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PEAK-CAR PHENOMENON REVISITED FOR URBAN AREAS: MICRODATA ANALYSIS OF HOUSEHOLD TRAVEL SURVEYS FROM FIVE EUROPEAN CAPITAL CITIES

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ABSTRACT

This study investigates the peak-car phenomenon for the five European capital regions of Berlin, Copenhagen, London, Paris, and Vienna. Household Travel Survey (HTS) microdata was harmonized for the five regions and transferred to one consistent database; all time-series date back at least 20 years. Developments in car use were found to be surprisingly similar despite the substantial differences between the regions in terms of size, governance structures, built environments, transport systems, and societal framework conditions. Car use peaked earliest in Paris in the early 1990s; followed by Berlin, London and Vienna in the late 1990s; and lastly in Copenhagen in the late 2000s. Working persons and mandatory trips were found to be the most relevant person group and trip purpose for the observed peak-car developments, both with declining overall trip numbers and a modal shift towards the non-car modes. Young working persons had the most significant decline with substantial cohort effects. People seem to carry forward their behavior adapted in early life cycle stages as they age. The person groups of seniors and women both damped the peak-car effect. Shopping trips were the second most relevant trip purpose for car use: Car use for this purpose was high and stable over time. This study has elaborated potentials for reducing car use in terms of person groups and trip purposes. Findings from this retrospective analysis can be used for purposefully shaping future transport systems.

Keywords: Peak Car, Travel Behavior, Car Use, Household Travel Surveys, Time Series, Travel Demand, Young Adults, Generations, Cohort Analysis, Car Access, Modal Split, Urban Transport

INTRODUCTION

The peak-car debate emerged from a long history of research on car use and car ownership and their determinants. In the 1950s, studies were already predicting there would be a saturation level of car ownership in time (*1*). Research on car use dates back to the 1970s when Household Travel Surveys (HTS) were set up in many countries both at the national and municipal levels. By the late 2000s, in correlation with the economic recession at the time, slower rates of growth and the levelling off or decline of car use were being observed in many countries. These attracted growing research interest even though car use had peaked already in the 1990s in some countries or cities. The phrase "peak car" was increasingly being used and is now an established (though not always clearly defined) term for describing an occurrence when car use first increases, peaks, then decreases afterwards. Such developments are promising for transport planners and policy makers as reduced car volumes are related to various benefits such as decreased pressure on the transport networks and improved environmental quality. A better understanding of the peak-car phenomenon is therefore not only relevant for research but also for policy making.

There is consensus in the literature that the peak-car phenomenon results from a complex set of determinants in the three fields of (a) macro trends, (b) policy making and governance, as well as (c) changes in behavior and mind-sets. Macro trends include economic factors such as the GDP or fuel prices (see (*2*)), changes in population size and structure (*3*), modifications in company car taxation leading to reductions in the amount of subsidized car travel (*4*), high rates of net immigration in the first decade of the 21st century coupled with a lower propensity to drive within immigrant communities (*5*), the emergence of new technologies supporting e-commerce, home-working, and online shopping (*6*) and also (re-)urbanization trends (see (*7*) and related discussions). Policy making and governance cover all efforts for achieving reductions in car use. Buehler et al. (*8*) demonstrate the effectiveness of mutually reinforcing transport and land-use policies that make the car less attractive while at the same time increasing the attractiveness of the alternative transport modes. Based on the theoretical concept of the transport policy evolution cycle (*9*), Halpern (*10*) describes how urban-transport policymaking and governance structures have evolved over time from a car-oriented approach to multi-faceted objectives and strategies supporting reductions in car use.

This paper focuses on the behavioral aspects of travelers. The goal of this paper is to decompose the components of the overall peak-car effect, based on a unique HTS dataset. For the first time (to our best knowledge), HTS microdata from different areas have been harmonized resulting in a consistent HTS database that covers at least a 20-year span for the five European capital regions of Berlin, Copenhagen, London, Paris Ile de France and Vienna. Based on this unique dataset, we trace the development of car use over time; identify the time period when car use peaked in each of the five regions; and decompose the components of the overall development. The availability of consistent HTS microdata allows for analyses which expand beyond the aggregated analyses reported thus far in the literature. We thoroughly investigate the developments of travel indicators for specific person groups, including: trip rates and distances, travel times, transport mode, and trip purpose. Age-Period-Cohort (APC) analyses are performed for Paris Ile de France because the longest HTS data series is available there, dating back to the 1970s. The aim of these detailed analyses is to provide a better understanding of the peak-car developments in the five study areas as well as to establish transferable recommendations that support transport policy makers in their efforts to strengthen sustainability and to reduce car use in urban transport systems.

LITERATURE REVIEW

Vehicle Kilometers Travelled (VKT) are most commonly used when discussing the peak-car phenomenon (see, e.g., (*11*)). For urban areas, car trip rates have higher relevance. They are a key performance indicator and target figure for urban transport policy making; reducing the modal share of the automobile is one main criterion for success in many cities all over the world. (Car) trip rates are less frequently used in the literature concerning peak car because these are more difficult to quantify (*12*). They are often not included in official statistics and, in addition, are more sensitive to changes in HTS survey methods. Instead, modal-split values are often referred to for demonstrating the peak-car effect (see, e.g., (*8*)), but these should be interpreted with caution. Changes in modal split values only assess relative shifts between transport modes. Stapleton et al. (*13; 14*) recommend using vehicle kilometers instead of passenger kilometers when discussing the product of vehicle kilometers and average load factors. The choice of passenger rather than vehicle kilometers made little difference in their analysis, and load factors changed only slightly; peak-car developments happened mainly on the vehicle level (see also (*15*)). Stapelton et al. (*13*) emphasize the relevance of normalization. They show for Great Britain (1970–2011) that peak-car development is more distinct when measured in VKT per capita or per adult compared to VKT per driver.

Few studies actually identify the turning point of car use because continuous HTS data is rarely available, and changes in survey methods over time superimpose the actual developments in travel behavior (*11*). Buehler et al. (*8*) analyze the trip-based modal split over time based on a cross-sectional HTS. Car use peaked around the late 1990s in Berlin and in the early 2000s in Munich and Zurich. The turning point could not be identified for Hamburg and Vienna because the peak occurred before the analysis period (Hamburg 1991, Vienna 1993). Cornut & Madre (*16*) find the maximum mileage-based car use for the Paris region in the 1990s with differences between the zones of residence. Peak car happened earlier within the city of Paris compared to the outer region. Headicar (*5*) identifies the mileage-based peak car around 1990 for London and in the early 2000s for the other parts of the UK (see also (*15*)). Focas & Cristidis (*17*), based on Eurostat data, show the development of car-passenger kilometers from 1995 to 2011 for various European countries and identify four clusters: "Countries Facing the Economic Crisis" (peak car in late 2000s related to the economic recession), "Western Peak" (peak car around 2000), "Western Stable" (no distinct peak car but plateaued until 2011), and "East Growth" (increasing car use until 2011). There are some indications for weakened dynamics of reduction in car use or even increases, e.g., in London (*18*).

