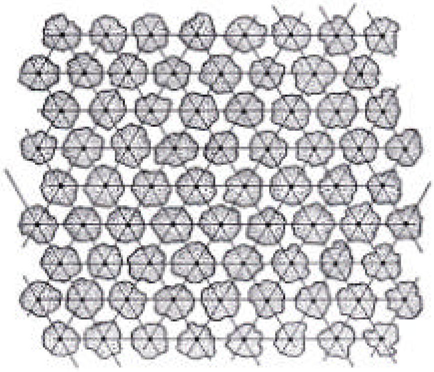
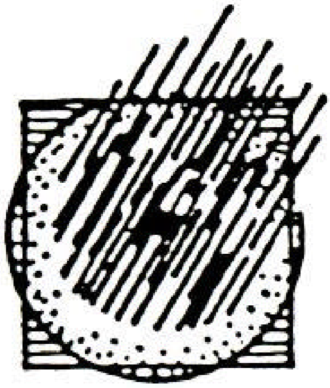
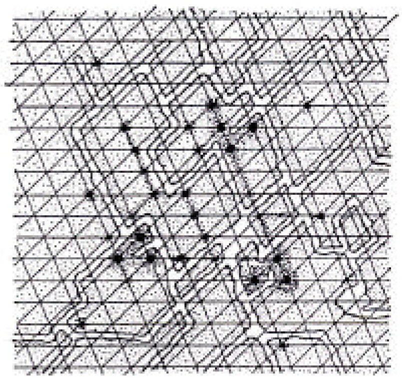
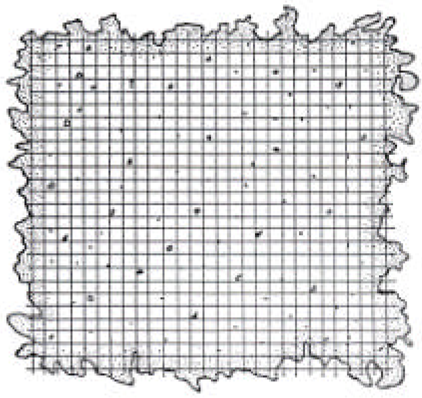

Some notes on space, location and travel behaviour

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Some notes on space, location and travel behaviour

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Abstract

The unique 6-weeks longitudinal Mobi*drive* travel data not only offers opportunities to analyse the temporal structures of individual travel behaviour but also for the investigation of spatial aspects of mobility.

This conference paper focuses on results concerning the character of the travellers' action spaces as well as the importance of location for the spatial scope of travel behaviour.

Keywords

Travel behaviour – space – location – Mobi*drive* – Swiss Transport Research Conference - STRC 2001 – Monte Verità

Front page illustration taken from: Banerjee, T. and Southworth, M. (1990) City Sense and City Design, Writings and Projects of Kevin Lynch, The MIT Press, Cambridge/Massachusetts.

