12th International Conference on Transport Survey Methods

# Mixed-method approach to compare travel surveys as preliminary work for individual matching

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## Abstract

A mixed-method approach is used to compare data from a traditional travel diary and an approach called travel skeleton, which is used to capture typical travel behavior. 97 participants first complete the travel skeleton and then a travel diary for one week. The aim of this paper is to quantitatively and qualitatively analyze whether behavioral data from the two approaches can be used as a basis for statistical matching of individuals to generate a synthetic travel diary dataset with multidimensional information. Results show promising intrapersonal overlap between diary and skeleton with inference due to the randomness of reported diary week.

## 1. Introduction

In international research on travel behavior, a large number of different national and regional travel behavior surveys can be found. In general, survey methods can be divided into cross-sectional and longitudinal surveys depending on the reporting period. When looking at common trip-based travel diary surveys for transport planning and forecasting it becomes clear that relevant aspects of mobility, such as long-distance travel and psychological factors, are often ignored. In order to derive effective measures for the transformation of urban mobility, it is not enough to focus on the current demand for transport. Considering only sociodemograhic characteristics and everyday travel behavior omits important elements of one's individual mobility, such as long-

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distance travel (Magdolen et al., 2022) or the influence of attitudes (Moody, 2019). Despite the knowledge gained in transportation research in recent years, the understanding about mobility decisions of individuals and their determinants is still relatively limited, e.g., the possible influences of attitudes or the relevance of long-distance trips. Indeed, recently more studies, for example Moody (2019), Groth et al. (2021), and Rahimi et al. (2020), with questions on psychological factors have been used to capture non-objectively measurable parameters on individuals' travel behavior. Moreover, increasing attention is also being paid to the interrelationship between long-distance trips - which have a massive influence on the $CO_2$ balance of people - and peoples' everyday travel behavior. Long-distance travel, for example, plays an important role to explain car ownership for urbanites (Magdolen et al., 2022). However, both dimensions, attitudes and long-distance travel behavior, are insufficiently addressed in common travel surveys. Due to the respondent burden, usually only reduced designs for long-distance travel or a short period (i.e. one day) are applied as a compromise, whereas psychological factors are usually missing at all in traditional travel surveys.

An innovative travel skeleton approach that captures "typical" everyday and long-distance travel behavior as well as attitudinal data can be a solution to provide a multidimensional perspective on mobility. However, within the travel skeleton approach everyday mobility is not captured by a traditional travel diary, as this would be too burdensome, but in a more efficient, and consequently less detailed manner. Although the approach delivers different dimensions per individual, the omission of a typical travel diary has difficulties to provide key mobility figures (e.g., trips per day) and to use the obtained data for transportation planning models as detailed trip information (e.g., departure and arrival times) is missing. The shortcomings of the travel skeleton approach lead to the idea of "artificially" providing the missing information by means of the feeding from a secondary survey with a longitudinal travel diary over one week such as the "German Mobility Panel" (MOP).

In summary, it must be stated that capturing all mentioned dimensions would fail due to the respondent burden. However, their knowledge is important to be able explain peoples' travel behavior in-depth. For this reason, different datasets have to be matched in order to generate a synthetic dataset that meets the specified requirements to analyze urban mobility. Bayart et al. (2009) already pointed out that data matching or fusion is necessary to counteract increasing difficulties (cost, response rates …) in data collection. As an objective, an "act-a-like matching procedure" could be applied (act-a-like means same travel behavior), in which the travel information of individuals from the travel skeleton sample is matched with the travel behavior of individuals from the secondary survey. To achieve a synthetic dataset, which provides information from a detailed longitudinal travel diary as well as long-distance and attitudinal data, appropriate datasets have to be matched on a sociodemographic and behavioral level.

In order to get advantage of both types of data (trip diary and skeleton) occurs to examining whether the data from the innovative skeleton approach can be matched intrapersonally with data from a travel diary of a secondary survey at the behavioral level to generate a synthetic dataset. Hence, the aim of this paper is to determine whether similar travel behavior is observed when the same person participated in both survey designs. If this would be the case, it is possible to match persons without major complications in a potential matching procedure. So this paper can be seen as an important preliminary work for statistical matching (e.g., propensity score matching).

In this paper, we used a mixed-method approach with 97 participants first completing the travel skeleton and then filling out a travel diary over one week. With a subgroup of 38 participants, problem-centered interviews were conducted in order to evaluate discrepancies between the quantitative surveys. To our knowledge, there are only a few studies that carry out such a comparison between two different approaches such as "typical" and diary-based behavior. Existing studies, for example, show an overestimation of the use of environmentally friendly modes of transport when querying typical behavior (Kagerbauer et al., 2014). For our study, we designed a mixed-method approach, which consists of three phases: travel skeleton questionnaire, one-week travel diary and problem-centered interview with stimulus materials.

This paper is structured as follows: First, we give an overview of traditional survey approaches in transportation research and introduce approaches that capture typical travel behavior. We also describe the concept of the travel skeleton. Second, we explain the structure of the mixed-method approach and the data collection. Third, we present results of the quantitative and qualitative analysis and give recommendations. Fourth, we draw a conclusion and give recommendations for a potential matching procedure, discuss the limits of our approach and refer to further work.

## 2. Travel survey approaches with different focus

In this chapter, we first provide an overview of the focus of established travel surveys and discuss the white spots in the surveys. Then, we briefly describe the travel skeleton approach with its four modules to capture "typical" travel behavior and attitudinal characteristics.

### 2.1. Main focus of traditional travel behavior surveys with travel diaries

In international research on travel behavior, a large number of different national and regional travel behavior surveys can be found. The survey methods can be divided into cross-sectional and longitudinal surveys depending on the reporting period (see Armoogum et al., 2009; Chlond and Eisenmann, 2018). In Germany, for example, there are three major travel surveys with various emphases.

