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Stability in individual daily activity-travel-location patterns: A study using the Herfindahl-Hirschman Index

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ABSTRACT

Using Herfindahl-Hirschman Index and the Mobidrive and Thurgau six-week travel diary datasets this paper examines the stability of individuals' choices of their daily activity-travel-location combinations within multi-day period. The results show that the stability of individual activity-travel-mode-location combinations is highly influenced by the individuals' out-of-home commitments, the intra-household conditions and the availability and the accessibility of the activity locations. Different type of activity gives different pattern of stability. The stability of individual's daily activity-travel pattern is less correlated to the travel mode choice, but more to the individuals' commitments and obligations. The stability of mode choices is more related to the conditions or the accessibilities of the location of the activity, but not directly to the activity itself.

Keywords: Individual spatial-travel behaviour variability, activity-travel-mode-location combination, Herfindahl-Hirschman Index, six-week travel diary data.

1. STABILITY AND INNOVATION

Since the needs and the desires of individuals are not constant from day-to-day, an individual's travel pattern is neither totally repetitious nor new every day. There are some activities (e.g., eating, sleeping) that are repeated every day, but other activities such as shopping, personal business and social recreation are not necessarily repeated on a daily basis. Routine obligations, different needs on different days, commitments between household members, changes of travel environment, historical dependencies, individual's desire to vary their travel-activity patterns and to explore the available opportunities as well as a desire to spread their risks, transform the individual daily travel and activity pattern into a dynamic process with learning and change on the one hand and rhythms and routines on the other.

Many previous studies have shown that individual activity-travel behaviour varies from day-to-day and no one weekday can be identified as a representative day for the majority of individuals (Hanson & Huff, 1982, 1986, 1988; Huff and Hanson, 1986, 1990). However, participation in certain core activities, such as commuting, occurs with some degree of temporal regularity (Huff and Hanson, 1990). The level of repetition is different for different travel behaviour/socio-demographic groups and that the types of behaviours that are most repetitious differ for each group (Pas, 1987; Pas and Koppelman, 1986; Pas and Sundar, 1994). Recent studies with Mobidive six-week travel diary data (e.g. Schlich and Axhausen, 2003) also confirm the day-to-day variability of individual activity-travel behaviour. Many approaches have been adopted by researchers to describe this day-to-day variability. For example, Kitamura (1988) described the variation in travel as a stochastic process. He used Markovian processes to define the "latent" (representative) pattern and its recurrence structure. Wilson (1998) adopted the sequence alignment technique from molecular biology, which was later improved and expanded to the multi-dimensional case by Joh et al. (2001 a,b).

As an individual's activity engagement varies from day to day, it is reasonable to expect that the locations of his/her non-obligatory activities tend to vary over time. However, this is not the case. Huff and Hanson (1990) found a considerable persistence in the locations of the stops, even when they measure location very precisely. Hanson (1980) shows that over half of the individuals' stops were made at similar places. Based on the Mobidrive survey data, Schönfelder and Axhausen (2001) found that, although the maximum number of visited locations during six-weeks period reached 60, about 70% of all trips were made to the same 2-4 locations. Using data from Cedar Rapids, Iowa, Marble and Bowlby (1968) showed that, approximately, 75 % of all stops over the observation period occurred at repetitiously visited locations.

Hägerstrand (1970) and Lenntorp (1976) argue that the individual's possibilities of engaging in events and processes are constrained and depend on a set of circumstances linked to the individual as well as to his environment. Consequently, the level of spatial repetition of individual activity location is different for different travel behaviour/socio-demographic groups and that the types of locations that are most repetitious differ for each group. Marble and Bowlby (1968) found the repetitiveness of destination selection varies with the purpose of the trip. Based on panel data from Toronto, Buliung and Roorda (2006) demonstrate that different activity types and different travel mode produce different spatial repetition indexes. Susilo and Kitamura (2005) show that workers and students exhibit a stable spatial behaviour on weekdays, but that the weekday action spaces of non-workers and the weekend action spaces of all respondents are generally more varied in nature. Furthermore, Horton and Reynolds (1971) note even when a group of individuals had perfect information concerning opportunities and their locations, their mental maps and the perceptions of urban space would differ from each other.

This brief review indicates, that repetitiveness of spatial activity location depends on several factors, such as activity parameters (activity type, activity location and occurrence time), travel conditions (travel mode and trip parameters), and socio-demographic variables. The variability in the spatial, temporal, and modal constraints faced by the individual as well as different levels of satisfaction given by different locations contribute to the variability of daily activity location (Hanson, 1980). Understanding the stability of individual activity location choices within the variability of individual daily activity-travel-mode-location pattern over time provides insights for sustainable urban development as well as travel behaviour analysis. For example, one may examine how individuals either vary or repeat their location decisions overtime given changes in their travel mode. However, despite its importance, little attention has so far been paid to the spatial diversification due to the lack of suitable data sets and appropriate measurement approaches.

Employing the Herfindal-Hirschman index (HHI), regularly used in economics to look at the degree of concentration in markets, and multi-day travel diary datasets, this paper analyses how firm travellers are in their choice of activity attributes, defined here through two of four dimensions at a time: location, purpose, mode and timing; in particular: (1) activity type – location, (2) travel mode – location, (3) activity type – travel mode, and (4) activity type – departure time. The analyses use nine types of activities[1] and six types of mode[2]. The analysis uses the six-week travel diary surveys Mobidrive (Axhausen *et al*., 2002) and Thurgau 2003 (Löchl *et al*., 2005; Axhausen *et al*., 2007). The personal index values are

[1] The activities are pick-up/drop-off, private business, work related business, school, work, daily shopping, long-term shopping, leisure and other.

[2] The travel mode are walking, cycling, motorcycle, private vehicle, public transport and other.

analysed against the socio-demographics of the respondents to see, if the variability can be tied to particular attributes.

The next section offers a brief description of the Herfindahl-Hirschman Index and its implementation in this paper. The datasets used are described in Section 3. Following the description of the HHI values obtained, the exploratory analyses on the index values are provided in section 5. Regression models of the HHI values for several combinations of activity attributes are presented in Section 6. An analysis of the HHI values based on a classification of the respondents is provided in Section 7. Section 8 summaries the paper and suggests further work.

2. HERFINDAHL-HIRSCHMAN INDEX

In economics the Herfindahl-Hirschman Index (HHI), also known as Herfindahl Index, is a measure of the size of firms in relation to the industry and an indicator of the amount of competition among them. It is defined as the sum of the squares of the market shares of all firms in the market, which links to industry profits in the Cournot model (Cowling and Waterson, 1976). As such, it can range from 0 to 1 moving from a very large number of very small firms to a single monopolistic producer. Decreases in the Herfindahl index generally indicate a loss of pricing power and an increase in competition, whereas increases imply the opposite. The HHI has been adopted by the US department of Justice as a concentration measure for merger reviews. This method also has adopted by several other regulatory bodies in the US, such as Federal Reserve Board (banking), the Federal Energy Regulatory Commission (electricity), and the Department of Transport (aviation) (Lijesen et al., 2002).