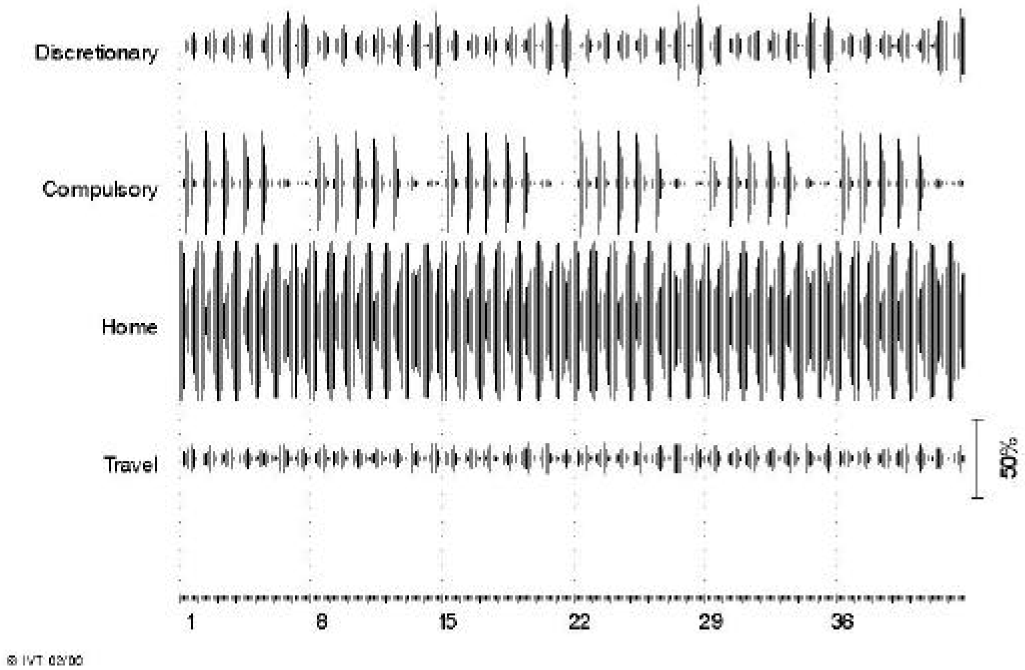
1. Complexity of travel behaviour

Designing transport strategies which meet the common political aims for the environment and the society requires a deeper insight into the routines of individual travel behaviour. In an era of almost complete motorisation of the society and historically low costs for mobility, travel behaviour of persons and households turns out to be temporally and spatially complex. For the optimisation of forecasts as well as policies facing this complexity, it seems crucial to direct one's attention to phenomenons such as variability, periodicity or dynamics of behaviour in time and space. The occurrence of a wide range of different lifestyles, the growing autonomy in the organisation of the daily life and the consequences for personal mobility suggest to intensify especially the analysis of intra-personal variability and stability of mobility.

1.1 Detecting temporal structures: The Mobi*drive* survey

With the implementation of a continuous six-week travel diary as part of the German research project Mobi*drive*, a unique data set of long-term individual travel behaviour is now available for analysis (see Axhausen, Zimmermann, Schönfelder, Rindsfüser and Haupt, 2000). The explorative investigation of the data and the initial stochastic modelling of the periodicity of daily life confirm the assumptions of a widely routinised character of travel behaviour (see Figure 1). This apparent stability is supplemented by a considerable background variability caused by the travellers' spontaneity as well as by the complexity of external factors shaping our behaviour (see Axhausen *et al.*, 2000; Schlich, König and Axhausen, 2000; Schönfelder and Axhausen, 2000a; b).

Figure 1 Aggregated time use structures for the Karlsruhe sample: Shares of activity categories of overall time use in percent



1.2 The next step: Spatial analysis

The longitudinal structure of the six-week Mobi*drive* data set offers not only unique opportunities to analyse the temporal structure of travel behaviour over the reporting period, there are also interesting points of departure for additional spatial explorations. Most of the 40.000 reported trips of the main study could be geocoded which means that we are now able to map the long-term travel behaviour of the survey participants by addresses or co-ordinates. The actual research background for the geocoding was the generation of shortest origin-destination relations with the model based travel times in order to estimate destination-, route- and mode-choice models (see STRC contribution of König and Axhausen). In an initial approach to the spatial aspects of travel behaviour (Schönfelder and Axhausen, 2001), the Mobi*drive* data was analysed to describe the structure and the extent of individual action spaces (see Horton und Reynolds, 1971; Klingbeil, 1978 for the basic methodology). The investigation proved a relatively routinised character also on the spatial level of individual mobility and remarkable results concerning the individual use of urban space depending on the socio-demographic attributes of the travellers (see next chapter for details).

This paper adds a further perspective of mobility, the accessibility of activity locations, i.e. the polarisation within the urban structure and its impact on the travel behaviour of persons and households. Realising the large number and variety of recent studies in this field of analysis (see e.g. Hanson and Schwab, 1987; Lundqvist, 2000; Naess, 2000), it seems worthwhile, though, to investigate the Mobi*drive* data in this respect. Its unique longitudinal data structure is leading to a high degree of validity in the analysis of intra-personal travel behaviour. The character of this paper is descriptive and initial, offering opportunities for future more detailed work.

