Structure and innovation of human activity spaces

Working Paper

Author(s):
Schönfelder, Stefan; Axhausen, Kay W.

Publication date:
2004-10

Permanent link:
https://doi.org/10.3929/ethz-b-000023551

Originally published in:
Arbeitsberichte Verkehrs- und Raumplanung 258

Full length manuscript for ISTTT 16

Structure and innovation of human activity spaces

S Schönfelder
KW Axhausen

Arbeitsbericht Verkehrs- und Raumplanung 258 **October 2004**

Institut für Verkehrsplanung und Transportsysteme
Institute for Transport Planning and Systems

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

1 Current assumptions for human activity spaces and current challenges

Ever since Eduard Lill's (1889) paper on the *Grundgesetze des Personenverkehrs* (basic laws of personal travel) transport analysts have assumed that the destinations chosen by a traveller are distributed smoothly across space; perfectly smooth in the case of the featureless plane of idealized models and suitably adjusted in all realistic cases. This assumption is embedded in all models of destination choice through smooth distance decay functions or equivalently exponential discounting of the generalized cost of travel between any two points. This understanding is static with respect to the individual traveller and does not allow for systematic change in destination choice while the structures of the generalised costs are constant.

Two developments are challenging this long-help assumption: a) the interest in dynamic agent-based models of travel, which account for learning at the individual level[1] and b) the interest in the spatial distribution of the members of the social networks to which a traveller belongs (see Axhausen, 2003 or Ohnmacht, 2004) and its impact on travel. The current understanding of the structure of mental maps and of the spatial realisation of social networks (Giddens, 1984) suggest that the set of destinations should have a structure, i.e. certain locations and directions of travel should be systematically preferred beyond what the availability of competing opportunities or their associated generalised costs suggest. They also suggest turnover in this set: new locations being added, while other locations are being dropped.

The data sources usually employed do not allow the investigation of these questions. The set of locations observed in a one-day or two-day diary period is too small to make useful statements at the individual level. Fortunately, a number of long-duration data sets have recently become available, which allow us to begin to address these issues.

Such individual panel data sets allow to investigate the complexity of daily life and the diversity of individual activity repertoires and related travel patterns over time – including human activity spaces. Due to the availability of exact location data for both, conventional data sets based on travel diaries and – by nature – GPS enhanced data sets, interesting opportunities arise for the analysis of spatial decision making and navigation.

---

[1] In principle, such models could be extended to address social learning, i.e. investment choices or regulatory change.

This paper offers an overview over the recent findings on structure, stability and variability of individual location choice. At the centre of the analysis is the question of how many places do we actually know, visit and discover over time. This question could not have been answered empirically before. This paper addresses it rigorously for the first in the literature drawing on six European data sets, five of which were recently collected.

The next section will briefly describe the data sets used for the analyses. The following section will discuss the measures used to describe the size and structure of the observed sets based on the idea of the activity space. The descriptive statistics and the models of the final substantial section will link these measurements to the socio-demographics and the life styles of the respondents, characterised here by their type of residential location and the ownership of mobility tools (car, motorcycle, bicycle and public transport season tickets). In conclusion, the paper will suggest directions for further research, in particular for destination choice modelling.

2 Long-duration data sets

Given the traditional aim of obtaining static equilibrium descriptions of flows on transport networks, short duration, as a rule one-day, diaries have been judged appropriate in the past. The higher cost per household recruited for a longer period was an additional impediment to a change of practice[2]. It is therefore no surprise that the five-week 1971 Uppsala survey of Hanson, Hanson and Marble (Marble, Hanson and Hanson, 1972) was not replicated until the late 1990s. The Uppsala survey was unusual for its time in a second way, as all locations were properly geo-coded by hand, whereas at the time locations were normally only coded to rather rough traffic analysis zones.

In the late 1990s the availability of GPS-based tracking and the increased interest in agent-based modelling of traffic flow and travel demand have changed the balance of interest. As a result, recently a number of long-duration observations of travel behaviour have become available. It should be noted though, that in many cases the motivation of the study arose from other concerns. Table 1 provides an overview over the datasets. These surveys span the range from rural village and small town (Canton Thurgau, Switzerland) to metropolitan environments (Copenhagen, Denmark). Our later analysis will try to trace the possible impacts of these scale differences.

The data sets differ substantially by style of data acquisition, structure and amount of information available. Whereas Uppsala, Mobi*drive* and both SVI studies were conducted as paper-and-pencil based travel diaries, the Borlänge Rätt Fart and the Copenhagen AKTA data was collected by in-vehicle Global Positioning System (GPS) devices. The latter approach is more comprehensive but also causes problems for data analysis and comparability. This includes for example the insufficient identification of the driver, their incomplete socio-economic description or lacking trip or activity purpose information. This is due to the fact that these two GPS studies were not designed for travel behaviour analysis but for a traffic safety experiment (Borlänge) or road pricing experiments (Copenhagen).

The question of how many places we actually frequent is methodologically connected with the term *unique location* employed below. A unique location is defined as the product of geocode and purpose of trips. The definition of a unique location has to differ substantially given the different sets of items and the differing geographical resolutions of the trip destination coding. The resolution, for example, ranges from post code area (centre of a post code area), to street address (geocodes of front door) and finally to the precision of GPS observations. This issue is treated in Table 1 and should be kept in mind when interpreting the results.

And finally, given the incomplete availability and the preliminary status of post-processing for the two GPS data sets, the analysis provided in this paper is based on sub-samples of the Borlänge and Copenhagen data. The size and structure of the sub-samples is clarified in the corresponding sections below.

---

[2] It should be noted though, that per trip one-day diaries are substantially more expensive.

Table 1 Overview over the data sources

Name of the survey	Year	Original focus	Locations	Reporting period	Resolution: geocoding	Resolution: purposes	Persons	Trips
Uppsala diary	1971	Travel behaviour research	Uppsala, Sweden	35 days	Building	All purposes	144	23’000
Mobi*drive* diary	1999	Stability of temporal patterns	Karlsruhe and Halle, Germany	42 days	Street block	All purposes	361	52’000
ISA Rattfärt GPS observation	2000-2002	Speeding behaviour	Borlänge, Sweden	up to 80 weeks	Trip ends: GPS; unique locations: Pre-defined clusters	Unknown, potentially all	189 veh.[3]	240’000 car trips
SVI Leisure diary	2002	Leisure activities	Zürich, Switzerland	84 days	Post code level	31 leisure purposes	75	9’900 leisure activities
SVI Stabilität diary	2003	Stability of temporal patterns	Frauenfeld and villages in the Thurgau, Switzerland	42 days	Building	All purposes	230	37’000
AKTA GPS observation	2001-2003	Route choice under road pricing	Copenhagen, Denmark	18-24 weeks	Trip ends: GPS; unique locations: Pre-defined clusters	Unknown, potentially all	500 veh.	250’000 car trips

[3] Private cars only

Uppsala diary

The first study to examine the variability in individual travel behaviour is the Uppsala Household Travel Survey (Hanson and Burnett, 1972). It covers a period of five continuous weeks. The survey was conducted in 1971 and is the basis of a series of publications by Hanson and collaborators concerning the stability of travel behaviour.

The city of Uppsala is located approximately 70 km northwest of Stockholm and had a population of about 130.000 at the time. A random sample of 20 percent of the total population was drawn. The persons who agreed to participate were divided into five waves of equal proportion of six different life cycle groups and began on five sequential days to fill in a diary for five weeks. The final sample size was 278 households with 488 persons of which 92 households (respectively 144 persons) were chosen for further analysis by Susan Hanson and colleagues. This group was representative for Uppsala's population. A detailed description of the sampling procedure and the survey instruments is given in Marble, Hanson and Hanson, 1972. The interviewed persons were contacted frequently. Due to this, the number of participants who dropped out of the survey was below 15%. No signs of fatigue effects could be detected (Hanson and Burnett, 1982).

The manual geocoding of the trip destinations for the available sample of 144 persons was successful for 17.138 of the 17.147 trips reported.

*Mobi*drive *diary*

The 1999-2001 Mobi*drive* project proved that the fear to obtain low quality responses in multi-week travel diary surveys was (still) unjustified (see Axhausen, Zimmermann, Schönfelder, Rindsfüser and Haupt, 2002). See http://www.ivt.ethz.ch/vpl/research/mobidrive for an overview of results and relevant publications based on this six week travel diary data set.

Based on the experiences made with the Uppsala survey, the Mobi*drive* survey was conducted in the German cities of Halle/Saale and Karlsruhe in autumn 1999 (Karlsruhe: 270.000 inhabitants, Halle: 250.000). A total of 317 persons over 6 years in 139 households participated in the main phase of the survey, after testing the survey instruments in a pre-test with a smaller sample in spring 1999 (44 persons). The paper-based travel-diary instrument was supplemented by further survey elements covering the socio-demographic characteristics of the households and their members, the details of the households' car fleet and transit season tickets owned and personal values as wells as attitudes towards the different modes of transport.

One main objective of the Mobi*drive* consortium was to provide exact locational data in order to facilitate the analysis of the variability in spatial behaviour over time (e.g. destination-, route and mode-choice). The precise locational data was obtained by geocoding the trip destination addresses of all main study trips (45.532 trips). The geocoding was positive for about 98% of the reported trips (45.026). Due to incomplete addresses and limited availability of digital address information outside the urban cores of the case study regions, the geocodes of the addresses have different degrees of resolution for the different areas. For the City of Karlsruhe and City of Halle, the street addresses could be geocoded on the basis of (small) street blocks (i.e. more than 90% of all geocoded trips), whereas outside the urban boundaries the addresses are available only as geocodes of the centroids of the municipality.

SVI Freizeitverkehr diary

The SVI Freizeitverkehr project aimed to collect long-duration travel data especially on leisure activities (Schlich, Kluge, Lehmann and Axhausen, 2002; Schlich, Simma, Rüssli and Axhausen, 2002). The 12-week travel diary survey which was in the centre of the study was conducted in Zürich/Switzerland (City of Zürich and two smaller suburbs) beginning of 2002. The sample size reached 71 respondents who did not show any significant fatigue effects in reporting. A pre-test in autumn 2001 with 16 respondents helped to finalize the structure of the main study survey.

The survey instrument had its focus on leisure travel requesting respondents' information about start and end times of each out-of-home leisure activity, detailed purpose, mode of travel, place, travel company, expenses and the frequency of recent visits. Besides, a simple time budget survey (one hour resolution) was added to place the leisure activities into context. The usual socio-economic data was collected to frame the travel diary data.

A total of 5'600 leisure activities was collected. The geocoding was limited to postcode level only. The very detailed coding of the leisure purposes balances this aggregation only to a limited extent. Due to the special focus on leisure travel only and its limited geocoding, the data is not analysed as intensely as the other data sets in this paper.