First, the cross-sectional survey "Mobility in Germany" (MiD) is a one-day travel diary that provides the opportunity to study trends and explain differences on an aggregated level. The main objective of the study is to obtain representative and reliable statistical figures. The one-day travel diary is extended through questions about "typical" mode choice and long-distance travel. Second, the cross-sectional survey "Urban Mobility" (SrV) has a focus on urban areas. Both surveys are comparable to the "National Household Travel Survey" in the U.S. or the "Dutch National Travel Survey" (OViN) in the Netherlands, just to name a few examples. However, capturing intrapersonal behavioral variance of individuals is only possible to a limited extent, as cross-sectional surveys almost exclusively record interpersonal variation (Senbil and Kitamura, 2009). Third, the "German Mobility Panel" (MOP) is a longitudinal survey over one week and is designed to study everyday travel behavior on an individual level. As a result, it is possible to provide information on multimodal behavior and day-to-day variation. These surveys have more of an exploratory research character rather than a transport statistics purpose. Nevertheless, the disadvantages of diaries over several days are obvious. Such longitudinal surveys are expensive and increase the respondent burden during the reported week (Chlond et al., 2013). Furthermore, they cause fatigue effects as well as attrition between survey waves. Individuals tend to report fewer trips towards the end of the reporting week. In panel studies, this effect of reporting fatigue is more visible among people participating for the first time, so-called first-time reporters, than among third-time reporters (Chlond et al., 2013). In addition, long-distance travel is recorded only randomly in the reported week. None of the three surveys in Germany considers psychological factors comprehensively. Generally, only a few surveys examine psychological factors and longitudinal travel behavior at all. As one of few examples, the "Netherlands Mobility Panel" (MPN) is a three-day travel diary to avoid diary fatigue. It includes attitudinal questions for subsamples, but long-distance travel is also not considered.

However, both aspects are essential, especially to understand and explain peoples' mobility requirements. Summing up: a desirable survey design would combine these three dimensions (longitudinal travel diary covering e.g., more than one week, psychological factors and long-distance travel). Such a high dimensional survey approach with a travel diary would increase the respondent burden extremely and it probably causes a selective sample.

### 2.2. Typical travel behavior and the travel skeleton approach

Chlond and Eisenmann (2018) describe the possibility of querying typical behavior rather than using travel diaries. Questionnaires are used for a typical behavior approach. The FGSV (2012) describes it as a concrete query "with regard to recurring basic travel patterns or summary indicators of mobility". The aim of the survey is to obtain the basic framework of mobility and the relevant patterns of respondents' travel behavior (FGSV, 2012). This type of survey is also used in combination with diaries. Respondents in the MiD are asked how frequently certain modes of transport are used "usually" to record multimodality over a longer period than one day. Other examples include studies by Kuhnimhof et al. (2019) and Moody (2019) that examined typical behavior together with psychographic characteristics.

Similar thoughts exist for longitudinal surveys as well. Lipps (2009) recommends for the MOP extension "[...] a kind of typical daily pattern or travel skeleton [...]" approach. The MOP is a rotating panel in which respondents participate in a maximum of three consecutive waves of the survey. A fourth wave with travel diaries would be expensive. But a one-time additional survey on "typical" travel behavior is significantly less expensive as a fourth

wave. The behavioral theoretical rationale for the existence of habitualized or typical behavior consists in the basic assumption "[...] that, given constant external circumstances, the individual strives to repeat, within a certain cycle, an established behavioral pattern that has proven itself in the past" (Lipps, 2001). The idea of Lipps (2009) served as the basis for the conception of the travel skeleton. The name stems from the fact that it only claims to represent the individual basic skeleton of everyday mobility of persons. The travel skeleton provides a reasonable compromise between the level of detail needed and the required effort to survey travel behavior. The aim of the travel skeleton is not to replace the approach of the travel diary. Rather, it is intended to provide an alternative if a travel diary with additional questions on other areas of interest is not possible for reasons of survey effort and costs. The travel skeleton has already been used in other studies in Hamburg, Munich and Berlin (Germany), San Francisco (U.S.), Shanghai, Beijing and six additional cities in China since 2016 (Magdolen et al., 2022; von Behren et al., 2021a; von Behren et al., 2021b; von Behren et al., 2018). More than 8,000 participants were interviewed with this design. The travel skeleton consists of four main modules:

- sociodemographic characteristics,
- typical everyday travel,
- long-distance travel (day trips and overnight stays), and
- psychographic characteristics (item sets).

The idea to capture everyday travel with the travel skeleton is adapted from the longitudinal travel diary of the MOP. Instead of asking people about every single trip during a random week, we ask them about relevant activities and their mode choice in a „typical" week as a „pseudo-longitudinal" approach. Therefore, we capture the everyday travel through the important activities:

- work/school,
- leisure activities,
- chauffeuring,
- errands, and
- shopping.

For a better understanding we illustrate in Figure 1 (right site) how we capture leisure activities (frequency, distance and mode choice). These leisure activities are in contrast to day trips at the weekend (left site). They are part of the long-distance travel module. Through such a questioning logic in different activity areas we can capture the typical everyday travel patterns. For a further explanation of the travel skeleton we refer to von Behren et al. (2021b).
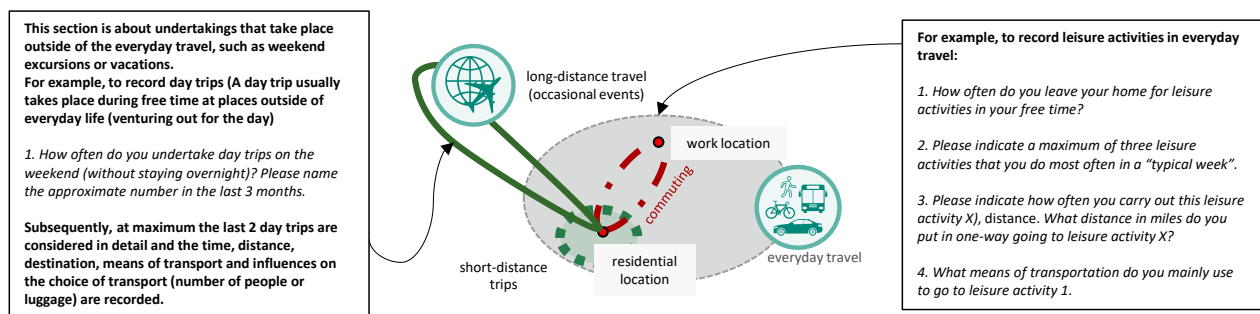


This section is about undertakings that take place outside of the everyday travel, such as weekend excursions or vacations.
For example, to record day trips (A day trip usually takes place during free time at places outside of everyday life (venturing out for the day)

*1. How often do you undertake day trips on the weekend (without staying overnight)? Please name the approximate number in the last 3 months.*

Subsequently, at maximum the last 2 day trips are considered in detail and the time, distance, destination, means of transport and influences on the choice of transport (number of people or luggage) are recorded.

