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Assessing car dependence: Development of a comprehensive survey approach based on the concept of a travel skeleton

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Abstract

We define objective (car needs for daily activities) and subjective dimensions (other aspects to a car than mobility) of car dependence. We develop an integrated survey design that allows to collect typical weekly travel behavior and sociodemographic data, as well as psychological constructs. To define differing types of car dependence we used the data from an international survey undertaken in Berlin (Germany), San Francisco (USA) and Shanghai (China). We identified dissonances between individuals based on subjective and objective dimensions. The findings also showed that respondents from San Francisco were more objectively dependent on cars than respondents from Berlin or Shanghai.

Keywords: Car dependence, travel behavior, travel skeleton.

1. Introduction

Market analysis for any form of vehicle or service-related mobility products in urban contexts requires a detailed understanding of the role and relevance of private cars in society. This understanding can be developed through the definition and measurement of "car dependence" rates. Determining the dependence of people on their own cars, and

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the comparison of dependence rates between the inhabitants of different cities is crucial to understanding distinctions between different markets. Based on this understanding, forecasts for services (e.g., car sales), and the likely acceptance and success of new mobility services (e.g., ODM – On-Demand-Mobility services) can be estimated.

Previous research has mainly focused on either objective or subjective dependence, however to more accurately analyze this issue at the level of the individual an integrated understanding is required of both dimensions. This integrated approach can be used to determine the importance of the car at the individual level, and also to identify different types of car dependent persons. To evaluate the two dimensions of dependence on an individual level in different cities, we developed an innovative, standardized survey approach, based on the following questions: what does car dependence on an individual level mean? Are there dissonances between subjective and objective car dependence? Which types of car dependence are prevalent in Berlin, San Francisco, and Shanghai?

This paper aims to build on existing research approaches, and provide a meaningful contribution to the discussion on car dependence in cities. Our research is based on the use of a survey tool combining "objective" questions on travel behavior with "subjective" questions on individual attitudes and norms. The combination of these dimensions provides a framework for determining car dependence at the individual level in selected worldwide cities.

The following sections describe the outcome and conclusions of our analysis, and are structured as follows; after a literature review and outline of survey approach, we describe a methodology to define and estimate the objective and subjective car dependence of car owners. Results of the two-det car dependence indicator related to different cities are presented, as well as grouping respondents to different types of car dependence.

2. Literature

Car dependence can be define in many ways (Lucas and Jones, 2009; Mattioli et al., 2016). Mattioli et al. (2016) suggest three analysis levels for car dependence: macro, micro, and meso. The macro-level refers to the entire society and cities as a whole, micro-level refers to individuals, and meso-level refers to specific car dependent trips or activities (Mattioli et al. 2016). In addition, attempts have been made to operationalize the concept of car dependence by calculating car dependence scores (MacKenzie, 2009; Motte-Baumvol et al., 2010).

As stated by Mattioli et al. (2016), most researchers focus on the micro-level (e.g., Gray et al., 2001; Cullinane and Cullinane, 2003; Verma, 2015) and macro-level of car dependence (e.g., Newman and Kenworthy, 1989; Dupuy, 2006). However, as noted by Handy et al. (2005), a differentiation between driving a car by choice and driving a car by necessity is also needed as approaches and solutions aimed at reducing car use will be different for these groups.

At the micro-level, researchers report a difference between "car reliant" people, activities, locations, and "car convenient" trips (Lucas and Jones, 2009). Farrington et al. (1998) considered two aspects of the car dependence groups at the micro-level, "conscious" (or "convenient") and "structural" (or "reliant") (quoted in Mattioli et al., 2016). This also raises broader questions in relation to the definition and use of the term "dependence" (Lucas and Jones, 2009). Due to the complexity of the underlying issues interdisciplinary based approaches have been taken to gain a better understanding of mobility behavior, for example, by combining psychological questions on norms and attitudes with questions related to realized travel behavior (Anable, 2005; Götz et al., 1998). Hunecke et al. (2010) identified five different groups by cluster analysis based on their mobility behaviors, norms and values, using a questionnaire including questions on attitudes and norms towards public transit, reliance on cars, and resistance towards weather and routine. Zhao (2011) examined car dependence using respondents' own assessments towards cars. Minster et al. (2016) presented an assessment of car dependence based on objective and subjective dimensions. Objective dimensions included frequency and variety of usage, and the number of cars in each household. Subjective dimensions were based on the attitudes and norms of the respondent (Minster et al., 2016).