2. Travel behaviour explored: Indicators of spatial scope

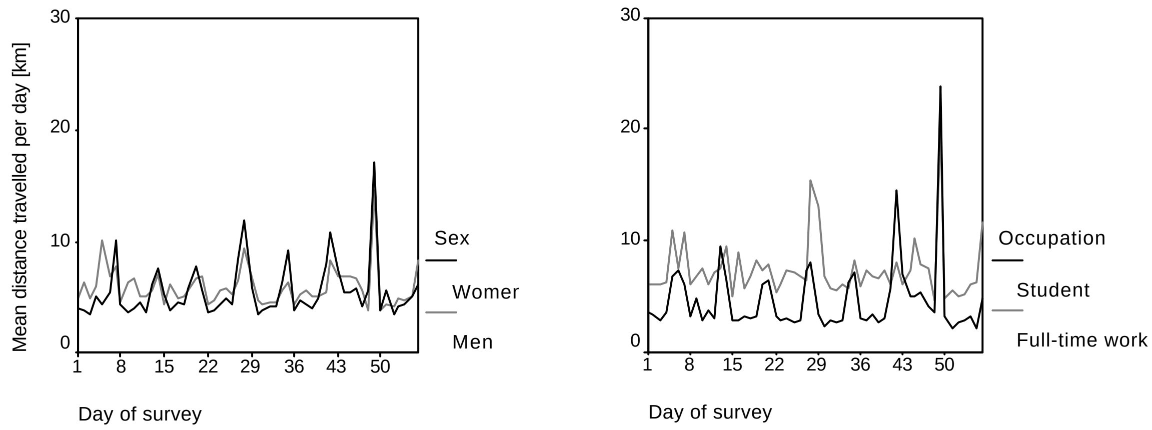
Describing the mentioned complexity of travel behaviour requires suitable indicators for the amount of travel as well as for the multifaceted structures of behaviour over time. There has been a substantial development of such measures especially in the field of activity-based analysis which considers travel in a wide context of time and space (see Jones and Clarck, 1988; Huff and Hanson, 1990). Transportation planning usually considers travel behaviour by a wide range of simpler parameters covering person as well as trip-specific characteristics (Herz, 1984). The most often used parameter are

- the share of immobile persons, e g. the share of the population which does not leave the house (during the reporting period)
- the total number of trips per day
- the total daily travel time
- the average trip duration by mode
- the average speed per trip / by mode
- the average trip distance by mode
- the total distance travelled per day.

In an analysis approach directed towards a spatial perspective, especially the latter two are of interest. They indicate the size of the urban area used to satisfy the demand for certain activities respectively the degree of mobility leading to a more or less intensive consumption of energy for transport.

The following figures give the total daily distance travelled per day over the course of the survey period for different socio-demographic groups. It may be seen that the total amount of travel is influenced on the one hand by the personal and especially by the occupational characteristics of the travellers, and on the other hand by the temporal (weekly) structure activity performance. The weekends show a significant increase in the average of total distance travelled for all groups presented. Considering the still dominating weekly work-leisure-pattern for the weekdays and the weekend, this increase is mainly caused by leisure and shopping activities during the non-working days.

Figure 2 Mean total daily travel distances for different groups



2.1 Measuring and visualising individual action spaces

Compared to the straightforward indicators mentioned above, the *action space* concept is based on a broader determination of space-time behaviour. In a wide sense, the activity space comprises both those locations of which a traveller has personal experience, as well as the knowledge space of locations, of which the traveller has second hand experiences through family, friends, books, films or other media (see e.g. Horton and Reynolds, 1971; Dürr 1979; Gould and White, 1986). In the following, action space is defined as a part of the cognition space whose particular locations the traveller does not only know but also visit frequently (Dürr, 1979). This definition is closely connected to the principles of space-time-geography which considers travel behaviour as an outcome of a complex system of individual and external constraints (Hägerstrand, 1974).

In order to analyse the internal structure of action spaces, quantitative methods were applied (see Fotheringham, Brundson and Charlton, 2000). The distribution of activity locations in space is considered as a point cloud whose inherent structure is influenced by different hierarchies and intensities.

Dispersion and scope (visualisation)

First, the standard distance d_s is taken as an indicator for the dispersion of the realised action spaces over the 42-days period. It is given by the root mean square distance of each point in

$$d_s^2 = \sum \frac{(x_i - \hat{m}_x)^2 + (y_i - \hat{m}_y)^2}{n}$$

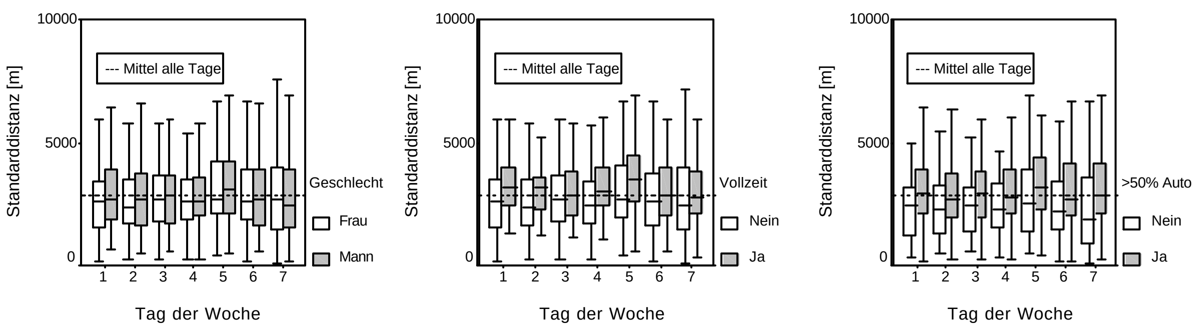
the data set from the mean centre (*centre of gravity*)

with

(x_i, y_i)	Coordinate of a visited acitivity lovation
$(\hat{m}_x, \hat{m}_y)$	Weighed arithetic mean
n	Number of all visited acitivity locations of a person