In this paper, HHI is used to measure the repetitiveness of identical combinations of individual's spatial-activity-travel mode choices within the observed period. Higher HHI index values indicate higher degrees of repetition of identical combinations of activity, mode, location and travel choices (i.e. activity-location, mode-location, activity-mode, activity-departure time) within the six-week period. Lower index values show that the individuals tend to change/modify their combinations of activity/mode/location choices more frequently. In another words, higher index values are associated with habitual, change-resistant behaviour and lower index values with flexibility and variety-seeking. It is calculated as:

$$H_i = \frac{\sum_{j=1}^{n_{ij}} \left(h_{ij} \cdot t_{ij}\right)}{\sum_{j=1}^{n_{ij}} t_{ij}}, \text{ where } h_{ij} = \sum_{k=1}^{n_{ijk}} \left(s_{ijk}^2\right) \quad (1)$$

H_i is the standardized Herfindahl-Hirschman index value of individual i based on combination j and k (e.g. doing activity j at location k, pursuing activity j with mode k, etc.). h_{ij} is the Herfindahl-Hirschman Index value of individual i with choice j based on combination j and k. t_{ij} is number of the occurrences of j for individual i during the six-week period. n_{ij} is the number of alternatives j that occurred for individual i during the six-week period. s_{ijk} is the share of the combination jk of individual i during six-week period. n_{ijk} is the number of the combination jk that occurred for individual i during six-week period.

For example, if there are two individuals (A and B) executing same number of activities within an observed period: 5 shopping trips and 2 leisure trips (see Table 1). Although both of A and B made a same number of trip for each activity type, they made the trip to different numbers of location. Individual A shopped at three different locations and made all of the leisure trips to one location. On the other hand, individual B shopped only in one place, but varied the leisure trips' destinations. Due to this variety in activity-location combinations, as shown in Table 1, individual A has a lower HHI value, marking a more flexible traveller.

[Table 1 is about here]

The main virtue of the HHI is its simplicity, but it also has a weakness. It relies on defining the industry or market correctly for which the degree of competitiveness is open to question. Different levels of classification (e.g. type of activity, travel mode, spatial unit, timing, etc.) influence the results significantly. To avoid a bias interpretation in the analysis, this paper uses the most detailed classifications available at the datasets.

3. THE DATASETS

As mentioned above, this analysis uses the Mobidrive and Thurgau six-week travel diary surveys. The Mobidrive survey is a continuous six-week travel diary survey that was conducted in the German cities of Halle and Karlsruhe in the spring and autumn of 1999, funded by the German Federal Ministry of Education and Research. A total of 317 persons over 6 years of age from 139 households participated in the survey. Please see Axhausen *et al*. (2002) for a detailed description of the survey.

The 2003 Thurgau data set is also a continuous six-week travel diary survey, essentially an improved replication of the Mobidrive survey. However, in contrast to Mobidrive, the study area was chosen to be within the rural Canton of Thurgau in North-Eastern Switzerland. A total of 99 households with 230 members were recruited in the City of Frauenfeld and in three villages of the Seerücken between the Frauenfeld, Lake Constance and the Rhine. Only households with children older than 10 years were recruited. For detailed description of the 2003 Thurgau survey, please see Löchl *et al*. (2005) or Axhausen *et al.* (2007). Considering the location of its collection, Mobidrive is considered representative of urban travellers and the Thurgau dataset of rural travellers. The profiles of both dataset are shown in Appendix A.

4. THE HHI VALUES

The descriptive statistics of the calculated HHI values are given in Table 2 and the correlation of between HHI values from different attribute combinations are shown in Table 3. The distributions of HHI values among different activity and locations types are provided in Figure 1 – 4. The results in Table 2 show that individuals who live in urban areas (Mobidrive dataset) have a higher stability in their daily activity-travel mode-location combination than individuals from rural areas (Thurgau dataset). Nevertheless, Table 2 and Figure 1 – 4 show similar trends for both urban and rural residents.

[Table 2 is about here]

On average, activity-mode and location-mode combinations have very high HHI values (0.70 and 0.87 for urban residents and 0.68 and 0.86 for rural residents, respectively). The respondents are not very likely to modify their activity-mode or location-mode combinations. These building blocks are comparatively fixed. Especially for the location-mode combination, very high HHI values are also due the fact that, within the six-week period, 63% (for urban residents) and 69% (for rural residents) of the activity locations that were visited by the individuals were only visited once, resulting in a HHI of one, increases the overall average.

[Table 3 is about here]

The correlations between HHI values from different attribute combinations are shown in Table 3. The stability of the activity and location combinations is relatively strongly correlated with the stability of activity departure time. But, the correlation is low with the stability of the chosen travel mode in pursuing the activity and the stability between the activity location and travel mode. The stability of activity-travel mode choice is highly correlated with the stability of the location of the activity. This shows that the stability of individuals' spatial movement and their daily travel pattern is less correlated to the stability of the travel mode choice, but more to the individuals' commitments and obligations. The stability of mode choices is more related to the conditions/accessibilities of the location of the activity, but not directly to the activity type itself.

Figure 1 shows the HHI values by type of the activity. As expected, commitments with relatively fixed locations (work and school) have the highest HHI Activity-Location (HHI_{AL}) values with low standard deviations. Pick-up and drop-off and work related business trips also tend to have stable activity-location combination patterns. Leisure and private business trips have higher flexibility in their activity-locations combination than other trips. Urban residents have less flexible activity-location combinations for their daily obligations (i.e. work, school, pick-up and drop) trips than rural residents. On the other hand, rural residents have fixer combinations for their daily shopping activity-travel patterns. The lower availability of stores/shopping locations in rural area encourage the residents to visit the same stores near their home location or visit the same stores at their daily commuting route. The rural residents show less flexibility in their activity-location combination for their private business trips, but more flexibility in their leisure trips, which is surprising, and like shopping activity, this might due to the number of activity locations in the area.

[Figure 1 is about here]

Figure 2 repeats the analysis for activity-mode combinations. Individuals are unlikely to vary their travel mode, especially in pursuing their routine activities (i.e. going to work or school). Pick-up and drop-off trips have very stable combinations mostly due to the need of car use in sharing the trip. As expected, for most types, except for work related and leisure trips, rural residents have more stability in their daily activity-mode choice combination than urban residents. This reflects the higher car dependency in the rural area.

[Figure 2 is about here]

The values for the HHI for mode-location combination by location type are shown in Figure 3. It shows that the individuals who performed their activities in CBD/centre areas have more varied location-mode combinations than individuals in suburban areas. Halle residents have more stable location-mode combinations than Karlsruhe residents. The residents of Seerücken villages also have a more stable pattern than residents of Frauenfeld. However, as mentioned in earlier, the high value of HHI_{LM} is also due to the high share of activity locations visited only once during the survey period (more than 60%).

[Figure 3 is about here]

Figure 4 shows the interaction of activity-departure time combinations with the activity type. As expected, routine commitments (work and school related trips, including pick-up and drop-off trip) have relatively more stable activity-departure time combinations than leisure and private business trips. Nevertheless, compared to other tested combinations, activity-departure time combinations have low HHI values with high standard deviations. This is possible, because, although the time frame (prism vertex) of the daily departure time of individuals has a relatively small variance, the real departure time of the morning trip tends to vary from day-to-day and is highly influenced by the individual heterogeneity (Kitamura *et al.*, 2006).

Interestingly, rural residents are more flexible in their departure time for work, school and leisure compared to urban residents. On the other hand, their time schedule for shopping and private business activity is more stable than urban residents'.