3. Survey approach

The analysis presented in this paper is based on a unique data collection approach, especially in terms of capturing comprehensive information related to individual attitudes and travel behavior. Our survey approach was divided into three survey components: travel behavior, psychological factors and "tech-savviness". The survey collected information on activities and mode choices using a travel skeleton based on travel behavior. It used a standardized psychological item set to investigate respondents' attitudes towards different transport modes. It also addressed

questions related to technical understanding and comfort in order to give an indication of a respondent's "tech-savviness". In the following sections, we describe these components in detail and show their importance for calculating car dependence on an individual level.

Figure 1 (below) illustrates the three components of the survey approach. These components help to define a comprehensive understanding of individuals concerning mobility, determinants of mobility, and the psychology behind realized behavior. The survey approach is able to support abstract research questions such as defining car dependence as it includes information about travel-related aspects such as daily and occasional travel behavior, as well as attitudes towards different means of transport.

3.1. Data collection

The research presented in this paper is based on data collected through three similar surveys, conducted in Germany (Berlin), China (Shanghai) and the U.S. (San Francisco) between October-2016 and January-2017. The three surveyed cities are well-developed and offer good public transport systems. In addition, each city has specific innovative transport services such as ODM (e.g., Uber, Didi or DriveNow). Berlin and San Francisco are "hybrid cities", which exhibit dense public-transit-oriented urban cores, surrounded by low-density car-oriented suburban areas. Shanghai is considered more of a "non-motorized" city, with a high population density which support the use of non-motorized transport (Institute for Mobility Research (ifmo), 2013). Furthermore, Shanghai has a comparably low car ownership rate resulting from restrictive transports policies.

To generate comparable datasets from each city we used a standardized survey approach based on a computer assisted personal interview (CAPI). The face-to-face interviews had a duration of approximately 40 minutes. To reduce monotony we combined the interview with some periods for self-completion by the respondent. We also included questions concerning psychological factors, including attitudes towards means of transport, and social and individual norms.

The complete sample size was 1,800 individuals with 600 respondents from each city. Respondents were randomly chosen to avoid selection bias. We conducted quota sampling regarding age, gender, household size, and net income to develop a representative survey group for each captured city. The survey was carried out by a professional market research firm (Spiegel Institut), using a slightly different approach in each city based on local cultural norms. In all cities an access-panel with telephone screening was used. On-street recruitment was used in Berlin and San Francisco. The aim of the surveys was to capture behavior and psychological factors for individuals above the age of 17 and, as far as possible, for the whole household.

3.2. Concept of a travel skeleton

Travel behavior is highly variable, impacts many aspects of life, and cannot be measured intra-individually by considering only short periods of time, and as such an integrated survey approach is required.

Existing longitudinal data collection methods, such as the German Mobility Panel (MOP), capture a period of one week. This period, and longer observation periods, allow for the identification of typical travel frequencies and, at least partially, for the identification of levels of variability of certain types of activities in everyday travel (e.g., Huff and Hanson, 1986; Pas and Koppelman, 1987). However, surveys which are based on trip diaries are expensive and increase the respondent burden of the participants. This high respondent burden also limits the inclusion of additional supplementary questions.

To create a cost-effective survey alternative and capture long distance travel, we developed a "travel skeleton", which focuses on the collection of typical elements of travel behavior. The skeleton provides a reasonable compromise