Figure 3 indicates the extent of the dispersion of action spaces for different groups over the days of a week. The boxplots allow a clear representation of the most important statistics and a comparative assessment of the extent of dispersion. The box of which the inner line shows the median, is limited by the first and the third quartile of the distribution. The whiskers are lines extending from each end of the box to show the extent of the rest of the data. They extend to the smallest and largest observations within 1.5 times the inter-quartile range (IQR). Outliers and extremes which are defined as data with values beyond the ends of the whiskers are not shown here.

Figure 3 Levels of dispersion of action spaces of different groups ; Karlsruhe sample only; all intraurban and regional trips (app. 96% of all reported trips); Mean of all persons and days: 2881 m; standard deviation 1146 m



Sex – grey: male

Occupation – grey: full-time work

Car use intensity– grey: > 50% of distances travelled

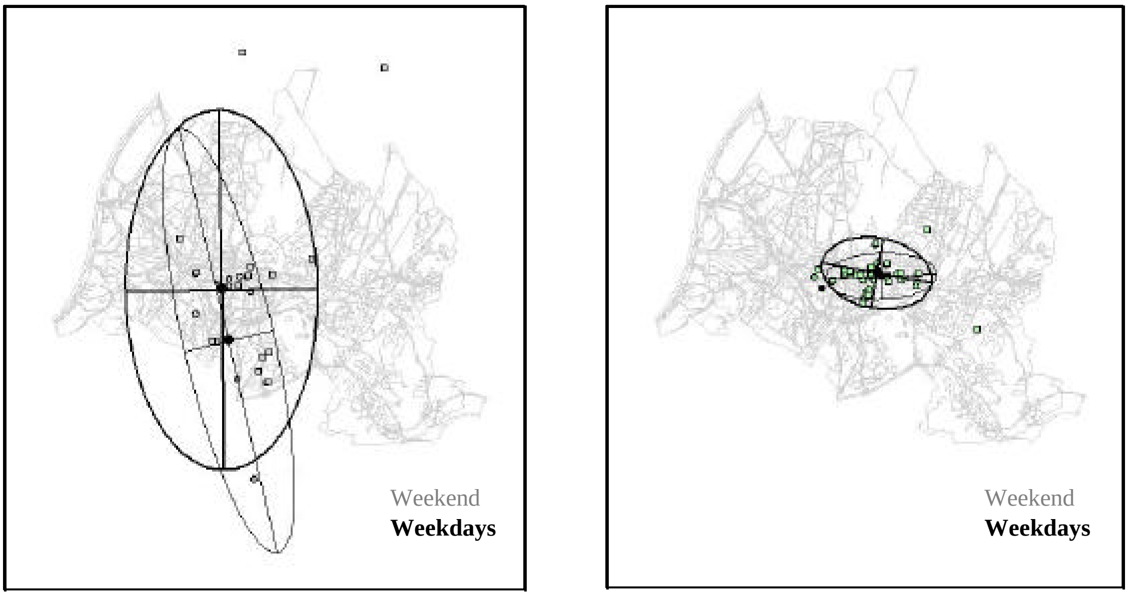
All in all, the degree of dispersion varies quite significantly by group and day. Again, an extensive use of urban space may be seen at the weekend and especially on Fridays for all groups considered. There are also considerable differences between full-time workers and others as well as between those using the car intensively (more than 50% of all distances travelled) and the rest of the sample. Parallelly, the availability of a car and the demand for using it due to the tendency of increasing distances between the household location and the work place tend to increase the dispersion of visited locations.

An interesting approach of visualising as well as estimating action spaces is the application of travel probability fields (Beckman, Golob and Zahavi, 1983a; b) as wells as home ranges based on concepts originally developed in ecology (Southwood and Henderson, 2000). The latter methodology based on the work of Jennrich and Turner (1968) should be introduced here and will be used as a behavioural indicator in the next chapter.

