iii) MAED respondents received an incentive after successful participation and were thus well motivated to fill out the diary carefully.

The goal of this paper is to better understand the strengths and weaknesses of HTS and TUS in terms of quantifying travel and non-travel activities. The core question to be answered is how reliable we can infer from both standard HTS and TUS on travel and non-travel activities in terms of the different indicators described above.

2. Literature Review

Higher immobility rates are consistently found in the literature for HTS compared to TUS (Hubert et al. 2008, Gerike et al. 2013). Soft refusal is identified as the main reason for this difference. Immobility rates in different HTS also vary substantially (Armoogum et al. 2014, Madre et al. 2007). This shows the sensitivity of this indicator and the importance of field work quality and the survey protocol besides the survey method.

The differences in the number of trips per mobile person between HTS and TUS are not consistent. There are studies that show on average greater numbers of trips in TUS compared to HTS (e. g. Stopher 1992, Harvey 2003) but other studies find no such difference (Bose and Sharp 2005, Ironmonger and Norman 2006, Hubert et al. 2008, Nakamya et al. 2007). Gerike et al. (2015) compare HTS and TUS for Germany in a detailed way by including location changes without a trip as described above. The authors find similar trip numbers in HTS and TUS if location changes without a trip in TUS are imputed as trips, but consistently higher trip numbers per person and day in the HTS for all socio-demographic groups if no trips are imputed in the TUS. The average number of location changes without a trip per respondent day was 0.9 for the German TUS (Gerike et al. 2015).

Trip rates in HTS and TUS are more consistent for subsistence (work, education) trips compared to non-discretionary (e.g. shopping, errands) and discretionary (leisure) trips (Aschauer et al. 2018, Bose and Sharp 2005, Gerike et al. 2015, Richardson 2007, Stopher 1992). Trip rates are less consistent for trips with either short durations themselves or with short durations of the subsequent activity (Aschauer et al. 2018). The TUS format reveals more odd numbers of trips per respondent and day (Gerike et al. 2015, Hubert et al. 2008, Stopher 1992). The reason for this effect might be that travel diaries perform better in supporting respondents to remember and to report trips to the destination and back home compared to TUS diaries. Recent findings by Aschauer et al. (2018) indicate, however, that non-reported trips within tours with more than two trips might be the reason for the higher number of respondents with even trip numbers in HTS. Tours are defined as a sequence of trips beginning and ending at home. Aschauer et al. (2018) find, based on a comparison of the Austrian HTS with the MAED-survey (both datasets are also used in this paper), that tours are well reported in the HTS but underreporting occurs on the trip level in the form that short or

irregular trips within longer tours are not reported. This happens mainly in the peak-hours on working days when trips tend to be chained into tours with more than two trips. Trips need to be imputed into reported tours, mainly in peak-hours on working days, with the mode used for the other trips in this tour and mainly non-discretionary and discretionary trip purposes.

Literature consistently reports on average higher travel times in TUS compared to HTS (Gerike et al. 2015, Harvey 2003, Hubert et al. 2008, Richardson 2007, Vilhelmson 1997, Yennamani and Srinivasan 2008). For example, using Swedish TUS and HTS data Vilhelmson (1997) calculate an average difference of 12 minutes travel time per person per day between the two surveys. For France, Belgium and Great Britain, Hubert (2003, see also Hubert et al. 2008) calculate a difference in daily travel times of 10, 20 and 30 minutes respectively, with consistently higher daily travel times in TUS data, also because the 10-minutes interval usually used for reporting activities in TUS-diaries artificially extends the duration of short trips (Gerike et al. 2015, Yennamani and Srinivasan 2008).

The few studies that compare the duration of non-travel activities in HTS and TUS (Aschauer et al. 2018, Gerike et al. 2015) show that we can reliably infer the daily duration of non-travel activities per activity type from HTS for respondents with at least two trips on their reporting day, except for the time subsequent to back-home trips for which by definition there is no information available in HTS. Coding schemes for activity types differ between HTS and TUS datasets. This might result in the need to aggregate the activity types from TUS in order to fit to the trip purposes in HTS. Aschauer et al. (2018) show e. g. that the duration for the individual activities types “errands”, “shopping”, “leisure” and “other” differ between the MAED-survey and the Austrian HTS but the total activity duration for these types is exactly the same in both surveys (120 minutes, see Gerike et al. 2015 for similar findings for the German National HTS and TUS).