SVI Stabilität diary

The SVI Stabilität diary (Buhl and Widmer, 2004) is a very recent Swiss attempt to 1) collect up-to-date panel data analogous to Mobi*drive* and 2) to develop approaches to explore the stability of travel over the course of one day, within the households and groups of travellers as well as of the mode choice. The survey performed in the canton of Thurgau (Eastern Switzerland) in 2003 covers a six week reporting period with a sample of 99 households (230 persons). The majority of destination addresses and household locations could be geocoded with high precision (Machguth and Löchl, 2004). 36’454 of the 36’783 available trips could be geocoded.

ISA Rättfart GPS study

The ISA *Rätt Fart* (Right Speed) data set contains fully automatically collected movement information for vehicles (single travellers) for more than two years (Schönfelder, Axhausen, Antille and Bierlaire, 2002; Schönfelder and Samaga, 2003; Wolf, Schönfelder Samaga and Axhausen, 2004). The vehicles were equipped with on-board data collection systems consisting of a GPS receiver, a data storage device running a GIS (Geographic Information System) for mapping all movements and a mobile power supply.

The traffic safety project *Rätt Fart* (Right Speed), based in the Middle-Swedish town of Borlänge (47.000 inhabitants in 2001), was one sub-project of the Swedish National Road Administration *Intelligent Speed Adaptation* (ISA) initiative (see Vägverket, 2000) Rätt Fart in Borlänge itself had its focus on providing speeding information to the drivers derived from the GPS devices. The study was conducted from 1999 to 2002 with more than 200 private and commercial cars which were equipped for periods of up to two years each. The essential characteristics (speed, acceleration, actual time, location etc.) were stored internally for analysis in logs every second respectively every tenth second depending to the road link.

The total movement file contains a total of about 240’000 private car trips. The area of detailed monitoring was limited, though, to the town of Borlänge plus some surrounding countryside – an area with a radius of about 20 km around the town centre of Borlänge.

As the data set was not collected for travel behaviour analysis, the vehicle movement data had to be cleaned and enriched to obtain usual survey data comprehensiveness and quality. For this analysis, a smaller sub-sample is used which was post-processed to identify all trip ends (Wolf, Schönfelder, Samaga and Axhausen, 2004). One main outcome of the process is the identification of unique destinations by clustering trip ends (parking locations and turn-offs from the public road network), as the final recorded positions of a trip in the raw data vary significantly due to transmission inaccuracies or simply by using different parking spaces for same destinations over the period of monitoring.

The sub-sample used consists of approximately 70.000 car trips made by 67 vehicles. The period of monitoring covers 5 to 470 reported days and 8 to 3.419 reported trips. The available survey period is 29 September 2000 to 4 March 2002. There is a limited range of sociodemographic variables available for the test drivers.

AKTA GPS study

The AKTA study (Nielsen and Jovicic, 2003) – which is part of the EU funded project *Pricing ROad use for Greater Responsibility, Efficiency and Sustainability in cities* (PROGRESS) – is a real life experiment of road pricing in the greater Copenhagen region. Copenhagen is the capital of Denmark and the metropolis of Southern Scandinavia. In 2002 the agglomeration had 500.000 inhabitants in the municipality itself, about 620.000 people in Greater Copenhagen (Koebenhavn kommun) and more than one million inhabitants in the Öresund region covering Greater Copenhagen and the neighbouring Swedish city region of Malmö.

Approximately 400 cars were equipped with a GPS-based device during a period of two times 8-10 weeks in 2001/2002. Vehicle movement data was collected each second. An onboard system simulated road pricing by providing cost information for every trip within the City of Copenhagen, which was virtually divided by cordon rings defining prizing zones. After two monitoring periods which differed by the pricing scheme virtually applied, the AKTA test drivers were paid an amount of money according to their observed route choice behaviour. The GPS monitoring was accompanied by a telephone based before-and-after survey containing of attitude questions and SP instruments.

The available sample includes 50 vehicles/persons with 44 to 135 reported days and 125 to 1044 reported trips each. The data covers the period from 14 September 2001 to 21 June 2002. The socio-economic data is limited and includes age class, sex, home address, work address, gross household income, car usage frequency (for work), prevalent mode chosen to the workplace, distance home to work, weekly, yearly as well holiday kilometrage, and various vehicle details.

In contrast to the Borlänge *Rätt Fart* data, no advanced post-processing has been applied so far, which potentially results in a higher share of undetected trips/trip ends. The trips and their attributes are predefined by the technical devices, i.e. the trip is defined by the first satellite signal received and ends with the engine switch off. The identification of visited locations followed a simple clustering technique which grouped adjacent trip ends into clusters using the

SAS Fastclus procedure (Anderberg, 1973). The clustering radius was conservatively set to 40 meters generating a larger number of unique locations than in Borlänge.

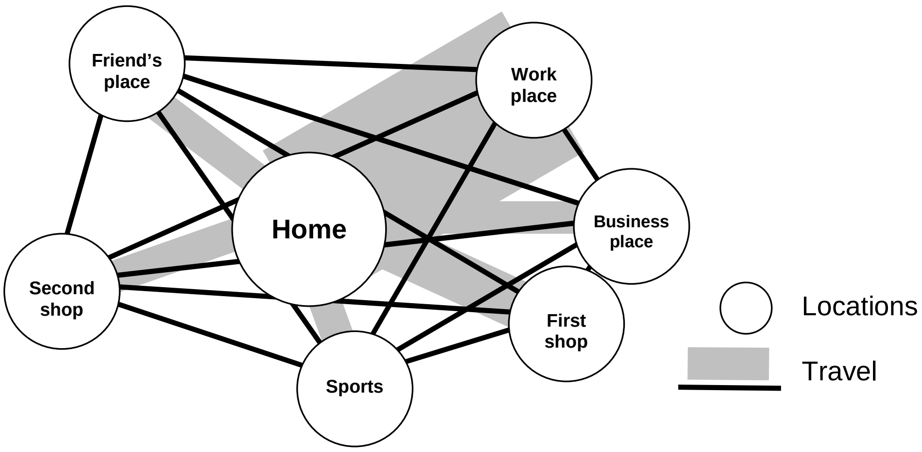
3 Measurement of the activity spaces

The micro-geographical *activity space* concept captures the structures of realised locational choices for single travellers. The concept – which was developed in parallel with a range of related approaches to describe individual perception, knowledge and actual usage of space in the 1960s and 1970s (see Golledge and Stimson, 1997 for a discussion) – aims to represent the distribution of places visited and the space which contains those places frequented over a period of time. Activity spaces are geometric indicators of the *observed* or *realised* daily travel patterns (see also Axhausen, 2002). This is stressed here as related concepts such as the action space (e.g. Horton and Reynolds, 1971), the awareness space (e.g. Brown and Moore, 1970), the perceptual space (e.g. Dürr, 1979), mental maps (e.g. Lynch, 1960) or space-time prisms (e.g. Lenntorp, 1976) describe the individual *potentials* of travel – based on spatial knowledge, mobility resources, the objective supply of opportunities etc.

Activity spaces are usually defined as a two-dimensional form which is informed by the spatial distribution of those locations a traveller has personal contact with. The geometry, size and inherent structure of activity spaces are supposed to be determined by three determinants (Golledge and Stimson, 1997) (Figure 1):

- *Home*: The position of the traveller's home location, the duration of residence, the supply of activity locations in the vicinity of home and the resulting neighbourhood travel
- *Regular activities*: Mobility to and from frequently visited activity locations such as work or school
- *Travel between and around the pegs*: Movements between the centres of daily life travel

Figure 1 Simplified activity space representation



Adopted from Maier, Paesler, Ruppert and Schaffer (1977) 57

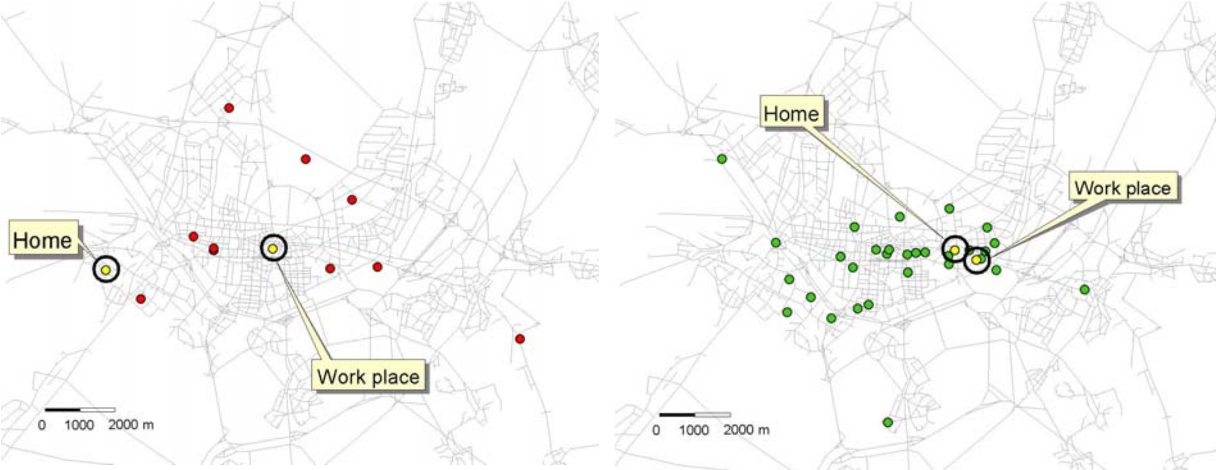
Empirical work on revealed activity spaces is rare. The physical mapping or enumeration of the places visited by individuals - such as shown for a Mobi*drive* example in Figure 2 – are only possible if there is longitudinal, geocoded travel data available or at least lists of visited places plus the frequency of visit. Where such work has been done, it was mostly done with a distinct focus on travel potentials or opportunities. This was often inspired by the conceptual approaches of space-time geography which puts spatial movement into a context of individual and societal and constraints (Hägerstrand, 1974). Only few other studies concentrated on the detailed measurement of individual activity spaces (e.g. Dijst, 1999)[4].

[4] It should be noted that there is a range of studies of spatial behaviour and activity spaces on the aggregate level of sociodemographic groups or zones. Those studies use cross-sectional travel or time-use data.