Home ranges are spatio-statistical concepts to analyse the competition and density effects of individuals, the assessment of resources and related problems. Applied to (human) activity analysis, they act as an indicator for the intensity of use of space by the travellers. Home ranges of individuals are generally considered to be the smallest sub-regions which account for a specified proportion of their total utilisation of space. In the Jennrich-Turner approach, areas of (non-circular) eliptic shape are calculated which represent this share of the total use – based on the visited activity locations reported. The ellipses are computed by the covariance matrix of all ordered capture points (activity locations) of a person. The underlying distributional assumption for the allocation of capture points in space is a bivariate normal distribution which is in line with attempts made in urban geography to describe the spatial distribution of activity patterns (Moore, 1970). The Jennrich-Turner methodology is fully integrated in the ARCVIEW extension *Movement* (Hooge, 2000) which was developed to ease the work within the field of habitat research.

Figure 4 shows a comparison of the action spaces of two individuals based on the Jennrich-Turner concept. The analysis included all activity locations (plotted as dots) in a radius of about 10 km around the city centre of Karlsruhe. The centre of the ellipse is the arithmetic mean of all observed locations, which is apparently near to home due the importance of the household's location as centre for activity performance.

Figure 4 Areas of intensive use of space represented by Jennrich-Turner home ranges



Full-time employed, 45 years, car, 3-person-household, one child

Female student, 21 years, car, single household

The calculated areas cover 95% of the individual space utilisation for the given persons (ARCVIEW *Movement* allows to set different probability limits depending on the analysis' aim). In other words, the probability of visiting locations outside the ellipse is small due to the reported distribution of localities in space. One can observe significant differences between the chosen persons, but also on the intra-personal level by weekdays and weekend. This is evident for the size of the fields, the location of the action spaces within the city structure and the main axis of the ellipse. The direction of the major axis is predominantly effected by the available supply of transportation systems such as the inner-urban route network.

Cluster structures

The spatial variability of travel behaviour appears relatively constant over the reporting period of six weeks - at least if travel is characterised by the activity location only. It could be found that only two to four main locations (including home) cover more than 70% of the overall trips. Even if only leisure trips with a an apparent discretionary structure are analysed, there is no significant difference. The two most strongly frequented destinations for leisure activities comprise approximately two third of all leisure travel, on average.

Those results show that the structural character of action spaces is dominated by few needs, self-commitments and obligations at certain fixed locations. It may be assumed that due to the travellers' strategies to minimise travel time and distances they build up spatial clusters around the household location and the most frequented other locations (e.g. work). Predominantly, those clusters are bipolar, leading to a mainly bipolar system travel demand between the travellers’ core localities.

Analysing the inner structure of such clusters within the reported action spaces of travellers may show which activities are performed within the adjoining area of the household location and which are spread over more distant parts of the urban area. For an initial approach, all activity locations were spatially categorised by means of a simple cluster analysis (Method: Disjoint Cluster Analysis (Anderberg, 1973)). Of a special interest is the household location cluster which is defined here as an area covering a radius of 1000m bee-line around the household’s locations. The 1000m distance to localities is believed to approximate the maximum walk distance from home.

Table 1 Share of activities performed in the household location neighbourhood; Basis: Karlsruhe sample; 103 persons; 1000m radius to household location

	Share of activities of this category [%]
Work	3
Professional business	6
Other	6
School	8
Long-term shopping	10
Drop off / pick up	13
Leisure	25
Private business	32
Daily shopping	38
Home	100
Share of all activities over six weeks	~ 59

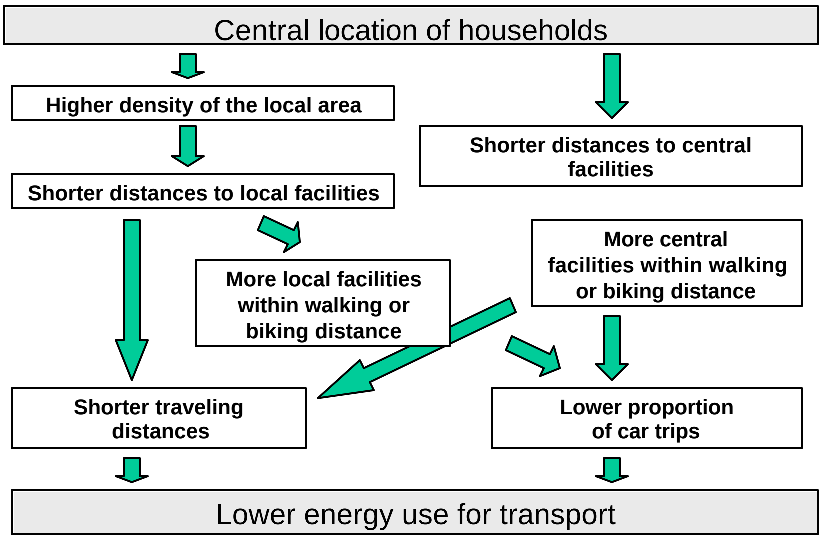
The results show that the household location dominates as the centre for most of all activities performed (app. 59% of all trips destinations are within the household cluster). A significant share of the daily shopping, personal business and leisure activities are localised in the adjacent area of home, whereas most travellers' compulsory activities, such as work and school are performed further away from home.