[Figure 4 is about here]

5. EXPLORATORY ANALYSIS

To gain a better understanding of the travel patterns behind the HHI values, an initial exploratory analysis plotted them against a set of relevant variables, such as average vehicle occupancy, number of visits/day[3], number of work visits/day, number of non-work visits/day, average travel time/trip, average travel distance/trip, average out-of-home activity duration, and share of private car, public transport and non-motorised trips/day. Solely due to the brevity of the paper, the plotted graphs are not shown in this paper. The complete graphs can be found at Susilo and Axhausen (2007). The salient results of the analyses are as follows.

Overall, both urban (Mobidrive) and rural (Thurgau) individuals show similar trends. It is also clear in all cases, that the rural residents have lower HHI values than urban residents. As expected, the routine work activity increases the stability of the daily activity-location and activity-departure time combinations significantly. In all combinations, it is found that activities with longer durations, which might represent routine obligatory activities (i.e. work and study), are likely to be repeated from day-to-day with the same activity-location-mode combinations. However, the stability of the combination is decreasing in line with the increase of the average number of trips, especially number of non-work visit, per day.

The results show that a higher vehicle occupancy / number of traveller in a group increase the variability of individual multi-day choices. This is understandable because, except for a special kind of trip (i.e. bus school trip), involving more persons in trip making with the same mode and/or to the same location and/or under the same time less likely to be happen on daily basis. The results also show that a trip that takes a long time and a long distance is less likely to be repeated to the same location in the following days. However, the relationships are not too clear.

[3] Number of visit/day refers to average number of out-of-home activities/day

It is found that individuals who use the same travel mode during six-week period tend to have more regular activity-location combinations (higher HHI value) compared to individuals who mix their travel mode, especially for private car users. However, the HHI value based on location-mode of urban residents did not show any clear correlation with mode usage. Overall, there are less clear correlations between HHI values and location-mode combination compared to other combinations.

6. REGRESSION ANALYSIS

To examine the influence of individual socio-demographic characteristics on the stability of the HHI values regression model is employed. The models are estimated two times: with and without the travel behaviour parameters. For simplicity and comparability of the estimation results, the values of HHI are standardized to a mean of zero and standard deviation of one. The parameter estimates are shown in Table 4 and reveal interesting differences. The complete estimation results of the models and the goodness-of-fit statistics can be found at Susilo and Axhausen (2007). The estimates results show that the bulk of the explanatory power is due to the behavioural variables, the socio-demographic and home location dummies pick up some of this in the first model through their correlations with the behaviours of interest, for example number of cars and share of car trips. As a result, only few of the socio-demographic variables retain their significance in the presence of the behavioural variables.

[Table 4 is about here]

Stability of daily activity-location combination: In the model without the travel behavioural variables, as expected, workers and students have less variability than non-workers. Individuals who married and/or own a vehicle license have more flexible daily activity-location combination than others. Interestingly, urban residents show less variance than the rural residents, especially in Halle. However, among the urban residents, the stability is decreasing from suburbs to CBD area. Smaller and more concentrated activity spaces of the core city residents limit their range and therefore the number of alternative locations. Yet, the availability of more locations in centre encourages the CBD residents to have more flexible activity locations than suburbs residents. Nevertheless, overall the Mobidrive respondents show more flexible activity-location combinations than Thurgau respondents. Household variables do not show any significant influence on the stability of individuals' activity-location combinations.

The inclusion of the mean behaviours to the model shows that activity duration and number of work visits positively influence the stability of activity-location combinations. On the other hand, higher vehicle occupancy, travel duration and number of non-work visits are associated with higher flexibility of the activity-location combinations. Interestingly, the share of car travel does not have a significant influence on the stability of the activity-location combinations. The individuals who tend to use only one mode tend to have more stable activity-location combinations than individuals who mix their travel modes. Non-motorised travellers tend to have more stable activity-location combinations than public transport travellers, which, again, might be due to the smaller activity spaces and fewer alternative locations for non-motorised travellers compared to public transit travellers.

Stability of daily activity-mode combination: Men, workers and middle-aged respondents (35-54) are unlikely to modify their activity-mode combinations. Higher number of vehicles in the household allows individuals to stick with their favourite mode and have less variance in their daily activity-mode combinations. On the other hand, higher number of household members and higher household income increase the flexibility of daily activity-mode choice of individual. Married individuals also tend to have more flexible daily activity-mode choice combination than others; however, the influence is very marginal.

The results also show that individuals from more urbanised areas have more flexible daily activity-mode combinations compared with individuals from less urbanised areas. Denser public transport networks and higher accessibility of activity locations in urbanised areas allow the residents to vary their daily activity-travel mode choice easily. On the other hands, the residents in a very rural area (i.e. Seerücken) are heavily dependent on their private vehicle and have only very limited access to public transport. The estimation results show that Seerücken residents have the most stable daily activity-mode patterns. Nevertheless, the individuals from Mobidrive dataset (Germans) have more stability in their daily activity-mode choice pattern than the individuals in Thurgau dataset (Swiss) all else being equal.

Examining the influence of mean behaviours, as expected, private car travellers have the most flexible and non-motorised travellers have the most stable activity-mode combinations. The ability to retain and to use one travel mode increases the stability of individual activity-mode combinations. Likewise, higher vehicle occupancy, travel duration, and number of non-work visits decrease the stability of the activity-mode combinations and number of work visits and longer activity duration increase the stability of the activity-mode combinations.

Stability of daily location-mode combination: Men are less likely to modify their location-mode combination compared to women. Older individuals (more than 35 year old) are also less likely to modify their daily location-mode combinations. On the other hand, individuals who belong to larger households, are married and own a vehicle license have more flexible daily location-mode choice combinations than others. Like activity-mode combination, higher numbers of vehicles in the household provide the individual the chance to retain a car for their personal use only. Although the influences are marginal, individuals who live in rural areas tend to have more stable daily location-mode choice pattern than individuals who live in urban areas. Again, the Mobidrive respondents show a higher stability in their daily location-mode choice than the Thurgau respondents, all other things being equal.

Regarding the mean behaviours, higher vehicle occupancy, travel duration, and number of visits (both for work and non-work) decrease the stability of individuals' location-mode combination. Like the activity-mode model, private car travellers tend to have more flexible location-mode combinations compared to public transport and non-motorised travellers. The ability to continuously use one particular travel mode increases the stability of individual location-mode combinations.

Stability of daily activity-departure time combination: Unlike other combinations, the residential locations do not influence the stability of individuals' daily activity-departure time combination. The results show that the stability of the combination is influenced by the individuals' daily commitments (employment status and household variables). Workers and students have less variable departure times for each activity. On the other hand, individuals with a vehicle license and respondents who belong to families with dependent children show more flexibility in their activity-departure time combination. Higher numbers of household members as well as the number of motor vehicles at household increase the stability of the combination of activity and its departure time. However, the influences are marginal.

Longer mean activities increase the stability of activity-departure time combinations. On the other hand, a longer travel time and a higher number of visits increase the flexibility of activity-departure time combinations. No significant influences from the travel mode variables are visible, except for individuals who rarely use public transport who are more flexible than others. This supports the previous section's finding that the stability of individual activity-travel engagements is more influenced by the individuals' commitments and obligations, rather than by the stability of travel mode choice.

7. SIMILARITY OF THE PATTERNS OF STABILITY

Schlich (2003, 2004) performed a careful analysis of the multi-dimensional similarity of the activity chains of the Mobidrive respondents. Based on this he performed two cluster analyses of the respondents: the first based, as usual in the literature, on their socio-demographics and average travel behaviour and the second on a day by day matrix of similarities of their activities. While the first classification, as usual, explained relatively little of the behavioural variance, the gain in behavioural explanatory power of the second classification came at the price of little socio-demographic distinctiveness of the cluster members.