The MAED-survey data enables, similar to TUS data, to calculate the ratio between the frequency of detailed activity episodes (reported in a TUS-like diary format) over the frequency of aggregated episodes. The latter are derived 'as if' the activities were reported in a HTS, i. e., the time between any two trips is assigned to only one 'main activity type', which is the type with the longest relative duration. Aschauer et al. (2018) find this ratio differing between 1.1 for shopping activities and 4.4 for “home-activity”. This means that 1.1 shopping activities would be reported in a TUS-diary per each single shopping activity inferred from the purpose of the preceding trip in a HTS; and that 4.4 activities are reported in TUS during an average stay at home in the HTS.

3. Data sources and methodology

3.1. Survey description

3.1.1. Mobility Activity Expenditure Diary (MAED)

The MAED-survey was conducted in spring and autumn 2015. It is a self-administered mail-back survey with a one-week reporting period and detailed questions about all trips as well as all activities for each diary day. The trip section in the questionnaire is close to the traditional HTS format, based on the New KONTIV design (NKD, see Brög et al. 2009, Socialdata 2009). However, the trip purpose section is much more detailed with a TUS-like diary format (see Rösel et al. 2015 for a detailed description of the diary) but categorised activity types instead of open text fields. The sample is based on a random selection of Austrian households for 18 pre-defined. Only employed persons were selected for the MAED-survey as a wage rate was needed for modelling the trade-off-processes between time and money using the transport economic models described in Jara-Diaz et al. (2008).

3.1.2. Austrian National Travel Survey (ANTS)

The ANTS survey method follows the guidelines of the KOMOD-Handbook (Fellendorf et al. 2011) with three options for participation (PAPI, CATI, CAWI). The survey material is based on the NKD (Socialdata 2009) with the major modification of two consecutive reporting days. The field work was carried out between October 2013 and November 2014. The ANTS was commissioned by the Austrian Ministry for Transport.

3.1.3. Austrian Time Use Survey (ATUS)

The ATUS was conducted by the federal governmental statistical agency Statistics Austria on behalf of the Federal Ministry for Women, Media and Public Affairs in 2008/2009. The self-administered PAPI-survey is based on the

HETUS guidelines (Eurostat 2009, UNECE 2013). The activity diary has one line per activity episode including information about main and parallel activities, about additional persons with whom the activity was carried out, and about whether or not the activity was carried out at home. The activities are reported for one day using 15-minute intervals (resp. 30-minute intervals from 11:00 p.m. to 05:00 a.m.) (Statistics Austria, 2011). Open text fields instead of pre-defined activity categories are used in order to obtain comprehensive information about what the respondents actually did in each time interval. The only available location information is a binary variable indicating whether or not the activity was carried out at home.

3.2. Data processing and analysis approach

In order to obtain comparable datasets, the gross samples of the ANTS and ATUS were filtered (i) for employed persons and (ii) for the same reporting season as the MAED survey (months April to June and September to December). The three samples were then matched by sociodemographic criteria on the reporting day level in order to receive net samples of the same size with comparable characteristics: For each person reporting day in the MAED data one person in the filtered ANTS and ATUS was selected, which exactly matched the criteria of categorical variables: level of urbanity, type of weekday, gender, age, education and the availability of private car parking. Car parking is the only variable in the ATUS that describes the availability of mobility tools in the household.

The preparation of the ATUS mainly focused on reshaping and processing the activity grid in order to retrieve information about the trips. The location information (home or not-home) was used to impute missing (non-reported) trips at those places in the activity grid, where the location changed without a reported trip in-between. Following from the binary nature of the location variable, only to- and from-home trips could be identified (no trips between two non-home locations). The ATUS sample with imputed trips is referred to as "ATUS total" in the following analysis. The characteristics of those imputed trips were inferred from the information about the activities prior and after the trip; these include starting time, trip purpose, duration of subsequent activities, and chosen transport mode; the latter was assigned as observed mode of a previous or following trip from within the same tour, if available. The trip duration could not be inferred; this is an important missing information. The preparation of the ANTS focused, on the contrary, on inferring information on activities from the reported trip purposes. A common coding scheme for the activity types in in all three surveys was applied in order to ensure cross-survey comparability of non-travel activities in the ANTS, ATUS and MAED dataset.