Few studies actually decompose the overall changes in car trip rates into their detailed components because of the lack of consistent HTS microdata over time and areas. Kuhnimhof et al. (*11*) find changes in total travel demand being the main driver for the reversal in the trend in car travel per capita in France and the U.S., whereas in Germany and Great Britain, the levelling off of motorization and shifts to other modes, were more important. Van der Waard et al. (*15*) and Mc Donald (*19*) include trip purposes into their analyses. For The Netherlands (1995–2010), van der Waard et al. (*15*) find an increase in car mileage for work and leisure and somewhat stable car mileage for shopping and education. McDonald (*19*) finds, for the U.S. (1995–2009), decreased car mileage for work, social/recreation, personal business, and almost no changes for shopping and school/church.

The literature consistently shows that young adults have contributed the most to peak-car developments, whereas seniors and especially female seniors have a damping effect (*11*). Lower driver licensure rates and decreased car access belong to the main drivers of this development (*20; 21*). Young person's today have generally fewer trips than previous generations; they cover shorter distances and have decreasing car modal shares. Young men had more substantial reductions in their car use than women (*20; 22; 15*). Garikapati et al. (*20*) find less travel time, more time at home, less working time and more leisure time for Millennials (see also (*15*)).

All these changes in travel behavior and car access are closely related to delayed life cycle stages: Today's young generations spend more time on education, delay their entry into (stable) employment and the establishment of a family (*23*). Thigpen & Handy (*24*) show that the delay in licensing is associated with travel attributes and attitudes, parental influences, and graduated driver's licensing policies. After controlling for these factors, the variables accounting for unexplained cohort effects had a minor and uncertain impact on delayed life-cycle stages. There might be synergistic effects of generational shifts in attitudes with policies designed to encourage non-automotive travel patterns. Additionally, more people live in urban areas (*21*), which correlates with higher education rates in youth. Multi-modal travel behavior learnt in this phase of urban life might also have an impact on later life cycle stages.

DATA AND DATA ANALYSIS METHODS

Study Areas

The five study areas differ substantially in their size and characteristics. The functional area types are defined to account for heterogeneity between the cities and within each study area as well as to improve the comparability of travel behavior and car use.

In the first step—and based on official administrative boundaries—, the following administrative area types are distinguished for the HTS analysis in order to acknowledge these spatial dependencies of travel behavior (see Figure 1):

- **Inner-city area:** City center, Central Business District (CBD)
- **Outer-city area:** City area beyond the inner city but within the municipal borders
- **Peri-urban I area:** Area bordering the city (e.g., closest ring of municipalities) with a high population density, a high density of workplaces, and a high number of commuters to and from the inner city and the outer city
- (Optional) **Peri-urban II area** (and further): Wider commuting catchment area

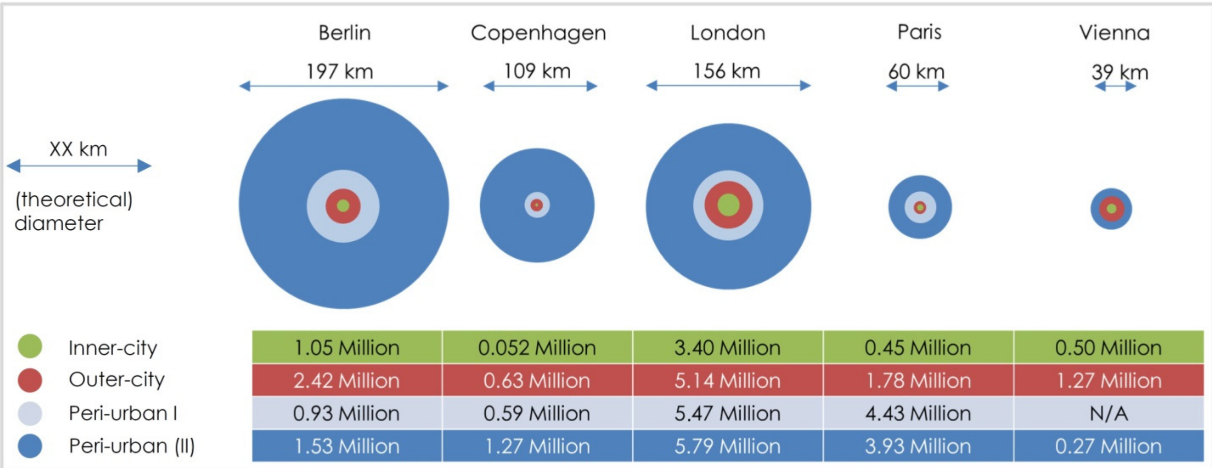

FIGURE 1 Overview of the Study Areas [population per area]

In the first steps of the analysis process, it became immediately clear that the administrative area types are not suitable for analyzing travel behavior and car use. The inner cities in Copenhagen and in Paris only marginally differ from the outer cities. The peri-urban I areas in these two cities are located outside the administrative municipal borders, but their functions and characteristics are similar to the outer cities in Berlin, London, and Vienna. The peri-urban I areas in Berlin, London, and Vienna, however, have similar functions compared to the peri-urban II areas in Copenhagen and Paris: These are clearly located outside the "actual" cities and are less focused on the city center. It was therefore decided not to use the administrative area types for HTS data harmonization and analysis but instead to use the following three functional area types:

- **Inner-urban area** (with the highest densities of residents): the inner city for Berlin, London, Vienna, and inner plus outer city for Copenhagen and Paris
- **Urban area** (with the second highest density of residents): the outer city for Berlin, London, Vienna, and peri urban I for Copenhagen and Paris
- **Agglomeration** (low-density area surrounding the urban area): peri urban for Berlin, London, Vienna, and peri urban II for Copenhagen and Paris

HTS Database and Methods for Data Harmonization

Four different fields of HTS-data harmonization were considered for preparation in this study (see (*25; 37)* for a detailed description of the harmonization method and also of the used HTS datasets):

1. **Survey Coverage:** This field included the harmonization of the covered population, type of trips, seasonal coverage, reporting period (only workdays), and survey periods.
2. **Survey definitions:** Trip purposes and the hierarchy of transport modes were standardized. Lowest common denominators of variable categories were identified and coded.

3. **Survey Methods:** These could not be ex-post harmonized for existing HTS, but method-related influences on survey results were minimized by eliminating inconsistencies, e.g., by excluding non-mobile persons.
4. **Area-Type Definitions:** Common area types were defined based on the above described approach.

Figure 2 summarizes the fields of HTS-data harmonization. All findings presented in the Result Section refer to the mobility on workdays of persons with at least one trip on the reporting day (called mobile persons or tripmakers), between 10 and 84 years of age, living in comparable area types within the metropolitan regions of the five study areas. Table 1 presents the unweighted sample sizes for the most comparable functional area type “Urban” in each study area.