A description of the clusters is available in Appendix B. The HHI values for each cluster are shown in Table 5 and 7 and the ANOVA tests of the HHI values for each cluster are shown in Table 6 and 8 for both groups of clusters.

HHI values and clusters that are defined on socio-demographics and average value of travel behaviour: Table 5 shows that the *public transport travellers* (cluster 1) have the most stable (the highest HHI values) activity-location and activity-departure time combination compared to others. This is understandable since public transport travellers have less accessibility and flexibility compared to others in their destination choice. They also depended on the public transport schedule, which make their activity-departure time is very stable. On the other hand, *parents with auto* (cluster 3), have the most flexible activity-location and activity-departure time compared with others. As expected, the *auto-addicted travellers* (cluster 5) will hardly change their mode at all. Their activity-mode and location-mode combinations are very stable. On contrary, the *older pedestrians* (cluster 4) tend to modify their location-mode as well as activity-mode combinations more frequently.

Interestingly, young *on-foot travellers* (cluster 2), mostly urban students and pupils, have relatively a stable pattern (although not the highest) in all of their daily activity-location-mode-departure time combinations.

The ANOVA analysis shows that there are significant differences of HHI values between the clusters (see Table 6). HHI values based on activity-mode combinations are explained best (37.6%).

[Table 5 is about here]

[Table 6 is about here]

HHI values and clusters that are defined on the multi-dimensional similarity of their daily activity chains: Table 7 shows that the dependent *travellers* (cluster 1) have the most stable activity-location-mode combinations (the highest HHI values). Presumably, it is because the individuals in this cluster tend to depend on others for their travel (most of them are children and old people, see the description of the clusters at Appendix B). *Parents with auto* (cluster 5) have the most flexible activity-location and activity-departure time patterns. But, as they depend on the auto as their daily travel mode, they have higher stability in activity-mode and location-mode combinations. Although *hard-work pedestrians* (cluster 4) make a lot of un-motorised trips, nevertheless they also like to modify their travel mode and use another travel mode frequently. That is why their activity-mode and location-mode combinations are the most flexible.

The ANOVA analysis shows that the differences between groups are only significant for the HHI values of activity-location and activity-departure time combinations (see Table 8). Clustering the individual based on the multi-dimensional similarity of their daily activity chains explains a much smaller share of the variance than socio-demographic clustering, which is surprising.

[Table 7 is about here]

[Table 8 is about here]

8. CONCLUSIONS

Using the Herfindahl-Hirschman Index this paper examines the stability of individuals' choices of their daily activity-travel-location combinations over the six-week period reported in the Mobidrive and Thurgau surveys. The results show that the stability of individual activity-travel-travel-location combinations is influenced by the individuals' out-of-home commitments, their intra-household conditions as well as their behavioural choices. Different types of activities result in different patterns of stability. Obligatory activities, such as work, school, pick-up and drop-off, have more stable activity-travel-location combination than others. As expected, leisure and private business trips have higher flexibility in their activity-locations-mode combination than other trips.

It is shown that, although the mode choice influences the stability of individual activity-location-mode combinations, it is less correlated to the stability of individual activity-travel engagements. Such stability is more influenced by the individual's commitments and obligations.

Urban residents show less variance in activity-location combination than rural residents, which is surprising. However, among the urban residents, the stability is decreasing from suburbs to CBD area. On the other hand, rural area residents tend to have a more stable mode choice pattern than urban residents due to their reliance on the car.

The analysis has demonstrated the value of the Herfindahl-Hirschman Index as a simple measure of the stability of behaviour, but the analysis in conjunction with Schlich's cluster has shown that it cannot replace the complex multi-dimensional measures of similarity. Still, it characterises the persons and their behaviours effectively and can be recommended for the analysis of other multi-day datasets.

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Table 1 Example of Herfindahl-Hirschman Index (HHI) value calculations

Conditions	Share within the same trip type	HHI for each trip type	HHI for the individual
Individual A: 5 shopping trips and 2 leisure trips			
Shopping Trips:			
2 shopping trips at location A	40%		
2 shopping trips at location B	40%	0.36†	
1 shopping trips at location C	20%		0.543††
Leisure Trips:			
2 leisure trips at location D	100%	1.00	
Individual B: 5 shopping trips and 2 leisure trips			
Shopping Trips:			
5 shopping trips at location E	100%	1.00	
Leisure Trips:			0.857
1 leisure trips at location F	50%	0.50	
1 leisure trips at location G	50%		

† : HHI for the shopping trips of individual A = $(0.4)^2 + (0.4)^2 + (0.1)^2 = 0.36$

†† : HHI for all trips of individual A = (5 x 0.36 + 2 x 1.00)/7 =0.543

Table 2 Herfindahl-Hirschman index values for four activity attribute combinations

HHI value per person	Combinations			
	Activity-location	Activity-mode	Location[†]-mode	Activity-departure time[‡]
Mobidrive six-week travel diary (N = 317 individuals)				
Average	0.441	0.701	0.868	0.241
Variance	0.186	0.159	0.104	0.143
Maximum	1.00	1.00	1.00	0.87
Minimum	0.13	0.33	0.54	0.06
Number of combinations within six-week period	10,243	3,696	9,641	14,622
Thurgau six-week travel diary (N = 230 individuals)				
Average	0.398	0.682	0.862	0.187
Variance	0.167	0.149	0.093	0.093
Maximum	0.96	1.00	1.00	0.64
Minimum	0.06	0.35	0.63	0.05
Number of combinations within six-week period	9,277	2,806	9,273	12,397

[†]: Activity location is defined based on Gauss-Krueger coordinate system, with building block resolution.

[‡]: The departure time is grouped by 15 minute-period.

Table 3 Correlation between the Herfindahl-Hirschman index values of the attribute combinations

	HHI_{AL}	HHI_{AM}	HHI_{LM}	HHI_{DT}
HHI_{AL}	1	0.322	0.122	0.657
HHI_{AM}		1	0.778	0.269
HHI_{LM}			1	0.195
HHI_{DT}				1

HHI_{AL} : HHI values based on the stability of daily individuals' activity-location combinations
HHI_{AM} : HHI values based on the stability of daily individuals' activity-travel mode combinations
HHI_{LM} : HHI values based on the stability of daily individuals' location-travel mode combinations
HHI_{DT} : HHI values based on the stability of daily individuals' activity-departure time combinations
All correlations are significant at the 0.01 level (2-tailed)

Table 4 Regression parameters of the standardized Herfindahl-Hirschman Index values (with and without behavioural variables) (bold are significant at 0.05% level)