2.2 Location, accessibility and travel-behaviour

The extensive suburbanisation within most of the urban areas has raised the question of how to spatially allocate land-uses and activity locations in order to develop an efficient as well as less energy consuming transport system. The ongoing urban sprawl has not only caused a considerable dependency of car use which is leading to high levels of energy consumption and emissions but also to monotonous land-use structures with poor attractiveness of the public space in some parts of our cities.

Apart from the socio-demographic characteristics of the traveller as well as their household contexts, the spatial attributes and service quality of the main activity places (household location, work place etc.) and their adjacent areas are assumed to have a measurable impact on individual travel behaviour. In planning theory, especially the centrality of such places in respect to the city centre is believed to have considerable effects on mobility – based on the assumptions of most spatial interaction models. Hence, land use strategies focussing on the allocation of housing in central areas of the agglomerations play a major role in tackling the suburbanisation problems mentioned above as well as tools to decrease energy consumption caused by motorised travel (see Figure 5 for an example of a feedback system).

Figure 5 Location, mobility and the environment



Source: Adopted from Naess (2000) 6

A simple operationalisation of the centrality (accessibility) concept

The uniqueness of the Mobi*drive* data provides interesting points of departure to analyse the location – travel behaviour interaction on the local level. Parallel to earlier work who did a similar investigation with multiday survey data from Uppsala/Sweden (Hanson and Schwab, 1987), we defined individual accessibility indices describing the centrality of the household location and other localities important for the travellers. This seems necessary in order to relate each individual's location to his or her reported travel pattern. In this initial analysis, simple accessibility measures were chosen which may be categorised mainly by the concept of *relative accessibility*. Here, accessibility is purely defined by the distance of one locality to others, i.e. by the physical separation of tow places (see Pirie (1979) for a review of accessibility measures). The assumption behind is the simplifying conception of a mono-centric urban structure with highest attractiveness in the city centre with most leisure, shopping and business facilities decreasing quality of service towards the edge of the agglomerations. The relative location to the city centre was obtained by calculating the distances (*bee-lines*) between the household location respectively one further activity location and a certain central point of interest.

Summarising the approach applied, the relationships (correlations) between the travel behaviour on the intra-urban level (i.e. all trips within a radius of 10km around the city centre) defined by

- reported travel distances
- mode choice
- extent of action space

and the accessibility aspects such as

- the relative location of household, i.e. distance to city centre
- the distance between home and a second most strongly visited location

were explored. The interactions are indicated by (bivariate) Pearson correlations and are presented for the city of Karlsruhe – considering reported activity locations within a radius of about 10 km around the city centre only (!).

Results

As can be seen from the figure and the tables presented below, especially the separation of work places respectively the other second most visited activity location and home turns out to be considerably correlated with the distances travelled and especially the size of the (realised) action spaces of the travellers. In addition to that, there is also high correlation between the relative location of the household within the city structure and some of the travel behaviour indicators. Especially those people who live at the edge of Karlsruhe travel noticeably longer by motorised means of transport compared to the residents of more central parts of the city. In contrast to that, the mode share of the more sustainable slow modes such as walking or cycling is higher in the core city compared to the outer parts, which proves that the proximity to and the amount of facilities in the central areas encourages people to make more trips by foot or bike.

