Variability versus stability in daily travel and activity behaviour. The case of a one week travel diary

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Abstract

Temporal rhythms in travel and activity patterns are analysed thanks to a seven-day travel diary collected on 707 individuals in the city of Ghent (Belgium) in 2008. Our analysis confirms the large level of intrapersonal variability whether for daily trips, home-based tours, time use and activity sequence. However our analysis goes further by studying this variability along various time periods within the week. Moreover, we show that the systematic day-to-day variability has an extremely low share in intrapersonal variability. The influence of socio-demographic characteristics on intrapersonal variability is weak, whether for daily trips, tours, time use and activity sequence. Repetitive activity-travel behaviour is then detected, through attributes of activity at trip destination, travel mode, trip arrival time and destination location. The picture is at the same time one of diversity and of specificity in activity-travel across the week. People tend to concentrate their weekly activity-travel patterns on few combinations of attributes, despite a large dispersion. Our results on core stops are somewhat encouraging by showing some kind of concentration of activity patterns on a few "anchor" points.

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1 Introduction

Various travel demand management policy measures which are at stake today, such as flexible or staggering work hours, incentive to use enhanced bus or light-rail services, integration of various transport modes as alternatives to the car (e.g. bike and public transport), car pooling and car sharing or even congestion pricing, all need accurate prediction of their effectiveness in changing behaviour. Obviously these old and new policy measures will demonstrate their effectiveness only if they match with day-to-day behaviour of transport users at which theses measures are aimed.

Conventional four-step models are the main tool to produce this kind of prediction, however they are generally based on household travel surveys which measure individual travel (and sometimes diary) on one day only (as in France, Switzerland and Belgium; see Raux et al, 2011). There are abundant examples of errors when comparing ex-ante prediction with ex-post realisations, such as with the London Congestion Charging Scheme which endured an unpredicted level of traffic decrease in the charging zone after implementation. Unsuspected levels of flexibility or rigidity in travel behaviour may be revealed in response to travel demand policy measures.

This is why the search for regularity, variability, flexibility or “anchor points” in activity-travel behaviour is of crucial interest for modelling.

The literature upon individual day-to-day activity-travel behaviour has delivered, at least since the eighties, a definite picture of large variability in various dimensions of this behaviour.

Hanson and Huff (1982, 1988) analyses day-to-day variability of travel patterns on a 35 consecutive days (Uppsala Household Travel Survey) and conclude that while a seven-day record of travel does not capture all the variability of behaviour, it does capture a good sampling of individual’s typical daily travel patterns. However, conclusions on variability depend on the way “behaviour” is measured. Hanson and Huff (1986) takes the working hypothesis that individual behaviour is neither completely habitual, neither completely random. They conduct classification analysis on time allocation and travel indicators on a five-week observation period. They identify travel-behaviour groups but considerable intra-group variability remains.

Pas and Koppelman (1986), using a five-day record of travel, show that employed people have much lower levels of intrapersonal variability in trip frequency when compared with people who are not employed outside the home. Social class and the availability of travel and related resources are important factors of intrapersonal variability. Household role related variables (such as gender related effect of children) are also important.

Jones and Clarke (1988) develop different measures of variability on multiday data and raise the issue of which variability is at stake and hence the way in which behaviour is measured.

Using a three-day travel data set, Pas and Sundar (1995) conclude that there is a considerable level of intrapersonal variability in daily trip frequency, trip chaining and travel time.

When discussing the Mobidrive six-week travel diary Axhausen et al (2002) stress the need to focus on the dynamic processes in travel behaviour, which requires observation on long durations. Schlich and Axhausen (2003) use the Mobidrive dataset and use different methods to measure similarity of travel behaviour. Travel day-to-day behaviour is more stable on work days. They argue that two weeks are required at minimum in order to measure variability. Schlich et al (2004) also provide measures of repetition on leisure travel.

Ettema and van der Lippe (2009) analyse a one-week time use survey held over couples in The Netherlands. They explore day-to-day variability and the influence of role expectations, of role in the household on time allocation, and specialisation of tasks within the household (linked to time constraints, e.g. the presence of young children or the level of accessibility to jobs or stores). They conclude that spatial factors play a limited role in task allocation, compared to personal and household characteristics (presence of young children, work status, age, gender). This last result is also in line with Raux et al (2011).

Kang and Scott (2010) describe day-to-day variability in activity time-use patterns within households, taking account of interactions between household members, and develop structural equation models of these patterns.

However most of these studies do not take account of scheduling of activities and trips. Sequential alignment method (SAM) was introduced by Wilson (1998) for comparing sequence of activities in activity patterns. This method has been extended to multidimensional SAM taking into account the dependencies between different attributes of activity patterns (activity type, location and duration, beginning and ending time, travel mode; see Joh et al, 2002). However this extension raises some critical issues of choosing the various attributes and categorisation of interval-scaled variables such as activity duration or trip distance, which lack of theoretical justification.

Multiday data sets are rare (even if originating in the 70's as referred to in the literature), and this paper takes the opportunity of availability of a new 7-day data set to explore again the issue of day-to-day activity-travel behaviour.

Beyond the expected day-to-day variability, another issue is also to find some empirical indications of stability or regularity in individual activity patterns along the week. A seminal idea is that of "core stops" developed by Hanson and Huff (1988): these are elaborated as combinations of activity, mode, arrival time and location, repeated a certain number of times within a period of several days, that serve to "anchor" the rest of the individual's travel.

The questions which guide our analysis are the following:

- What are the relative levels of interpersonal and intrapersonal variability, according to various attributes of activity-travel patterns?
- What are the days which are the most similar along the week from the point of view of activity-travel behaviour?
- Do individual characteristics influence this variability and to what extent?
- Can we find stability (i.e. "core stops") in activity-travel patterns, according to travel modes, activity performed, arrival times and places visited?

Our analysis confirms the large level of intrapersonal variability whether for daily trips, tours, time use and activity sequence. However our analysis goes further by studying this variability along various time periods within the week. Moreover, we show that the systematic day-to-day variability has an extremely low share in intrapersonal variability. Another perspective is then taken by searching for repetitive activity-travel behaviour, through attributes of activity at trip destination, travel mode, trip arrival time and destination location. Our results on core stops are somewhat encouraging by showing some kind of concentration of activity patterns on a few "anchor" points.

The organization of the paper is as follows. First the data, a one-week travel diary in Ghent (Belgium), are introduced. Then the overall methodology for measuring variability is presented. This method is applied in the next section successively to travel indicators (trips and home-based tours), time use over various activities, and daily activity sequence. Influence of socioeconomic characteristics on intrapersonal variability is also tested. In the following section a search for potential "core stops" in the week is performed. Finally, we discuss the results and draw some conclusions.

2 The data

The data for the analysis is based on a seven-day travel diary collected in the city of Ghent in Belgium. The objective of this survey was to investigate individual's weekly activity patterns and their impact on day-to-day variation of travel behaviour.

The surveyed households are randomly drawn from the population in the city of Ghent based on the stratification of household size, gender and age of household head (12 to 75). The surveyed individuals are based on randomly selected individuals in the household because sampling whole household members over a week may reduce the response rate. The survey methodology is based on paper and web survey followed by phone support. Although this survey cannot collect the activity patterns of all members in the household, it still allows us to investigate individual's daily activity patterns and the determinants related to individual's socio-demographic characteristics.