Parameter estimates	Combination of choices							
	Activity - location		Activity - mode		Location – mode		Activity – Departure time	
	w/o	with	w/o	with	w/o	with	w/o	with
Constant	-0.17	1.33	0.24	3.71	0.10	3.71	-0.28	1.14
Male	0.10	-0.04	**0.19**	-0.02	0.15	0.02	0.12	0.03
Married	**-0.25**	-0.08	-0.15	-0.09	-0.15	-0.10	-0.10	0.02
25 – 34 years old	0.08	0.15	-0.05	-0.06	0.12	0.03	-0.02	-0.02
35 – 44 years old	-0.07	0.11	0.31	0.14	**0.55**	0.30	0.00	0.10
45 – 54 years old	0.16	0.15	0.36	0.11	**0.50**	0.22	0.10	0.09
55 - 64 years old	0.09	0.19	0.23	0.04	**0.56**	0.27	0.06	0.05
65 years old plus	-0.26	-0.06	-0.11	-0.03	**0.49**	0.26	-0.13	-0.14
Worker	**0.59**	0.04	**0.27**	0.04	0.05	0.01	**0.47**	0.06
Student	**0.37**	**0.30**	0.12	0.24	0.31	**0.49**	**0.46**	**0.52**
License holder	**-0.46**	-0.14	-0.12	**-0.23**	-0.24	-0.19	**-0.54**	**-0.23**
Household size	0.03	-0.03	-0.09	-0.03	-0.09	-0.07	0.07	0.01
Dependent children	0.08	0.17	-0.04	-0.08	-0.17	-0.11	-0.26	-0.15
Motor vehicles	0.03	-0.02	**0.15**	0.04	**0.15**	**0.07**	0.06	0.01
HH income [k€]	-0.003	0.02	-0.05	-0.01	-0.02	0.01	-0.01	-0.001
Occupancy	-	**-0.15**	-	**-0.19**	-	**-0.20**	-	-0.08
Trip duration [h]	-	**-0.78**	-	**-0.42**	-	-0.30	-	**-0.24**
Activity duration [h]	-	**0.24**	-	0.02	-	-0.01	-	**0.17**
Work activities	-	**0.13**	-	0.02	-	**-0.31**	-	**-0.17**
Non-work activities	-	**-0.37**	-	**-0.21**	-	**-0.27**	-	-0.40
0 – 25 % car trips	-	-0.06	-	**-1.75**	-	**-1.36**	-	-0.09
25 – 50 % car trips	-	-0.05	-	**-1.67**	-	**-1.53**	-	-0.02
50 – 75 % car trips	-	-0.15	-	**-1.27**	-	**-0.99**	-	-0.08

Table 4 Regression parameters of the standardized Herfindahl-Hirschman Index values (Continued)

Parameter estimates	Combination of choices							
	Activity - location		Activity - mode		Location – mode		Activity – Departure time	
	w/o	with	w/o	with	w/o	with	w/o	with
Public transport share								
0 – 25 % trips	-	**-0.80**	-	**-1.18**	-	**-1.22**	-	**-0.71**
25 – 50 % trips	-	**-0.85**	-	**-1.32**	-	**-1.28**	-	**-0.67**
50 – 75 % trips	-	**-0.76**	-	**-0.68**	-	-0.54	-	-0.38
Non-motorised share								
0 – 25 % trips	-	**-0.56**	-	**-0.84**	-	**-0.70**	-	-0.21
25 – 50 % trips	-	**-0.42**	-	**-0.89**	-	**-0.64**	-	-0.18
50 – 75 % trips	-	**-0.28**	-	**-0.56**	-	**-0.38**	-	-0.05
Residential location								
Karlsruhe CBD	0.75	0.10	**-1.82**	-0.47	-1.16	-0.18	0.33	0.03
Karlsruhe innercity	0.52	0.17	**-1.77**	-0.86	-1.37	-0.53	0.00	-0.08
Karlsruhe suburbs	0.96	0.52	**-1.53**	-0.65	-1.10	-0.27	0.29	0.08
Halle CBD	1.05	0.51	-1.15	-0.22	-0.52	0.30	0.27	0.08
Halle innercity	1.15	0.56	**-1.48**	-0.69	-1.10	-0.35	0.60	0.29
Halle suburbs	**1.43**	0.76	-1.13	-0.45	-0.84	-0.22	0.68	0.23
Frauenfeld	-0.12	-0.02	**-0.49**	**-0.19**	**-0.44**	-0.20	-0.11	-0.02
Mobidrive	-0.85	-0.19	1.21	0.88	0.86	0.47	-0.04	0.22
N	547		547		547		547	
F	10.18	21.91	4.81	20.66	2.90	9.72	8.00	13.14
df	22	36	22	36	22	36	22	36
R^2	0.299	0.607	0.168	0.593	0.108	0.407	0.251	0.481
Adjusted R^2	0.270	0.580	0.133	0.565	0.071	0.365	0.220	0.445

Table 5 Herfindahl-Hirschman Index values for the Mobidrive clusters defined on socio-demographics and average travel behaviour

Cluster classification	Combinations			
	Activity-location	Activity-mode	Location†-mode	Activity-departure time‡
Cluster 1: Public transport travellers (N = 36 individuals)				
Average	0.519	0.692	0.870	0.332
Variance	0.200	0.116	0.087	0.159
Maximum	0.20	0.51	0.66	0.06
Minimum	1.00	1.00	1.00	0.62
Cluster 2: On foot travellers (N = 56 individuals)				
Average	0.498	0.701	0.884	0.277
Variance	0.178	0.141	0.092	0.166
Maximum	0.13	0.33	0.61	0.06
Minimum	1.00	1.00	1.00	0.87
Cluster 3: Parents with auto (N = 81 individuals)				
Average	0.369	0.646	0.850	0.199
Variance	0.158	0.123	0.097	0.130
Maximum	0.14	0.42	0.60	0.07
Minimum	0.87	1.00	1.00	0.72
Cluster 4: Older pedestrians (N = 76 individuals)				
Average	0.434	0.607	0.812	0.222
Variance	0.167	0.150	0.119	0.106
Maximum	0.15	0.39	0.54	0.09
Minimum	0.93	1.00	1.00	0.65
Cluster 5: Auto-addicted traveller (N = 68 individuals)				
Average	0.446	0.876	0.940	0.233
Variance	0.204	0.087	0.060	0.142
Maximum	0.13	0.65	0.76	0.06
Minimum	0.91	1.00	1.00	0.73

† : Activity location is defined based on Gauss-Krueger coordinate system, with building block resolution; ‡ : The departure time is grouped by 15 minute-period

Table 6 ANOVA analysis of Herfindahl-Hirschman Index values on the cluster membership that defined based on socio-demographics and average travel behaviour

		Sum of Squares	% of Total Sum of Squares	df	Mean Square	F
HHI_{AL}	Between Groups	0.83589	7.67%	4	0.208972	6.48109
	Within Groups	10.05995	92.33%	312	0.032243	
	Total	10.89584	100.00%	316		
HHI_{AM}	Between Groups	2.992584	37.60%	4	0.748146	47.00965
	Within Groups	4.965397	62.40%	312	0.015915	
	Total	7.957981	100.00%	316		
HHI_{LM}	Between Groups	0.633505	18.62%	4	0.158376	17.84219
	Within Groups	2.769468	81.38%	312	0.008876	
	Total	3.402972	100.00%	316		
HHI_{DT}	Between Groups	0.541639	8.36%	4	0.13541	7.112682
	Within Groups	5.939794	91.64%	312	0.019038	
	Total	6.481433	100.00%	316		

HHI_{AL} : HHI values based on the stability of daily individuals' activity-location combinations
HHI_{AM} : HHI values based on the stability of daily individuals' activity-travel mode combinations
HHI_{LM} : HHI values based on the stability of daily individuals' location-travel mode combinations
HHI_{DT} : HHI values based on the stability of daily individuals' activity-departure time combinations
All differences are significant at the 0.01 level