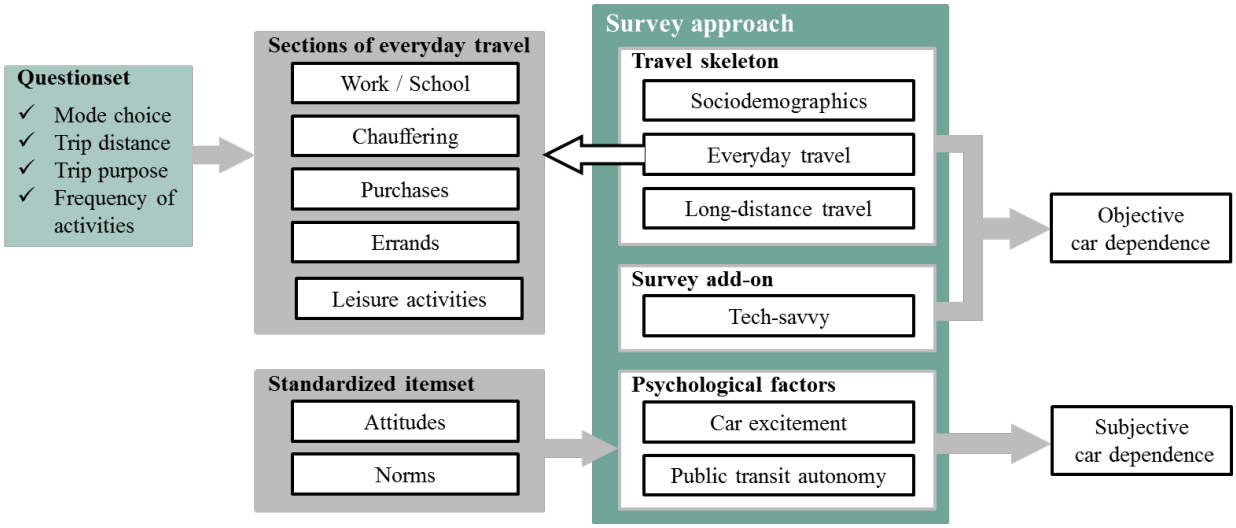

Figure 1. Survey approach of a travel skeleton

between the level of detail needed and the required effort to survey travel behavior. The idea of using a skeleton to identify routines and typical behavior is common in travel behavior research (Dianat et al., 2017; Doherty et al., 2002; Joh et al., 2007; Saneinejad and Roorda, 2009).

"Typical" behavior refers in our research to the frequent, daily repetition of activities across many weeks. Similar to trip diary surveys, in this survey the respondents had to report their behavior in a typical week in order to capture their usual mobility pattern and its determinants (e.g., chauffeuring of children). The "typical" week approach acts to reduce random noise as it excludes incidental trips, which are usually reported in trip diaries in traditional travel surveys. Thus, the skeleton approach reduces the impact of intrapersonal variance, and has the advantage of requiring a smaller sample size to achieve similar research outcomes. For capturing everyday travel using the skeleton we posed questions regarding the frequency (e.g., use of modes), variation (e.g., multimodality) and location of travel activities, segmented by different purposes (also see Figure 1). The purposes are defined as follows: *Work/school* (commuting), *Chauffeuring* (regular driving services and taking children to and from school), *Purchases* (shopping for daily needs and clothing), *Errands* (doctor's appointments and trips to the post office), *Leisure activities* (hobbies, clubs, and sports, volunteering and taking walks with pets). The respondents were asked to select the travel purposes and types of activities that influence and structure their routine in the course of a regular week. This comprehensive description of activities and associated mobility data can be analyzed to determine the everyday travel behavior and travel needs of the respondents. We also asked questions aimed at capturing less frequent travel activities on a more abstract level, e.g., weekend day trips, holiday trips.

3.3. Psychological factors

Significant elements of travel mobility cannot be explained using only the "objective" dimension. Our assumption, based on existing research, is that travel behavior can be better understood when we know more about people's attitudes towards different transport modes, and their motivations around car usage. To estimate the respondent's dependence on their own car we also need a better understanding of relevant psychological factors. In order to address these additional considerations a tested and internationally accepted set of 27 questions about attitudes, social and personal norms was added to the questionnaire (Hunecke et al., 2010; Hunecke et al., 2007). The questions were based on the Likert scale, which provides the opportunity to use the results as quasi-metric values and conduct ordinary mathematical operations. Only a portion of these items is needed to calculate car dependence (see Table 1).

Table 1. Psychological items for subjective car dependence

Used psychological items		
Variable	*Items*	*Questions*
Public transit autonomy (PTA)	PTA1	I can structure my everyday life very well without a car.
	PTA2	I can take care of what I want to with public transit.
	PTA3	It is difficult for me to travel the ways I need to go in everyday life with public transit instead of by car.
	PTA4	If I want, it is easy for me to use public transit instead of a car to do my things in everyday life.
Car excitement (CE)	CE1	Driving a car means fun and passion for me.
	CE2	Driving a car means freedom to me.
	CE3	When I sit in the car I feel safe and protected.
	CE4	Being able to use my driving skill when driving a car is fun for me.