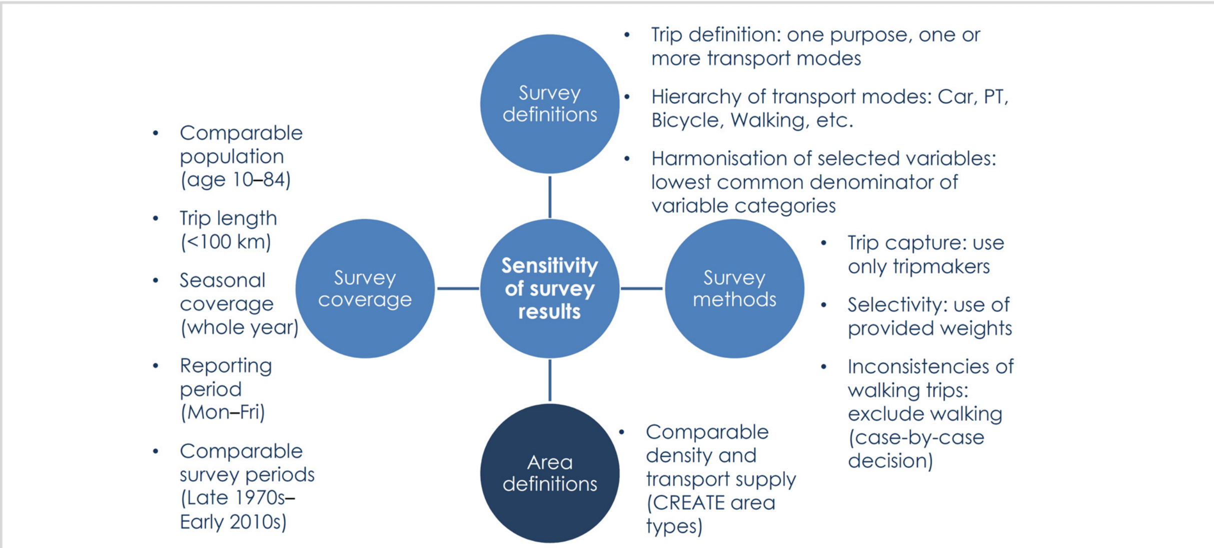

FIGURE 2 Fields of Data Harmonization. Source: own elaboration based on (*26*)

TABLE 1 Unweighted Net Cases (Persons) by Survey Period and Functional Area Type “Urban" (10–84 years, workdays Mon–Fri)

Survey Periods/ (Persons, Unweighted)	Berlin City	Copenhagen + PU I	London City	Paris + PU I	Vienna City
Late 1970s (1975–1979)	0	0	0	9,460	0
Early 1980s (1980–1984)	0	0	0	8,688	0
Late 1980s (1985–1989)	0	0	0	0	0
Early 1990s (1990–1994)	0	0	0	11,692	1,317
Late 1990s (1995–1999)	54,790	3,133	0	0	2,923
Early 2000s (2000–2004)	1,864	5,576	0	10,491	5,467
Late 2000s (2005–2009)	34,949	4,261	47,458	0	5,392
Early 2010s (2010–2014)	13,419	5,991	50,879	13,719	6,530
Late 2010s (2015–2019)	0	815	0	0	0

Age-Period-Cohort Analysis

Age-Period-Cohort analysis (APC) is an established approach for systematically studying age-specific data, collected at different points in time from different sets of individuals. The analytic problem can be described as an investigation of different outcome contributions from three time-related changes (*27–29*):

1. **Age Effect:** Respondents get older from one survey year to the next. Changes in their life-stage such as the natural aging process, having children, beginning or finishing a job, may lead to changes in their individual travel behavior.
2. **Period Effect:** Framework conditions such as the built environment, population income, fuel prices, and transport services, may change from one survey period to the next. These changes impact the travel behavior of all age groups simultaneously.
3. **Cohort Effect:** Respondents of two birth cohorts each have unique experiences in the same age group due to their exposure to different external conditions. The same age group in two surveys at two points in time may therefore behave differently due to their cohort-specific socializations.

APC-analyses give a holistic perspective of causes behind observed changes in behavior (see (*29; 30*)) but do not enable the clear separation of the three effects. Three different perspectives exist for analyzing time-series data based on the APC-approach. They are visualized in the Figure 3 (left side, adapted from (*31*) and briefly described as follows.

- **Longitudinal analysis (B – A):** Two age groups are analyzed in a pseudo-panel approach as if the same person were analyzed at two different points in time. The observed differences in travel behavior can be attributed either to the age effect or the period effect, or to both effects together. No cohort effect can exist since the same cohort is analyzed.
- **Cross-sectional analysis (C – A):** Two age groups are analyzed in one point in time, i.e., in the same survey year. Behavioral differences might result from differences between the generational cohorts to which the two age groups belong, or from the different ages of the two groups. No period effect can exist since the analysis covers only one survey year.
- **Time-Lag analysis (B – C):** Individuals of the same age group are compared in two subsequent survey periods. Time-lag differences might result from the period effect or the cohort effect, or to both together. No age effect can exist as the same age group is analyzed.

For the APC-analysis in this study, we use the six generational groups—called birth-cohorts, as defined in the European Union's Horizon 2020 funded MIND-sets research project (see right side of Figure 3 from (*32*)). Generations are classified into 15-year groups based on generation theory.

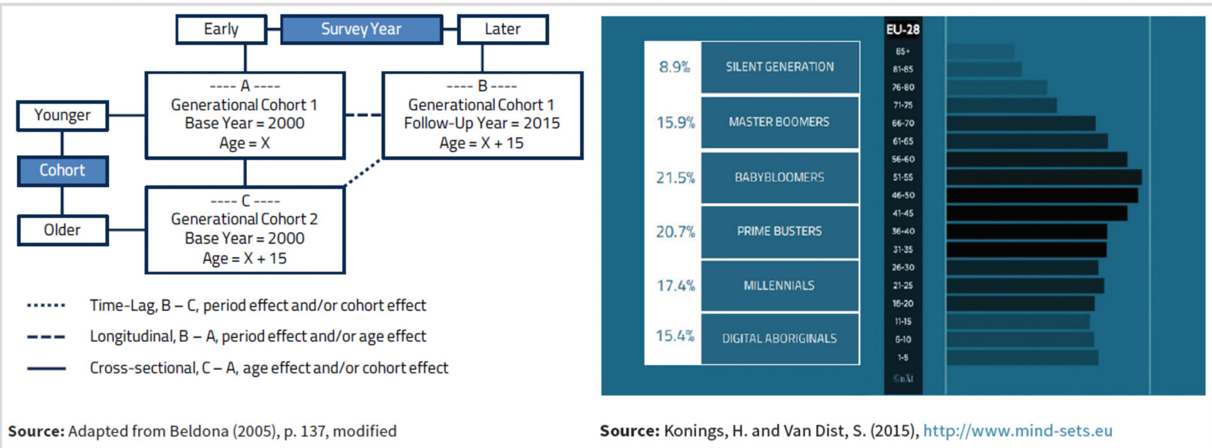

FIGURE 3 Perspectives for Analyzing Time-Series Data (Left) and Birth Cohorts Used (Right)