Figure 6 Example of location - travel relationship (Karlsruhe sample, n=145)

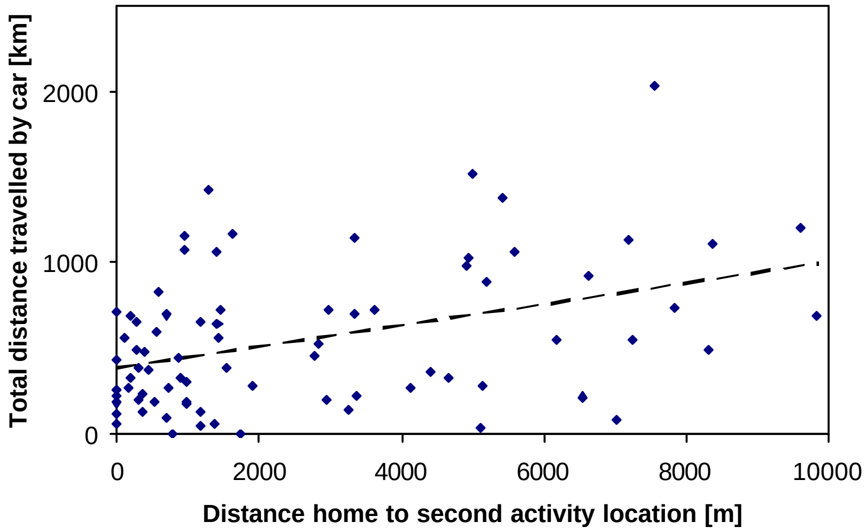


Table 2 Urban structure and travel behaviour: Correlation coefficients (a)

		Indicators of travel behaviour and action space			
		Total distance travelled	Total distance travelled by car	Share of distances travelled by car	Share of car trips (number)
Indicators of urban form / centrality	Distance home to city centre	-	0.19 *	0.20 *	0.25 **
	Distance second most important activity location to city centre				
	Work	-	0.31 *	0.27 *	0.26 *
	Other	-	0.23 *	0.24 *	0.32 **
	Distance home to second most important activity location (all)	0.46 **	0.40 **	0.17 *	0.34 **

- Correlation is not significant
* Correlation is significant at the 0.05 level (two-tailed)
** Correlation is significant at the 0.01 level (two-tailed)

Table 3 Urban structure and travel behaviour: Correlation coefficients (b)

		Indicators of travel behaviour and action space		
		Share of distances travelled by public trans.	Share of public transport trips (number)	Share of slow modes trip (walk/bike) (number)
Indicators of urban form / centrality	Distance home to city centre	-	-	-0.18 *
	Distance second most important activity location to city centre			
	Work	-	-	-
	Other	-	-	-
	Distance home to second most important activity location (all)	-	-	-0.37 *

- Correlation is not significant
* Correlation is significant at the 0.05 level (two-tailed)
** Correlation is significant at the 0.01 level (two-tailed)

Table 4 Urban structure and travel behaviour: Correlation coefficients (c)

		Indicators of travel behaviour and action space	
		Size of Jennrich-Turner home-range (42 days)	Dispersion of action space (*Standard Distance*)
Indicators of urban form / centrality	Distance home to city centre	0.43 **	0.43 **
	Distance second most important activity location to city centre		
	Work	0.50 **	0.48 **
	Other	0.35 **	0.47 **
	Distance home to second most important activity location (all)	-	-

- Correlation is not significant
* Correlation is significant at the 0.05 level (two-tailed)
** Correlation is significant at the 0.01 level (two-tailed)

All in all, the correlations remain moderate on this level of the analysis. This proves not only the initial character of the chosen indicators of accessibility and behaviour, but also the entirely intra-urban perspective of the investigation with excluding the regional travel level. Finally, the structure of the sample with only city of Karlsruhe based households has effects on the found inter-relationships. This is especially apparent with the fact that we could not find any significant relationship between the centrality of workplace or household location and the share of public transport trips. There would be certainly different results for larger agglomerations or if households from the surrounding suburbanised districts of Karlsruhe were chosen. Nevertheless, we could confirm that higher densities (caused by higher distances of locations from the city centre) are related to more nonmotorised travel and especially to less disperse realised action spaces which may be interpreted as a more sustainable mobility style for those living in the core of the city.

3. Conclusions and outlook

The Mobi*drive* database allows to visualise and measure time – space interrelations from a new perspective: The longitudinal basis of the survey offers opportunities to represent individual daily life mobility which exceeds the level of detail of studies concentrating on cross-sectional data. The findings provide an important insight into the temporal and spatial structure of travel demand, eventually leading to improved and tailor-made strategies and services supplied by policy, planning and public transport companies.