Likert scale: 1 = does not apply; 2 = rather does not apply; 3 = applies in part / does not apply in part; 4 = rather applies; 5 = applies

3.4. Survey add-on tech-savviness

The lean survey design and relatively low respondent burden allowed for the inclusion of additional questions regarding the respondent's "tech-savviness". These questions were included to provide an assessment of an individual's affinity towards new technologies and services, including acceptance of app usage for mobility and usage of ODM services. In this way we captured information related to user frequency, currently used providers and services, and trip purposes, for which ODM services are used. This information helped to identify individuals who more frequently use ODM services and therefore may be less dependent on their own car (e.g., respondents who use UBER for commuting).

The three parts of the survey - objective, psychological and tech-savviness - create a comprehensive picture of the respondent's mobility, which can be used to investigate complex questions related to car dependence.

4. Calculating the level of car dependence

To calculate car dependence on a personal level requires an understanding of subjective and objective dimensions of an individual's mobility based on their travel behavior and attitudes. The subjective dimension describes a combination of the "affinity" (whether the respondent finds driving fun, and the respondent's subjective assessment of public transport), and "perceived need" of car use (whether the respondent believes they need a car for everyday travels). The objective dimension describes realized behavior and determinates of behavior, and is used to evaluate if everyday life without a car is difficult or easily feasible for the individual (see Table 1).

4.1. Subjective car dependence

Investigating "objective" realized behavior alone is not sufficient to determine measures of car dependence. If a respondent does not report any car trips in the survey this does not necessarily mean that this person is not car dependent. It is possible that this person is influenced to use other modes of transport due to a lack of transport availability, or a poor traffic situation. Thus, to determine a car dependence measure, a subjective dimension is also required.

A preliminary assessment, including factor analyses, was used to identify factors influencing car dependence on a subjective level. We completed factor analysis with all 27 psychological items. Factor analysis results were similar to von Behren et al. (2018) and showed a three-factor solution with a car-oriented factor. This factor was dominated by car excitement and autonomy without car (inversion of Public Transit Autonomy, see Table 1). To confirm our preliminary assessment we used results of an ordered logit regression (Wooldridge, 2010). On this basis we identified significant psychological factors influencing car use in the three surveyed cities. Regression analysis was used to identify how the 27 psychological items (independent variables) influence the probability of the frequency of car use

(dependent variable). The results of regression analysis confirmed our preliminary assessment. The developed model showed a high significance for Car Excitement (CE) and Public Transit Autonomy (PTA) at a 1% level (McFadden's R-squared 0.334). The subjective car dependence indicator contains a combination of CE and PTA. Table 1 illustrates both variables and the questions used in the interviews. Each variable results from the average value of the used questions. PTA3 has a contrasting meaning compared to the other questions in the group, and we corrected the results for a commutated meaning. The subjective car dependence indicator explains car affinity (e.g., driving a car means fun) and the perceived need of car use (e.g., daily life is manageable without a car). Persons with a high affinity and a low perceived need differ from persons with a high affinity and a high perceived need.

Table 2. Objective car dependence score parameters.