CROSS-CITY ANALYSIS OF THE PEAK-CAR PHENOMENON

Key Travel Estimates and Car Use Over Time

Figure 4 (left side) shows the total number of car trips per tripmaker (driver or passenger) for the area type "urban". Seeing the substantial differences in the cities' size and characteristics, the trip rates and also their development over time are surprisingly similar. Trip rates even seem to converge in the latest survey periods. The average reduction in trip rates is, at 25 percent, substantial: One out of four car trips "disappeared" in the analysis period. Figure 4 (right side) visualizes the assumed peak period in car use for the five cities. Peak car happened first in Paris in the early 1990s, followed by Vienna in the late 1990s and Copenhagen in the early 2000s. The peak-car effect in Berlin and London cannot be assigned to a specific time period based on the HTS data as this data is only available from the late 1990s (Berlin) and early 1990s/late 2000s (London) onwards. At that time, the peak-car effect had already happened in Berlin. Seeing the specific history of Berlin with the re-unification of the formerly divided city in October 1990, it is highly likely that car use peaked in Berlin in the late 1990s because of the substantial increase in car use in the Eastern parts of the city in the early 1990s like in all other Eastern German cities (see (*33*)). No HTS-data point exists for the late 1990s for London, but data from transport models show peaked car use in this time (*34*). Therefore, it is highly likely that peak car happened in London in the late 1990s.

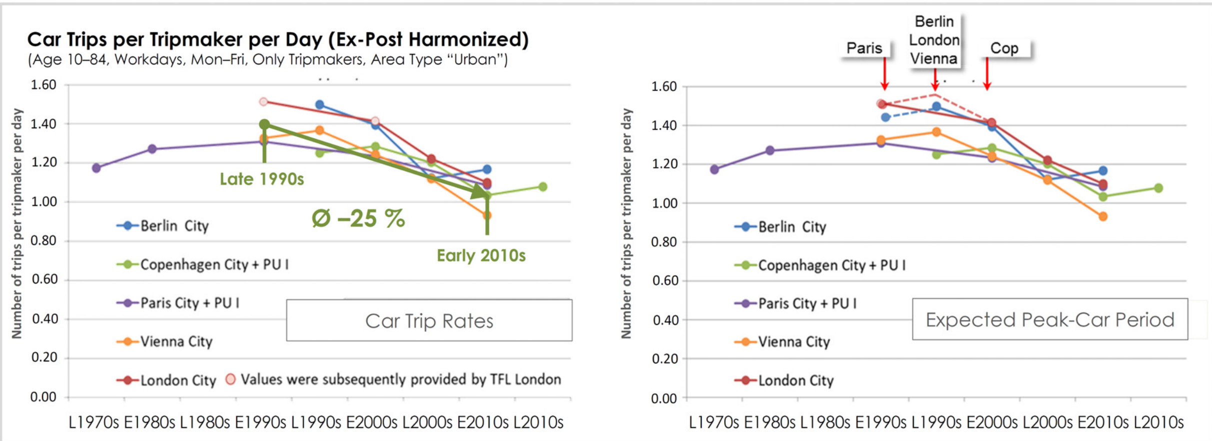

FIGURE 4 Car Trips per Tripmaker in Area Type Urban (Left) and Estimated Peak Car Period (Right)

Table 2 shows key travel estimates over all transport modes and time periods. The number of car-driver trips per trip maker and day (car-driver trip rate) differs from the earlier survey period by 0.3 trips per tripmaker per day with 1.2 car driver trips per day in Berlin as the maximum and 0.9 in London as the minimum. Car-driver trip rates are almost equal for all cities, with a difference of only 0.1 trips per tripmaker per day between the cities in the early 2010s. The car-passenger trip rates are low and stable over time; the use of alternative modes increased especially for cycling. Inconsistencies were found for walking trips.

Overall, the mode-specific trip rates confirm the typical characteristics of the cities (*8; 35; 36*). Copenhagen with the highest number of cycling trips and Vienna with, specifically, many public transport trips stand out. Berlin and London have a more balanced distribution of trips between the transport modes, and Paris has a high number of walking trips. It is interesting that the differences in the overall trip numbers are mainly caused by public transport, bicycle, and walking but far less by car trips. The biggest differences in trip numbers exist for cycling. This means that differences in cycling trips between the cities explain most of the deviation of overall trip numbers.

TABLE 2 Key Travel Behavior Indicators in the Urban Areas of Five European Capital Cities

Ex-Post Harmonized (Age 10–84, Workdays Mon–Fri, Tripmaker Only, Comparable Area Types)	**Berlin City**			**Copenhagen City + PU I**			**London City**			**Paris City + PU I**			**Vienna City**		
	L90s ('95–'99)		E10s ('10–'14)	L90s ('95–'99)		E10s ('10–'14)	L00s ('05–'09)		E10s ('10–'14)	E90s ('90–'94)		E10s ('10–'14)	E90s ('90–'94)		E10s ('10–'14)
Car-Driver (CD) Trips	1.2	↘	0.9	1.0	↘	0.8	0.9	↘	0.8	1.0	↘	0.8	1.1	↘	0.8
Car-Passenger Trips	0.3	↘	0.2	0.2	→	0.2	0.3	→	0.3	0.3	↘	0.2	0.2	→	0.2
Public-Transport (PT) Trips	1.1	→	1.1	0.7	↘	0.6	0.9	↗	1.0	1.0	↗	1.1	1.2	↗	1.4
Bicycle Trips	0.4	↗	0.5	0.8	↗	1.1	0.06	↗	0.09	0.02	↗	0.08	0.1	↗	0.2
Walking Trips	0.8	↗	1.2	0.7	→	0.7	1.0	→	1.0	1.5	↗	1.9	1.1	↘	0.9
Daily Trip Chains With CD as First Transport Mode	0.6	↘	0.4	0.2[1]	→	0.2	N/A		N/A	N/A		N/A	0.4	↘	0.3
Daily Car-Driver Travel Time	34	↘	24	17	↘	14	23	↘	20	24	↘	22	26	↘	17
Daily Car-Passenger Travel Time	7	↘	4	4	↘	3	7	↘	6	5	→	5	5	↘	4
Daily PT Travel Time	23	↗	40	20	↗	23	45	→	46	41	↗	50	43	↗	50
Daily Bicycle Travel Time	6	↗	10	11	↗	17	1	↗	2	0.5	↗	2	0.4	↗	4
Daily Walking Travel Time	9	↗	16	6	↗	8	14	↗	17	20	↗	24	17	↘	14
Daily Car-Driver Travel Distance	18	↘	9	13	↘	9	6	↘	5	6	↘	5	11	↘	9[2]
Daily Car-Passenger Travel Distance	3	↘	2	3	↘	2	2	→	2	1	→	1	2	→	2[2]
Daily PT Travel Distance	6	↗	11	10	↘	8	7	↗	8	6	↗	7	9	↗	10[2]
Daily Bicycle Travel Distance	1.0	↗	1.9	2.9	↗	4.4	0.2	↗	0.3	0.04	↗	0.18	0.1	↗	0.5
Daily Walking Travel Distance	0.6	↗	1.0	0.7	↗	0.8	0.6	↗	0.9	0.8	↗	0.8	0.9	↘	0.8