Figure 2 Spatial distribution of places visited over time – two Mobi*drive* examples

Man, 50, Full-time, 1 child, 120 trips / 6 weeks

Women, 24, Full-time, Single, 216 trips / 6 weeks



4 Analyses

The analysis of activity spaces based on the data sets described above follows two streams:

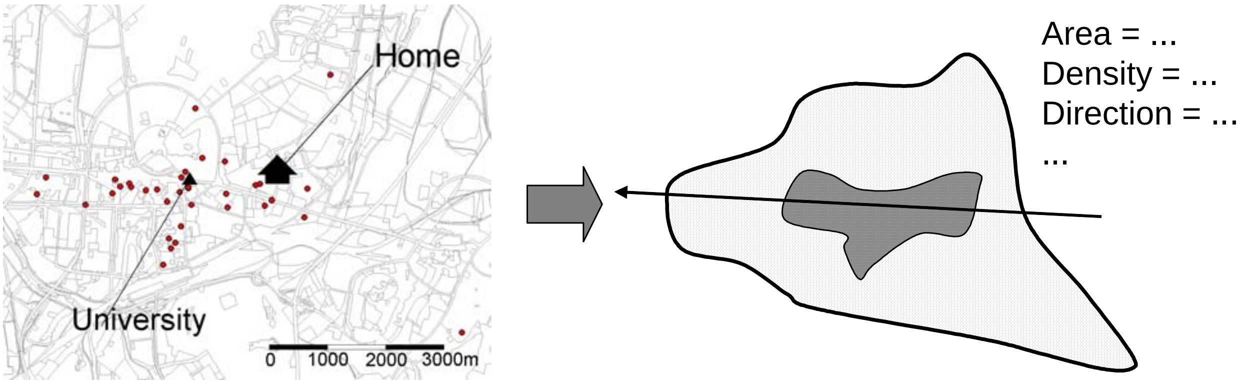
- the characterisation and enumeration of locations visited over time and
- the measurement of activity space sizes by continuous space representations

The latter stream requires approaches which allow the transformation of point patterns - such as the spatial distribution of activity locations - into geometrical forms (Figure 3). The transformation process will provide answers to the following questions:

- Given observed locational choices, which further locations are likely (probability of visit)?
- Which urban space is used intensively according to one’s needs and preferences (density / intensity of usage)?
- When moving through nets, which adjacent area is perceived and possibly memorised (perception / memorising of infrastructure)?

In addition, the primary measures can be used to define other measures, such as local density distributions or main direction (orientation) of the activity space.

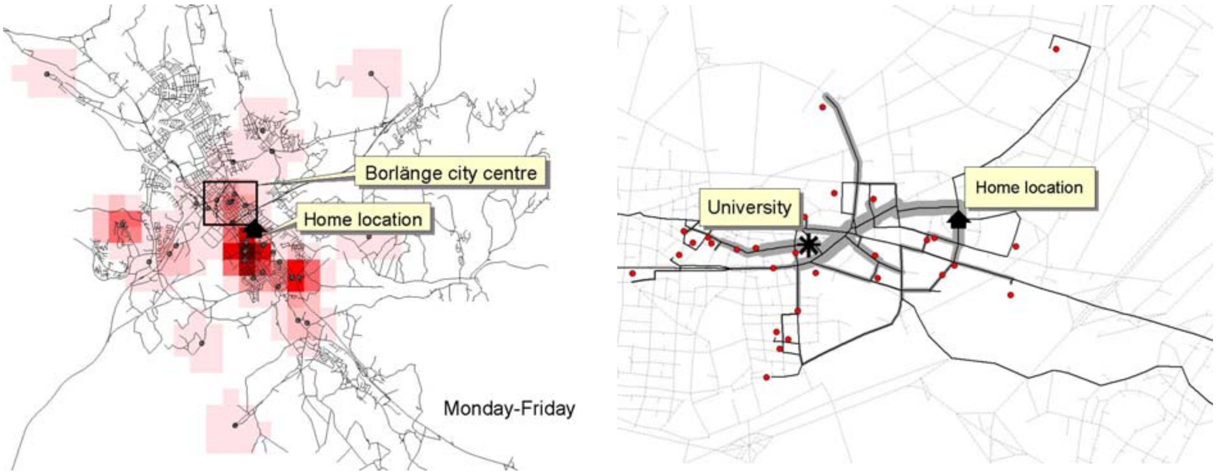
Figure 3 Transforming activity point pattern into continuous space representation



In a series of papers, the authors have developed a number of suitable approaches such as confidence ellipses, a two-dimensional version of the well-known confidence interval; kernel density estimates of activity density and finally a shortest path network approach connecting locations visited (Schönfelder, 2003; Schönfelder and Axhausen, 2003a and b).

Confidence ellipses will be later described in this paper as a suitable measure of the dispersion of activity spaces. Although the visualisation of kernel densities (see Silverman, 1986 or Fotheringham, Brunsdon and Charlton, 2000 for an introduction) and shortest path networks (i.e. the road links used over reporting period) is powerful (Figure 4), their information content is not so high. The densities measures, for example, correlate highly with the number of points considered, i.e. the number of trips made and the number of unique locations visited. Therefore, the distribution of the activity space size follows the distribution of trips and unique locations as shown in the sections below. This was also found in respect to the number of unique locations for the shortest path network measure (Schönfelder, 2003).

Figure 4 Visualising human activity spaces: Kernel density and *shortest path network* example



Listing and enumeration of places frequented over prolonged periods

The earlier analysis of the long-duration data sets Mobi*drive* and Uppsala underpinned the hypothesis that the amount of travel has direct effects on the number of unique locations and their spatial distribution. In order to provide an impression of how much travel one can expect if people are observed over prolonged time periods, the observed trip rates are reported below.

The trip rates across all modes follow a normal distribution with a slight right skew. The median is about 25 trips per week which corresponds to cross-sectional results of 3 to 4 trips per day per traveller.

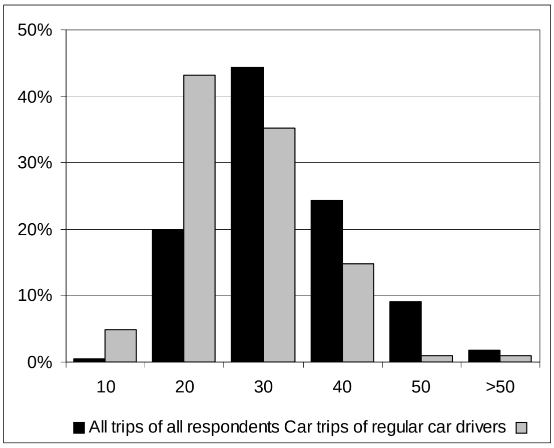
The figure also shows the significant difference in trip rates between the GPS tracking data and the travel diary data sources. The weekly as well as daily trip rate for drivers is about 25% higher in the (socio-demographically unweighted) GPS data compared to regular car drivers[5] in the travel diary data. Note also, the left skewed distributions. The difference in numbers is caused by the exact capturing of short car trips. In Borlänge for example, the average distance travelled per trip is only 3.8 km with an average trip duration of about 6 minutes. In Mobi*drive* – with an admittedly larger local survey area – the corresponding figures are 21 min-

[5] For the travel diary survey data, respondents who made more than 50% of their trips by car are considered as "regular car drivers". This sub-sample acts as a comparative group for the GPS observations.

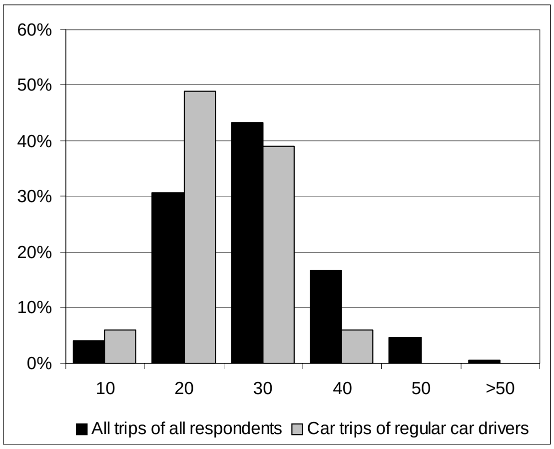
utes and 13 km. For Copenhagen the average trip duration is under 15 minutes which is small considering the size of the Copenhagen agglomeration.

Figure 5 Mean number of trips per week (unweighted): distributions by mode

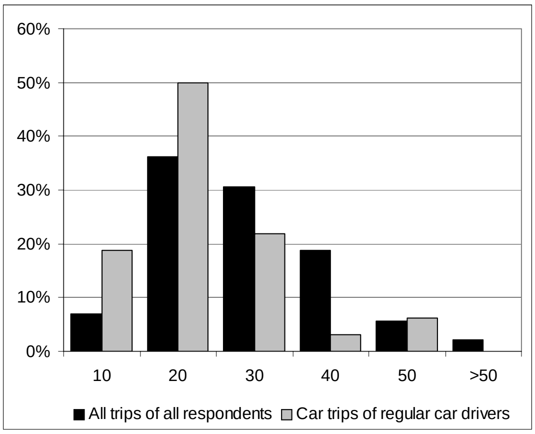
Mobi*drive* 6 weeks (n=317, 100 regular car drivers)



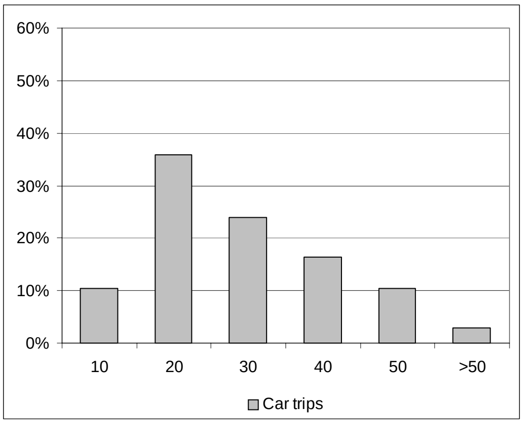
Thurgau 6 weeks (n=230, 102 regular car drivers)



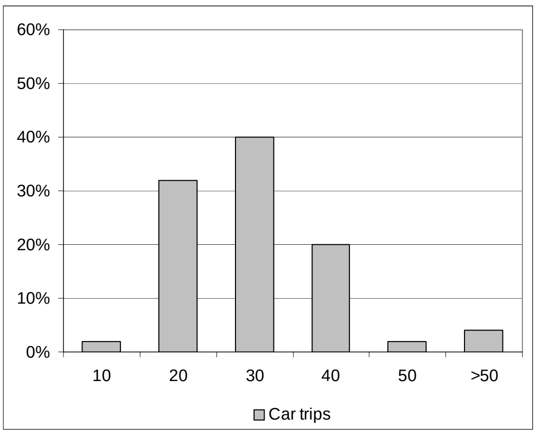
Uppsala 5 weeks (n=144, 32 regular car drivers)



Borlänge (n=67 car drivers)



Copenhagen (n=50 car drivers)



Study	Mean	St. Dev.
All trips		
Uppsala	24.2	11.3
Mobi*drive*	24.4	8.8
Thurgau	28.2	9.2
Regular car driver car trips		
Uppsala	19.2	9.8
Mobi*drive*	19.9	6.8
Thurgau	22.3	8.4
Borlänge	25.1	12.2
Copenhagen	25.6	10.4

Number of trips - Number of locations

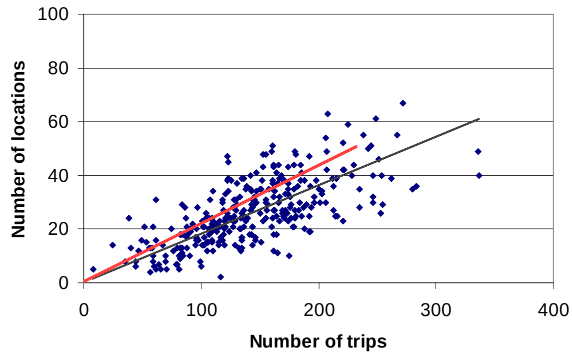
The ratio of trips to unique locations (see discussion above) was previously unknowable, as cross-sectional surveys cannot provide a credible estimate of this parameter. The available long-term travel data now permit an insight into this aspect of spatial choice behaviour. If the number of unique locations grows consistently with the number of trips, then variety seeking, for its own sake, becomes a credible explanation of these choices.