The collected information contains continuous trip chain information over a week (trip purposes of 12 categories, approximate address of destination, departure and arrival time of trip, travel cost, used modes and travel time) and its potential influence factors (socio-demographic characteristics and mobility practices). The survey was conducted from September to November 2008 and 717 individual 7-day mobility diaries were collected (starting from any day within a week).

The initial 12 activity types are classified into six categories in our empirical analysis: 1 home (home), 2 work and school (work, school), 3 shopping (daily and long-term shopping), 4 personal business (personal business (bank, doctor etc.)), 5 social-recreation (eating, visit to family or friends, walking, riding, leisure, sport, culture etc.), 6 others (drop off/pick up someone and others).

3 Methodology for measuring variability

Multidimensional statistical techniques could be applied (e.g. factor analysis), however the travel-activity pattern is so complex in its multiple dimensions that a cautious approach is adopted by analysing separately the various indicators. These are number of trips and number of home-based tours per day, time allocation to activities per day (i.e. daily time-budget), activity sequence each day, all of them computed at the individual level.

Variability in day-to-day behaviour can be attributed either to interpersonal differences or to intrapersonal differences. Basic theoretical results regarding the splitting up of variance may be applied, along with the ideas of Pas (1987) who originally developed these measures for analysing day-to-day variability in individuals' travel behaviour.

The total variability of any daily travel/activity indicator (total sum of squares *TSS*) can be split up into interpersonal variability (between person sum of squares *BPSS*) and intrapersonal variability (within person sum of squares *WPSS*).

Indeed considering some indicator of daily activity-travel behaviour n_{ij} (e.g. number of trips made by the individual *i* on day *j*), we have

$$\sum_{i=1}^{I}\sum_{j=1}^{J}(n_{ij}-\overline{n}_i)=0$$

where

I is the number of persons in the sample

J is the number of days in the observation period

and $\overline{n}_i$ the mean daily travel/activity indicator for individual *i* over period *J*, $\overline{n}_i=\frac{1}{J}\sum_j n_{ij}$

It follows that $TSS=\sum_i\sum_j\left(n_{ij}-\overline{n}\right)^2=\sum_i\sum_j\left(n_{ij}-\overline{n}_i\right)^2+\sum_i\sum_j\left(\overline{n}_i-\overline{n}\right)^2=WPSS+BPSS$

with $\overline{n}$ the mean daily travel/activity indicator over all individuals *I* and period *J*, $\overline{n}=\frac{1}{IJ}\sum_i\sum_j n_{ij}$

$WPSS=\sum_{i=1}^{I}\sum_{j=1}^{J}(n_{ij}-\overline{n}_i)^2$, the within-person sum of squares,

$BPSS=\sum_{i=1}^{I}J(\overline{n}_i-\overline{n})^2$, the between-person sum of squares,

When it comes to socio-economic analysis or modelling, the interpersonal variability *BPSS* is generally explained by between-person differences in socio-demographic or place-based attributes.

The intrapersonal variability *WPSS* can be further split up into a systematic day-of-week variability (between-day sum of squares *BDSS*) and a residual variability (within-day sum of squares *WDSS*).

$$WPSS=\sum_{i=1}^{I}\sum_{j=1}^{J}(n_{ij}-\overline{n}_i)^2=\sum_i\sum_j\left[\left(n_{ij}+(\overline{n}_j-\overline{n})-\overline{n}_i\right)-\left(\overline{n}_j-\overline{n}\right)\right]^2=WDSS+BDSS$$

$\overline{n}_j$ is the mean daily travel/activity indicator over individuals on day *j*, $\overline{n}_j=\frac{1}{I}\sum_i n_{ij}$

$n_{ij}+(\overline{n}_j-\overline{n})$ is the travel/activity indicator for person *i* on day *j* adjusted for the systematic effect of day *j*

$$WDSS=\sum_i\sum_j\left(n_{ij}+(\overline{n}_j-\overline{n})-\overline{n}_i\right)^2$$

$$BDSS=\sum_j I(\overline{n}_j-\overline{n})^2$$

4 Variability on various dimensions of activity-travel behaviour in the week

4.1 Variability in the number of trips and home-based tours per day

Table 1 gives an overview of the mean number of trips per person over the week for various activities. The 717 people surveyed all perform at least one outside activity (at least 1 return trip to home) and on average perform 10.3 return trips to home over the seven days with a standard deviation of 3.8. Other activities are practiced at various levels, e.g. 57% for work, 26% for school, 87% for shopping and 95% for social recreation. However the variability in trip numbers is large (compare "mean" and "S.D.") when compared with that for home return trips.

Table 1: Number of trips per person per week

Activity	Number of trips per person per week								
	N*	% of N	Mean	S.D.	Min	Q1	Q2	Q3	Max
Home	717	100	10.3	3.8	1	8	10	12	25
Work	406	57	4.9	2.5	1	3	5	6	17
School	186	26	3.8	2.4	1	1	4	5	11
Shopping	627	87	4.0	2.7	1	2	3	5	17
Personal business	368	51	1.9	1.3	1	1	1	3	8
Social recreation	684	95	5.3	3.6	1	3	4	7	27
Others	528	74	4.8	4.0	1	2	4	7	32
Total (N=717)	717	100	27.0	10.2	2	20	26	33	58

N*: Number of individuals with number of trips >0

Moreover, as shown in Table 2, the variability in trip numbers (over all activities) remains high whatever the period considered in the week.

Table 2: Mean number of trips per day for different types of day (minutes, N=5019)

Period	Monday-Friday		Monday-Saturday		Monday-Friday, Sunday		Monday-Sunday		Saturday, Sunday	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Number of trip per day	4.0	2.4	4.0	2.4	3.8	2.4	3.9	2.4	3.5	2.4

Table 3: Mean number of home-based tour per day for different types of day (minutes, N=5019)

Type of day	Monday-Friday		Monday-Saturday		Monday-Friday, Sunday		Monday-Sunday		Saturday, Sunday	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Number of home-based tours per day	1.5	0.9	1.5	1.0	1.5	1.0	1.5	1.0	1.3	1.0

Table 4 shows the inter- and intrapersonal variability in number of trips per day. One finds again the large level of intrapersonal variability in daily trip numbers denoted in the literature like in Pas (1987, with a seven-day data set) and Pas and Sundar (1995, with a three-day data set). However one can go further by analysing this variability along various time periods within the week.

First, the total variability of daily trip number (TSS, divided by the number of days on which this statistics is computed) is roughly the same whatever the five periods considered (from Monday-Friday to Saturday-Sunday). This indicates that the number and the type of days on which the variability is computed have no incidence on its level.

The between person variability (BPSS) is in general less than the within person variability (WPSS): the share of BPSS in total variability is minimum (35.8%) when considering the whole week (Monday to Sunday); it increases to make up 45% of total variability when considering Monday to Friday period (working days); and it is maximum (60.6%) when narrowing the period to the week-end (Saturday and Sunday). It is only over the week-end that the between person variability is above the within person variability.

These results suggest that socio-demographic characteristics attached to the person, which are generally used to explain differences in travel behaviour, should perform better on week-end days and less on working days period (Monday-Friday). The impact of these socio-demographic characteristics is explored later in this paper.