[1] Value from Late 2000s ('05–'09), information not surveyed in earlier survey periods

[2] Value from Early 2000s ('00–'04) due to inconsistency of the most recent survey period

Car Use by Purpose

Figure 5 presents car-driver trip rates distinguished by individual trip purpose, assigned according to the type of activity carried out at the trip destination. Three trip purposes could be harmonized for all HTSs:

1. **Mandatory Activities:** all trips related to compulsory activities, such as education, work and work-related activities, daycare, etc.
2. **Shopping/Errands:** all trips related to commercial or recurring activities, such as grocery shopping, visit to the doctor, etc. This category also includes the dropping off and picking up of people.
3. **Leisure:** all trips related to non-compulsory activities, such as exercise, go out for dinner, meeting friends, etc.

In addition, there exists a category for "Other Purposes" which contains all trips that could not be assigned to any of the three above listed categories. "Other" varies between zero (Copenhagen and Paris) and a maximum of five percent of all trips (Berlin, early 2000s). This category was not considered for the analyses of trip rates by purpose. Back-home trips were assigned to the purpose of the previous activity.

The left side of Figure 5 shows the magnitudes and the developments of car-driver trips by purpose. Mandatory trips and trips for shopping/errands are, with 0.3–0.4 car-driver trips per tripmaker per day, the most important trip purposes in terms of car driver trips. The car-driver trip rates for leisure are, with almost 0.2 trips per tripmaker and day, substantially lower over the whole analysis period. Car-use reductions are clearly visible for mandatory car-driver trips. This results from both a decline in the overall trip rates for mandatory trips over all transport modes (*37*) and a modal shift to other modes as shown in the right side of Figure 5. Trip rates for mandatory trips increased for cycling in all urban areas, and, in Berlin, Paris, and London the trip rates also increased for public transport. Leisure trips are slightly decreasing in Berlin, Copenhagen and Vienna and are stable in Berlin and slightly increasing in London, but changes in trip rates over time are small. Shopping/errands is the most heterogeneous trip purpose both in terms of the absolute car-driver trip rates as well as in their developments over time. Shopping/errands is, aside from mandatory car driver trips, the most interesting trip purpose with a substantial potential for reductions in car use. First indications of reduced dynamics in terms of car-use decline in recent years are observable in particular for Copenhagen.

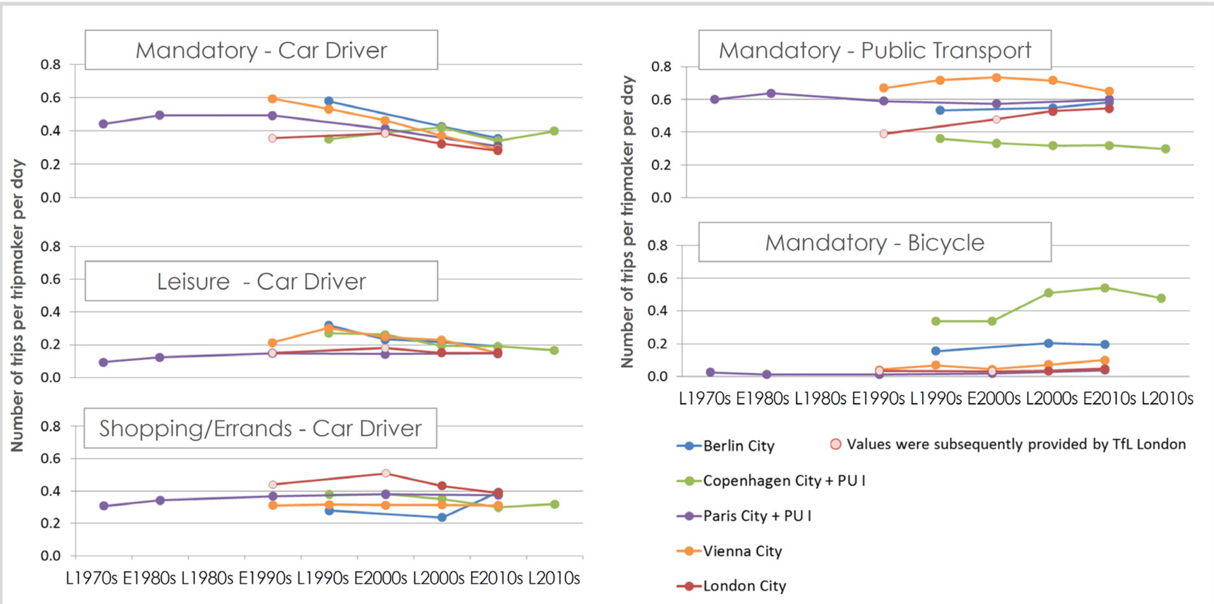

FIGURE 5 Car-Driver Trips per Tripmaker per Day by Purpose (Left) and Number of Mandatory Trips by Public Transport and Bicycle (Right) in the Urban Area Type

Car Use for Different Person Groups

Figure 6 visualizes car-trip rates for tripmakers by person group for all trip purposes. The peak-car effect is most distinct for working people with a reduction in car use of around 35 percent from the peak to the latest survey period. Both the magnitude of car-trip rates and also the change over time is surprisingly similar in the five urban areas. Substantial reductions also occurred for the person groups "Other", including all persons who are above 17 years old but not working and not retired. Values are more heterogeneous for this group and car use is at a much lower level than for working people.

Pensioners show a substantial increase in their car-trip rates, confirming the findings from the literature (*11; 15*). Car trip rates are highest in Berlin and London for this person group. In these two cities, car trip rates for pensioners and working people are almost the same in the latest survey period. Car-trip rates for children and teens mainly consist of car-passenger trips and are comparably low. The slight increase in car use of this person group confirms the hypothesis of an increasing pick-up and drop-off mentality of parents (helicopter parents). The impact of this development on the overall car use is small, but socialization and education in early life stages form perceptions, attitudes, and, ultimately, travel habits in later life stages and, therefore, deserve special attention.

For each person group, its relative size and the direction of change are also shown in Figure 6. The person groups "Other" and "Pensioners" have approximately the same size. Changes in car use in these two person groups almost balance each other out.

The person group "Children, Teens" is the least important for understanding the peak-car effect as the group size is small and car use is low. Working people have the highest car-trip rates and are, in addition, by far the biggest person group. They are the main generator of the peak-car phenomenon in the five urban areas.