For example, to record leisure activities in everyday travel:

*1. How often do you leave your home for leisure activities in your free time?*

*2. Please indicate a maximum of three leisure activities that you do most often in a "typical week".*

*3. Please indicate how often you carry out this leisure activity X), distance. What distance in miles do you put in one-way going to leisure activity X?*

*4. What means of transportation do you mainly use to go to leisure activity 1.*

Figure 1. Capturing and differentiating between everyday and long-distance travel

## 3. Methodological approach

For a potential statistical act-a-like matching with the travel skeleton, it first must be verified that the travel skeleton has sufficient overlap with travel diaries. To investigate, if this overlap exists, we developed a mixed-method approach that consists of three phases: travel skeleton, travel diary and problem-centered interview. The study design is presented in Figure 2. We started the mixed-method approach with the travel skeleton survey. The order of having the travel skeleton (phase 1) completed before the diary (phase 2) was deliberately chosen so that participants would not

be influenced in responding to the typical behavior by the intensive reporting of their behavior during one week. The quantitative information on travel behavior from the first two phases can be used for comparison at the individual level. For an appropriate assessment of the similarities and differences between the individual responses in both survey designs a problem-centered interview was conducted in the third phase, which was developed specifically for the comparison. The findings may provide initial indications as to whether a comparable basis for statistical matching is present or not. According to the methodology, the problem-centered interview was designed semi-structured and is
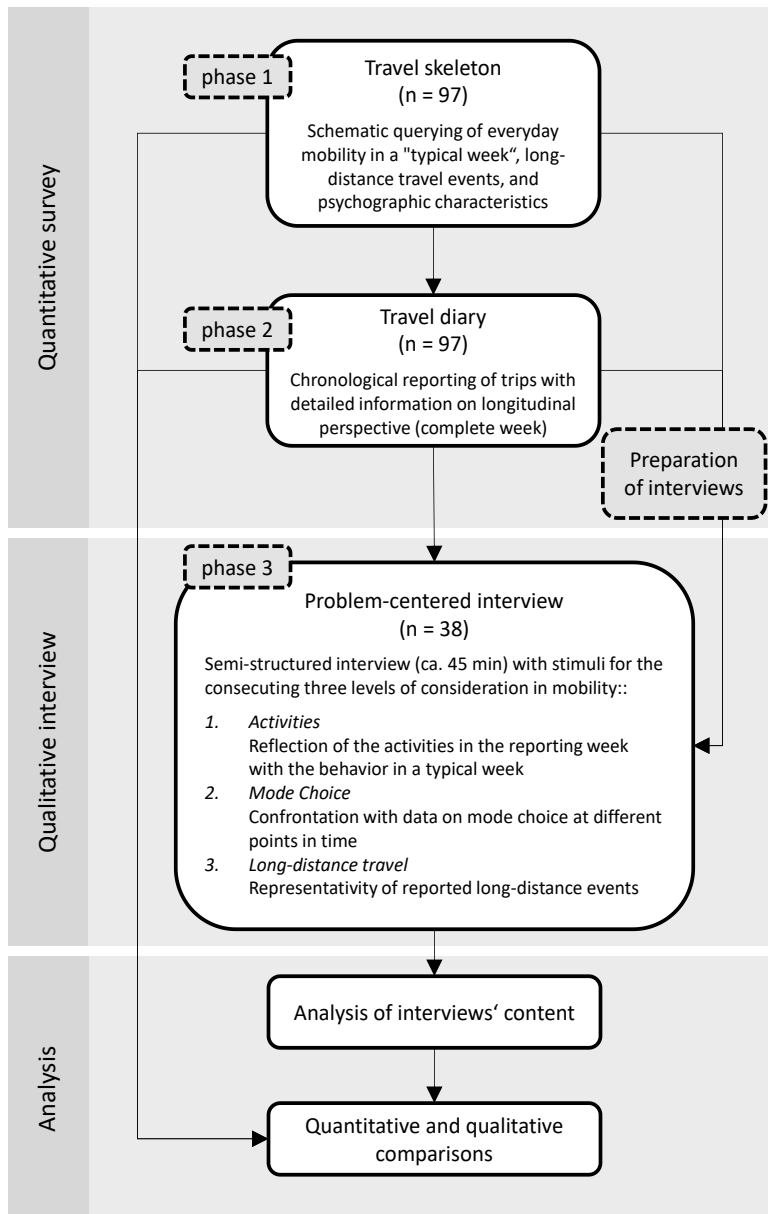
Figure 2. Mixed-method approach with 3 phases to compare survey designs

intended to be conducted in a guided manner to activate participants. It focuses on activities, mode choice, and long-distance travel behavior.

In the further course of this chapter, first the sample used in this study is presented. Second the mixed-method design as well as its application to the sample is described in more detail. The focus of the description is on the qualitative interviews, since travel diaries are already known and the travel skeleton has been explained in the previous chapter.

## 3.1. Sample and data preparation

The participants for the comparative study were not selected randomly, but according to fixed selection rules. They were selected from two sociodemographic subgroups: students and employed persons without underage children. The selection criterion is based on the assumption that, in contrast to households with children, both groups have a certain freedom of choice, apart from employment. However, in terms of the social obligations imposed on them by others and by society, the two groups of students and employed persons differ. With regard to mobility needs, the selection criterion excluded people who have sometimes complicated daily travel patterns due to small children in the household. In total, 97 people from Karlsruhe participated in both survey designs for the quantitative comparison (see Figure 2). The participants were mainly students (65 out of 97) recruited from a lecture at the Karlsruhe Institute of Technology (KIT). The data from the travel skeleton and the travel diary from phases 1 and 2 were digitized for further use and analyzed with the statistical software SAS.