Table 4: Inter and intrapersonal variability in number of trips per day

Period	TSS	BPSS	WPSS	BPSS /TSS (%)	BDSS	WDSS	BDSS /WPSS (%)
Mon-Fri	4.16	1.88	2.29	45.1%	0.03	2.26	1.2%
Mon-Sat	4.23	1.72	2.52	40.6%	0.02	2.49	0.9%
Mon-Fri, Sun	4.15	1.58	2.57	38.0%	0.15	2.43	5.7%
Mon-Sun	4.22	1.51	2.71	35.8%	0.13	2.58	4.7%
Sat, Sun	4.18	2.53	1.65	60.6%	0.21	1.44	12.5%

Remark: BPSS, WPSS, BDSS, WDSS and TSS is divided by 10^3 and by the number of days considered

When it comes to further breakdown of within person variability (WPSS) into between-day (systematic day-to-day) and within-day variability, the results show that the systematic day-to-day variability (BDSS) has an extremely low share of WPSS (about 5% on Monday-Sunday period). This is again in line with Pas (1987) but one can analyse the variations of this share along the various periods.

First, if we consider the first four lines of the table, which include the working days (Mon-Fri) and Saturday or Sunday, the level of within-day variability (WDSS) remains approximately the same (from about 2.3 to 2.5). However, the share of BDSS changes significantly when Sunday is included (from about 1% to 5%), and peaks up to 12.5% when the period is narrowed to Saturday-Sunday (BDSS increases while WDSS decreases sharply). Somewhat expected, regarding variability in trip numbers, Sunday appears definitely as a different day from other days of the week, including not only the traditional working days but also Saturday.

Overall this indicates that the within person variability has to be explained by factors other than systematic day-to-day variability.

Table 5 shows the same structure as Table 4 but now for the number of daily home-based tours. However the view offered by home-based tours is rather different from that regarding trips.

The total variability of daily trip number (TSS) is roughly the same for the first four periods considered (less than 0.7, from Monday-Friday to Monday-Saturday) but different regarding the period Saturday-Sunday (1.61, with BPSS tripling and WPSS roughly doubling).

The between person variability (BPSS) is always less than the within person variability (WPSS) whatever the period considered, and goes from about 30% to 39%.

Regarding breakdown of within person variability (WPSS), the systematic day-to-day variability (BDSS) has an extremely low share of WPSS, as for trips, while WDSS remains approximately the same for the first four periods. However while WDSS doubles for the Saturday-Sunday period, BDSS stays at the same level.

Table 5: Inter and intrapersonal variability in number of home-based tours per day

Period	TSS	BPSS	WPSS	BPSS /TSS(%)	BDSS	WDSS	BDSS /WPSS(%)
Mon-Fri	0.65	0.25	0.40	38.5%	0.00	0.39	0.9%
Mon-Sat	0.67	0.23	0.44	34.3%	0.00	0.44	0.7%
Mon-Fri, Sun	0.65	0.21	0.44	32.4%	0.01	0.43	3.0%
Mon-Sun	0.68	0.21	0.47	30.4%	0.01	0.46	2.4%
Sat, Sun	1.61	0.62	0.99	38.5%	0.01	0.98	0.9%

Remark: BPSS, WPSS, BDSS, WDSS and TSS is divided by 10^3 and by the number of days considered

4.2 Variability in the individuals' daily time use

The daily travel/activity indicator under study here is the duration of activity *a* on day *j* for individual *i* (in minutes) d_{ija}. Only out-of-home activities are distinguished while in-home activities are not available in detail. Table 6 shows mean duration (and standard deviation) of activities for various periods in the week.

Table 6: Mean daily duration of activity for different types of day (minutes, N=5019)

Type of day	Monday-Friday		Monday-Saturday		Monday-Friday, Sunday		Monday-Sunday		Saturday, Sunday	
	Mean	Std	Mean	Std	Mean	Std	Mean	Std	Mean	Std
Home	1013	262	1035	261	1040	265	1055	263	1162	233
Work/School	247	247	210	243	208	243	182	238	21	96
Shopping	17	43	20	46	16	42	18	45	21	51
Personal business	7	26	6	24	6	25	6	24	3	18
Social-recreation	54	103	65	116	68	123	76	130	130	168
Others	24	78	25	79	24	77	24	79	24	81

Hence $\bar{d}_{ia}$ refers to the mean duration of activity *a* for individual *i* over period *J*,

$$\bar{d}_{ia} = \frac{1}{J}\sum_{j} d_{ija}$$

$\bar{d}_{ja}$ is the mean duration of activity *a* over individuals on day *j*, $\bar{d}_{ja} = \frac{1}{I}\sum_{i} d_{ija}$

and $\bar{d}_{a}$ is the mean duration of activity *a* over all individuals *I* and period *J*, $\bar{d}_{a} = \frac{1}{I}\sum_{i} \bar{d}_{ia}$

$$BPSS = \sum_{i=1}^{I}\sum_{a=1}^{K} J(\bar{d}_{ia} - \bar{d}_{a})^2$$

$$WPSS = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{a=1}^{K} (d_{ija} - \bar{d}_{ia})^2$$

$$BDSS = \sum_{j}\sum_{a} I(\bar{d}_{ja} - \bar{d}_{a})^2$$

Table 7 shows the various figures of variability for time allocation to activities per day. TSS is remarkably stable across the various periods of observation, except for a decrease in variability on Saturday-Sunday period. Within this variability the share of between-person variability (BPSS) is in the majority only when considering working days (Monday-Friday, 58%) or the week-end (Saturday-Sunday, 59%). On the opposite the share of BPSS is minimal (and less than half) when considering the whole week (Monday-Sunday): the intrapersonal variability in time allocation over the whole week takes the lead.

Regarding the breakdown of intrapersonal variability (WPSS), the share of systematic day-to-day variability is again in the minority (BDSS, less than 20%), however with significant differences when considering various periods in the week. This share is almost null (0.6%) on the working days period (Monday-Friday) and about 1% on the week-end period.

This indicates that within whether the working days or week-end period intrapersonal variability is not driven by alternation of days but by other kinds of variability.

Table 7: Inter and intrapersonal variability in time allocation to activities per day

Period	TSS	BPSS	WPSS	BPSS /TSS(%)	BDSS	WDSS	BDSS /WPSS(%)
Mon-Fri	0.11	0.06	0.04	58.0%	0.00	0.04	0.6%
Mon-Sat	0.11	0.05	0.06	44.0%	0.01	0.05	12.0%
Mon-Fri, Sun	0.11	0.05	0.06	43.3%	0.01	0.05	14.6%
Mon-Sun	0.11	0.04	0.07	35.8%	0.01	0.06	17.0%
Sat, Sun	0.07	0.04	0.03	59.2%	0.00	0.03	1.4%

Remark: BPSS, WPSS, BDSS, WDSS and TSS is divided by 10^9 and by the number of days considered

The opposition of working days on the one hand and week-end days on the other hand, when compared to the whole week indicates a probable effect of socio-demographic individual status which makes the allocation of time more heterogeneous between people during the working days and during the week-end. Thus the same table is computed by restricting to workers only, with figures shown in Table 8. With this subsample, compared to the previous table, the total variability (TSS) is divided by two, reflecting the homogenization of time allocation across individuals (and probably the impact of work activity on daily time use). There is only a slight decrease of intra-personal variability (WPSS) and thus the share of inter-personal variability (BPSS) decreases significantly. BPSS is in the majority only when considering week-end (Saturday-Sunday) and it is minimal when considering the whole week (Monday-Sunday), as previously. Finally the share of systematic day-to-day variability (BDSS) increases but remains in the minority.

Overall, when restricting to the subsample of workers, there is more homogeneity in time allocation across the sample and the days, but the intra-personal variability increases its share.