Table 7 Herfindahl-Hirschman Index values for the Mobidrive clusters defined on the multi-dimensional similarity of the their daily activity chains

Cluster classification	Combinations			
	Activity-location	Activity-mode	Location†-mode	Activity-departure time‡
Cluster 1: Dependent travellers (N = 84 individuals)				
Average	0.499	0.730	0.887	0.287
Variance	0.130	0.445	0.595	0.067
Maximum	1.00	1.00	1.00	0.87
Minimum	0.21	0.16	0.10	0.16
Cluster 2: Activity seekers (N = 65 individuals)				
Average	0.417	0.718	0.873	0.232
Variance	0.135	0.391	0.638	0.060
Maximum	0.83	1.00	1.00	0.56
Minimum	0.15	0.14	0.09	0.12
Cluster 3: Public transport lovers (N = 88 individuals)				
Average	0.443	0.683	0.868	0.245
Variance	0.138	0.391	0.569	0.061
Maximum	0.93	0.97	1.00	0.67
Minimum	0.19	0.17	0.11	0.15
Cluster 4: Hard work pedestrians (N = 47 individuals)				
Average	0.441	0.664	0.835	0.233
Variance	0.182	0.392	0.540	0.073
Maximum	1.00	1.00	1.00	0.60
Minimum	0.17	0.14	0.12	0.13
Cluster 5: Parents with auto (N = 32 individuals)				
Average	0.337	0.695	0.863	0.143
Variance	0.130	0.329	0.651	0.062
Maximum	0.75	0.98	0.99	0.44
Minimum	0.13	0.17	0.09	0.08

† : Activity location is defined based on Gauss-Krueger coordinate system, with building block resolution; ‡ : The departure time is grouped by 15 minute-period

Table 8 ANOVA analysis of Herfindahl-Hirschman Index values on the cluster membership that defined based on the multi-dimensional similarity of the their daily activity chains

		Sum of Squares	% of Total Sum of Squares	df	Mean Square	F
HHI_{AL}	Between Groups	0.66627	6.12%	4	0.166568	5.068196
	Within Groups	10.2211	93.88%	311	0.032865	
	Total	10.88737	100.00%	315		
HHI_{AM}	Between Groups	0.186303	2.34%	4	0.046576	1.86651 *
	Within Groups	7.760532	97.66%	311	0.024953	
	Total	7.946835	100.00%	315		
HHI_{LM}	Between Groups	0.081664	2.41%	4	0.020416	1.91731 *
	Within Groups	3.311604	97.59%	311	0.010648	
	Total	3.393268	100.00%	315		
HHI_{DT}	Between Groups	0.496448	7.68%	4	0.124112	6.472069
	Within Groups	5.963906	92.32%	311	0.019177	
	Total	6.460354	100.00%	315		

HHI_{AL} : HHI values based on the stability of daily individuals' activity-location combinations
HHI_{AM} : HHI values based on the stability of daily individuals' activity-travel mode combinations
HHI_{LM} : HHI values based on the stability of daily individuals' location-travel mode combinations
HHI_{DT} : HHI values based on the stability of daily individuals' activity-departure time combinations
* : differences are not significant at the 0.10 level

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Figure 1 HHI values for activity type-location by purpose