Figure 6 represents the corresponding ratios for the data sets analysed. It is interesting that the ratios are rather similar. The ratio varies in a narrow band, approaching about five trips to one unique location over time[6]. The GPS observations deviate slightly from that figure indicating that the parameters of the clustering processes used to identify unique locations need to be re-considered for the observed trip ends. In the case of Copenhagen the parameters seem to ha-ven been chosen too tightly, while the reverse is true for Borlänge.

[6] This figure turns out to be the same for the travel diary data if the trips are stratified by mode of transport.

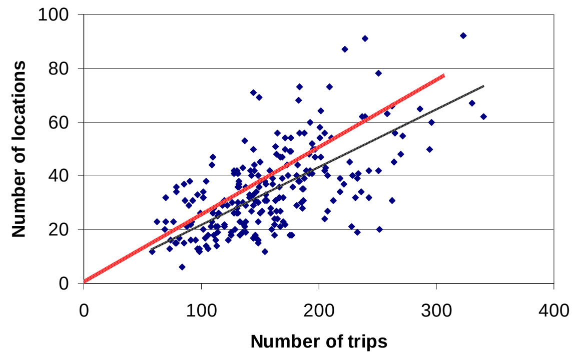
Figure 6 Relationship of number of trips and number of unique locations

Mobi*drive**



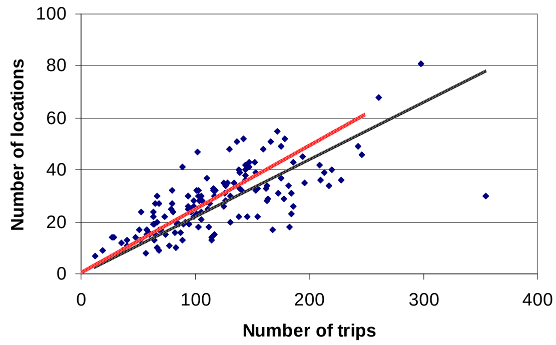
Unique locations: Mean: 26 Std.: 0.7 Skewness: 0.5

Thurgau*



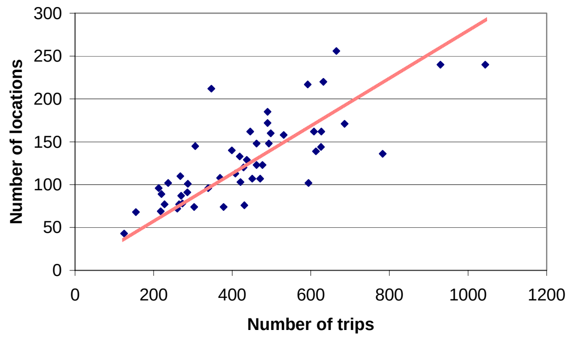
Unique locations: Mean: 35 Std.: 1 Skewness: 0.9

Uppsala*



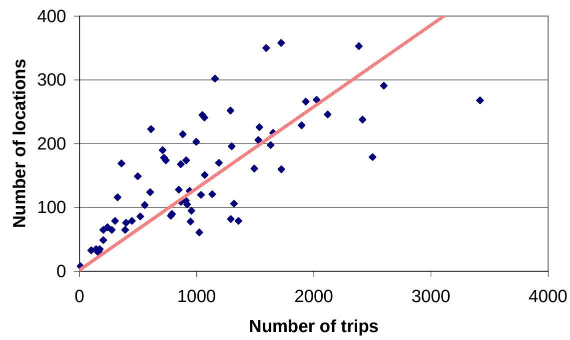
Unique locations: Mean: 28 Std.: 1 Skewness: 0.9

Copenhagen**



Unique locations: 129 Mean: 7 Std.: Skewness: 0.8

Borlänge**



Unique locations: Mean: 153 Std.: 11 Skewness: 0.5

		Slope	R^2
Mobi*drive*	All trips	0.18	0.47
	Car trips of regular car drivers	0.21	0,53
Thurgau	All	0.22	0.37
	Car trips of regular car drivers	0.25	0.48
Uppsala	All	0.22	0.40
	Car trips of regular car drivers	0.24	0.57
Copenhagen	Car trips	0.28	0.51
Borlänge	Car trips	0.13	0.39

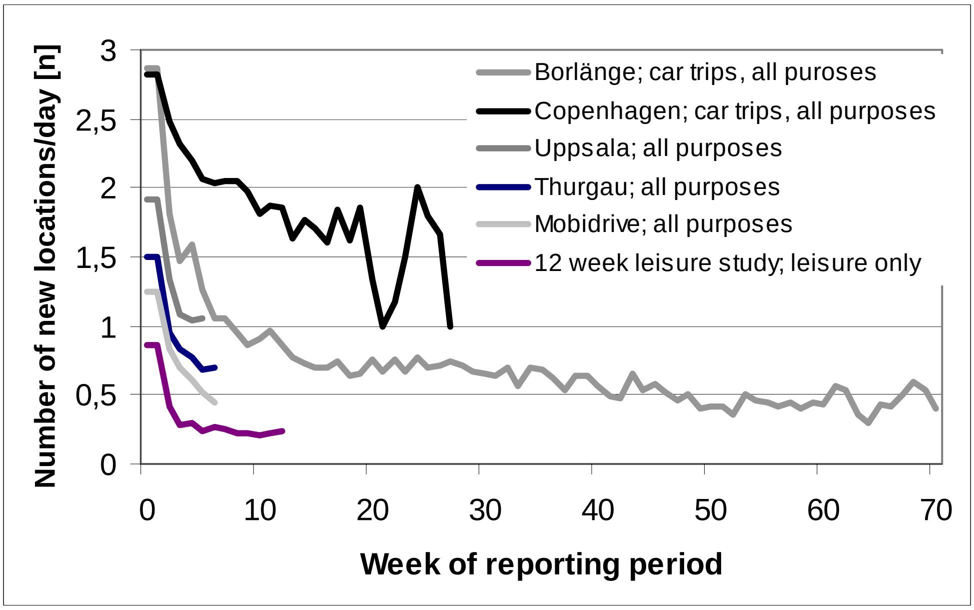
* Dots shown and dark trend line: All trips/locations of all respondents, red/grey trend line (no dots): Car trips/locations of regular car drivers
** All GPS-monitored car trips

Number of new locations over time

Earlier analyses of the temporal aspects of travel have shown that there is strong regularity in travel behaviour over the prolonged observation periods but against a background of substantial variability (e.g. Schlich, 2004 and references there). The question arises therefore if this is also true for the locations visited. Or in other words, do people have a restricted number of places they know and visit?

The following graph shows the average number of additional locations per day that had not yet been visited previously during the survey periods. There seems to be an almost unlimited number of places people know, because even after many weeks (Borlänge, Copenhagen) there are still places people travel to for the first time. In the long run, the Borlänge GPS observations shows an average of about 0.5 previously not observed locations added per day. Note that this refers only to the rather limited observation area of the Borlänge study.

Figure 7 Comparison of studies: New locations/day



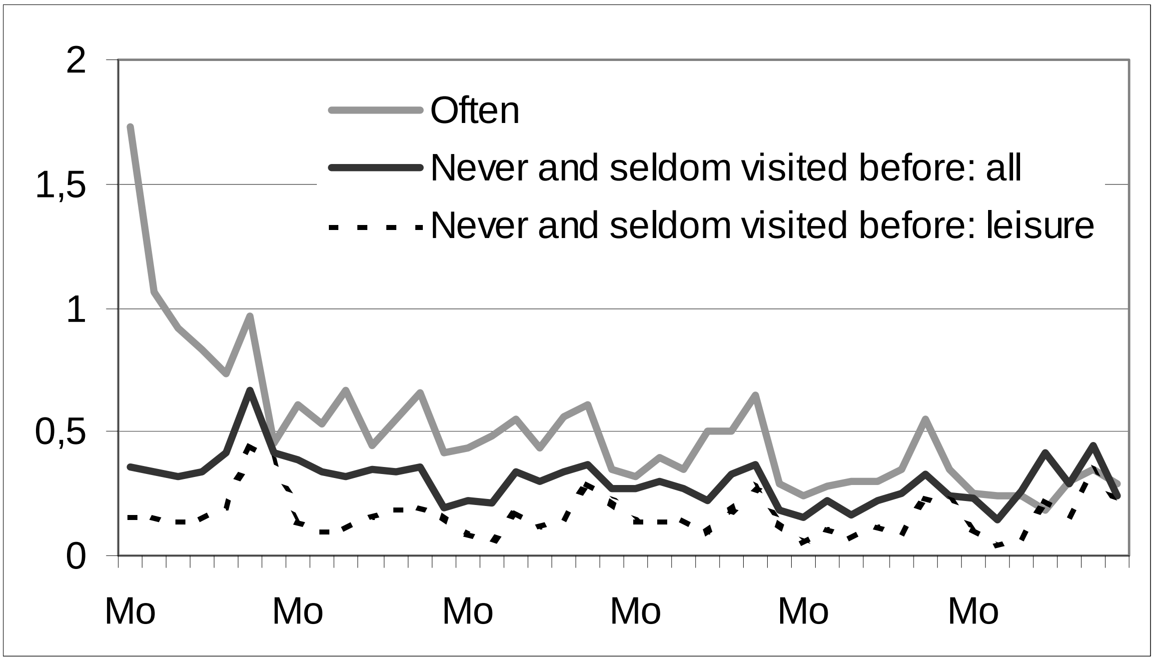
Of course, the term "new" or "novel" location is a misnomer, as people have some activity locations which they visit with very low frequency, such as for example the dentist. These locations are not genuinely new or previously unknown. In the two SVI surveys (Thurgau and

Leisure study), the respondents were asked to identify, if they had ever visited the place before, and if yes, how often.