Table 8: Inter and intrapersonal variability in time allocation to activities per day (workers, N = 389)

Type of day	TSS	BPSS	WPSS	BPSS /TSS(%)	BDSS	WDSS	BDSS /WPSS(%)
Mon-Fri	0.05	0.02	0.03	39.6%	0.00	0.03	0.8%
Mon-Sat	0.06	0.02	0.04	27.1%	0.01	0.03	19.1%
Mon-Fri, Sun	0.06	0.02	0.04	26.8%	0.01	0.03	23.3%
Mon-Sun	0.06	0.01	0.05	21.3%	0.01	0.03	27.2%
Sat, Sun	0.04	0.03	0.02	57.2%	0.00	0.02	1.8%

Remark: BPSS, WPSS, BDSS, WDSS and TSS is divided by 10^9 and by the number of days considered

4.3 Variability for individuals' daily activity sequence

The similarity of activity chains (patterns) has been a widely studied research issue in activity-based travel demand analysis. The comparison of activity patterns is the basis for longitudinal analysis of travel behaviour. The question concerns how different activity patterns vary over a week. In the past, most similarity indicators compare the corresponding elements between a pair of activity patterns. The distance is measured by summation of 0-1 scores resulting from pairwise comparison of sequences. The sequential (order) information between elements is neglected. As the sequential relationships reveal the dependency of travel/activity participations of individual's activity chaining behaviour, it is important to take it into account.

For this issue, Wilson (1998) firstly introduced a Sequential Alignment Method (SAM) for activity pattern analysis. The SAM allows comparing the similarity between a pair of sequences by incorporating its ordering information. The method is originated from molecular biology, aiming to identifying segments of similarity reflecting some functional relationship between sequences of DNA or protein. The sequence is defined as a set of ordered elements arranged as a string. The difference (dissimilarity) between sequences is evaluated as the efforts to equalize them, which allows one takes into account the sequential information in the measurement of similarity between sequences. The SAM has gained its popularity in comparing the similarity between activity patterns recently (Schlich and Axhausen, 2004; Shimamoto et al., 2009). Some methodological advancement in the SAM for activity pattern analysis has also been reported (Joh et al. 2002; Wilson, 2008).

The similarity of activity patterns can be measured based on a variety of attributes of each activities between two activity chains, such as activity type, transport mode, destination and activity duration etc. If we consider only one attribute, the ordered attribute values represent corresponding travel/activity characteristics in the activity chain. To measure the similarity, a distance function needs to be defined. The SAM utilizes a process for which a set of operations, i.e., deletions, insertions and substitutions, are utilized to equalize the sequences. Each type of operations is associated with a cost (score) for which substitutions are generally assigned as two times of deletion/insertion costs. This is because one substitution needs to implement one deletion and one insertion. For example, to equalize the sequence [ACB] to [ABC], one needs to delete [C] before [B] and inset it at the end of the sequence [AB]. The corresponding cost is 2. More precisely, in one dimension case, the dissimilarity $\mathrm{d}(s_1, s_2)$

between sequences s_1 and s_2 can be calculated as the smallest summation of these operations costs or *alignment cost*, namely,

$$d(s_1, s_2) = w_d o_d + w_i o_i + w_r o_r \qquad (1)$$

where w_d, w_i and w_r is the costs (weighting coefficients) of deletion, insertion and replacement, respectively. The distance (Levenshtein distance) between two sequences can be calculated by applying a dynamic programming algorithm, computing the least number of operations necessary to equalize two sequences.

As activity patterns are generally characterized by different attributes, the similarity between these patterns should take into account all important attributes, which make the calculation of similarity more complex. As mentioned by Schlich and Axhausen (2004), different attributes may depend on each others, i.e. trip duration, transport mode and destination choice are correlated. Hence, the similarity between activity chains with multiple attributes cannot be obtained by simply summing uni-dimensional alignment costs for all attributes. For this issue, Joh et al. (2002) propose a multidimensional alignment method by taking into account the interdependence information among the attributes in activity patterns. The idea is that first a multidimensional sequence is constructed with each line representing corresponding attribute. The operation set for each attribute is identified based on the calculation of Levenshtein distance. If the operations for attributes are identical, the costs are counted once as one simultaneously aligns a bundle of elements. They further proved that the minimum cost of multidimensional alignment can be obtained efficiently by searching the combination of one-dimensional alignment results for each attribute. Joh (2004) proposed a heuristic method to calculate the multidimensional alignment costs. However, some issues concern the choice of attributes and the categorisation of interval-scaled variable such as activity duration or trip distance still lack theoretical justification. Because different ways of selecting, weighting and categorizing attributes may generate trivial results, we applied one-dimensional alignment method to compare activity type sequences.

In the general formulations n_{ij} is replaced by s_{ij} the SAM distance for individual *i*, between day *j* and the other days of the week, defined as $s_{ij} = \sum_{k=1}^{J} d(q_{ij}, q_{ik})$ with q_{ij} being the activity sequence on day *j* performed by individual *i*.

Thus $\bar{s}_i$ is the mean SAM distance for individual *i* of all days *j* of period *J* to all other days in the same period *J*, $\bar{s}_i = \frac{1}{J}\sum_j s_{ij} = \frac{1}{J}\sum_{j=1}^{J}\sum_{k=1}^{J} d(q_{ij}, q_{ik})$

$\bar{s}_j$ is the mean SAM distance over all the individuals of day *j* to all other days in period *J*, defined as $\bar{s}_j = \frac{1}{I}\sum_i s_{ij} = \frac{1}{I}\sum_i \sum_{k=1}^{J} d(q_{ij}, q_{ik})$

$\bar{s}$ is the mean SAM distance over all the individuals and all days of period *J*, $\bar{s} = \frac{1}{I}\sum_i \bar{s}_i$

Other statistics are straightforward:

$$BPSS = \sum_i J(\bar{s}_i - \bar{s})^2$$

$$WPSS = \sum_i \sum_j I(s_{ij} - \bar{s}_i)^2$$

$$BDSS = \sum_j I(\bar{s}_j - \bar{s})^2$$

Table 9 shows the overall mean SAM distance for different periods in the week. The SAM distance is minimal in the week-end period (Saturday-Sunday), at a significantly lower level than on other days, and maximal when considering the whole week (Monday-Sunday). This indicates a specificity of Saturday and Sunday in activity sequences, when compared with the remainder of the week, and also a significant degree of homogeneity of these two days in the nature of activities when compared with the working days.

Table 9: Overall mean SAM distance for different periods

Period	Monday-Friday	Monday-Saturday	Monday-Friday, Sunday	Monday-Sunday	Saturday, Sunday
$\bar{s}$	14.1	19.3	18.6	23.4	3.6

Remark: $\bar{s}$ is divided by 10^9

Table 10 shows the inter- and intrapersonal variability of SAM distances for various periods in the week. The total variability (TSS) is minimal on week-end and maximal when considering the whole week. The main difference with previous indicators is the high level of between-person variability, always over intrapersonal variability (with a share of more than 70%). This share is maximal on the working days period (Monday to Friday). Thus the heterogeneity of individuals would explain a large part of variability in the sequencing of activities.

Hence the intrapersonal variability (WPSS) is small and within it, the systematic day-to-day variability (BDSS) is even smaller (roughly between 1% and 9%).