In addition, 32 employed persons from Karlsruhe participated. Of the total sample, a subsample of 38 persons was interviewed. An advantage of qualitative analysis with non-numerical data is that even a small sample is sufficient to obtain findings and implications. In the in-depth interviews, we balanced the ratio of students (19) and employees (19), in order to capture a broad spectrum of articulated reasons for deviations between typical and actual behavior. The surveys span from 2017 to 2019 and were conducted in the fall of each year.

Due to the interview duration, we applied audio recording followed by transcription. The content analysis of the transcriptions was performed using MAXQDA software. A total of 1,843 minutes (30 hours, 43 minutes) of audio material was transcribed into 464 pages of text. In the qualitative content analysis of the interviews we used inductive category formation, meaning that the categories were developed and coded directly on the interview documents. The categories were revised and back-checked during the analysis process.

## 3.2. Application of the mixed-method approach

At the beginning of the interview, respondents were given a schedule for one week (see Figure 3 – part 1) in which recurring activities outside home during a typical week should be filled in. This represents a change in perspective, as we did not ask about trips as in the travel diary. The narrative prompt was: "Describe what a 'typical' week looks like for you in terms of your everyday travel behavior! Orient yourself to recurring activities in different weeks!". In this context, the goal is to separate obligatory, recurring activities and flexible, random activities. This is to check whether persons can identify typical activities for themselves. The interviewees can freely report their activities. Follow-up questions are used to evaluate the weekly variance of specific activities. However, locating "typical" activities in this schedule for one week may lead to under-reporting of activities, since spontaneous activities – even if they occur every week – may not be located in the weekly schedule by respondents. As a result, this leads to a "systematic" underreporting. For this reason, they are confronted the interviewees with the activity schedule from the travel diary (see Figure 3 – part 2). In addition to the activities, the typical mode choice was queried in the interview by answering a mode choice matrix (see Figure 4 – part 1). Before filling out the matrix, an introductory guiding question was asked: "Name the most important modes of transport for you in everyday life and describe why these in particular are so important to you?" The guiding question helps to clarify for which activities, which modes are used, but also how seasonal or weather-dependent individual modes are. In this context, purpose-driven use, stability, and the role of infrequently used modes were discussed.
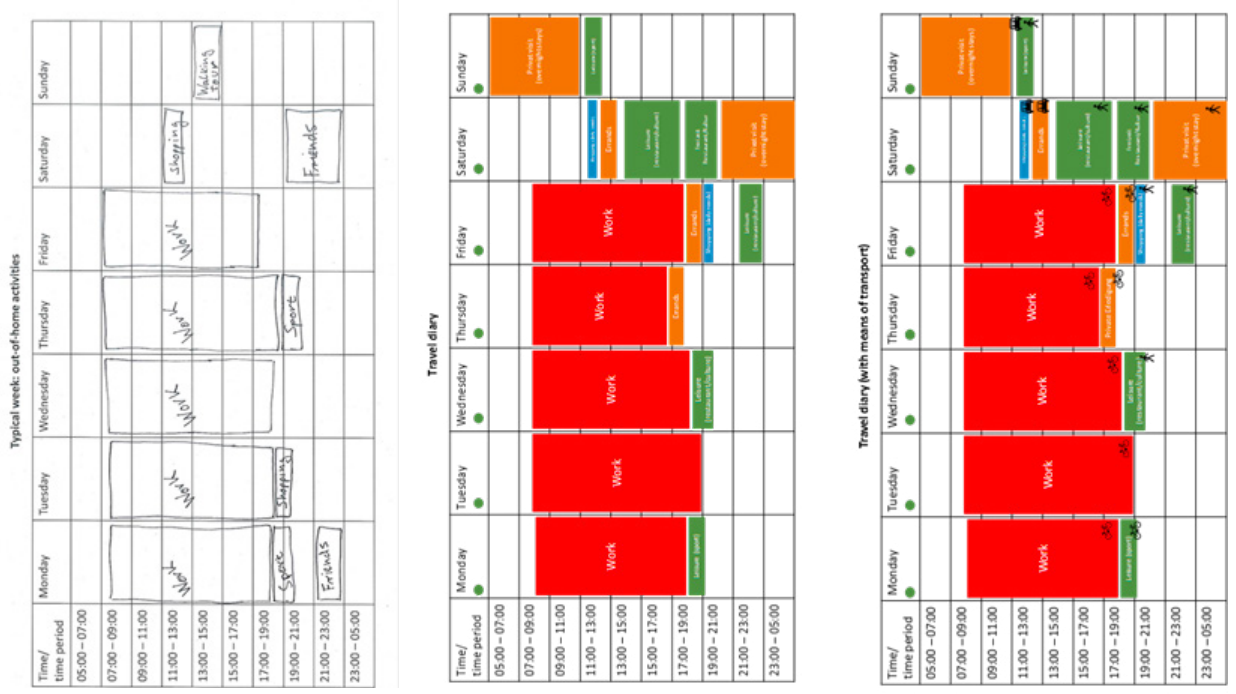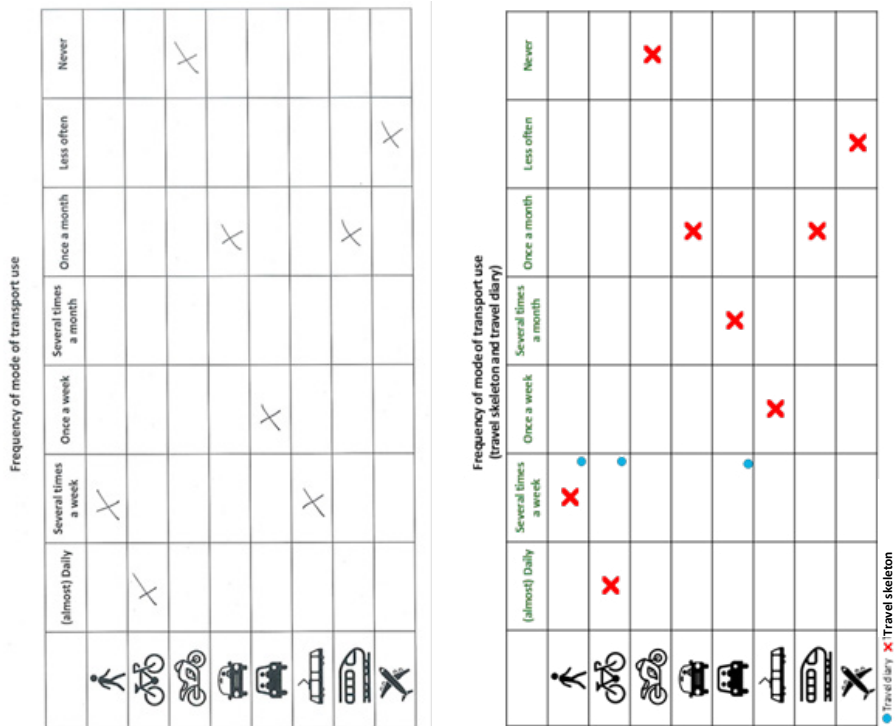
Figure 3. Stimulus to capture everyday travel