Combining this with the previous analysis (Figure 8), it becomes clear that most of the "added" locations shown in the figure above are not genuinely new. Still, there is steady number of actually never before visited, truly new locations. In the Thurgau data, the mean of the latter number is 0.30 locations/day (Std.: 0.1) for all days and purposes over the six-week reporting period. The Saturday even shows a higher mean with 0.42 novel places visited (Std.: 0.13) whereas the Sundays yield an average below all weekdays with 0.26 (Std.: 0.08).

Leisure travel obviously contributes significantly to the amount of new locations discovered over time. On average, 53% of all previously never or only seldom visited locations are leisure places (dotted line in Figure 8). Similar results could be found in the SVI Leisure study. The mean for genuinely new locations (defined by post code and purpose) added per day and person over the twelve weeks of reporting was 0.14 (Std.: 0.08)

Figure 8 SVI Stabilität: Mean number of previously not observed locations per day and mobile person and share of actual visiting frequency



Share of trips to one location

Although people seem to have many places they visit for different activities, this does not mean that each place is visited with the same frequency. On the contrary, there is a small number of locations which is predominant for particular activities within the observation period. From a methodological but also from a planning point of view it seems interesting to know how many locations are necessary to know to describe a substantial part of a person's travel behaviour.

Figure 9 shows the average shares of non-home trips which are directed to the 10 most important unique locations identified. The cumulative share of for these first ten locations is about 80% of all trips in the travel diary surveys and between 40 to 60% in the GPS observations. Given the fact, that in total about 40% of all trips are home-directed (e.g. Mobi*drive*: 42%, Thurgau: 37%, Borlänge: 34%), this proves that over longer periods daily life is notably concentrated at few places only.

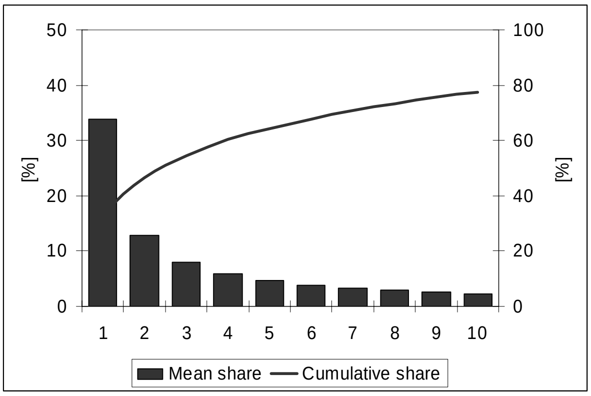
Furthermore, there is inequality within the set of relevant out-of-home locations concerning the amount of travel which is related to them. The Lorenz curve and the Gini coefficient which are developed analogous to Figure 9 are used here as indicators for this imbalance.

The Lorenz curve plots the cumulative share of total travel absorbed by the ten most important locations ordered from the most important to the least important one. If all locations absorb the same amount of travel, the Lorenz curve would be a straight diagonal line (line of equality). If there is any inequality, the Lorenz curve falls below this line. The total amount of inequality can be summarized by the Gini coefficient, which is the ratio between the area enclosed by the line of equality and the Lorenz curve, and the total triangular area under the line of equality. The Gini coefficient may take values between 0 (total equality) and 1 (total inequality).

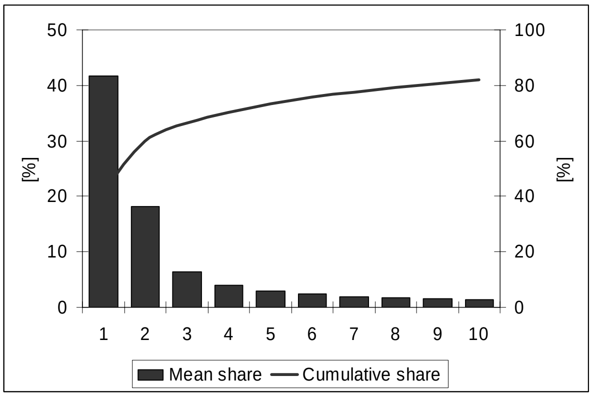
Here, the Gini takes a value of about 0.3-0.4 which is sign for considerable disparity. This is mainly due to the fact that the most important location behind home attracts in average a large share of trips with about 30% of the total non-home directed travel. This is relatively obvious considering that mainly work or education obligations still dominate daily activity and travel patterns. To sum up, there is strong evidence that locational choice is reasonably routinised with the dominance of few locations – in particular home and one second important core.

Figure 9 Mean shares of trips to the ten most frequented locations (excluding home)

Mobi*drive* (all trips)



Thurgau (all trips)



Uppsala (all trips)

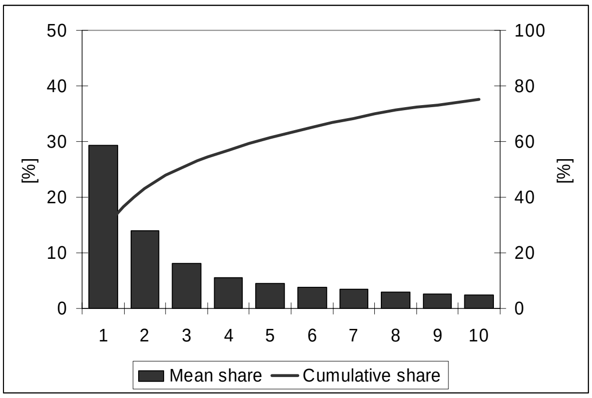
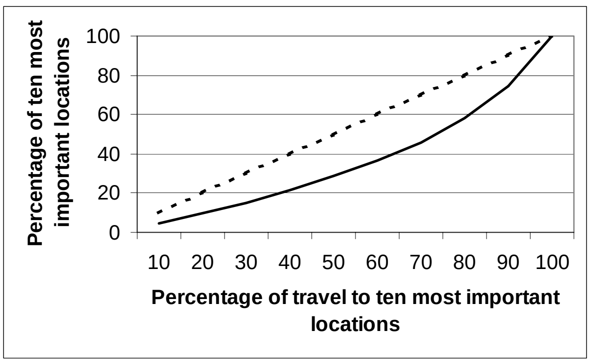


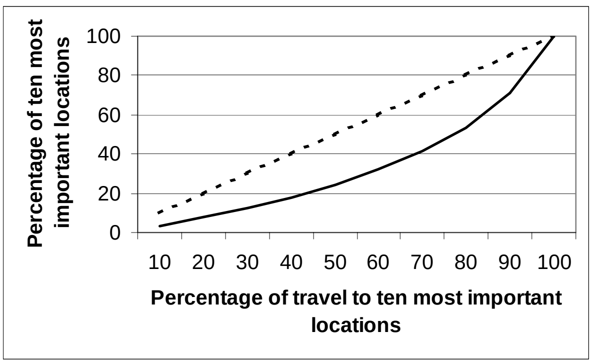
Figure 10 Lorenz curves and related Gini coefficients: Share of trips directed to 10 most frequented locations by person (excluding home)

Copenhagen AKTA



Gini = 0,31

Borlänge Rätt Fart



Gini = 0,38

Clustering locations

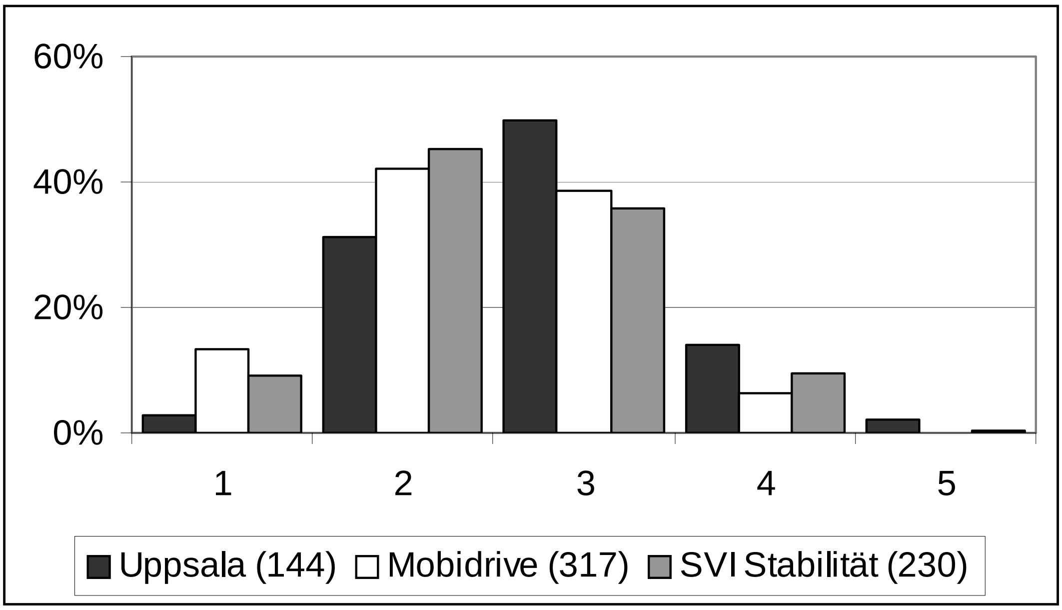
Another interesting question in locational choice is whether and how intensely travellers cluster their activities in subcentres of their daily activity space. There has been always clear evidence that the character of the activity space is determined by the requirements and fixed commitments of travellers and that most activity demand is satisfied at few locations in space. In order to minimise travel times and distances and due to the fact that activity opportunities (spatial supply) are organised in clusters, too, people tend to group their activity demand for example in the vicinity of home or in city centres.

Figure 11 shows that almost all respondents of the surveys presented here behave this way. Given a rather rough definition of a cluster, i.e. a common catchment radius of 1000m crow-fly distance, a minimum of 10% of all trips directed to the cluster and at least three unique locations associated with it, the majority of the travellers have at least one of such distinct centres of daily life[7]. There is an indication that the number of clusters seems to increase with the duration of the reporting period but never exceeds five even after up to 70 weeks of monitoring as in Borlänge.