Table 10: Inter and intrapersonal variability in individuals' daily activity sequence

Period	TSS	BPSS	WPSS	BPSS /TSS(%)	BDSS	WDSS	BDSS /WPSS(%)
Mon-Fri	0.05	0.04	0.01	78.7%	0.00	0.01	1.3%
Mon-Sat	0.07	0.05	0.02	72.5%	0.00	0.02	8.4%
Mon-Fri, Sun	0.07	0.05	0.02	73.6%	0.00	0.02	3.7%
Mon-Sun	0.10	0.07	0.03	71.3%	0.00	0.03	4.5%
Sat, Sun	0.00	0.00	-	100.0%	-	0.00	NA

Remark: BPSS, WPSS, BDSS, WDSS and TSS is divided by 10^9 and by the number of days considered

Because of this high level of between person variability on working days, the impact of individual socio-demographic status on daily activity sequence is explored further with Table 11 relative to workers subsample.

Compared to Table 10 the workers subsample shows no significant change in structure. There is a slight decrease of total variability (TSS), which is expected as the subsample is more homogeneous, and no change in the share ranking of BPSS. There is a slight increase in the share of day-to-day systematic variability (BDSS) but it is still in the minority.

Table 11: Inter and intrapersonal variability in individuals' daily activity sequence (workers, number of individuals = 389)

Type of day	TSS	BPSS	WPSS	BPSS /TSS(%)	BDSS	WDSS	BDSS /WPSS(%)
Mon-Fri	0.03	0.02	0.01	76.4%	0.00	0.01	1.8%
Mon-Sat	0.05	0.03	0.01	69.4%	0.00	0.01	12.7%
Mon-Fri, Sun	0.04	0.03	0.01	71.2%	0.00	0.01	6.4%
Mon-Sun	0.06	0.04	0.02	68.5%	0.00	0.02	8.0%
Sat, Sun	0.00	0.00	-	100.0%	-	0.00	NA

Remark: BPSS, WPSS, BDSS, WDSS and TSS is divided by 10^9 and by the number of days considered

4.4 Does socio-demographic status explain intrapersonal variability?

Since we suspect that socio-demographic status might explain the level of intrapersonal variability, linear regression models are employed to investigate the effects of socio-demographic variables on individual intrapersonal variability.

Referring to the general notation the endogenous variable is

$$WPSS_i = \sum_{j=1}^{J} (n_{ij} - \overline{n}_i)^2$$

More than twenty socio-demographic and lifecycle variables are included as explanatory variables for intrapersonal variability analysis. They are listed in Table 12 and include gender, age (in groups), household type (couple or single), the presence of young children (under 12) in the household, work status, holding of a driving license, work duration (in groups) and a combination of variables describing the role of the individual (head, spouse or child) and the household structure (single, couple; child, no child; zero, one or two workers).

Holding a driving license is retained as a proxy for car availability. Indeed we know by the survey the number of cars available in the household but not the number of driving licenses within the household. Previous studies indicate that the possession of driving license influences individual's travel and activity participation (Bhat and Srinivasan, 2005; Lee and Timmermans, 2007).

Table 12: Summary statistics of explanatory variables in terms of individuals' socio-demographic characteristics and lifecycle types

Variable	Definition	mean
Density	Population density of statistic zone of residence (persons/km^2) (mean)	4376
Socio-demographic		
Gender	Gender (1 if male, 0 female)	0.49
Age15	1 if the age of the individual is less than 15 years, 0 otherwise (% of 1)	0.05
Age15_25	1 if the age of the individual is in $[15, 25)$ years, 0 otherwise	0.17
Age25_55	1 if the age of the individual is in $[25, 55)$ years , 0 otherwise	0.54
Age55_65	1 if the age of the individual is in $[55, 65)$ years, 0 otherwise	0.14
Age65	1 if the age of the individual is greater than 65 years, 0 otherwise	0.10
H_type	Household type (1 if couple, 0 if single)	0.79
Children_12	1 if the presence of children of age less than 12 years in the household, 0 otherwise	0.26
Work_status	1 if the individual performance a job (fulltime/part-time), 0 otherwise	0.55
License	1 if the individual has a driving license, 0 otherwise	0.80
Dur_work_zero	1 if work hours per week iszero, 0 otherwise	0.44
Dur_work_21h*	1 if work hours per week is greater than 0 and less than 21 hours, 0 otherwise	0.14
Dur_work_21_31h	1 if work hours per week is in [21,31), 0 otherwise	0.13
Dur_work_31_41h	1 if work hours per week is in [31,41), 0 otherwise	0.15
Dur_work_41h	1 if work hours per week is at least 41 hours, 0 otherwise	0.15
Role in the household		
Child	1 if the role of the individual is child, 0 otherwise	0.29
H_Sing_Child	1 if the individual lives alone with the presence of children of age less than 12 in the household and his/her role is head/spouse, 0 otherwise.	0.01
H_Sing_NChild	1 if the individual lives alone without the presence of children of age less than 12 in the household and his/her role is head/spouse, 0 otherwise.	0.15
H_Coup_Child_NW	1 if the individual lives in couple with the presence of children of age less than 12 and with no worker in the household, and his/her role is head/spouse, 0 otherwise.	0.00
H_Coup_Child_1W	1 if the individual lives in couple with the presence of children of age less than 12 and with one worker in the household, and his/her role is head/spouse, 0 otherwise.	0.02
H_Coup_Child_2W	1 if the individual lives in couple with the presence of children of age less than 12 and with more than two workers in the household, and his/her role is head/spouse, 0 otherwise.	0.18
H_Coup_NChild_0W	1 if the individual lives in couple without the presence of children of age less than 12 and with no worker in the household, and his/her role is head/spouse, 0 otherwise.	0.13
H_Coup_NChild_1W	1 if the individual lives in couple without the presence of children of age less than 12 and with one worker in the household, and his/her role is head/spouse, 0 otherwise.	0.06
H_Coup_NChild_2W	1 if the individual lives in couple without the presence of children of age less than 12 and with more than two workers in the household, and his/her role is head/spouse, 0 otherwise.	0.16

* the segmentation of work duration ("Dur_work") is based on 25%, 50% and 75% quantiles of the number of hours of work made by the individual per week

The previous analysis suggests that the intrapersonal variability of individuals' daily travel, time use and activity sequence might depends on individuals' socio-professional status. Hence we distinguish four categories as: 1. students, schoolboys(girls); 2. house-wife/husband, unemployed, invalid; 3. pensioners; 4 workers. A regression analysis is performed for each category in order to examine the effects of explanatory variables. Linear regression models are estimated based on stepwise regression method. Moreover, the validity of calibrating separate models for these four categories is tested with likelihood ratio tests and this breakdown of model is significant in all cases (see Table 18, Table 21, Table 24 and Table 27 in appendices).

Overall the models show that the influence of socio-demographic status on intrapersonal variability is weak, whether for daily trips, tours, time use and daily activity sequence.

However some variables have a systematic effect.

Gender is always significant in nearly all categories of the sample and men have in general lower intrapersonal variability than women.

Adults living single without young children (H_Sing_NChild) have also in general lower variability in all intrapersonal variability dimensions, although depending on the category (students, etc.). However they are only 1% in the sample.

Sometimes age appear significant but without definite meaning.

Holding a license has a positive significant effect on intrapersonal variability for students only. Potential access to car driving is associated with more intrapersonal variability in activity-travel pattern.

5 Searching for core stops in the week

The search for core stops starts with the measure of repetition of travel behaviour based on trip characteristics. Each trip can be classified based on one- or multi-dimensional trip attributes. These four attributes are activity type, transport mode, arrival time at destination and activity location. Activity is classified as 6 categories: 1. work; 2. school; 3. shopping; 4. personal business; 5. social recreation; 6. others; 7. home. Mode is classified as: 1. walk; 2. bicycle; 3. car; 4. public transportation. Arrival time is classified as: 1. 0:00- 8:30; 2. 8:31-10:30; 3. 10:31-12:30; 4. 12:31-16:00; 5. 16:01-18:30; 6. 18:31-23:59. Location of activity is based on the 45 zones actually visited by the overall sample.