Figure 4. Stimulus to capture typical mode choice

For comparison, the participants were confronted with the reported mode use from the travel skeleton and the actual frequency of use from the reported travel diary in matrix form (see Figure 4 – part 2). Based on this, the differences

in the responses of the matrices were discussed. The matrix of the interview (Figure 4 – part 1) or the travel skeleton (red crosses in Figure 4 – part 2) does not only cover one week by answering the typical behavior. Thus, less frequently used transport modes become relevant and can be discussed. The last part of the interview addressed long-distance travel, but this is not focus of our presented paper and will not be explained in more detail.

## 4. Quantitative comparison

Before analyzing the interviews, the first step is to conduct a quantitative comparison based on the travel skeleton and travel diary from the first two phases. This is to find out, where differences between both survey designs occurred in our sample. In the first step of this chapter, we compare multimodality and mode use frequencies between responses in both survey designs. In the second step, we investigate activity choice by comparing activity frequencies.

### 4.1. Mode choice and multimodality groups

First, we compared the 97 respondents across the multi- or monomodal mode user groups with weekly reference (see Figure 5). The bicycle-public transport combiners represent the largest group, both in the travel skeleton and in the diary. For these groups there are differences between the skeleton and the travel diary. The proportion of monomodal bicyclists is significantly higher in the travel skeleton. But it is not only among monomodal bicyclists that we see differences. Overall, 72% of the individuals report using a bicycle at least once a week. In the travel diary, 66% of respondents actually use the bicycle. Similar to this conducted comparison, the MiD 2017 provides a value of 53 % for persons from Karlsruhe with at least weekly bicycle use in the means of transport frequency matrix (quasi-longitudinal section). However, on the assigned reporting day in the MiD, only 26% of respondents actually use it (Nobis, 2019). At this point, the strength of a longitudinal survey over one week is again evident, as the variation in mode use can be captured better.
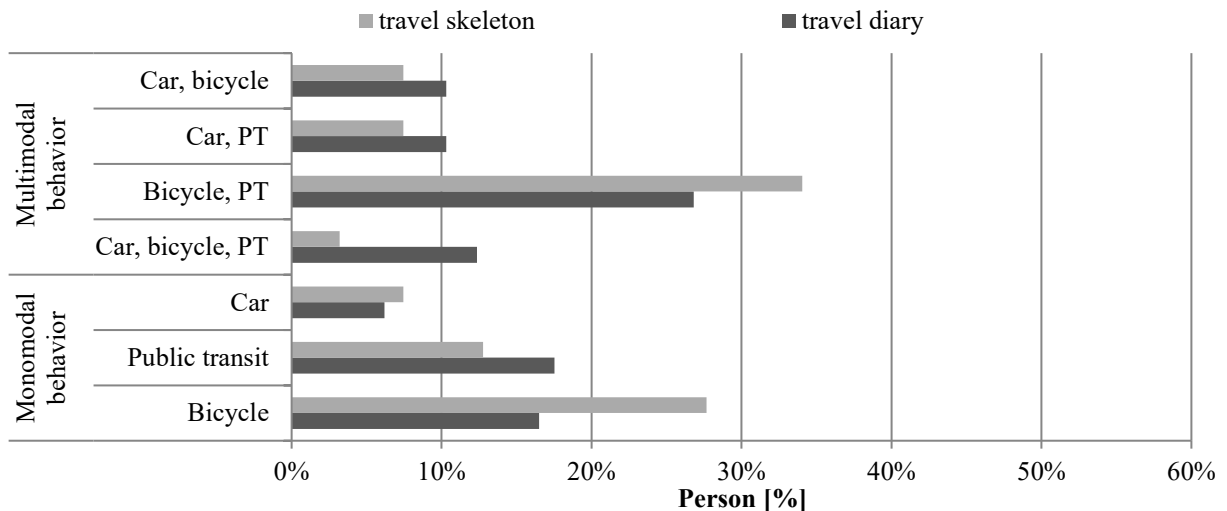
Figure 5. Multimodality groups between travel skeleton and travel diary

Second, we analyze mode choice in more detail between travel skeleton (SK) and travel diary (TD) for students (Stud) and employees (Empl). To compare use frequency, we applied the approach (see Table 1) from Kagerbauer et al. (2014). The mean values of the considered variables are close together. Figure 7 shows differences for bicycle and public transit use. In addition, Table A 1 shows the differences in mean, standard deviation and the t test of the difference.