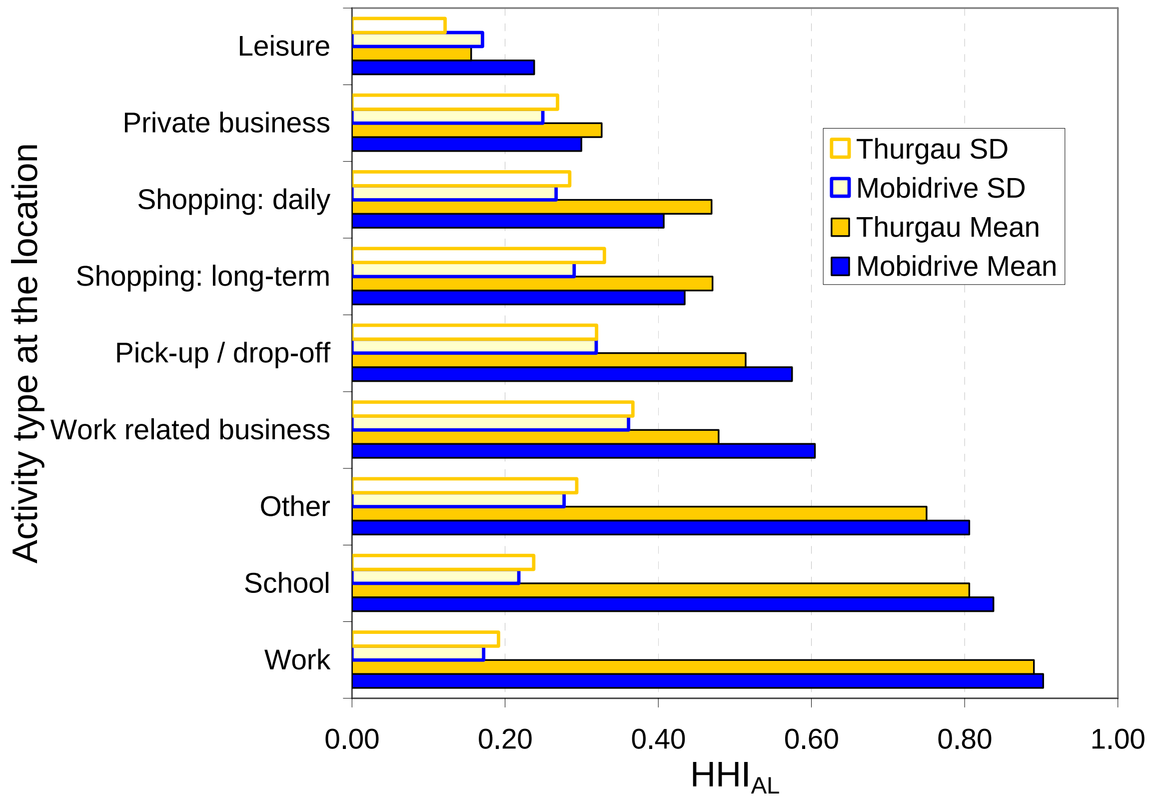


Figure 2 HHI values for activity type-mode by purpose

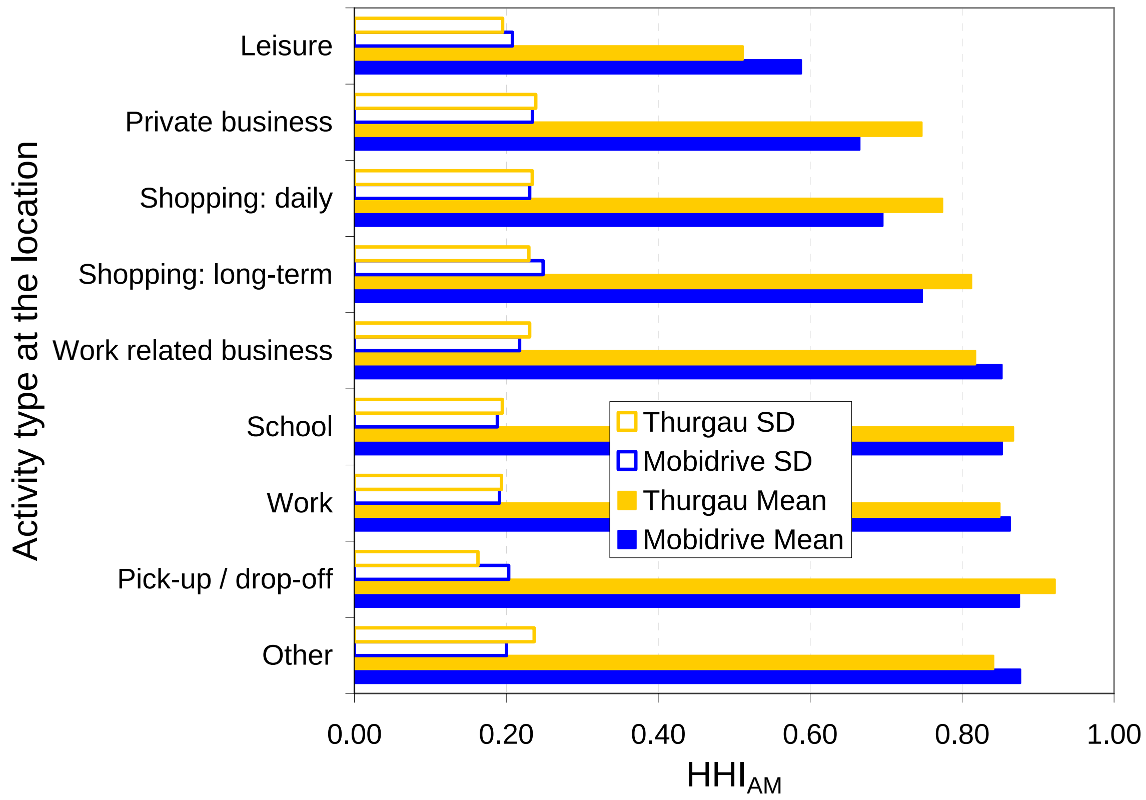


Figure 3 HHI values for location – mode by location

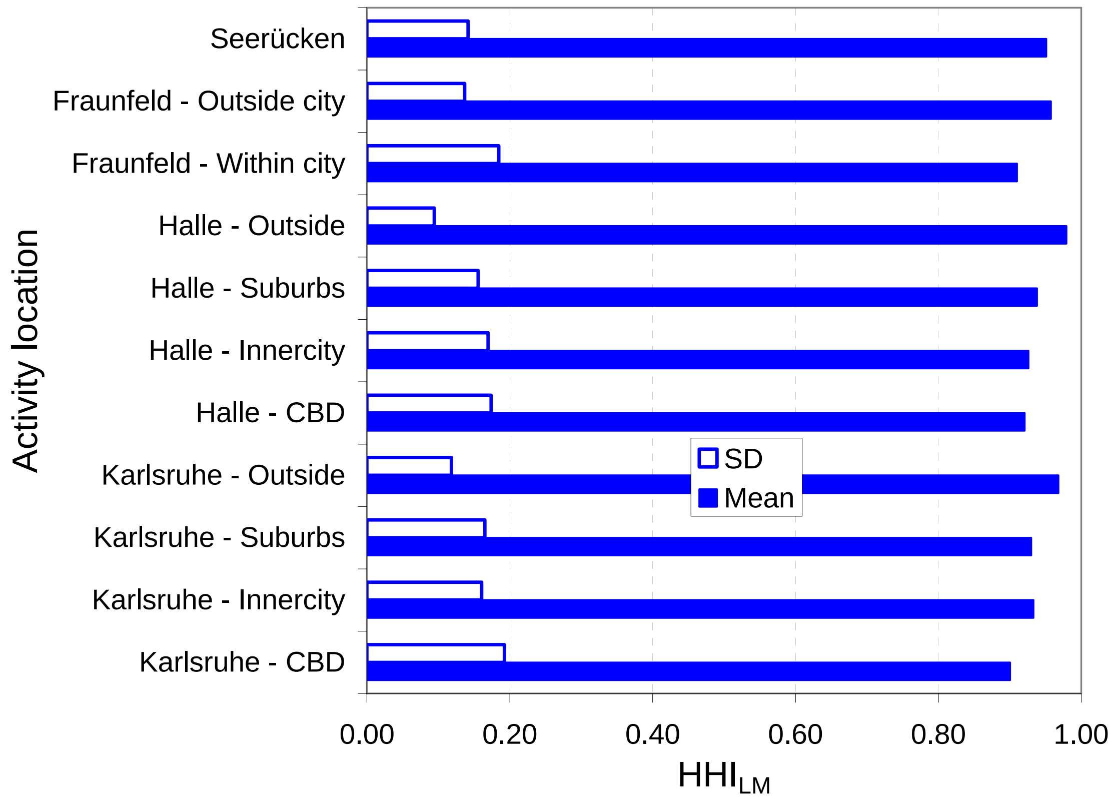
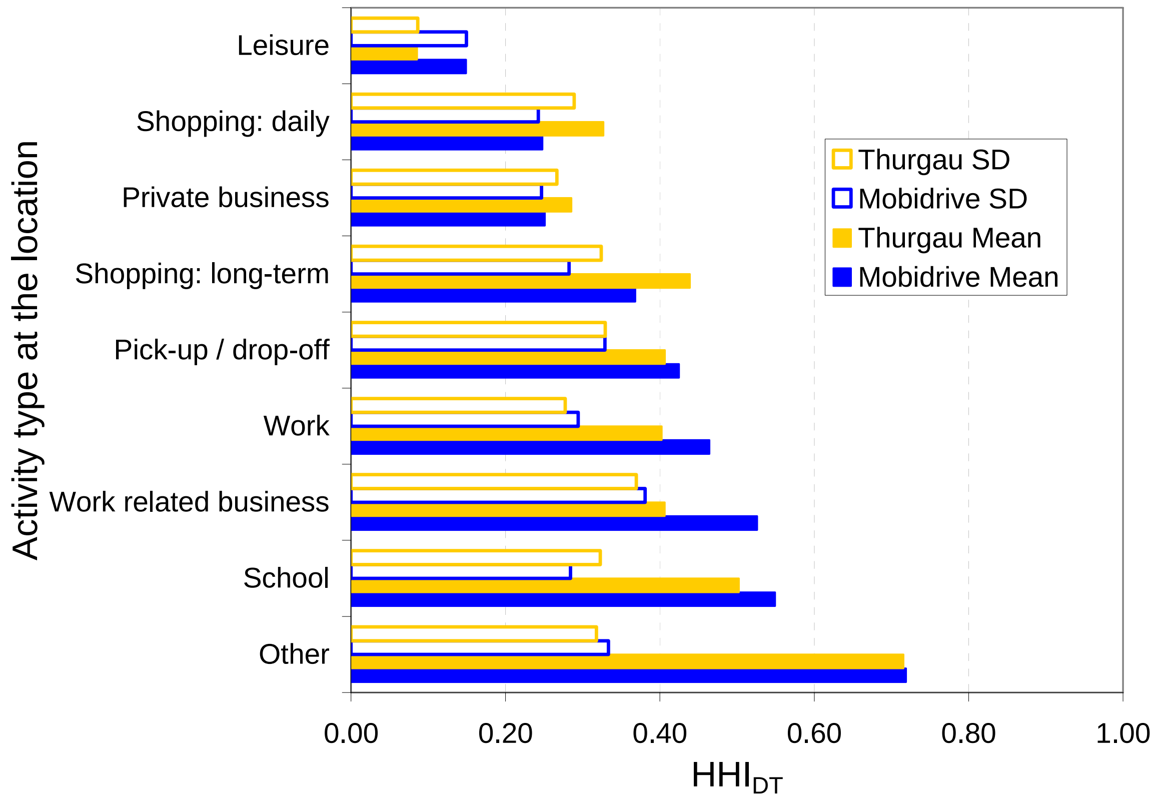