Table 13 gives an overview of the frequency of trip attributes according to activity, mode, arrival time and location. On average, individuals perform almost five activities among the seven potential, they use three of the four potential modes, arrival times of their trips fall within five intervals of the six possible and they visit only six locations (with a maximum of 14) among the 45 visited overall by the sample. This first overview indicates at the same time diversity and specificity in activity-travel across the week. People seems to perform the whole range of activities (except work for non-workers and school for adults and non-students), they use various transport modes and at any time. However, they visit only a few places among the infinity of potentials.

Table 13: Number of trip types performed by individuals, according to activity, mode, arrival time and location (over the week, N=717)

	Mean	S.D.	Minimum	Maximum
Activity (7)	4.9	1.0	2.0	7.0
Mode (4)	2.6	0.9	1.0	4.0
Arrival time (6)	5.3	0.9	1.0	6.0
Location (45)	5.5	2.1	1.0	14.0

Remark : number in the parenthesis means total number of classes

As in Hanson and Huff (1982) measures of repetition of individual's trips on various combinations of two to four attributes are given in Table 14. On average, 12 combinations of four attributes (activity x mode x arrival time x location) are enough to describe all the types of trips performed in the week, compared to the 6480 theoretical possibilities. However, standard deviation is high since it amounts to almost half the mean.

Looking at the number of cells with more than one trip, the combination of four attributes shows that on average about 3 types of trips are repeated, which on average concentrate each more than 10% of trips.

Moreover, looking at the last columns, on average 40% of trips may be described by one combination of travel mode and location among the 24 potential, 30% by a combination of one activity, travel mode and location among the 1080 potential. Promising, about 20% of trips may be described by only one combination of activity, travel mode, arrival time and location (see last line, 23.3%), among the 6480 potential. However dispersion around these mean values is large.

Definition of "core stops" has somewhat to do in the arbitrary. Hanson and Huff (1988) define them as stops which occur at least half the "representative days" they have elaborated on a 35-day recording period. Here only a 7-day recording period is available. In our application core stops are defined for each individual as the trips, classified by four-attribute characteristics (activity, mode, arrival time, location), *occurring at least three different days in the week*. Since, as analysed above, Saturday and Sunday are very different compared to the five remaining working days, a frequency of three times in a week is somewhat large.

Table 15 shows the distribution of core stops based on four-attribute characteristics of trips (activity, mode, location, arrival time), overall (last line of the table) and broken down over activity type. With the definition above, for almost everybody there is no core stops for activities like shopping, personal business, social recreation and "others" (see column "% of zero" in the first section of the table, which goes from the 80% to the 100%). For school less than half of people concerned have core stops (100-55.4 = 44.6%), while they are in the majority for work (100-35.8 = 64.2%) and return to home (100-21.8 = 78.2%). This definitely separates mandatory activities (i.e., work, school) and home as anchors while other activities are far more flexible in location, time and mode used.

When it comes to the distribution in percentage, for half of the sample (see column "Q2" in the "percentage of trips" section of the table) at least 30% of all trips are core stops. This percentage of core stops rises to more than 40% for home trips (they occur with the same combination of mode x arrival time) and to more than 60% of work trips (they occur with the same combination of mode x arrival time x location).

However we suspect that the “arrival time” attribute blurs the concentration of trips in core stops. This can be detected in Table 14 when arrival time combines to two attributes, which decreases significantly the percentage in the cell with largest value (last column): compare Activity * Mode * Arrival time (26%) to Activity * Mode (39%), Activity * Arrival time * Location (25%) to Activity * Location (35%) and Mode * Arrival time * Location (26%) to Mode * Location (40%).

Thus core stops based on three attributes (excluding the “arrival time” attribute, leaving only activity, mode and location) are analysed in Table 16. With this restriction to three attributes, nearly everybody has home return trips as core stops (3% in the column “% of zero” in the first section of the table): this is somewhat expected in this specific case since as place and activity (“home”) are fixed, the only attribute remaining is mode. The percentage of zero trips in core stops for individuals engaging in mandatory activities is decreasing, or in other words, three-quarter of workers have work trips in core stops (100-23.9 = 76.1%) and more than half of schoolgirls(boys) and students have school trips in core stops (100-46.2 = 54.8%). Flexibility of shopping, personal business, social recreation and “other” activities is confirmed since the percentages of individuals having no trips as core stops for these activities are still high (from 71% to 97%).

The distribution in percentage shows a significant increase of core stops shares. Over all activities the minimum percentage of trips being core stops for half of the individuals goes from 30% with four attributes to 56% now with the three attributes activity x mode x location (more than 43% for three-quarter of the sample). Breaking down by activity, and thus having only two attributes (mode x location), at least 86% of home return trips are core stops for half of individuals (and at least 75% of trips for three-quarter of the sample). These figures are respectively 83% and 43% for work trips for the sample of workers. 57% of school trips are core stops for half of the sample of schoolgirls(boys) and students.

Finally, the linkage of core stops with individual socio-demographic characteristics is tested with regression analysis. The endogenous variable is the percentage of core stops in the week, with two models, one for workers (N=389) and one for non-workers (N=307), and two series of tables, respectively for core stops based on four-attribute characteristics of trips (see Table 44 in appendices) and core stops based on three-attribute characteristics of trips (see Table 45).

As shown by these tables, the influence of socio-demographic characteristics on percentage of core stops is weak. For workers the only significant variable is work duration where duration shorter than 21 hours induces a lower percentage of core stops, and duration longer than 41 hours induces a higher percentage of core stops.

For non-workers, gender is significant as men have a higher percentage of core stops and the same positive effect is observed when young children are present, for those living in couple or those under 25. On the opposite, holding a driving license is associated with a lower percentage of core stops.

Table 14: Some measures of repetition of individual's out-of-home trips (based on two, three and four attributes)

Contingency table	Number of cells with at least one trip				Number of cells with more than one trip		Number of cells with more than 10% of trips		Cell with the largest percent of trips (%)	
	Mean	S.D.	Max	Min	Mean	S.D.	Mean	S.D.	Mean	S.D.
Activity*Mode (24)	6.2	2.3	29	1	3.7	1.7	3.4	1.0	38.9	14.3
Activity*Arrival time (36)	8.8	3.4	21	1	4.0	2.2	3.1	1.3	28.9	13.4
Activity*Location (270)	8.0	3.3	21	1	3.4	1.7	3.1	1.2	35.4	14.4
Mode*Arrival time (24)	7.3	2.7	19	1	4.0	1.9	3.6	1.2	32.9	13.4
Mode*Location (180)	7.1	2.9	18	1	3.3	1.6	3.1	1.2	40.2	16.4
Arrival time*Location (270)	9.6	4.0	25	1	3.5	2.0	3.1	1.5	28.4	13.0
Activity*Mode*Arrival time (144)	10.4	4.4	33	1	3.5	2.1	3.0	1.5	26.0	13.4
Activity*Mode*Location (1080)	9.5	4.1	24	1	3.2	1.9	2.9	1.4	31.3	14.8
Activity*Arrival time*Location (1620)	11.5	5.1	31	1	2.9	1.9	2.6	1.7	24.9	13.5
Mode*Arrival time*Location (1080)	10.9	4.7	33	1	3.2	2.0	2.8	1.6	25.6	13.4
Activity*Mode*Arrival time*Location (6480)	12.3	5.6	38	1	2.6	1.8	2.4	1.8	23.3	13.6

Remarks:

1. Number in the parenthesis means total number of cells in the contingency table
2. Return trips to home are excluded. Out-of-home activity is classified as 6 categories : 1.work, 2.school, 3.shopping, 4.personal business, 5.social recreation and 6.others
3. Mode is classified as: 1 walk, 2 bicycle, 3 car 4 public transport
4. Arrival time is classified as: 1 0:00- 8:30, 2 8:31- 10:30, 3 10:31-12:30, 4 12:31-16:00, 5 16:01-1830, 6 18:31-23:59
5. Location of activity is based on 45 zones.