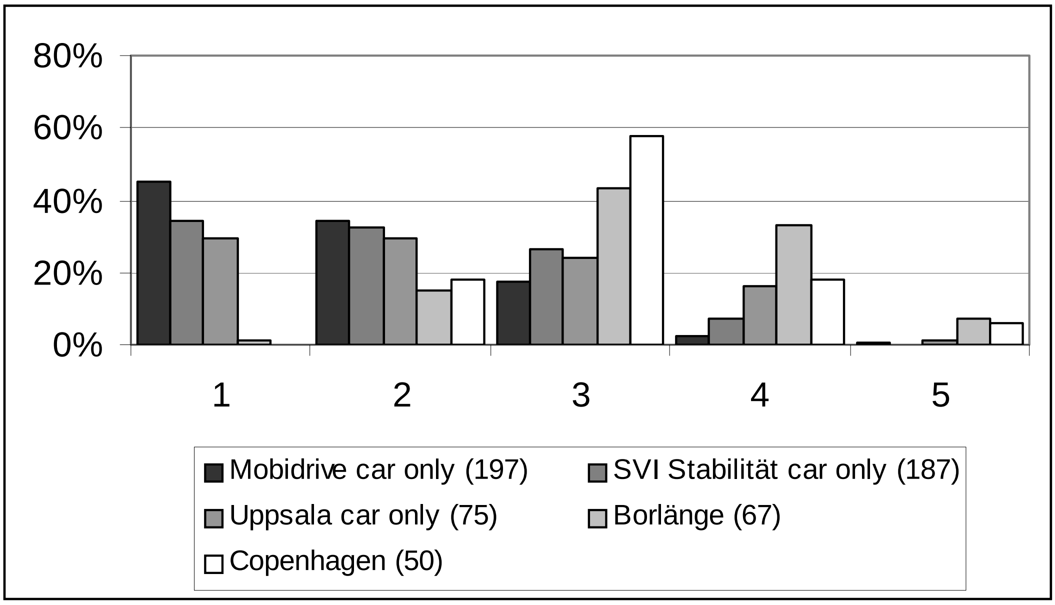
[7] The clusters were generated using a nearest centroid sorting cluster method (Anderberg, 1973) which is implemented in the SAS software package.

Figure 11 Number of spatial clusters[1]

Travel diary surveys, all trips



All surveys, car only trips



Clusters defined by: Catchment radius 1000m, minimum 10% of all trips in cluster, minimum three unique locations associated with cluster

Using the same definition of activity clustering, it becomes clear that clusters evolve to a large extent around the home location. This underpins the importance of home for one's activity patterns. About a half of all cluster centres, i.e. the core defined by the most important location in terms of visiting frequency, are home whereas other activity purposes are of only little importance (Table 2). It looks slightly different if one stratifies the samples by the occupation status of the respondents. For full-time workers, about a quarter of all defined cluster centres is work related. Nevertheless, that is no clear indication that the workplace and the surrounding area play a significant role for the efficient and distance minimising combination of work and the remaining activities.

Table 2 Internal structure of activity spaces: Activity cluster cores*

Purpose	Mobi*drive* all	Mobi*drive* Full-time	Thurgau all	Thurgau Full-time	Uppsala all	Uppsala Full-time
Home	55	57	43	42	44	44
Leisure	12	11	14	10	12	12
Work	11	24	15	22	18	25
School	8	1	8	11	0	1
Daily shopping	6	4	9	5	19	12
Private business	5	0	3	1	2	1
Long-term shopping	1	1	0	1	1	0
Serve passenger	1	1	4	4	2	3
Work related	1	0	4	4	0	0
Other	0	1	0	0	2	2

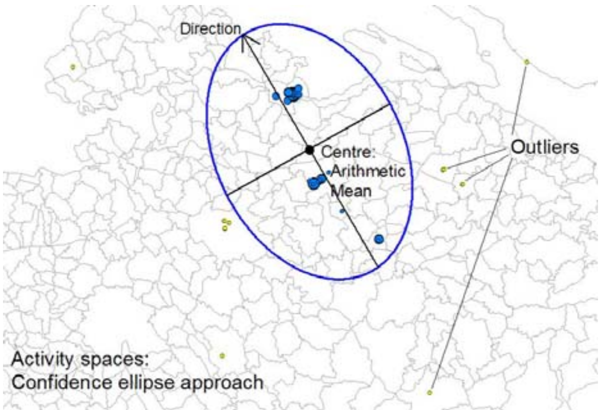
* Results only available for travel diary data as trip purposes have not yet been imputed for GPS observations

Continuous representation of human activity spaces: Confidence ellipses

Confidence ellipses – also called prediction interval ellipses – are an explorative method to investigate the relationship between two variables (bivariate analysis). They are often used for hypotheses testing and to detect outliers. Confidence ellipses are analogous to the confidence interval of univariate distributions defined as the smallest possible (sub-)area in which the true value of the population should be found with a certain probability (e.g. 95%). Similar methodological techniques to indicate space usage have long been used in habitat research (see Jennrich and Turner, 1969; Southwood and Henderson, 2000) as well as in the activity space oriented work of the 1970s UMOT project (*Unified Mechanism of Travel*) and subsequent studies (Zahavi, 1979; Beckmann, Golob and Zahavi 1983a; 1983b).

The basic mathematics and its application to activity space research are given in Figure 12. The size of the area is estimate of the activity space size and may be used to compare travellers or one respondent on different days of the week. The orientation of the ellipse is determined by the sign of the linear correlation coefficient between the coordinates x and y of the activity locations; the longer axis of the ellipse (if shown) is the regression line.

Figure 12 Confidence ellipse approach – application to activity spaces and mathematical basics



Covariance matrix S of all points

$$S = \begin{pmatrix} s_{xx} & s_{xy} \\ s_{yx} & s_{yy} \end{pmatrix}$$

Defined by

$$s_{xx} = \frac{1}{n-2}\sum_{i=1}^{n}(x_i - \bar{x})^2$$

$$s_{yy} = \frac{1}{n-2}\sum_{i=1}^{n}(y_i - \bar{y})^2$$

$$s_{xy} = s_{yx} = \frac{1}{n-2}\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})$$

Dots show location and intensity of observed activity locations of one respondent

Ellipse size A

$$A = 6\pi|S|^{\frac{1}{2}}$$

To achieve a more realistic representation of human behaviour, modifications of the concept are desirable. In the following, the home location is taken as a substitute for the arithmetic mean point in the calculation of the covariance matrix. This stresses the importance of home for daily travel and uses a real-world location instead of the artificial mean point of the chosen locations. Other modifications, such as the amalgamation of two ellipses – covering the activity locations related to home and those of a further peg (work etc.) – are possible (see Holzapfel, 1980 for early applications).

For the comparative analysis of these surveys from different spatial reference frames, concessions had to be made to create comparable sub-samples. We concentrate the analysis of confidence ellipses on local trips in order to avoid biases caused by the extent of the survey or observation area (Table 3). Certainly, this limits the maximum size of the ellipses which can be accepted though for comparative purposes. In addition to that, the travel diary data sets are stratified again by the intensity of car usage: all trips (all respondents/all modes), car trips of respondents with car trips and car trips of regular car drivers (more than 50% car trips reported).

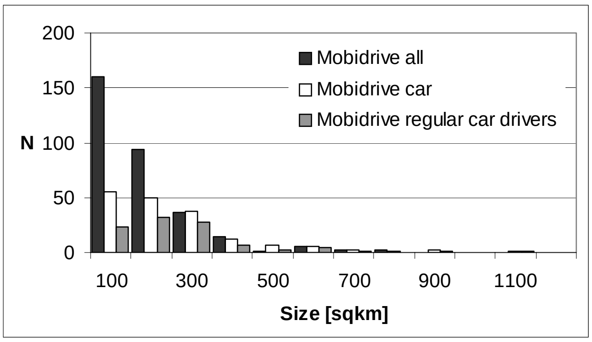
Table 3 Definition of local trips

Survey	Definition
Mobi*drive*, Thurgau, Uppsala, Copenhagen	Trips not further than 20 km from home location
Borlänge	All trips; monitoring was limited to the town of Borlänge and surrounding area (20 km radius around the centre of town).

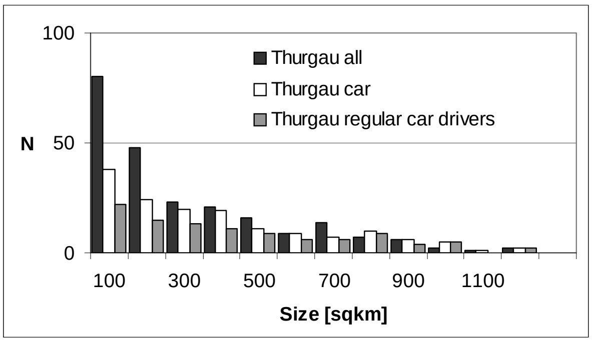
The pattern of activity space sizes for all surveys follows a common trend. In contrast to the number of trips and locations which is almost normally distributed over the population the distribution is strongly left skewed (similar to a Gamma like distribution). That is true for both types of surveys, i.e. the travel diary data including all modes and purposes as well as the car based GPS observations.

Figure 13 Distribution of activity space sizes measured by confidence ellipses

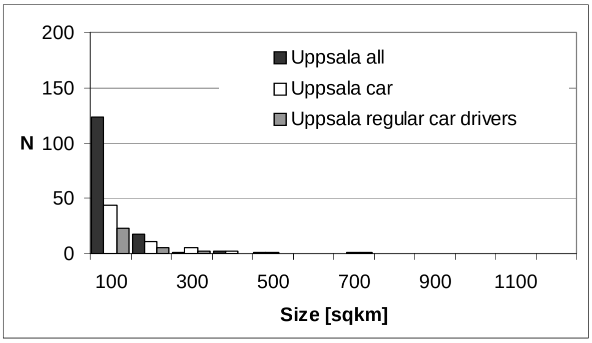
Mobi*drive*



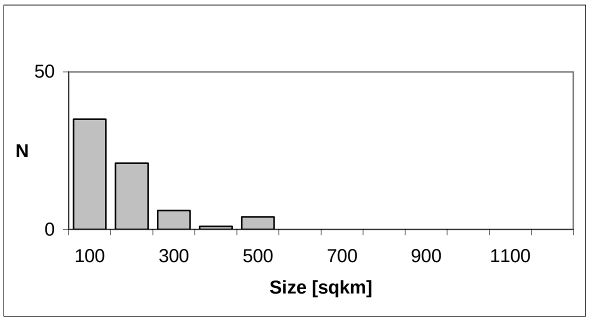
Thurgau



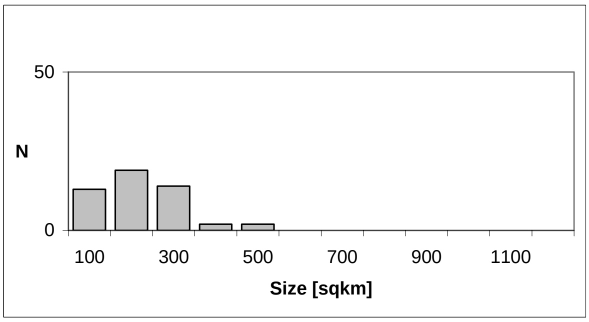
Uppsala



Borlänge



Copenhagen



* All local out of home trips; 95% confidence ellipse; centroid = home location

Having a look at the characteristics which describe the shown distributions (Table 4), no perfectly clear picture emerges. Nevertheless, a few assumptions could already be made here: The size of the activity space grows with availability and usage of the car which is shown by the difference in the means for the travel diary data. This could have been expected and will be confirmed in the concluding analysis of variance. Second, the clustering of activities in groups of nearby locations as shown above has a slightly negative impact on the size of the activity space. This is natural as the confidence ellipse is by definition a measure of dispersion. The finding is at least true for the all-mode analysis for Mobi*drive* and Thurgau data with correlations of –0.1 with the cumulative share of trips to the five most important locations.