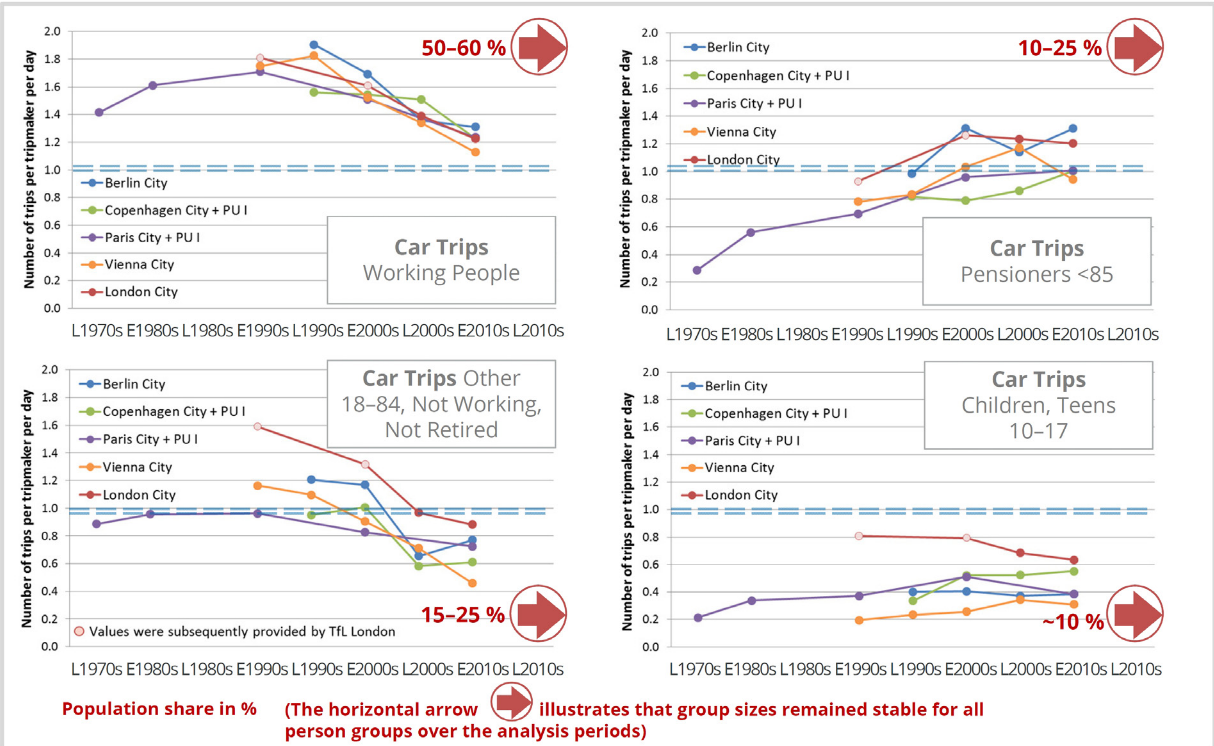

FIGURE 6 Car Trips per Tripmaker per Day by Different Person Groups in Area Type Urban

Figure 7 shows car-trip rates for working people and pensioners distinguished by gender. Peak-car developments are most distinct for working male persons. Car trip rates of men and women converge over time for both person groups, but the values are still lower for women in the latest survey period, especially for pensioners. It appears likely that the rise in car use for women continues and damps peak-car tendencies.

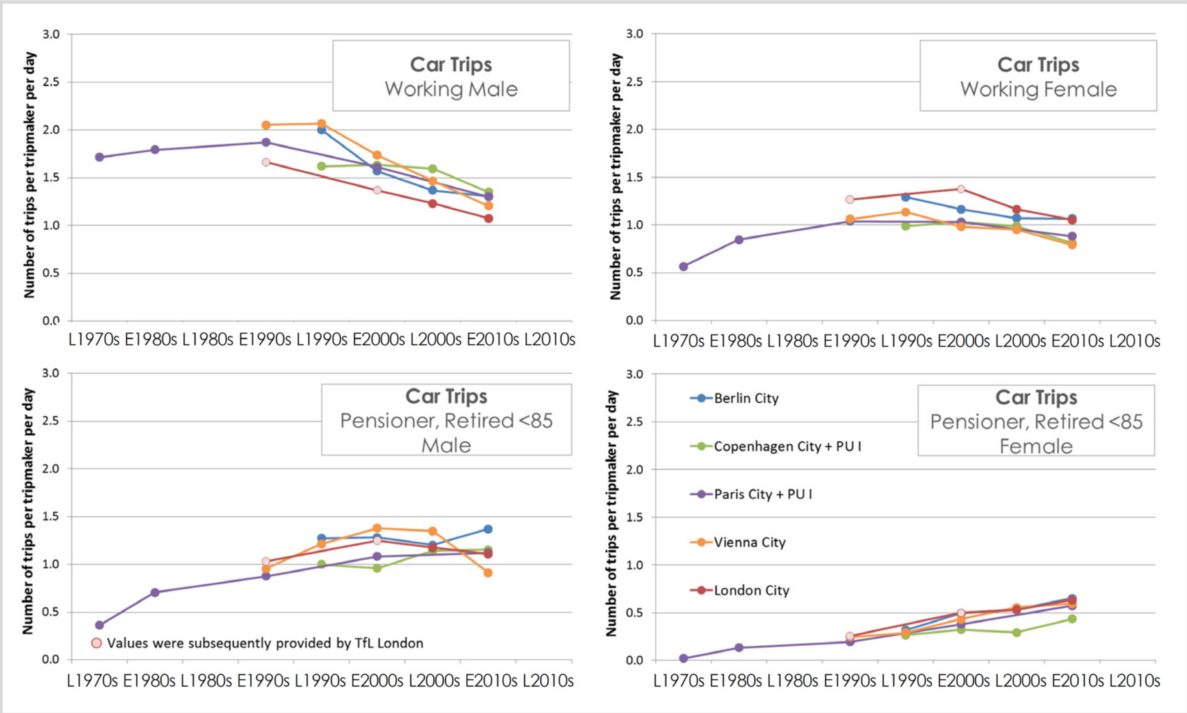

FIGURE 7 Car Trips per Tripmaker per Day of Different Person Groups by Gender in Area Type Urban

Figure 8 provides car-driver trip rates for the most relevant person group (the working people) and for the most relevant trip purpose (mandatory trips). Trip rates are additionally distinguished by age group in order to compare our dataset with the literature that consistently finds age to be a main determinant of car use with substantial differences between cohorts. Interestingly, all age groups contribute to the peak-car effect.

Reductions in car use are more substantial in Berlin, Paris, and Vienna than in Copenhagen and London. In the two latter urban areas, car use for mandatory trips even slightly increased for the higher age groups. Averaging all urban areas, the youngest age group has, with around 0.4 car driver trips per tripmaker per day, the lowest trip rates in the latest survey period, but the two other age groups also show declining car use over time, with on average 0.6 car-driver trips for mandatory purposes in the early 2010s.

Figure 9 focuses on the youngest age group (18–34 years) and shows car access and car use especially for this person group; the direct car access (driver's license holding with a car available in the household) of all working people is included for comparison. Young working persons had a substantial reduction in car access over time. Both the absolute car-access shares as well as the reduction thereof are more substantial than for the whole person group of working people, including all age groups. Figure 9 also shows the high relevance of car access for car use. Car trip rates of young persons without car access are very low over the whole analysis period.