The shown results are still of an initial character. Future research work will especially concentrate on

- the advanced visualisation and measuring of activity spaces and travel densities by new and successfully applied methodology (e.g. urban fields by Angel and Hyman (1976)),
- the more detailed investigation of activity clusters, especially by socio-demographic groups,
- the refinement and the adjustment of more detailed accessibility indicators for the local analysis such as the availability of facilities,
- the definition of travel behaviour indicators which go further than distances travelled and mode choice (i.e. spatial structure of activity performance, dispersion, clustering etc.),
- the incorporation of accessibility measures into the existing Mobi*drive* model approaches covering the periodicity of daily life (see Schönfelder and Axhausen, 2000a; b).

From a policy and planning point of view, the presented results concerning space and travel behaviour underline important questions of current discussions:

- How to improve the opportunities to satisfy the activity demand in the household's neighbourhood and how to (re-)organise land-use patterns to allow people to behave mores sustainable?
- How to improve service supply in public transport and especially how to adopt service supply to the actually observed temporal and spatial structure of demand?

- How to control and influence individual travel demand by pricing policies and improved information?

4. References

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

Angel, S. and G.M. Hyman (1976) *Urban fields*, Pion, London.

Axhausen K.W., A. Zimmermann, S. Schönfelder G. Rindsfüser and T Haupt (2000) Observing the rhythms of daily life: A six-week travel diary, *Arbeitsbericht Verkehrs- und Raumplanung*, **25**, Institut für Verkehrsplanung, Transporttechnik, Strassen- und Eisenbahnbau der ETH Zürich, Zürich.

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

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

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

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

Gould, P. und R. White (1986) *Mental Maps*, Routledge, London.

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

Hanson, S. and M. Schwab (1987) Accessibility and intra-urban travel, *Environment and Planning A*, **19**, 735-748.

Herz, R. (1984) Verkehrsverhaltensänderungen 1976-1982, Ergebnisse einer vergleichenden Auswertung der KONTIV 76 und 1982, Institut für Städtebau und Landesplanung, Universität, Karlsruhe.

Hooge, P.N. (2000) Movement, Animal Movement analysis arcview extension, http://www.absc.usgs.gov/glba/gistools/animal_mvmt.htm, Alasca Biological Science Center, Glacier Bay.

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

Huff, J.O. und S. Hanson (1990) Measurement of habitual behaviour: Examining systematic variability in repetitive travel, in P.M. Jones (Hrsg.) *Developments in Dynamic and Activity-Based Approaches to Travel Analysis*, 229-249, Gower, Aldershot.

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

Jones P.M. and M.I. Clarke (1988) The significance and measurement of variability in travel behavior, *Transportation*, **15** (1) 65-87.

Kickner, S. (1998) Kognition, Einstellung und Verhalten, *Schriftenreihe*, **56**, Institut füt Verkehrswesen, Universität Karlsruhe, Karlsruhe.

Klingbeil, D. (1978) Aktionsräume im Verdichtungsraum, Zeitpotentiale und ihre räumliche Nutzung, Münchener Geographische Hefte, **41**, Verlag Michael Lassleben, Kallmünz/Regensburg.

Lundqvist, L (2000) Land Use and Travel Behaviour, Some modelling and Policy Perspectives, Paper presented at the International Conference Land Use and Travel Behaviour, Amsterdam, June 2000.

Moore, E.G. (1970) Some spatial properties of urban contact fields, *Geographical Analysis*, **2**, 376-386.

Naess, P. (2000) Urban structures and travel behavior: Experiences from empirical research in Norway and Denmark, Paper presented at the International Conference Land Use and Travel Behaviour, Amsterdam, June 2000.

Pirie, G.H. (1979) Measuring accessibility: a review and proposal, *Environment and Planning A*, **11**, 299-312.

Schlich, R., A. König und K.W. Axhausen (2000) Stabilität und Variabilität im Verkehrsverhalten, *Straßenverkehrstechnik*, **44** (9) 431-440.

Schönfelder, S. und K.W. Axhausen (2001) Mobidrive - Längsschnitterhebungen zum individuellen Verkehrsverhalten: Perspektiven für raum-zeitliche Analysen, presentation at CORP 2001, Wien, February 2001.

Schönfelder, S. and K.W. Axhausen (2000a) Periodizität im Verkehrsverhalten: Erste Ergebnisse mit Überlebenszeitmodellen, *Stadt Region Land*, **69**, 131-144, Institut für Stadtbauwesen, RWTH Aachen.

Schönfelder, S. und K.W. Axhausen (2000b) Analysing the rhythms of travel using survival analysis, *Arbeitsbericht Verkehrs- und Raumplanung*, **43**, Institut für Verkehrsplanung und Transporttechnik, Strassen- und Eisenbahnbau, ETH, Zürich.

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