Objective car dependence	**Weighting**
Time loss / time savings by using alternatives	very high
Score considers loss or savings in time by using an alternative mode instead of a private car. Zumkeller et al. (2005) used this method to calculate a virtual mode shifting away from car use. This idea was transferred by using the information about alternative modes for commuting. A high time loss caused by shifting away from car use is assessed with a high score. If an individual does not use a car for commuting or does not work, the score is low.	
Distance and Duration of commuting	very high
Short distances and durations for commuting result in a lower dependence because other modes like bicycle or public transit are easily usable.	
Car ownership in the household (# cars/ # adults; car age, annual mileage)	low
A higher number of cars per adult, a higher age of the car (except vintage cars), and low annual mileage result in a lower dependence from the own car.	
Parking situation	middle
If the parking situation is bad the person may use their car less frequently. Parking could mean a pain point for car use. As a result the person may indirectly move away from their car and become more independent. Persons with a private parking space are not affected by bad parking situations in the neighborhood.	
Chauffeuring and age of children	high
This considers the need for dropping off and picking up persons. Frequent transport of children and other persons means a higher dependence. We also considered the number and age of children in the household.	
Car use for regular leisure activities and errands	middle
A high driving performance for leisure activities and errands in a typical week with the car implies a higher dependence.	
Occasional leisure activities	high
Score includes occasional activities such as daytrips at the weekend and journeys with overnight stays. These aspects represent mostly long-distance travel behavior. Frequent, occasional activities with longer distances can determine car ownership, because these destinations are often only accessible by car (e.g., travelling into the mountains for skiing).	
Multimodality (mode choice stability)	high
To evaluate the willingness of using other modes the realized multimodality was included. The Herfindahl-Hirschman-Index (HHI) as used by Mallig and Vortisch (2017) was applied to calculate a mode choice stability of car users. A low mode choice stability of car users implies a higher multimodality. Multimodal persons are not strongly dependent on car use. These persons are more flexible as they change their mode intuitively, reducing the potential of car dependence.	
ODM service usage	middle
If persons frequently use ODM services (e.g., car sharing or ride sharing), they have a low dependence concerning their own car. These services are often a substitute for car use for specific trips.	

4.2. Objective car dependence

Based on the comprehensive data from the "travel skeleton" we developed a measure for objective car dependence. This used a scoring system based on the idea of a value benefit analysis. It contains various criteria and aspects of travel behavior. For scoring we considered determinants of mobility (e.g., need for the transport of children, travel time and distance to workplace), mode alternatives and potential time losses (e.g., accessibility of the work location by public transport), mobility options (e.g., number of cars per person), as well as realized travel behavior (see Table 2 for criteria).

Within the scoring different criteria are weighted based on their potential impact to objective car dependence. This weighting is based on a literature review and expert interviews, combined with the researchers' subjective perspective

and interpretation. Mandatory activities such as commuting or chauffeuring have a higher weighting than leisure activities for example. Table 2 shows the individual weightings of the criteria.

Respondent answers were used to calculate an individual's score out of a maximum possible total. After normalization respondents received a score between 0 and 1. This score can be used to compare individuals, and on an aggregated level, comparison of cities is also possible.

5. Results

5.1. Car dependence of car owners

In order to identify different types of persons and their car dependence, we combined both objective and subjective dimensions. Figure 2 illustrates the combination of objective and subjective car dependence of the three captured cities. For our calculations we used respondents from the survey who have a car in their household and possess a driving license (Berlin: n=329; San Francisco: n=455; Shanghai: n=244). The number of used observations reflects the car-ownership ratio in the three cities. Results show an interpersonal variance in each city. In both dimensions 0.0 is the lowest possible score and 1.0 is the highest possible score. We received scores in the subjective dimension between 0.0 and 1.0 and in the objective dimension scores from nearly 0.22 to above 0.86. Respondents with a high score are more dependent on the car than respondents with a low score. If respondents have a high score in both dimensions, they are subjectively and objectively dependent.

Aggregated results can be used to compare cities concerning their car dependence. Car owners in San Francisco are more objectively car dependent than in the other cities (average=0.43). Berlin and Shanghai are more similar concerning objective car dependence (0.39 and 0.40). In contrast, San Francisco and Shanghai are equal with regard to the subjective score (San Francisco=0.56 and Shanghai=0.56). Respondents in these two cities assess the car as more important than in Berlin (average=0.53). In particular, Berlin and Shanghai show a wide distribution in both dimensions. There are less respondents in Shanghai who objectively, but not subjectively, need their car for everyday travel. Both dimensions are more correlated in Shanghai than in Berlin or San Francisco.

5.2. Types of car dependent persons

To identify different types of car dependent persons we defined five different groups of individuals related to subjective and objective car dependence in urban areas. Using the calculated average in both dimensions we created four sections split by the horizontal and vertical average line (see Figure 2). Based on the respondent's strong dissonance or correlation between subjective and objective dependence, they were assigned to the different groups.

Respondents with an objective car dependence above the average were split in two groups: *Car captives* with a low subjective dependence and *Convinced car-users* with a high subjective dependence. Furthermore, we grouped respondents with a low objective car dependence in three different groups: *Car independent pragmatics* with low subjective dependence, *Car affine pragmatics* with high subjective dependence, and *Inhibited car enthusiasts* with a low value in the perceived need of car use but a high value in car excitement. Figure 2 illustrates the distribution of the different groups and highlights the spatial and transport-related characteristics of each city. In the following sections we describe these different groups in detail and compare the characteristics of these groups between the different surveyed cities.