Deviations of the ATNS and ATUS from the MAED are referred to as over- or underreporting effects. Travel estimates of the ATUS-total dataset (with imputed trips) are included as a 4th sample whenever these are available.

3.3. Sample description

The three matched samples correspond well to each other by definition as most of the variables have been used for matching. Differences occur for those variables, which differ in the original samples and were not considered in the matching procedure (or which were matched on a higher aggregated level).

Compared to the official Austrian National Census data (Statistics Austria, 2014), females are slightly overrepresented in the three matched samples. The age group 50 to 59 years is strongly over-represented in the matched MAED/ANTS sample at the expense of the younger age groups. The age distribution in the matched ATUS sample corresponds better to the census data although younger respondents are still somewhat underrepresented.

Similarly, persons with higher educational level (above compulsory school) are substantially overrepresented in all three datasets but least in the ATUS and most in the MAED. This may reflect the higher intellectual challenge of reporting trips, activities and expenditures over a whole week, which was requested from MAED participants. On a more aggregated level, if the share of persons with and without matura is compared, all four datasets yield similar results. One person households are strongly under-represented in the three matched samples, with the ATUS sample being again closest to the census data.

All three matched samples include fewer households from urban areas than the census data because urban areas had lower response rates in the MAED survey and the urbanity type was a matching criterion. The high availability of cars and parking facilities in comparison to the census data is a result of the bias towards rural residents.

4. Results

4.1. Travel estimates

Table 1 shows the key travel estimates for MAED/ANTS/ATUS, and ATUS total with imputed trips. The results for the share of mobile persons and the number of trips per mobile person are similar: ATUS (without imputed trips) reveals the lowest values, ATUS total (with imputed trips) the highest values; MAED and ANTS are in the middle. However, MAED yields consistently higher values than ANTS (with the exception of Sundays), so that ANTS is closer to ATUS, whereas MAED is closer to ATUS total. The ATUS (without imputed trips) obviously suffers from a substantial underreporting of trips, as does the ANTS but to a lesser extent. The effect of the imputed trips in ATUS is that the mobility indicators of ATUS total increase considerably and exceed those of MAED, suggesting that there is also some underreporting of trips in MAED. The unusual high value of 90% mobile persons on Sundays gives however rise to doubts if the location information provided in the ATUS can be fully trusted.

The trip imputation in ATUS total not only generated new trips but also new tours, resulting in a large number of 1.87 tours per mobile person. This result contradicts the initial hypothesis that tours are reliably reported and underreporting mainly occurs on the trip level within tours of more than two trips (Aschauer et al. 2018, Scheiner 2010). The imputed tours in ATUS total stem predominantly from location changes (from home to out-of-home or vice versa) with no reported trip in-between, which are followed by a second location change in the opposite direction, again without a trip being reported. These short tours of usually two trips are typical for weekend days (Aschauer et al. 2018). This may explain why the number of imputed tours in ATUS total is particularly high at the weekend.

The average trip duration shows a different pattern. It is lowest in MAED, while ATNS and ATUS are at a similar (somewhat higher) level. This is in line with the literature and might result from different effects: underreporting of short trips in ANTS and rounding effects in ATUS. The total daily travel shows an inverse result; it is highest in MAED and lowest in ATUS; the higher average trip duration of the ATUS does not outweigh the lower trip rate. Underreporting in the ATUS seems to be stronger than in other TUS for which the literature reports higher daily travel times in comparisons with HTS (Gerike et al. 2015).

The modal split corresponds well for all analysed datasets with the low share of public transport in ATUS (5.2% vs. 10.8% in MAED and 10.2% in ANTS) as the only exemption. A possible reasons for this could be the missing modes in the ATUS.

Underreporting of trips in ANTS and ATUS is visible in the higher number of respondents with few trips. The number of persons who reported only one trip on the diary day is highest in ATUS; the number of persons with two trips is also substantially higher in ANTS and ATUS than in MAED. The effect of the imputed trips in ATUS total is substantially; this dataset shows the highest number of persons with many trips.