Figure 4 HHI values for activity-departure time by activity type



APPENDIX A: DESCRIPTION OF THE TWO DATA SETS

	Mobidrive	2003 Thurgau
Male	49.84%	50.87%
Married	52.05%	62.17%
Less than 24 years old	13.56%	29.57%
25 – 34 years old	10.41%	7.83%
35 – 44 years old	19.24%	16.09%
45 – 54 years old	17.98%	22.17%
55 - 64 years old	16.72%	15.22%
65 years old or older	8.83%	9.13%
Vehicle license holding	35.02%	42.61%
Workers	21.14%	23.48%
Students	27.13%	18.70%
Non-workers	67.51%	76.09%
Number of household members	2.84	3.18
Family with dependent children	34.70%	51.30%
Number of motor vehicles	1.33	2.06
Monthly household income [k€]	2.25	5.60
Karlsruhe residents	50.16%	
Halle residents	49.84%	
Frauenfeld residents		43.04%
Seerücken residents		56.96%
N	317 Individuals	230 Individuals

APPENDIX B: DESCRIPTION AND PROFILES OF SCHLICH'S CLUSTERS

1. The description of the clusters based on socio-demographics and average travel behaviour:

- *Cluster 1 (public transport travellers)*: This cluster is dominated by workers and students/pupils. 70% of them are live in the suburbs areas and 30% of them are live in the mixed area – none of them are live in CBD. This cluster has a lot of young people (less than 24 year old). They make a frequent work, school, and leisure trips. Many of them are own a discount card for public transport.
- *Cluster 2 (on foot travellers)* dominated by students. They made very frequent non-motorised trips. Many of them are living in the CBD and in the inner-city area. They have a large fraction of very young, but also very old people; and many of them are single and women. They made a lot of school and work leisure trips. About 70% of them are unemployed.
- *Cluster 3 (parents with auto)* dominated by parents (also married) who live in Karlsruhe area and live in suburbs area. This cluster has high fraction of non-workers and individual whose age between 35 – 54 year old. They make a lot of car and shopping trips.
- *Cluster 4 (older pedestrians)*. This cluster has a high fraction of old people and non-workers. Many of them who live in CBD and inner-city area. They made frequent non-motorised trips and some public transport trips.
- *Cluster 5 (auto addicted travellers)* dominated by male, full time worker, who travelled with auto. They make a lot of work trips. Most of them are in productive age (25 – 64 year old). They hardly use public transport.

Table B1 Profiles of clusters based on socio-demographics and average travel behaviour

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Male	44.44%	42.86%	55.56%	40.79%	61.76%
Married	36.11%	26.79%	66.67%	51.32%	64.71%
Less than 24 years old	25.00%	17.86%	9.88%	13.16%	8.82%
25 – 34 years old	8.33%	5.36%	12.35%	7.89%	16.18%
35 – 44 years old	5.56%	10.71%	20.99%	19.74%	30.88%
45 – 54 years old	25.00%	10.71%	25.93%	14.47%	14.71%
55 - 64 years old	13.89%	5.36%	19.75%	14.47%	26.47%
65 years old or older	2.78%	14.29%	8.64%	14.47%	1.47%
Worker	36.11%	16.07%	39.51%	30.26%	50.00%
Student	33.33%	51.79%	9.88%	21.05%	2.94%
Non-Worker	13.89%	19.64%	34.57%	36.84%	20.59%
Vehicle license holding	36.11%	41.07%	87.65%	57.89%	92.65%
Number of household members	2.97	3.11	2.80	2.84	2.60
Family with dependent children	27.78%	48.21%	30.86%	38.16%	27.94%
Household income [x 1,000 euro]	2.31	2.40	2.37	2.03	2.20
CBD resident	0.00%	12.50%	2.47%	10.53%	2.94%
Inner-city resident	30.56%	32.14%	22.22%	31.58%	26.47%
Suburbs resident	69.44%	55.36%	75.31%	57.89%	67.65%
Karlsruhe Resident	44.44%	41.07%	60.49%	55.26%	42.65%
Halle Resident	55.56%	58.93%	39.51%	44.74%	57.35%
N	36	56	81	76	68

2. The description of the clusters based on the multi-dimensional similarity of the their daily activity chains:

- From Cluster 1 to 5, the household income is increasing gradually.
- *Cluster 1 (dependent travellers)*, the cluster with the lowest income, is dominated pupil and non-workers (with high fraction of retirement) who live in suburbs areas. Most of them are single, who are really young or really old and the resident of Halle city.
- *Cluster 2 (activity seekers)* consist a large fraction of individual who live in CBD. Most of the individuals are between 25 - 34 year old and 45-54 year old, who have a high number of shopping trip. Many of them are unemployed and part-time employed.
- *Cluster 3 (public transport lovers)* dominated by women, who live in inner-city area and frequently use public transport. This cluster has high fraction of student, as well as school trips, and also high fraction of individual who between 55 - 64 year old.
- *Cluster 4 (hard work pedestrians)* dominated by married workers, whose age between 35 – 54 years old. This group makes a very high proportion of work and un-motorized trips.
- *Cluster 5 (parents with auto)* dominated by auto traveller parents. They make a lot of shopping and school trips, with a lot of household-makers and self-employed among them. Most of them are Karlsruhe residents and live in suburban areas. Individual in this cluster have the highest average household income compare to other clusters.

Table B2 Profiles of clusters based on the multi-dimensional similarity of the their daily activity chains

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Male	54.8%	56.9%	40.9%	51.1%	46.9%
Married	44.0%	50.8%	53.4%	61.7%	59.4%
Less than 24 years old	17.9%	6.2%	9.1%	14.9%	25.0%
25 – 34 years old	4.8%	16.9%	11.4%	10.6%	9.4%
35 – 44 years old	10.7%	18.5%	18.2%	25.5%	37.5%
45 – 54 years old	19.0%	24.6%	11.4%	21.3%	15.6%
55 - 64 years old	19.0%	10.8%	27.3%	8.5%	6.3%
65 years old or older	14.3%	7.7%	6.8%	8.5%	3.1%
Worker	25.0%	38.5%	38.6%	44.7%	31.3%
Student	22.6%	20.0%	22.7%	19.1%	15.6%
Non-Worker	36.9%	26.2%	23.9%	21.3%	21.9%
Vehicle license holding	52.4%	67.7%	70.5%	78.7%	81.3%
Number of household members	2.75	2.76	2.68	3.09	3.31
Family with dependent children	28.6%	35.4%	30.7%	40.4%	53.1%
Household income [x 1,000 euro]	2.02	2.12	2.24	2.51	2.71
CBD resident	2.4%	12.3%	4.5%	6.4%	6.3%
Inner-city resident	13.1%	27.7%	44.3%	31.9%	18.8%
Suburbs resident	84.5%	58.5%	50.0%	61.7%	75.0%
Karlsruhe Resident	39.3%	49.2%	55.7%	51.1%	65.6%
Halle Resident	60.7%	50.8%	44.3%	48.9%	34.4%
N	84	65	88	47	32

Notes on Contributors

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