Car affine pragmatics are persons who like to drive a car, but also use alternative modes of transportation. They have a low objective score. These persons behave multi-modally and could manage their daily life without their own car. However, these persons also consider having access to a car as important and desirable.

Car captives require their car for their travel behavior, but do not enjoy driving. These individuals need a car for everyday or long-distance travel and use a car due to the lack of alternatives.

A *Car independent pragmatic* is a person who does not need a car and does not enjoy driving. Subjective and objective car dependence is very low. These persons are largely able to handle their daily life without a car, and choose the best transport mode depending on the actual travel purpose. Individuals within this group are on the edge of no car possession. In urban areas many persons are not dependent on their own car due to the existence of alternative transport modes which are not available in suburban or rural areas.

Convinced car-users are highly dependent in both dimensions, they must use their car and also enjoy driving. Persons within this group often do not reflect on their own behavior as they consider a car as the only option for traveling without restriction from external factors.

Inhibited car enthusiasts are observable in urban environments only. They can be described as persons who enjoy driving a car but have no opportunity in their everyday travel to use it. Often these persons have poor parking facilities at their residential or work location. In addition, poor traffic conditions in the city further reduce car use.

To determine differences between the surveyed cities we also compared types of car dependent persons. Shanghai and Berlin show more similarities in comparison to San Francisco. Results show less *Car captives* in Shanghai, due to an effective and widely-used public transit system, persons who must use their car but do not like to drive are rare. In contrast, *Car captives* are mostly observable in San Francisco. Many jobs are located outside the city in the Bay Area (e.g., Mountain View) and these workplaces often require a car for commuting. *Car captives* have a strong dissonance between both dimensions of dependence. There is a difference between low subjective and higher objective dependence. A large share of *Convinced car users* is visible in San Francisco.