The ANTS shows many tours with two trips and a few tours with three or more trips in comparison to MAED. This is the typical pattern of trip underreporting mainly within longer tours. ATUS and ATUS total include especially many tours with only one trip (compared to MAED and ANTS). This also indicates missing trips or other inconsistencies, because the vast majority of tours should consist of two trips at least.

An analysis of the over- and underreporting of trips by the time of day (morning peak: 7-9am; afternoon peak: 3-6 pm; off-peak) shows different reporting characteristics of the respective surveys. The ATUS shows strong and consistent underreporting throughout the day. For the ANTS, underreporting is highest in the afternoon-peak. This is in line with the literature (Aschauer et al. 2018), which shows that tours in peak-hours are longer and trips within these longer tours have a higher chance of being underreported in HTS. The difference between ATUS and ATUS total indicates that imputed trips in ATUS total occur throughout the day but least during the morning peak. This pattern needs to be further investigated. A possible reason could be that morning trips are often longer or subjectively more important (working trip, business trip) and thus better reported.

Table 1. Travel estimates for MAED, ANTS, ATUS (matched samples)

	MAED 2015	ANTS 2013/14	ATUS 2008/09	ATUS total* 2008/09	Anova *F*	Anova *p-value*
n person reporting days	2,072	2,072	2,072	2,072		
n mobile person reporting days	1,931	1,856	1,802	1,998		
n trips	7,221	6,385	5,341	7,842		
Share of mobile persons						
Overall	**0.93**	**0.90**	**0.87**	**0.96**	46.6	< 0.001
Working day	0.97	0.92	0.91	0.98		
Saturday	0.92	0.84	0.77	0.92		
Sunday*	0.68	0.78	0.68	0.90		
Number of trips per mobile person						
Overall	**3.73**	**3.44**	**2.96**	**3.92**	103.5	< 0.001
Working day	3.82	3.49	3.03	3.97		
Saturday	3.70	3.42	2.89	4.00		
Sunday*	2.94	3.04	2.46	3.57		
Number of tours per mobile person						
Overall	**1.48**	**1.45**	**1.45**	**1.87**	1.0	0.391
Working day	1.48	1.46	1.46	1.86		
Saturday	1.59	1.53	1.49	2.00		
Sunday*	1.40	1.36	1.30	1.78		
Duration of trips [min]						
Per trip	23.6	25.0	26.4	-	2431	< 0.001
Per day	88.8	87.0	78.3	-	8262	

* 'ATUS total' contains reported and imputed trips as described in Section 3.2.

The number of trips by duration classes (Fig. 1) is only displayed for the three datasets MAED, ANTS, and ATUS; ATUS total is not included, because the trip duration of imputed trips could not be inferred so that no difference exists between ATUS and ATUS total. MAED and ANTS correspond very well with respect to the detailed 5-minute classes over the whole range. The ATUS looks very different due to the predefined 15-minute intervals, which cannot be further disaggregated, but the number of trips per mobile person, which are shorter than or equal to 15 minutes, is still very similar in all three datasets (1.90, 1.84 and 1.75 in MAED, ANTS and ATUS, respectively). This pattern contradicts our previous hypothesis that the missing trips in ATUS are mainly short trips, which fall through the 15-minute interval grid. It rather seems that these missing trips are evenly spread and also include longer trips.