Table 1. Comparison approach between travel skeleton and travel diary (adapted from Kagerbauer et al., 2014)

| | | Self-assessed typical mode use behavior (SK) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | (Almost) daily | Several times a week | Once a week | Several times a month | Once a month | Less than once a month | Never |
| **Reported mode use in travel diary (TD)** | 0 days | | | | | | | |
| | 1 day | | | | | | | |
| | 2 days | | | | | | | |
| | 3 days | | | | | | | |
| | 4 days | | | | | | | |
| | 5 days | | | | | | | |
| | 6 days | | | | | | | |
| | 7 days | | | | | | | |

| Legend | More often (SK > TD) | Equal (SK = TD) | Less often (SK < TD) |
|---|---|---|---|

## 4.2. Frequency of activities

For extended quantitative analysis, the activity choice in the reported week of the travel diary is compared to the indication of typical behavior in the travel skeleton. For this purpose, the activities work, education and leisure are analyzed. The mandatory activities work and education have an agreement (SK = TD) of at least 80% (see Figure 6).
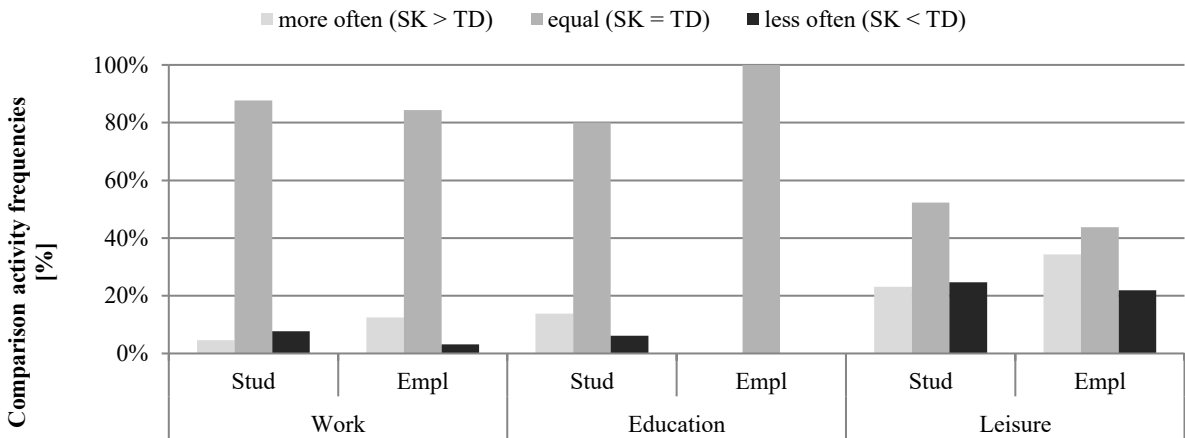
Figure 6. Comparison of activity frequencies of work, education and leisure.

The leisure activities, on the other hand, are subject to greater deviations between the two survey designs. The variation in frequency per week is higher for employed individuals than for students. This is probably related to the greater variation in frequency between weeks. Students may perform activities on alternate days and times of day, but their activity frequency during the week appears to be more stable. Tarigan and Kitamura (2009) examine variability in the frequency of leisure activities between weeks using 'Mobidrive' data. They find that work trips, in particular, have high stability. In contrast, leisure activities have high variability in frequency from week to week.
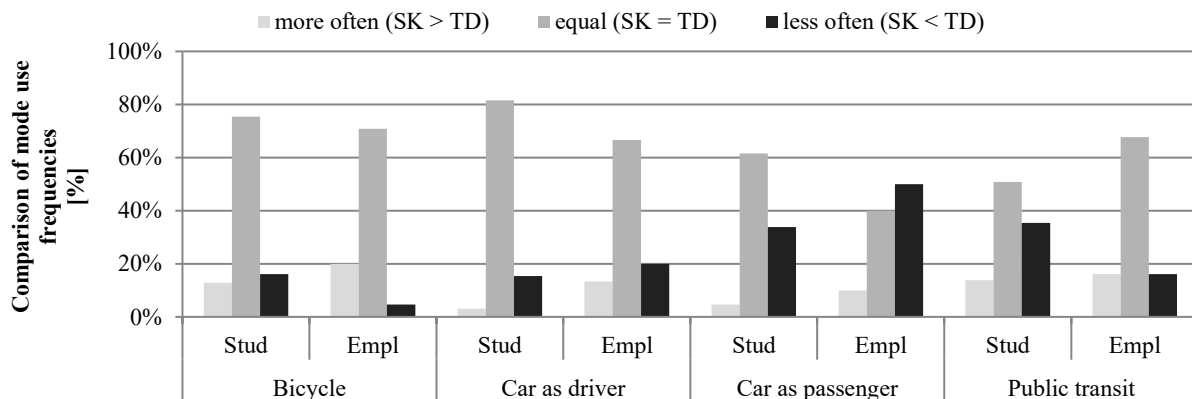
## 5. Qualitative comparison



Figure 7. Comparison of mode use frequencies

Only a subsample of 38 people was interviewed for the qualitative analysis (see Table A 2). The aim of the problem-centered interviews is to investigate causes for the discrepancies between the travel skeleton and the travel diary in order to determine whether reporting biases exist or are caused by a high intrapersonal variability between the weeks.

### 5.1. Mode choice

**Weather related deviation**

Kagerbauer et al. (2014) already assumed in their comparison that the weather primarily influences bicycle use. This weather-related influence may cause the actual usage in the observed (random) week to fluctuate to other (unobserved) weeks. This weather-related fluctuation is also described by interview participants. This may cause frequent users to use the bicycle less during the observed week.

*"I actually ride my bike all the time. So, if it's raining or it's really bad weather, my wife takes me [in the car]."*

**[ID19]**

Infrequent users may also have no observed use at all during the week, even though regular bicycle use was reported in the travel skeleton.

*"When it rains, I certainly don't ride a bike. Then I take the car or stay at home. [...] I'm a good-weather rider."*

**[ID14]**

This unstable, weather-dependent behavior complicates the recording of mode use in the travel diary and travel skeleton equally, which can result in a discrepancy between the results of both designs. In the travel diary, much depends on weather conditions during the reporting period, and in the travel skeleton, such behavioral variance cannot be accounted for when reporting bicycle use frequency. In the travel skeleton, however, psychological characteristics such as bicycle orientation or weather resistance provide another useful perspective. Indeed, weather does not always have an impact on bicycle use. Higher weather resistance in individuals increases stability in behavior. They adapt to changing weather conditions, e.g. by wearing special rainwear.

*"[...] I am a convinced cyclist and I am happy every time I wear these rain pants."*

**[ID29]**

**Randomness of the reporting week**

The randomness of the reported week in the travel diary can also lead to deviations due to other particularities. The statement "several times a month" describes a less frequent, possibly also more random use. The mode of transportation is not subject to a perceived regularity in a weekly rhythm. Therefore, a more frequent use in a random week is possible without giving a distorted answer in the travel skeleton.