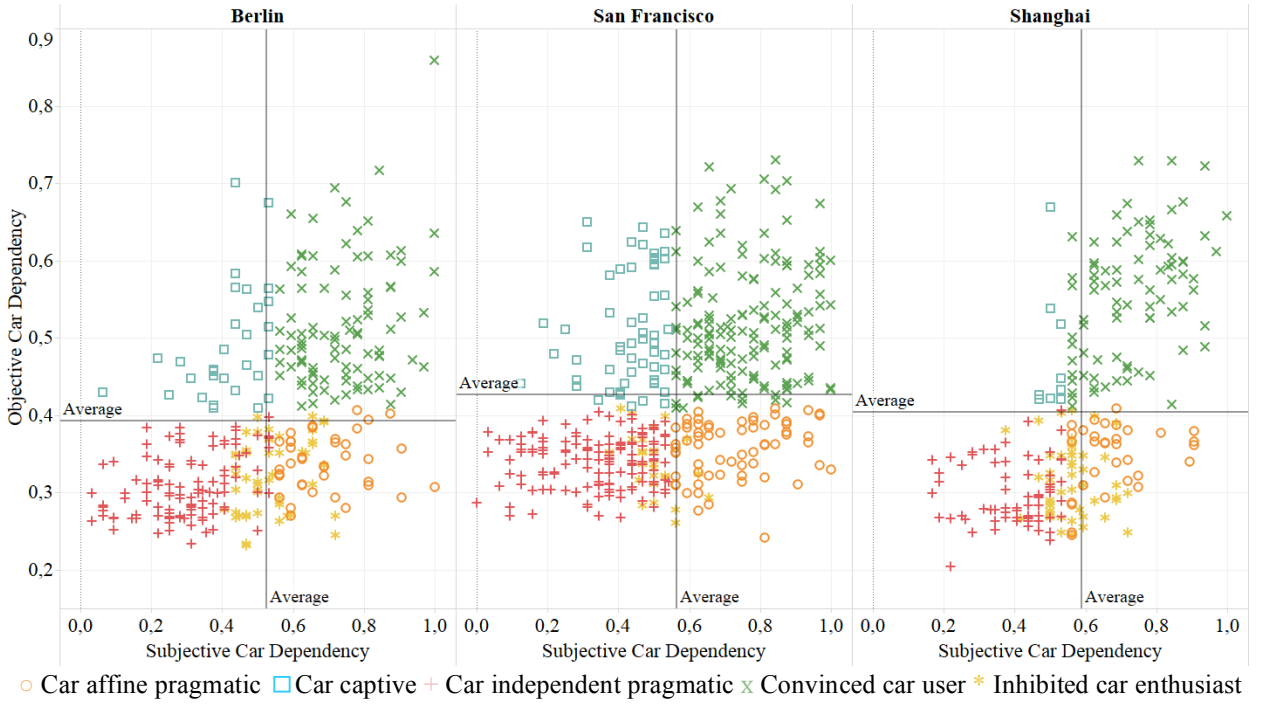

Figure 2. City comparison concerning different types of car dependent persons.

This group must use their car for everyday travel and this correlates with their attitudes towards car driving. A large group of *Car independent pragmatics* is observable in each city. This group of persons has a potential to give up their own car and use other modes for their everyday travel.

4. Conclusion and further research

Determining mobility markets in urban areas requires a detailed understanding of car dependence related to personal car ownership. Through the evaluation of results from the surveyed cities, it is possible to identify likely potential future development paths related to motorization levels and innovative mobility services. Based on our approach we were able to calculate both subjective and objective measures of car dependence. We combined a travel skeleton survey design, which captured “typical” travel behavior, defined as the objective dimension, with a standardized and well-tested psychological item set, defined as the subjective dimension. One of the key strengths of this approach was the efficient documenting of comprehensive travel behavior by asking only questions related to the

typical behavior of everyday travel in combination with occasional trips (e.g., day trips and journeys), instead of the one-day or one-week trip diary approach. This helped to reduce the random noise and cost of the survey. Using the standardized survey approach in San Francisco, Berlin and Shanghai we were able to compare data from these cities and observe city-specific differences. People living in San Francisco are objectively more car dependent than in Berlin and Shanghai. Berlin is the city with the lowest subjective car dependency. The ability to make these observations demonstrates the feasibility and robustness of the empirical approach used in our study.

We highlighted a large variation in surveyed populations regarding both subjective and objective car dependence. We could identify, for relevant groups within the population, individuals with intra-individual dissonances between both dimensions, which presents opportunities for urban transport policies, transport solutions, and the development of targeted services. Concerning the types of car dependent people, results of clustering showed more objective car dependent car owners in San Francisco than in the other surveyed cities. In contrast, San Francisco and Shanghai are equal with regard to the subjective score, only Berlin has a lower subjective car dependence.

We grouped five distinct types of car dependent persons: *Car affine pragmatic*, *Car captive*, *Car independent pragmatic*, *Convinced car-user* and *Inhibited car enthusiast.* These groups differ in a number of key areas, including their use of cars and their use of other means of transport (multimodal behavior). Overall, our results show a higher similarity between Shanghai and Berlin. *Car captives* are mostly observed in San Francisco. In contrast, results from Shanghai show few *Car captives*. In each city a large share of *Car independent pragmatics* was identified. People in this group have the potential to give up their own cars and may thus be potential users of other means of transport such as ODM services (e.g., car sharing or ride sharing). We also discovered a large number of *Convinced car-users*.

The travel skeleton survey approach was successfully tested in the three pilot cities. It was used to identify people who are subjectively relatively independent of their cars and as a result would be good potential targets for offers such car sharing services as alternatives to personal car ownership. It also identified *Inhibited car enthusiasts,* who like driving. This group may useful, for example, for estimating requirements for the provision of a shared fleet of vehicles with a range of different characteristics. This type of structured and more granular understanding can be used to develop and realize new potential markets.

Further development of the travel skeleton method is required to gain a deeper understanding of car dependence and impacting factors. For example, with knowledge of the geo-coordinates of the places where the respondents live, work and attend school, we would be able to also assign the characteristics of alternative modes based on route calculations (e.g., using Google maps). This means that a subjectively biased answer could be avoided, for example, individuals who do not know public transport at all are not able to assess its quality. In addition, an important aspect of car ownership is the emotional, instrumental and/or symbolic motivation for usage. Based on an expanded set of questions the subjective indicator could measure ownership related to symbolic reasons.

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