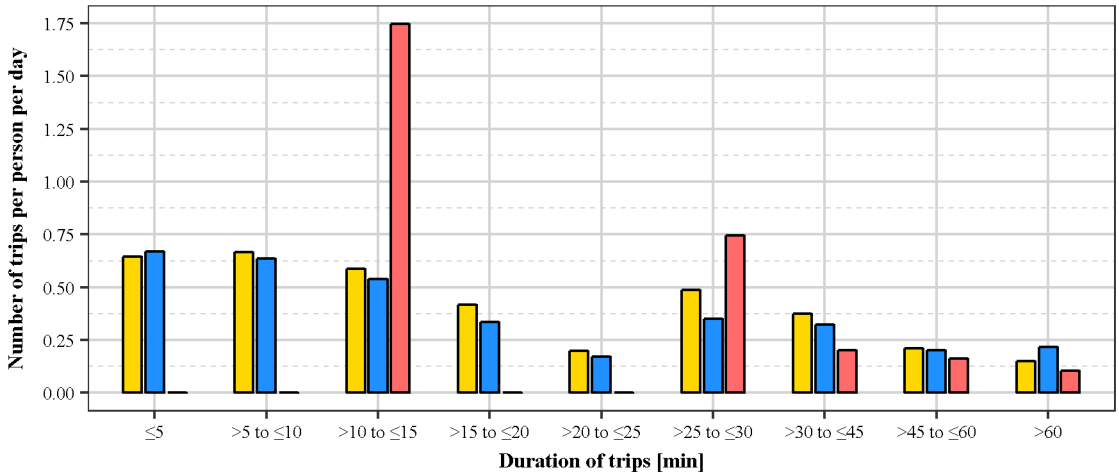

Fig. 1. Distribution of trip durations of all trips per mobile person per day.

Fig. 2 shows the number of trips by duration of the subsequent activity at the destination of the trip. The literature suggests that underreporting occurs either for short trips or for trips with short duration of the subsequent activity. Using MAED as benchmark, the latter effect is moderately confirmed for the ANTS (slightly lower number of trips with low duration of subsequent activity) and strongly confirmed for the ATUS; the number of trips with ≤ 15 minutes' duration of the subsequent activity is 55 % lower than in MAED. The difference diminishes but still exists in ATUS total, where missing trips were imputed. Based on this result and the result in Fig. 1, it seems that the missing trips are (i) trips of an average (or evenly spread) duration with (ii) a short duration of the subsequent activity.

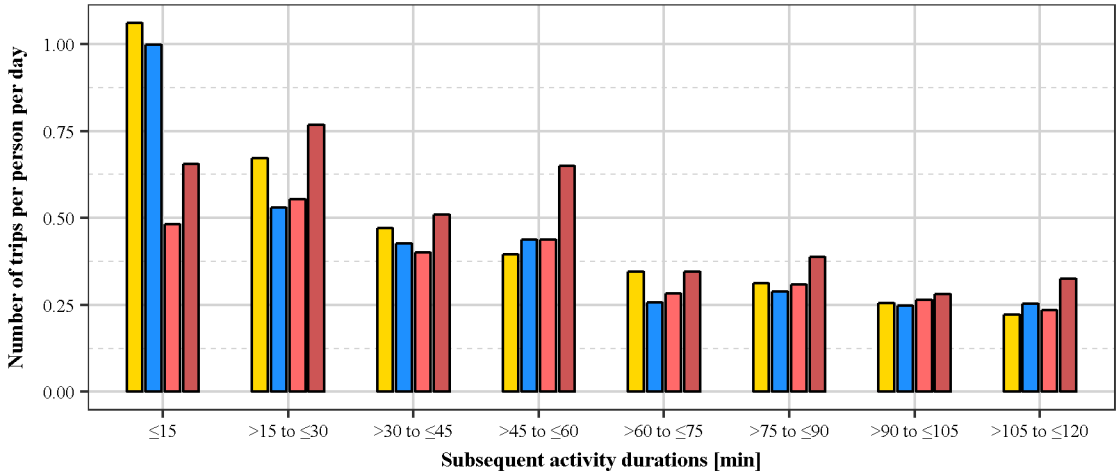

Fig. 2. Distribution of trips with regard to their subsequent activity duration (up to 120 minutes) choices of all trips per mobile person per day.

Walking and cycling trips have similar numbers in all four datasets. ATUS and ATUS total deviate from MAED and ANTS in terms of a lower number of motorised trips (car and public transport) and a high number of missing modes. The high share of missing modes reveals in any case a serious downside of time use surveys for capturing the travel behaviour: travel modes are not well reported even if the trip as such is reported.

All four datasets have similar numbers of working and education trips. Taking MAED as benchmark it turns out that ANTS has also similar numbers of leisure, errands and home trips; only the number of shopping trips is lower than in MAED. ATUS deviates somewhat stronger from MAED by a smaller number of errands and shopping trips (with shopping trips being close to ANTS). ATUS total deviates most from MAED, mainly in terms of a higher number of leisure trips and home trips.

The results of the trip analysis suggest that all three survey formats included in the analysis are affected by underreporting of trips: MAED to the least extent, ANTS to a moderate extent, and ATUS at most. Particularly susceptible to non-reporting seem to be motorised trips (by car or public transport) on the weekend with any duration (short or long) with a short leisure activity at the destination.