*"[I use public transport] several times a month [...], because here in Karlsruhe short distances [are covered] from time to time or when I go to my parents."*

**[ID30]**

In the case of students, there is also another peculiarity. Some of the students travel to their parents' home for the weekend at intervals of two to three weeks. There, in contrast to their situation at their place of study, they often have a car at their disposal and find themselves in a different spatial type and in a different social environment, which leads to more intensive car use.

*"So, when I'm at home [with parents], I just drive [...], because we live in the countryside. There's nothing accessible there and I don't really have a bike at home then."*

**[ID29]**

The qualitative analysis makes clear that the observation period of one random week in the travel diary is not sufficient on the individual level to conclusively verify the typical mode use in the travel skeleton. Reported mode use in the travel skeleton do not necessarily have to be used every week and can therefore be omitted from the travel diary. A relevant finding from the interviews is that the randomness of the observation week can explain the intrapersonal deviations in the report. However, it is also difficult for individuals to adequately reflect their, for example, lack of weather resistance in rainy weather when indicating frequency of use in the travel skeleton, e.g., for bicycles or public transport. This represents a weakness of the schematized query, since people may deal with this problem differently.

**Categorization of reasons for deviation**

The results in Table 2 show that especially the randomness of the week leads to a lower estimation of car rides in the travel skeleton. In addition, the participants have difficulties to indicate the typical frequency of use for this mode. The cause of the overestimation of bicycle use in the travel skeleton is much more diverse. Here, the weather, the randomness of the week and the difficulty of reporting in the travel skeleton play a role. In combination with the underestimation, however, the weather-related deviation comes to the fore. In total, seven out of 15 deviations (47%) are due to the weather.

Table 2. Reasons for deviation in mode choice

| | More frequent (SK > TD) | | | | | Equally frequent (SK = TD) | Less frequent (SK < TD) | | | | | Σ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Other reasons | Weather related deviation | Randomness of reporting week | Social desirability | Difficulties in indication | | Other reasons | Weather related deviations | Randomness of reporting week | Social desirability | Difficulties in indication | |
| Car as driver | 1 | | 2 | | 1 | 27 | 1 | 1 | 3 | 1 | 1 | 38 |
| Car as passenger | 1 | | 2 | | | 18 | 1 | | 12 | 1 | 3 | 38 |
| Bicycle | | 4 | 4 | 1 | 3 | 23 | | 3 | | | | 38 |
| Public transit | 1 | 1 | 1 | | 1 | 24 | 1 | 6 | 1 | | 2 | 38 |

*5.2. Activity choice*

**Mandatory activities**

In the travel diary, only trips and out-of-home activities are reported. This means that a working day at home cannot be recorded at all and leads to a discrepancy between the designs. The travel skeleton explicitly asks about the frequency of home office in a month. If one or two home office days are reported in the random week, then the deviation occurs even if the person is rarely in the home office.

*"[...] in the last three months, if at all, I have had two Fridays when I was in the home office."*

**[ID9]**

**Leisure activities**

Higher deviations can be observed in the leisure activities between the three survey time points (TD, SK and interview). This was already evident in the quantitative analysis. Weekend activities in particular are not subject to stability for a large number of participants.

*"Typical weekend is difficult. I sometimes ride my bike out somehow in the Black Forest, there a round. I'm sometimes at home for the weekend working [...]"*

**[ID23]**

*"Then there are often activities on the weekends. But that varies a lot."*

**[ID9]**

With the travel diary, this irregularity cannot be captured due to the short time period. In the travel skeleton, the variation is partially captured by the longitudinal approach, since a distinction is made between the two categories of leisure activities in everyday life and leisure activities outside the everyday environment. In the case of the travel diary, it is difficult to track whether the activities are recurrent or occur purely randomly throughout the week.

**6. Conclusion and further research**

The paper focused two focal points. On the one hand, we described the travel skeleton approach as a "quasi-longitudinal" survey approach. Second, we compared the travel skeleton approach with travel diary as a basis for a "act-a-like-matching". Therefore, we compared the travel skeleton approach with a travel diary using a mixed-method approach to find out whether "act-a-like-matching" is possible between both survey designs.

We could show in the comparison of both survey designs that in the travel skeleton random effects in the reporting period, such as weather, are masked out, whereas in the travel diary the reported behavior is strongly dependent from the reporting week. The target of the travel skeleton is to report an average individual travel behavior whereas in the travel diary the average effect is generated by an increased sample size. Hence, the travel skeleton is efficient for researchers and additionally induces a comparatively low effort for the respondents. However, the average effect of the travel skeleton prevents the design from capturing intrapersonal variance between days, as is the case in longitudinal surveys. As a result, random trips and transport mode used are masked out. Nevertheless, due to less effort for respondents more additional information can be collected in the travel skeleton, e.g. on attitudes and long-distance events without increasing respondent's burden beyond acceptable levels.

To find out, which aspects are suitable for "act-a-like-matching", we applied a mixed-method approach. The quantitative comparison between the travel skeleton and travel diary showed a suitable overlap to the established travel diary approach when comparing the mode choice in terms of frequency and multimodality. Although the quantitative comparison shows deviations, these are not one-sided (e.g., it does not show that the mode use frequencies in the travel skeleton are always overestimated). This does not indicate any systematic error in the recording. Relevant discrepancies between the designs are observed for cycling and car as passenger, what is in line with existing literature. When comparing activities, strong discrepancies are observed for leisure activities. The frequencies of leisure activities are subject to high variability between different weeks. Therefore, it is not clear whether the travel skeleton

over- or underestimates frequency values or whether the random week represents a strong deviation from the typical behavior of individuals. Quantitative analysis has its limitations in answering such questions. The qualitative interviews can reveal the articulated reasons for the deviations between typical and reported behavior. In purely quantitative studies on mode choice, these reasons can only be speculated. In a comparison, the question inevitably arises as to which design, the reporting week or the typical behavior, better reflects the mobility of the individual. The content analysis of the interviews showed that the answer requires a case-by-case approach. There is not one "fundamental truth", but each person has his own truth. The results of the problem-centered interviews make clear that especially the randomness of the week leads to deviations between the travel diary and the travel skeleton on an individual level.