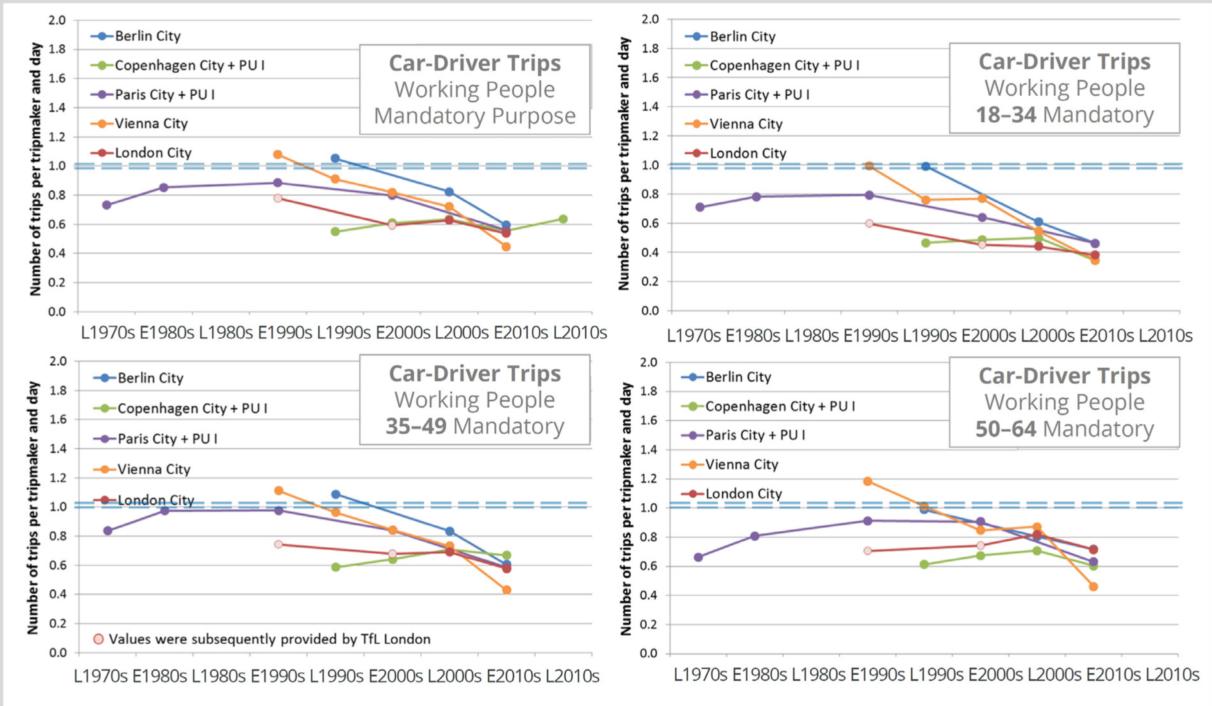

FIGURE 8 Car-Driver Trips per Tripmaker for Mandatory Purposes of Working People by Age in Area Type Urban

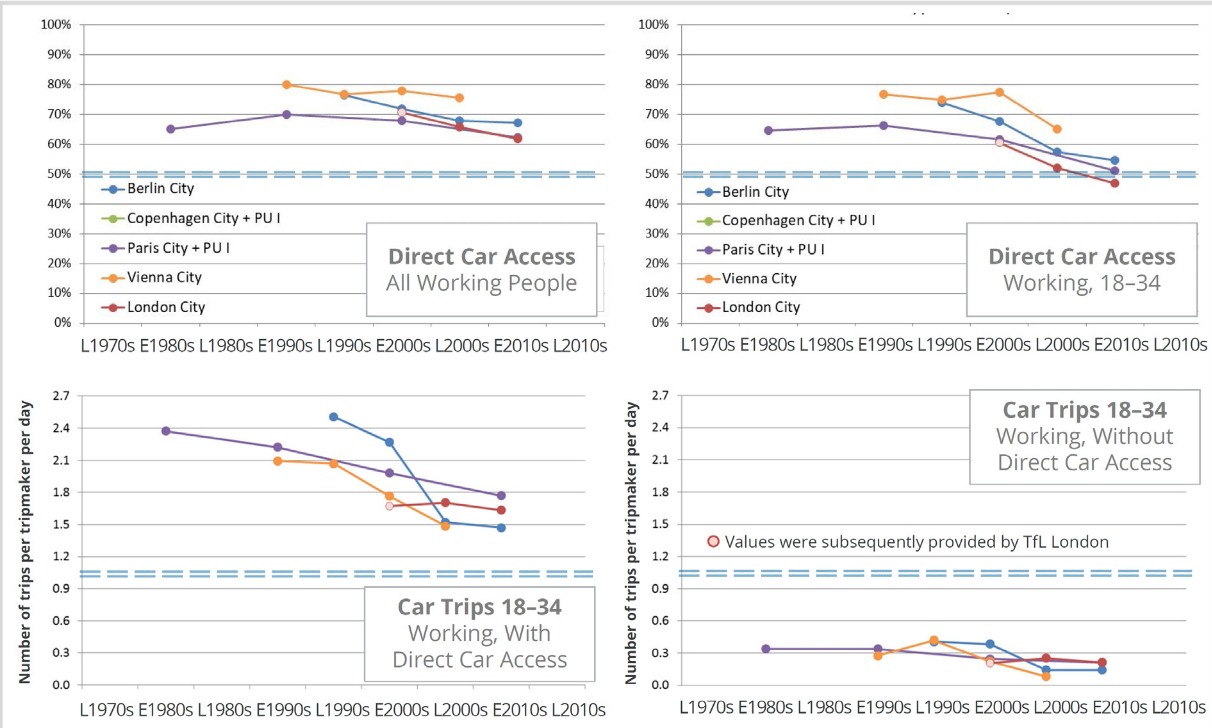

FIGURE 9 Direct Car Access of Employees (Upper Part) and Car Trips of Young Employees by Car Access (Lower Part) in Area Type Urban

AGE-PERIOD-COHORT ANALYSIS FOR PARIS ÎLE DE FRANCE

HTS-microdata harmonization for Paris has been successfully completed back to the late 1970s. All generational cohorts are available with an adequate sample size for each group. Data availability in the other urban areas was not as comfortable, and, in addition, descriptive analyses showed various similarities between the study areas. Therefore, APC-analysis was specifically done for the example of Paris. An overview of different studies using APC approaches for analyzing travel behavior is given in *(37)*. Cohort-specific developments were analyzed for working people only, as they turned out as the main generator for the observed peak-car effects.