Table 15: Core stops distribution per activity type, based on four-attribute (activity, mode, location, arrival time) characteristics of trips

	Number of trips which are core stops, per person per week									Percentage of trips which are core stops, per person (%)							
Activity at destination	N*	Mean	S.D.	% of zero	Min	Q1	Q2	Q3	Max	N*	Mean	S.D.	Min	Q1	Q2	Q3	Max
Home	717	4.4	3.4	21.8%	0	3	4	7	19	717	41.2	27.1	0	25.0	43.8	61.5	100.0
Work	406	2.7	2.4	35.8%	0	0	3	4	14	406	50.2	40.9	0	0.0	60.0	83.3	100.0
School	186	2.0	2.4	55.4%	0	0	0	4	9	186	37.5	43.7	0	0.0	0.0	83.3	100.0
Shopping	627	0.4	1.3	91.2%	0	0	0	0	10	627	4.7	16.0	0	0.0	0.0	0.0	85.7
Personal business	368	0.0	0.2	99.5%	0	0	0	0	3	368	0.4	5.8	0	0.0	0.0	0.0	100.0
Social recreation	684	0.6	1.9	88.2%	0	0	0	0	20	684	6.0	17.5	0	0.0	0.0	0.0	100.0
Others	528	1.0	2.5	81.6%	0	0	0	0	16	528	10.6	24.2	0	0.0	0.0	0.0	100.0
Total (N=717)	717	8.1	5.9		0	3	7	12	34	717	29.8	19.4	0	15.2	30.0	42.9	85.7

N*: Number of individuals with number of trips >0

Remark: Core stops are defined for each individual as the trips, classified by four-attribute characteristics (activity, mode, arrival time, location), occurring at least three different days of a week

Table 16: Core stops distribution per activity type, based on three-attribute (activity, mode, location) characteristics of trips

	Number of trips which are core stops per person per week									Percentage of trips which are core stops per person (%)							
Activity at destination	N*	Mean	S.D.	% of zero	Min	Q1	Q2	Q3	Max	N*	Mean	S.D.	Min	Q1	Q2	Q3	Max
Home	717	8.6	4.0	3%	0	6	8	11	23	717	81.5	21.0	0.0	75.0	85.7	100.0	100.0
Work	406	3.7	2.6	23.9%	0	3	4	5	17	406	67.2	40.3	0.0	42.9	83.3	100.0	100.0
School	186	2.6	2.6	46.2%	0	0	3	5	11	186	47.4	45.8	0.0	0.0	57.1	100.0	100.0
Shopping	627	1.0	2.2	79.7%	0	0	0	0	16	627	13.8	28.7	0.0	0.0	0.0	0.0	100.0
Personal business	368	0.1	0.6	96.5%	0	0	0	0	4	368	2.5	13.9	0.0	0.0	0.0	0.0	100.0
Social recreation	684	1.3	2.8	75.0%	0	0	0	1.5	21	684	15.3	28.4	0.0	0.0	0.0	10.0	100.0
Others	528	1.8	3.5	71.2%	0	0	0	3	22	528	20.8	34.7	0.0	0.0	0.0	48.3	100.0
Total (N=717)	717	14.9	7.7		0	10	13	19	40	717	54.0	18.2	0.0	42.9	55.6	66.7	100.0

N*: Number of individuals with number of trips >0

Remark: Core stops are defined for each individual as the trips, classified by three-attribute characteristics (activity, mode, location), occurring at least three different days of a week

6 Discussion and conclusion

The large level of intrapersonal variability in daily trip numbers (or home-based tours) already demonstrated in the literature is confirmed. However our analysis goes further by studying this variability along various time periods within the week.

First of all overall variability in daily trip numbers is roughly constant whatever the periods considered within the week (number and type of days). Then within this overall variability, intrapersonal variability is generally greater than interpersonal variability, except in the week-end period. And finally the systematic day-to-day variability has an extremely low share in intrapersonal variability. Overall this indicates that intrapersonal variability has to be explained by factors other than systematic day-to-day variability.

When it comes to daily time allocation to activities a slightly different picture appears. Overall variability in time allocation is roughly constant whatever the periods considered within the week except on week-end (where it decreases). Unlike the case of trips, intrapersonal variability is lower than interpersonal variability either on working days or on week-end. However intrapersonal variability is still greater when considering the whole 7-day week. Moreover, as for trips, intrapersonal variability is not driven by alternation of days (systematic day-to-day variability) but by other sources of variability. Even when focusing the analysis to workers, the intra-personal variability gets a greater share, although there is more homogeneity in time allocation across the sample and the days.

The differences in activity sequence between days are minimal in the week-end period, at a significantly lower level than on other days, and maximal when considering the whole 7-day week. This indicates a significant degree of homogeneity of these two days in the nature of activities when compared with the working days. There is also a great difference with previous activity-travel indicators, since interpersonal variability in activity sequences is always over intrapersonal variability. However, even when focusing the analysis on workers, there is a decrease of overall variability but interpersonal variability keeps the major share.

The influence of socio-demographic characteristics on intrapersonal variability is weak, whether for daily trips, tours, time use and activity sequence. Men have in general lower intrapersonal variability than women which would mean either more flexibility or more irregular constraints (e.g. linked to maintenance, childcare, shopping) for women. Access to car for students (through holding a driving license) is also linked to greater intrapersonal variability. If socio-demographic characteristics explain weakly intrapersonal variability, what is left as explanatory factors?

Another perspective is then taken by searching for repetitive activity-travel behaviour, summed up through attributes of activity type at trip destination, travel mode, trip arrival time and destination location. The picture is at the same time one of diversity and of specificity in activity-travel across the week. People perform the whole range of activities (except for work or school depending on the individual status), they use the various transport modes, at any time. However, they visit only a few places among the infinity of potentials. This is a story of limited location choice set.

The picture is also one of concentration of activity-travel patterns on few combinations, despite a large dispersion. On average, 12 combinations of four attributes (activity x mode x arrival time x location) are enough to describe all the types of trips performed in the week. On average 40% of trips may be described by one combination of travel mode and location, 30% by a combination of one activity, travel mode and location, and about 20% of trips by only one combination of activity, travel mode, arrival time and location.

Core stops are defined for each individual as the trips, classified by four-attribute characteristics (activity, mode, arrival time, location), occurring at least three different days in the week. Core stops concern essentially mandatory activities (i.e., work, school) and home as anchors while other activities (like shopping, personal business, social recreation) are far more flexible in location, time and mode used. For half of the sample at least 30% of all trips are core stops. This percentage rises to more than 40% for home trips and to more than 60% for work trips.

Most of the percentage dispersion comes from the “arrival time” attribute. If we exclude this attribute, leaving only activity, mode and location, of course the percentage of trips which are core stops increases. Flexibility of shopping, personal business, social recreation and “other” activities is confirmed, opposite to mandatory activities. Over all activities the minimum percentage of trips being core stops for half of the individuals rises to 56% with the three attributes, and to 83% for work trips for the sample of workers, to 57% of school trips for half of the sample of schoolgirls(boys) and students.