4.2. Non-travel activities

MAED and ATUS provide detailed activity information: (i) duration and frequency of episodes, (ii) for the entire day regardless of whether people stay at home or travel out of home. This facilitates a detailed comparison of all activities throughout the day including their duration and frequency of episodes. The activity data of the ANTS come at a more aggregated level: (i) no frequency of episodes is available but instead only the total duration of the main activity between any two trips derived from the trip purpose of the preceding trip, (ii) no information about the type of activities performed at home exists, and thus (iii) no information at all about immobile persons. ANTS can thus be compared with MAED and ATUS only with respect to (i) the daily activity durations, (ii) for the activity types derived from the trip purpose, (iii) for mobile persons with at least two trips.

Table 2 provides the detailed comparison of the MAED and ATUS dataset. It shows the duration and the frequency of episodes of all activities per activity category. The ATUS provides a more detailed picture of the sequence of activity episodes throughout the day because of two main reasons:

- MAED uses open time intervals for each activity episode. This seems to encourage respondents to skip or to aggregate short activity episodes in order to save respondent burden The effect of merging short activity episodes into longer ones in MAED seems to outweigh the 15 minutes' grid in ATUS.
- The pre-defined activity categories might suggest a less detailed level of activity types in MAED, especially diligent ATUS respondent might have reported more detailed activity categories than the ten categories used in the original MAED, leading to more activity episodes per day.

The only activity category with more episodes in MAED than in ATUS is 'travel' (3.5 and 2.6 episodes, respectively; including immobile persons). This difference reflects again the different priorities of the surveys.

Table 2. Comparison of activity duration and frequency per day by detailed category for MAED and ATUS (matched sample, all persons)

Activity category	Mean activity duration MAED [min]	**Activity frequency**	Mean activity duration ATUS [min]	**Activity frequency**
Travel	82.7	**3.5**	68.7	**2.6**
Sleep	479.0	**2.0**	469.8	**2.0**
Eating	78.1	**1.9**	84.7	**2.7**
Work	326.0	**1.2**	346.7	**1.5**
Education	11.4	**0.1**	11.4	**0.1**
Personal	83.9	**1.8**	54.6	**2.1**
Domestic	103.7	**1.4**	137.3	**2.7**
Shopping	17.4	**0.5**	15.3	**0.4**
Leisure	253.8	**1.9**	236.4	**2.9**
Other	3.0	**0.0**	15.0	**0.2**

In line with the literature (Gerike et al. 2015), the activity durations per activity category are quite similar in MAED and ATUS. The most substantial difference is the lower duration of 'personal' activities and the higher duration of 'domestic' activities in ATUS, both with a difference of approx. 30 minutes. The sum of both categories is very similar for MAED and ATUS (188 and 192 minutes, respectively).

Table 3 shows the activity duration for the aggregated activity categories that could be derived for all three datasets including the ANTS. The activity types include 'home' as artificial activity type, which captures the time that people spent at home. The activity durations show similar pattern as observed before for MAED and ATUS for the detailed activity categories, and also the ATNS survey matches well. The ANTS by definition can only have one activity episode with one category (the trip purpose). The activity ratio for ATUS is consistently higher than for MAED, resulting from the higher number of activity episodes presented above. The activity ratio is lowest for 'errands' and 'shopping', this means that on average, 1.3 activity episodes are carried out subsequent to any trip with the purpose 'shopping in ATUS (1.1 in MAED). The activity ratio is highest for the 'home'-activity. The mean activity ratio over all activity categories is 1.5 in MAED and 1.8 in ATUS.

Table 3. Comparison of activity duration (of the main activity type) by aggregated category (matched sample, persons with two or more trips)

	MAED		**ANTS**	**ATUS**		**ATUS total**	
Activity category	Mean activity duration [min]	**Activity ratio**	Mean activity duration [min]	Mean activity duration [min]	**Activity ratio**	Mean activity duration [min]	**Activity ratio**
Home	892.2	**3.6**	916.8	880.9	**4.8**	856.9	**3.9**
Travel	88.7	**1.0**	87.6	81.4	**1.0**	81.4	**1.0**
Work	335.0	**1.6**	326.2	364.7	**2.2**	366.1	**2.0**
Education	8.4	**1.5**	6.3	9.2	**2.3**	9.1	**2.1**
Errands	13.0	**1.1**	22.0	13.2	**1.4**	14.8	**1.3**
Shopping	17.7	**1.1**	12.7	10.7	**1.3**	14.3	**1.2**
Leisure	78.2	**1.2**	60.1	71.6	**1.6**	88.5	**1.3**
Other	5.8	**1.1**	8.3	8.3	**1.8**	8.9	**1.4**