Table 4 Confidence ellipses: Characteristics and correlation with amount of travel

Survey	N	Mean	Std.	Med.	Skewness	Correlations*		
						N trips	N locations	Concentration of trips in 5 locations**
Mobi*drive* all respondents /all trips	316	133	122	99	2.3	-	-	-0.1
Car only	173	200	173	151	2.0	-	-	-
Car trips of regular car drivers	99	212	169	177	2.3	-	-	-
Thurgau all respondents /all trips	229	267	255	176	1.3	-	-	-0.1
Car only	152	342	286	278	0.9	-	0.2	-
Car trips of regular car drivers	102	382	297	311	0.7	-	-	-
Uppsala all respondents /all trips	144	54	65	31	3.3	-	-	-
Car only	65	104	114	64	2.2	-	-	-
Car trips of regular car drivers	32	94	112	69	3.5	-	-	-
Borlänge GPS trips	67	131	106	99	1.8	-0.3	-	-0.6
Copenhagen GPS trips	50	174	100	155	1.0	-0.3	-0.4	-

* (Pearson) Correlation shown is significant at the 0.05 level (2-tailed); unweighted

** Cumulative share of trips to the five most important locations

One of advantages of the multi-months GPS observations is the possibility to compare the size of the activity spaces over longer periods. The stability of activity spaces was already analysed for Mobi*drive* (Srivastava and Schönfelder, 2003) but with no definite results for long-term stability. This was mainly due to the limited length of the reporting period which does not allow to define sufficiently long continuous sub-periods.

For the Borlänge and the Copenhagen data set this is possible. As a straightforward analysis approach, the monitoring period was divided into (non-overlapping) three-weeks intervals for which each size of the confidence ellipse was calculated. A period of two to three weeks could be identified in the Mobi*drive* studies earlier as a duration of relative stability for temporal phenomena of travel behaviour (Schlich and Axhausen, 2003).

The investigation of the similarity of two consecutive sub-periods shows that there is a remarkable degree of stability. In average, the indicators number of trips, number of unique locations and size of the activity space of two successive periods of a test driver correlate considerably with each other – up to 0.7 (Table 5).

Table 5 Correlation coefficients between selected activity space characteristics of two consecutive sub-periods (3 weeks)

			"Last period"		
			Number of trips	Number of unique locations	95% confidence ellipse, local trips
"This period"	Number of trips	Bor.	0.71		
		Cph.	0.66		
	Number of unique locations	Bor.		0.62	
		Cph.		0.62	
	95% confidence ellipse, local trips	Bor.			0.62
		Cph			0.52
N (sub-periods of monitoring)		Bor.	849	849	849
		Cph	252	252	252

(Pearson) Correlation shown is significant at the 0.05 level (2-tailed).

Activity space and personal characteristics

Following the descriptive analysis of the measurements, which in itself is providing information never provided before, the paper will finally link the measurements to the socio-demographic and life-style variables describing the respondents. An analysis of covariance is performed to test selected personal attributes for their effects on activity space structure and size. These are the number of locations, the concentration of trips in few unique locations, the clustering of activities and the size of the local activity space indicated by the size of confidence ellipse (Table 6). Due to the limitation of socioeconomic attributes for the drivers in the GPS observations, the analysis focuses on few co-variables which are sex, age, occupation status, intensity and availability of car usage and home location. Besides, the combined effect of car usage and agglomerational type(s) are added. For Mobi*drive* at least, further relationships were tested elsewhere (Schönfelder and Axhausen, 2002; Schönfelder and Axhausen, 2003b).

Table 7 shows the significance probabilities for each effect of an analysis of variance based on the SAS General Linear Model (GLM) framework. The shown significance level (<0.05) implies that the variable has a significant main effect on the dependent variable or there is a crossed effect for the two defined combinations of classification variables.

The models have a poor fit in most the cases. Besides, there is no clear explanatory trend detectable given the limited number of co-variables and the small sample sizes for the regular car drivers data and the GPS observations. A consistent pattern is the effect of car usage and full-time occupation for most of the given activity space characteristics. Where urban density (i.e. potentially better conditions for a more efficient organisation of daily life and avoiding car usage) is a covariable like in the Thurgau and Borlänge survey, interactions with the activity space size becomes evident. Further investigations need to concentrate on both, a better harmonisation of the data bases and an imputation of the missing or unsinsufficient sociodemographic data, especially for the GPS observations.

Table 6 Variables

Variables	Description	Survey particularities
Locations	Mean number of locations/week	
Concentration	Cumulative share of trips directed to 5 most important reported locations	
Clustering	Number of real cluster over entire reporting period	
Area	Size of 95% confidence ellipse of local trips analogous to description above	
Co-variables		
Sex	Female = 0, Male = 1	
Age	Age classes < 30, >= 30 < 40, >= 40 < 50, >= 50 < 60, > 60	
Fulltime	Occupation status Fulltime worker yes/no	
Car	Intensity of car usage Non-regular = 0, Regular = 1	Mobi*drive*, Thurgau, Uppsala: More than 50% of all trips made by car Borlänge: >10000 km yearly kilometrage or more than 50% of trips stated to be made by car Copenhagen: >10000 km yearly kilometrage or 300 weekly kilometrage or frequency of car usage to work per week >= 5
Urban	Household location type 1: Agglomerational type Urban/Non-urban	Mobi*drive*, Copenhagen all households
Density	Household location type 2: Potential supply of facilities and shops in the vicinity of home	Mobi*drive*, Uppsala: all households, Thurgau: all households in the town of Frauenfeld, Borlänge: all households in inner-Borlänge, Copenhagen: all households in Greater Copenhagen

Table 7 Summary of the GLM results by data source, activity space indicator and model: significance level

Study	Mobi*drive* all trips of all respondents				Thurgau all trips of all respondents				Uppsala all trips of all respondents			
Variable	Locations	Concentrat.	Clustering	Area	Locations	Concentrat	Clustering	Area	Locations	Concentrat.	Clustering	Area
Sex		■					■					■
Age									■			
18<30	■		■									
>= 30 < 40					■	■					■	
>= 40 < 50					■	■		■				
>= 50 < 60	■			■	■	■		■		■		
> 60		■		■	■	■	■		-	-	-	-
Fulltime	■	■	■					■		■		
Car	■	■		■				■		■		■
Urban	-	-	-	-	-	-	-	-	-	-	-	-
Density	-	-	-	-			■	■	-	-	-	-
Car * Urban	-	-	-	-	-	-	-	-	-	-	-	-
Car * Density	-	-	-	-			■	■	-	-	-	-
N	316	309	316	316	230	230	230	229	144	144	144	144
R^2	0.13	0.15	0.10	0.14	0.25	0.34	0.14	0.35	0.10	0.13	0.08	0.15

cont.

Study	Mobi*drive* car trips of regular car drivers				Thurgau car trips of regular car drivers				Uppsala car trips of regular car drivers				Borlänge car trips				Copenhagen car trips			
Variable	Locations	Concentrat.	Clustering	Area	Locations	Concentrat.	Clustering	Area	Locations	Concentrat.	Clustering	Area	Locations	Concentrat.	Clustering	Area	Locations	Concentrat.	Clustering	Area
Sex			■														■			■
Age																				
18<30																	-	-	-	-
>= 30 < 40															■					
>= 40 < 50			■		■	■		■								■				
>= 50 < 60				■		■	■	■												
> 60					-	-	-	-	-	-	-	-					■	■		
Fulltime			■				■	-			■					■	-	-	-	-
Car	-	-	-	-	-	-	-	-	-	-	-	-	■	■						
Urban	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Density	-	-	-	-			■	■	-	-	-	-				■				
Car * Urban	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-				
Car * Density	-	-	-	-	-	-	-	-	-	-	-	-								
N	100	100	100	100	102	102	102	102	32	32	32	32	67	67	67	67	50	50	50	50
R^2	0.07	0.07	0.17	0.15	0.09	0.15	0.23	0.33	0.21	0.24	0.39	0.17	0.24	0.36	0.31	0.60	0.34	0.23	0.08	0.26

■ Significance level <0.05, RSS is weighted by number of reported weeks; Type I sum of squares relevant for significance test; - indicates that there is only one category in respective class

5 Outlook

The long-duration surveys and GPS studies provide new insights into the structure, size and stability of human activity spaces. Although, the results at the group level which were presented at the end of the analysis still lack explanatory expressiveness, this synopsis is a useful base for a deepening discussion about the theories on locational choice. The six data sets employed here cover a wide range of experiences in terms of spatial structure of the study areas and of the socio-demographic characteristics of the participants. While the samples were not drawn to be strictly representative of the population – Uppsala excepted – and while they have not be reweighted to a common socio-demographic profile, the comparison highlights common trends.

The distribution of the number of trips approaches a normal distribution in the long term. The left-skewed distribution typically observed in one or two day diaries is misleading for dynamic analyses. The associated distribution of local activity spaces, which was defined in line with the Borlänge study as trips in a radius of 20km of the home, is in comparison left skewed. The anchors are provided by a small number of regularly visited locations, which dominate the destination choice. These locations form the core of locations clusters, but the number of identifiable clusters (1000 m radius; 10% of trips; 3 unique locations) is small; two or three for most travellers. Contrary to previous assumptions the work place is not such a prominent core. The share of clusters around workplace is low, even for full time workers.

While the share of the most prominent locations is large, travellers do add new locations to their choice set regularly. The rates of innovation estimated here are 0.30 locations per day across all purposes and 0.15 locations per day for leisure purposes. If this question is not asked, then one can use the rate of newly observed locations as a proxy for the true rate of innovation. Theoretically these two should coincide after a very long observation period, but the experience so far indicates, that for all practical purposes the rate of newly observed locations will be about two time higher than true rate of innovation after about three to four weeks of observation (diary).

In spite of the clustering, there seems to be a stable ratio of one unique location to five trips. Together with the steady rate of location innovation this indicates that variety seeking is a strong motivation for the travellers.

Implications for transport analysis and modelling

The results presented here affect modelling practise in two ways: first, current model formulation and estimation at the aggregate level needs to be reconsidered; second, the next generation of microscopic dynamic simulation models should be built to reflect this empirical evidence.