Overall, results indicated for an "act-a-like matching" that active modes such as bicycle and car as driver (frequency of use) as well as multimodality groups have to be considered besides socio-demographic characteristics. In terms of activities, only the mandatory activities school and work showed sufficient overlap. But these results are only confirmed for students and employees.

Further research is needed to investigate other sociodemographic groups. In addition, a further research objective is, in a first step, the application of "act-a-like matching" between the travel skeleton and travel diary data sets. The second step should be an "act-a-like matching" of travel skeleton data of a whole city with official secondary statistics. In addition, more research is needed to prove that the travel skeleton is not case-specific, and can be used in any city or region to capture travel behavior and psychological factors.

## Acknowledgements

## Appendix A.

Table A 1. Quantitative comparison of travel skeleton (SK) and travel diary (TD)

| Variables | | Travel skeleton (SK) | | Travel diary (TD) | | Difference TD - SK (t test) | |
|---|---|---|---|---|---|---|---|
| | *Activities [days per week]* | *Mean* | *Std* | *Mean* | *Std* | *t Value* | *Pr > \|t\|* |
| | Work | 0.7 | 1.1 | 0.9 | 1.3 | 0.96 | 0.341 |
| | School/university | 3.8 | 1.3 | 3.5 | 1.6 | -1.32 | 0.191 |
| | Leisure | 3.5 | 2.1 | 3.6 | 1.8 | 0.34 | 0.734 |
| | *Distance mandatory activities [km]* | | | | | | |
| Students (n=62) | Work | 8.5 | 17.8 | 4.8 | 5.9 | 1.61 | 0.125 |
| | School/university | 10.2 | 24.3 | 8.9 | 21.3 | -0.48 | 0.635 |
| | *Mode choice [use frequency*]* | | | | | | |
| | Walking | 2.2 | 0.9 | 2.0 | 0.6 | -1.50 | 0.139 |
| | Cycling | 2.1 | 1.3 | 2.6 | 1.1 | 4.74 | <.0001 |
| | Car as a driver | 3.5 | 0.8 | 3.7 | 0.7 | -2.68 | 0.009 |
| | Car as a passenger | 3.8 | 0.5 | 3.2 | 0.8 | -4.93 | <.0001 |
| | Local public transit | 2.8 | 1.1 | 2.6 | 0.9 | -1.54 | 0.129 |
| | *Activities [days per week]* | Mean | Std | Mean | Std | t Value | Pr > \|t\| |
| | Work | 4.3 | 1.6 | 3.9 | 1.5 | -1.99 | 0.055 |
| | School/university | 0.5 | 1.2 | 0.5 | 1.4 | 0.37 | 0.711 |
| | Leisure | 3.6 | 1.9 | 3.3 | 2.0 | -0.93 | 0.361 |
| | *Distance mandatory activities [km]* | | | | | | |
| Employees (n=35) | Work | 16.0 | 34.8 | 13.0 | 26.2 | -1.85 | 0.074 |
| | School/university | 4.9 | 5.0 | 4.5 | 3.8 | -0.17 | 0.871 |
| | *Mode choice [use frequency*]* | | | | | | |
| | Walking | 2.3 | 1.2 | 2.0 | 0.7 | -1.44 | 0.160 |
| | Cycling | 2.3 | 1.3 | 2.6 | 1.1 | 2.05 | 0.048 |
| | Car as a driver | 3.2 | 1.1 | 3.1 | 1.0 | -0.75 | 0.458 |
| | Car as a passenger | 3.6 | 0.8 | 2.9 | 0.8 | -4.51 | <.0001 |
| | Local public transit | 3.1 | 1.2 | 3.1 | 0.9 | -0.17 | 0.865 |

Table A 2. Participants of the in-depth interviews

| | | | Employees | | | | | | Students | |
|---|---|---|---|---|---|---|---|---|---|---|
| ID | Gender | Age | household size | No. of cars (household) | Profession | ID | Gender | Age | household size | No. of cars (household) |
| 1 | female | 60 | small | 1 | Shipping agent | 20 | female | 22 | small | 1 |
| 2 | female | 30 | small | 1 | Telephone operator | 21 | female | 24 | small | 0 |
| 3 | female | 26 | small | 1 | Physician assistant | 22 | male | 23 | small | 2 |
| 4 | male | 27 | large | 0 | Researcher | 23 | male | 22 | middle | 0 |
| 5 | female | 31 | small | 1 | Transportation planner | 24 | female | 24 | middle | 0 |
| 6 | female | 54 | small | 2 | Real estate agent | 25 | male | 21 | middle | 1 |
| 7 | male | 26 | small | 1 | HR-consultant | 26 | male | 27 | large | 0 |
| 8 | female | 25 | small | 1 | Researcher | 27 | female | 24 | middle | 2 |
| 9 | male | 32 | small | 1 | IT-consultant | 28 | female | 30 | small | 1 |
| 10 | female | 31 | small | 1 | Hydrogeologist | 29 | female | 27 | small | 1 |
| 11 | female | 57 | large | 1 | Cleaner | 30 | female | 22 | large | 0 |
| 12 | male | 59 | middle | 1 | Researcher | 31 | female | 24 | small | 0 |
| 13 | male | 57 | large | 1 | Insurance agent | 32 | male | 29 | middle | 0 |
| 14 | female | 28 | small | 1 | Assistant | 33 | male | 23 | small | 0 |
| 15 | male | 34 | small | 0 | Researcher | 34 | female | 23 | small | 1 |
| 16 | female | 32 | small | 0 | Civil engineer | 35 | female | 27 | large | 3 |
| 17 | female | 28 | small | 2 | HR-manager | 36 | male | 26 | small | 0 |
| 18 | male | 65 | small | 1 | Civil engineer | 37 | female | 27 | large | 0 |
| 19 | male | 29 | small | 1 | Researcher | 38 | male | 21 | small | 0 |

Small (1-2 person); middle (3 person) and large (> 3 person)

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