5. Discussion and conclusion

The goal of this paper was to advance the understanding of the strengths and weaknesses of HTS and TUS in terms of quantifying travel and non-travel activities. Key indicators for travel and non-travel activities were compared for the three datasets MAED, ANTS and ATUS (the latter without and with imputed trips).

For travel estimates, the typical underreporting pattern of household travel surveys from the literature could be confirmed in the ANTS. Mainly short trips and shopping trips are underreported. The ATUS data show strong underreporting for all travel estimates if location changes without a trip in-between are not imputed as trips. With the imputation, however, unexpectedly high travel estimates have been found in ATUS. The immobility rate is very low (4% on average), and the number of trips per mobile person is with almost four trips per day substantially higher than in the MAED and ANTS data. The number of tours per day is also higher, because many tours with mainly two trips have been imputed in ATUS total especially for weekend days. These findings question the hypothesis of MAED being a reference source which is close to "ground truth", as originally assumed for this paper. There seem to be missing trips also in the MAED despite the extensive validation checks and the incentive. This finding relies on the assumption that the binary location variable in the ATUS dataset (home or not-home) is a reliable indicator of location changes, which indicate missing trips if no trip was reported in-between. We have no reason to doubt the quality of this variable, but it should be re-checked before we fully trust our far-reaching conclusion.

The activity data obtained from the three survey formats have different levels of detail: MAED and ATUS provide detailed activity information: (i) duration and frequency of episodes, (ii) for the entire day regardless of whether people stay at home or out of home. This facilitates detailed comparisons, it shows the opposing strengths and weaknesses of the MAED format and ATUS survey format: ATUS provides a more detailed sequence of activities throughout the day; MAED provides a more complete and accurate reporting of travel activities. Activity duration by category is very similar in both surveys. Activity data of ANTS come at a more aggregated level – and have thus a priori a limited usability for analysing non-travel activities. The ATUS is a rich dataset with much information about all activities throughout the day. Its suitability for analysing travel estimates and behaviour, however, was found to be limited. Modes are not reliably reported, rounding leads to 15-minutes-steps in the trip duration, and many trips are missing.

However, one has to be aware that there are additional potential sources of bias beside the different survey design when interpreting the results, e.g. the surveys were carried out some years apart from each other, different sampling methods were applied and the different forms of contacting the respondents caused selectivity.

6. Outlook

The results can be used for ex-ante improving the survey methods in order to optimize the output of each survey. In addition, imputation methods can be developed based on the insights gained in this paper for ex-post improvements of data quality in the data processing phase. The insights of the detailed analysis of non-travel activities in the ATUS and in the MAED-survey are especially useful for activity-based modelling of the relationship between travel behaviour and activity scheduling.

Further research should extend the work done in this study to a sample of the whole population in order to prove the transferability of the insights gained for employed persons. This work is also needed for advancing the understanding of the high numbers of tours and trips in ATUS total. TUS with a more careful collection of travel data and more detailed location information would be required for advancing research about strengths and weaknesses of of this survey method for analysing travel behaviour. It could be gained e. g. from a combination of time use surveys with smartphone-based tracking. For analysing travel behaviour in TUS data, it would be helpful to have a grid of maximum 10 minutes per activity episode, in order to have short trips reliably coded as trips and not merged with the subsequent non-travel activity in the data processing. Additionally, a more detailed record of the household's mobility tools and information about the location of each activity would enhance TUS data quality. Such TUS data would have an enormous potential for more detailed analyses of the interactions between travel and non-travel activities.

For an improvement of future NTS designs, an in-depth analysis of trips that were gained only in the validation phase in MAED could give further insights about item-non-response in general and furthermore provide an assessment of the applied MAED data validation process. This future strand of research could help to improve existing data imputation methods that contribute to obtaining more comprehensive ("closer-to-truth") NTS datasets.

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