Disaggregate choice models, even if used in aggregate contexts, normally ignore the choice set issue. It is assumed for simplicity and convenience, that all alternatives are known to the traveller. In the case of destination choice modelling this leads to the assumption, that a random sample of locations can be used as the choice set for the estimation. The results here have made it clear, that in the case of destination choice this should lead to biased parameter estimates, as the alternatives of which the traveller is aware are limited, clustered and very unevenly known. The observed choices reflect therefore tradeoffs, which cannot be replicated by a random sample of alternatives; at least it is unlikely that they do. The challenge of defining choice set generators needs to be addressed in future work

The generally low correlations between trip numbers, number of unique locations and activity space size with the socio-demographics of the travellers raises the issue of the appropriateness of current market segmentations for transport models (see also Schlich, 2004 –for similar conclusions drawn from the time-domain of behaviour).

The vision of dynamic microsimulation models of travel behaviour is based on the idea of (household) activity scheduling over longer periods, say a week in the first instance. (see Axhausen and Gärling, 1992, Ettema and Timmermans, 1997 or Meister, Frick and Axhausen, 2004 for overviews). In the previous discussion of these ideas the question of learning has often been neglected. The results shown here demonstrate that inertia caused by the spatially limited mental maps of the travellers needs to be incorporated into such models from the start. Otherwise, they will not be able to reconstruct the behavioural patterns observed correctly. There is a tendency in these microsimulation models to use choice models derived from crosssectional data. Given the strength of observed variety seeking behaviour, this is not appropriate. The models need to be formulated to allow for the benefit of the new, as such, which requires an awareness of what is known. In the same vein, the models will need to allow for forgetting (change of fashion) to reflect the shifts in spatial choices over time.

The long-duration surveys and observational studies have opened up new avenues of research and are starting to provide new insights into travel behaviour. The results presented here are only the start to work, which will help to provide better based simulation model of travel behaviour.

6 Acknowledgements

We would like to thank the providers of data which was not originally collected or processed at the Institute for Transport Planning and Systems:

The Uppsala travel diary data was kindly supplied by Prof. Susan Hanson, Clark University, Worcester.

The GPS data set *Rätt Fart* was made available for travel behaviour analysis by transport psychologists from the universities of Dalarna and Uppsala (Sweden) after 2002. We also would like to thank Geostats/Atlanta for their help with cleaning and post-processing of the data.

The Centre for Traffic and Transport of the Technical University of Denmark kindly provided the Copenhagen AKTA data.

7 References

Anderberg, M.R. (1973) *Cluster Analysis for Applications*, Academic Press, New York.

Axhausen, K.W. (2002) A dynamic understanding of travel demand: A sketch, *Arbeitsbericht Verkehrs- und Raumplanung*, **119**, IVT, ETH, Zürich.

Axhausen, K.W. (2003) Social networks and travel: Some hypotheses, *Arbeitsberichte Verkehr- und Raumplanung*, **197**, IVT, ETH Zürich, Zürich.

Axhausen K.W. and T. Gärling (1992) Activity-based approaches to travel analysis: conceptual frameworks, models, and research problems, *Transport Reviews*, **12**(4) 323-341.

Axhausen, K. W., S. Schönfelder, J. Wolf, M. Oliveira and U. Samaga (Forthcoming) 80 weeks of GPS-traces: Approaches to enriching the trip information, *Transportation Research Record*.

Axhausen, K. W., A. Zimmermann, S. Schönfelder, G. Rindsfüser and T. Haupt (2002) Observing the rhythms of daily life: A six-week travel diary, *Transportation*, **29** (2) 95-124.

Beckmann, M.J., T.F. Golob and Y. Zahavi (1983a) Travel probability fields and urban spatial structure: 1. Theory, *Environment and Planning A*, **15** (5) 593-606.

Beckmann, M.J., T.F. Golob and Y. Zahavi (1983b) Travel probability fields and urban spatial structure: 2. Empirical tests, *Environment and Planning A*, **15** (6) 727-738.

Brown, L.A. and E.G. Moore (1970) The intra-urban migration process: a perspective, *Geografiska Annaler*, **52**(B) 1-13.

Buhl, T. and P. Widmer (2004) SVI Forschungsarbeit 2001/514 Stabilität des Verkehrsverhaltens, Feldbericht, Büro Widmer/ IVT, Frauenfeld and Zürich.

Dijst, M. (1999) Two-earner families and their action spaces: A case study of two Dutch communities, *GeoJournal*, **4** (3) 195-206.

Draijer, G., N. Kalfs and J. Perdok (2000) Global Positioning System as data collection method for travel research, *Transportation Research Record*, **1719**, 147-153.

Dürr, H. (1979) Planungsbezogene Aktionsraumforschung – Theoretische Aspekte und eine Pilotstudie, *Beiträge der Akademie für Raumforschung und Landesplanung*, **34**, Hannover.

Ettema D. and H. Timmermans (1997) Theories and models of activity patterns, D. Ettema and H. Timmermans (eds) *Activity-based Approaches to Travel Analysis*, 1-36, Pergamon, Oxford.

Fotheringham, A.S., C. Brunsdon and M. Charlton (2000) *Quantitative Geography*, Sage, London.

Giddens, A. (1984) *The Constitution of Society*, Polity Press, Cambridge.

Golledge, R.G. and R.J. Stimson (1997) *Spatial Behavior*, The Guilford Press, New York/London.

Hägerstrand, T. (1970) What about people in regional science?, *Papers of the Regional Science Association*, **24** (1) 7-21.

Hanson, S. and K.O. Burnett (1982) The analysis of travel as an example of complex human behaviour in spatially-constraint situation: Definition and measurement issues, *Transportation Research A*, **16** (2) 87-102.

Holzapfel, H. (1980) Verkehrsbeziehungen in Städten, *Schriftenreihe des Instituts für Verkehrsplanung und Verkehrswegebau*, **5**, Technische Universität, Berlin.

Horton, F. and D.R. Reynolds (1971) Effects of Urban Spatial Structure on Individual Behaviour, *Economic Geography*, **47**, 36-48.

Jennrich, R.I. and F.B. Turner (1969) Measurement of non-circular home range, *Journal of Theoretical Biology*, **22**, 227-237.

Lill, E. (1889) Die Grundgesetze des Personenverkehrs, *Zeitschrift für Eisenbahnen und Dampfschiffahrt*, 2 (35) 697-725.

Lenntorp, B. (1976) Paths in space-time environment: a time geographic study of possibilities of individuals, *Lund Studies in Geography, Ser. B. Human Geography*, **44**, Department of Geography, The Royal University, Lund.

Lynch D. (1960) *The Image of the City*, MIT-Press, Cambridge.

Maier, J., R. Paesler, K. Ruppert and F. Schaffer (1977) Sozialgeographie, Westermann, Braunschweig.

Marble, D.F., P.O. Hanson and S. Hanson (1972) Field Operations and Questionnaires, Household Travel Behavior, Study 1, Department of Human Geography, State University of New York, Buffalo.

Meister, K., M. Frick and K.W. Axhausen (2004) A GA-based household scheduler, *Abeitsberichte Verkehrs- und Raumplanung*, **241**, IVT, ETH Zürich, Zürich.

Nielsen, O. A. and G. Jovicic (2003) The AKTA Road Pricing Experiment in Copenhagen, paper presented at the 10th International Conference on Travel Behaviour Research, Lucerne, August 2003.

Ohnmacht, T. (2004) Soziale Netze und persönliche Mobilität: Grundlagen für eine empirische Erhebung, *Arbeitsbericht Verkehrs- und Raumplanung*, **250**, IVT, ETH Zürich, Zürich.

Schlich, R. (2004) Verhaltenshomogene Gruppen in Längsschnitterhebungen, Dissertation, ETH Zürich, Zürich.

Schlich, R. and K. W. Axhausen (2003) Habitual travel behaviour - evidence from a six week travel diary, *Transportation*, **30** (1) 13-36.

Schlich, R., B. Kluge, S. Lehmann and K. W. Axhausen (2002) Durchführung einer 12-wöchigen Langzeitbefragung, *Stadt Region Land* **73**, 141-154.

Schlich, R., A. Simma, P. Rüssli and K. W. Axhausen (2002) Entwicklung eines Tagebuchs zur Erhebung von Freizeitverhalten, *Arbeitsbericht Verkehr- und Raumplanung*, **121**, IVT, ETH, Zürich.

Schlich, R., S. Schönfelder, S. Hanson and K.W. Axhausen (2004) Structures of leisure travel: Temporal and spatial variability, *Transport Reviews*, **24** (2) 219-238

Schönfelder, S. (2003) Between routines and variety seeking: The characteristics of locational choice in daily travel, paper presented at the 10th International Conference on Travel Behaviour Research, Lucerne, August 2003.

Schönfelder, S. and K.W. Axhausen (2002) Measuring the size and structure of human activity spaces – the longitudinal perspective, *Arbeitsbericht Verkehrs- und Raumplanung*, **135**, Institut für Verkehrsplanung und Transportsysteme (IVT), ETH Zürich, Zürich.

Schönfelder, S. and K.W. Axhausen (2003a) On the variability of human activity spaces, in M. Koll-Schretzenmayr, M. Keiner und G. Nussbaumer (eds.) *The Real and Virtual Worlds of Spatial Planning*, 237-262, Springer, Heidelberg.

Schönfelder S. and Axhausen K. W. (2003b) Activity spaces: Measures of social exclusion? *Transportation Policy,* **10** (4) 273-286.

Schönfelder, S. and U. Samaga (2003) Where do you want to go today – More observations on daily mobility, paper presented the 3rd Swiss Transport Research Conference, Ascona, March 2003.

Schönfelder, S., K.W. Axhausen, N. Antille and M. Bierlaire (2002) Exploring the potentials of automatically collected GPS data for travel behaviour analysis – A Swedish data source, in J. Möltgen, and A. Wytzisk (Eds.) GI-Technologien für Verkehr und Logistik, *IfGIprints*, **13**, Institut für Geoinformatik, Universität Münster, Münster, 155-179.

Silverman, B. W. (1986) *Density Estimation for Statistics and Data Analysis*, Chapman and Hall, London.

Southwood, T.R.E. and P.A. Henderson (2000) *Ecological Methods*, Blackwell Science, Oxford.

Srivastava G. and S. Schönfelder (2003) On the temporal variation of human activity spaces, *Arbeitsberichte Verkehrs- und Raumplanung*, **196**, Institut für Verkehrsplanung und Transportsysteme (IVT), ETH Zürich, Zürich.

Vägverket (2000) ISA Intelligent Speed Adaptation, Vägverket, unpublished, Vägverket, Borlänge.

Wolf, J., S. Schönfelder , U. Samaga and K.W. Axhausen (2004) 80 weeks of GPS-traces: Approaches to Enriching Trip Information, Paper presented at the 83rd Annual Meeting of the Transportation Research Board, Washington, D.C., (in press).

Zahavi, Y. (1979) The “UMOT” Project, *US Department of Transportation RSPA-DPB*, **20-79-3**, US Department of Transportation, Washington.