The visualization of APC results can be organized differently along the three dimensions of age, cohort and period. In Figure 10, the survey period is only indirectly assessable whereas age and cohort are chosen for visualization. Generations move across time/survey years while aging. A certain age group of a cohort might be included either in one survey period or in the next one. For example, Millennials (born 1985–1999) can be observed as Young Adults (18–34) in the early 2000s but also in the early 2010s. A person who is born 1985 was already 19 years of age in 2004 (early 2000s) but 29 years of age in 2014 (early 2010s) and therefore remains still within the group of Young Adults. In this case, a Young Adult from the millennial generation can be surveyed at different points in time.

Figure 10 illustrates car-driver trip rates and car access of Parisians by generation. Some data points are not included in the diagrams since not every age group is available for each generation (e.g., Millennials are not aged 65+ today). The analysis reveals clear cohort-specific travel patterns. The younger a generation is, the fewer car-driver trips it has. This pattern particularly applies for the Millennials (the Young Adults aged 18–34 years in the early 2010s). People in this group have less car-driver trips than all previous generations. Only one data point is available so far for this generation but the developments in the former generations across age support the hypothesis that the Millennials will carry forward their behavior as they age. Prime Busters show significantly fewer car-driver trips compared to previous generations even in their middle ages (35 to 49). Only the Silent Generation had fewer car-driver trips at this age group. This is intuitively comprehensible because data points for people of the Silent Generation mainly result from survey years when motorization and driving license ownership (car access) were lower than for later generations at the same age. The use of public transport and cycling is opposite to the described generational relationships for car-driver trips (see also (*37*)).

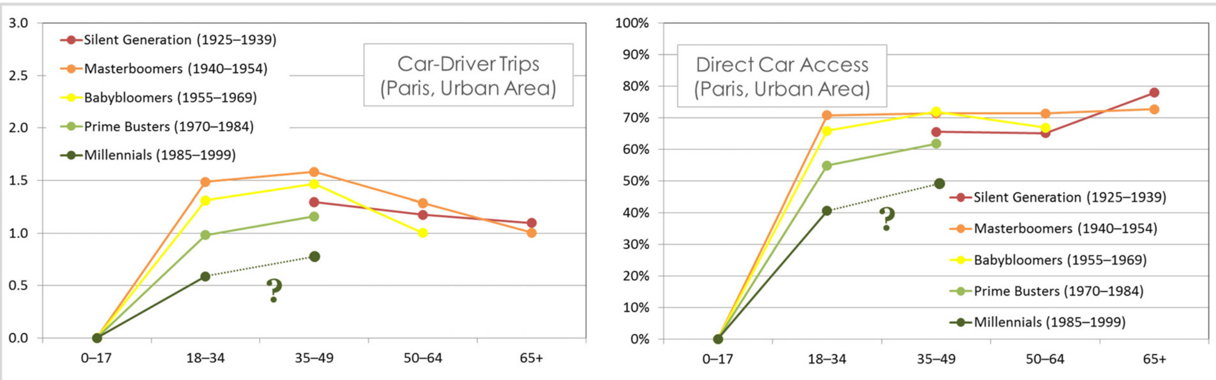

FIGURE 10 Car-Driver Trips (Left) and Direct Car Access (Right) by Generational Cohorts in the City of Paris

DISCUSSION AND CONCLUSION

The goal of this paper was to prove and decompose the peak-car phenomenon in urban areas with the example of the five European capital regions Berlin, Copenhagen, London, Paris, and Vienna. Developments in car use were found to be surprisingly similar despite the substantial differences between the regions in terms of size, governance structures, built environment, transport systems, and societal framework conditions. The typical characteristics of the regions were confirmed: Public transport use is highest in Vienna; bicycle use is highest in Copenhagen; walking is highest in Paris; Berlin and London show more balanced modal splits. However, car use is almost the same in all urban areas and even converges in the more recent time periods.

Car use peaked earliest in Paris in the early 1990s; followed by Berlin, London and Vienna in the late 1990s; and lastly in Copenhagen in the late 2000s. This is consistent with the literature that finds similar peak-car periods also for other cities (*8*) and partly also on the national level (*17*). Car use peaked mainly before the economic recession in the late 2000s; this crisis might have supported declining trends in car use but it rarely was the main cause.

Working persons/mandatory trips were found to be the most relevant person group/trip purpose for the observed peak-car developments with both declining overall trip numbers and a modal shift towards the non-car modes. Our work confirms the particularly high contribution of the young generation to reduced car use but it adds the perspective of the employment status. Working persons of all age groups have reduced their car use over the analysis period and are thus also a relevant target group for transport policy making aimed at reducing car use. Young working persons had the most significant decline with substantial cohort effects. As they age, people tend to carry forward behaviors adopted in early life cycle stages. Young Adults as well as teens and children should, therefore, receive high priority in travel-demand management initiatives supporting the use of alternative modes. The literature was confirmed for seniors and women who both damp the peak-car effect. Measures supporting multi-modal travel behavior might avoid further increases in car use for these person groups or even achieve reductions. Shopping trips are the second most relevant trip purpose for car use. Car use for this purpose is high and stable over time.

With these findings, this paper supports transport policy making by identifying person groups that seem to be particularly relevant for the overall car-use developments and/or responsive to mobility management strategies; these are young persons, working persons, seniors, and women. Young people deserve special attention as they carry forward their behavior to later life cycle stages. Persons in life-cycle changes are also a promising group for behavioral changes. Mobility management strategies targeting these person groups could either approach the members of the person groups or the institutions at their trip destinations (such as companies). In addition, we identified for the overall population, the most relevant trip purposes for car use are mandatory trips and shopping trips. Policy measures specifically targeting these trip purposes toward a modal shift away from the car to alternative modes or toward changes in trip generation, destination choice or the choice of departure time have a substantial potential for reducing car use. This study substantiated the peak-car phenomenon for HTS-resident samples in urban areas. Similar studies in other spatial contexts and based on harmonized HTS microdata would further improve our understanding of car use in areas outside agglomerations and also within different parts of agglomerations.

This study reports a retrospective analysis, and the question remains open to how car use will develop in the years to come. There are some indications for weakened dynamics of reductions in car use or even increases, e.g., in London (*18*). There are also indications of substantial changes in (travel) behavior patterns. For example, the Commission on Travel Demand (*38*) finds, in the case of the UK, substantially reduced overall travel in terms of trip rates (16 % lower today than in 1996), distances (10 % fewer miles than in 2002), and also travel times. There are three possible future developments of car use: ‘Interrupted Growth’, ‘Saturation’, and ‘Peak Car’ *(3)*. Which of these developments will actually occur will be influenced by all the aforementioned fields of (a) macro trends, (b) policy making and governance, as well as (c) changes in behavior and mind-sets. Transport policy making is an important means for promoting reductions in car use. The findings from this paper are meant to support efforts in this respect.

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AUTHOR CONTRIBUTION STATEMENT

The authors confirm contribution to the paper as follows: study conception and design: Regine Gerike, Rico Wittwer; data collection: Rico Wittwer, Stefan Hubrich.; analysis and interpretation of results: Rico Wittwer, Regine Gerike; draft manuscript preparation: Rico Wittwer, Regine Gerike, Stefan Hubrich. All authors reviewed the results and approved the final version of the manuscript.

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