As for variability of previous activity-travel indicators, the influence of socio-demographic characteristics on percentage of core stops is weak. Men (non-workers) have a higher percentage of core stops, while holding a driving license is associated with a lower percentage of core stops. As the percentage of trips which are core stops may be considered as an indicator of stability, there is an obvious convergence with intrapersonal variability.

Overall this analysis of variability of activity-travel behaviour over a 7-day period shows that individual behaviour is neither completely habitual (or routine), neither completely random, in agreement to what was initially a working hypothesis of Hanson and Huff (1986). However, a limitation of our analysis is the reference to the day as the basis for computing the activity-travel indicators, while the rhythm of repetition could be every other day or on three days, or so on.

The global picture is both that intrapersonal variability is large, and the role of systematic day-to-day variability is marginal. Moreover, a striking result is that socio-demographic characteristics are mostly unable to explain the level of intrapersonal variability.

However results on core stops are somewhat encouraging by showing some kind of concentration of activity patterns on a few “anchor” points. This is a stimulating perspective for modelling behavioural adaptations to changes in transport context.

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Appendixes

Annex 1

Table 17: Regression analysis for intrapersonal variability (WPSS) of the number of trips per day (Monday-Friday)

	Students etc.			House-wife etc.			Pensioner			Worker		
	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F
Intercept	55.9	1.4	<.0001	81.9	3.5	<.0001	95.2	2.7	<.0001	79.8	2.2	<.0001
Gender	-41.3	2.0	<.0001	-46.2	5.2	<.0001	-47.4	3.3	<.0001	-44.4	2.9	<.0001
Age55_65				12.7	5.3	0.019						
H_Sing_NChild				-40.9	7.1	<.0001	-53.7	4.7	<.0001	-14.7	3.7	<.0001
H_Coup_Child_1W	36.0	5.6	<.0001									
License	7.8	2.4	0.002									
N	113			90			104			389		
F value	174.4			44.4			145.0			121.8		
DF	112			89			103			388		
Model Fit statistics (Pr>F)	<.0001			<.0001			<.0001			<.0001		

Table 18: Model comparison for the regression analysis of the number of trips per day (Monday-Friday)

Models	**All**	**Students etc. (1)**	**House-wife etc. (2)**	**Pensioner (3)**	**Worker (4)**
Number of variable	23	18	18	18	23
LnL	-3205.3	-419.1	-404.1	-432.8	-1847.4
Likelihood ratio test	model 1+ model 2+model 3+model 4 - model all				
LR	101.73				
df	54				
p-value	<0.0001				

Table 19: Regression analysis for intrapersonal variability (WPSS) of the number of trips per day (Monday-Sunday)

	Students etc.			House-wife etc.			Pensioner			Worker		
	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F
Intercept	152.0	9.7	<.0001	136.5	5.9	<.0001	158.2	4.4	<.0001	132.9	3.7	<.0001
Gender	-68.0	3.3	<.0001	-77.1	8.7	<.0001	-78.9	5.4	<.0001	-73.8	4.8	<.0001
Age55_65				20.6	8.8	0.022						
Child	-59.8	9.5	<.0001									
H_Sing_NChild				-68.2	11.8	<.0001	-89.2	7.7	<.0001	-24.9	6.1	<.0001
License	13.4	4.1	0.002									
N	113			90			104			389		
F value	166.7			44.6			146.7			122.6		
DF	112			89			103			388		
Model Fit statistics (Pr>F)	<.0001			<.0001			<.0001			<.0001		

Table 20: Regression analysis for intrapersonal variability (WPSS) of the number of home-based tour per day (Monday-Friday)

	Students etc.			House-wife etc.			Pensioner			Worker		
	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F
Intercept	9.6	0.2	<.0001	14.1	0.6	<.0001	16.3	0.5	<.0001	13.7	0.4	<.0001
Gender	-7.0	0.3	<.0001	-7.9	0.9	<.0001	-8.1	0.6	<.0001	-7.6	0.5	<.0001
Age55_65				2.1	0.9	0.023						
H_Sing_NChild				-7.0	1.2	<.0001	-9.1	0.8	<.0001	-2.5	0.6	<.0001
H_Coup_Child_1W	6.1	0.9	<.0001									
License	1.3	0.4	0.002									
N	113			90			104			389		
F value	177.6			45.19			143.3			123.8		
DF	112			89			103			388		
Model Fit statistics (Pr>F)	<.0001			<.0001			<.0001			<.0001		

Table 21: Model comparison for the regression analysis of the number of home-based tour per day (Monday-Friday)

Models	**All**	**Students etc. (1)**	**House-wife etc. (2)**	**Pensioner (3)**	**Worker (4)**
Number of variable	23	18	18	18	23
LnL	-1973.2	-217.0	-244.4	-249.7	-1158.9
Likelihood ratio test	model 1+ model 2+model 3+model 4 - model all				
LR	103.05				
df	54				
p-value	<0.0001				

Table 22: Regression analysis for intrapersonal variability (WPSS) of the number of home-based tour per day (Monday-Sunday)

	Students etc.			House-wife etc.			Pensioner			Worker		
	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F
Intercept	16.4	0.4	<.0001	23.7	1.0	<.0001	11.9	1.3	<.0001	23.1	0.6	<.0001
Gender	-11.8	0.6	<.0001	-13.1	1.5	<.0001	-13.3	0.9	<.0001	-12.7	0.8	<.0001
Couple							15.4	1.3	<.0001			
Age55_65				3.4	1.5	0.026						
H_Sing_NChild				-11.8	2.0	<.0001				-4.4	1.0	<.0001
H_Coup_Child_1W	10.1	1.6	<.0001									
License	2.2	0.7	0.002									
N	113			90			104			389		
F value	180.7			45.2			143.1			123.4		
DF	112			89			103			388		
Model Fit statistics (Pr>F)	<.0001			<.0001			<.0001			<.0001		

Table 23: Regression analysis for intrapersonal variability (WPSS) of individuals' daily time use allocation (Monday-Friday)

	Students etc.			House-wife etc.			Pensioner			Worker		
	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F
Intercept	12.0	0.3	<.0001	17.2	0.6	<.0001	18.5	0.5	<.0001	16.1	0.4	<.0001
Gender	-8.8	0.4	<.0001	-9.1	1.0	<.0001	-8.1	0.6	<.0001	-8.6	0.5	<.0001
Age25_55	5.9	1.0	<.0001									
H_Sing_NChild				-8.1	1.3	<.0001	-10.6	0.9	<.0001	-3.4	0.7	<.0001
License	1.4	0.5	0.004									
N	113			90			104			389		
F value	199.9			67.59			140.2			130.60		
DF	112			89			103			388		
Model Fit statistics (Pr>F)	<.0001			<.0001			<.0001			<.0001		

Table 24: Model comparison for the regression analysis of individuals' daily time use allocation (Monday-Friday)

Models<	All	Students etc. (1)	House-wife etc. (2)	Pensioner (3)	Worker (4)
Number of variable	23	18	18	18	23
LnL	-2040.6	-233.0	-252.3	-256.2	-1197.1
Likelihood ratio test	model 1+ model 2+model 3+model 4 - model all				
LR	101.74				
df	54				
p-value<	<0.0001				

Table 25: Regression analysis for intrapersonal variability (WPSS) of individuals' daily time use allocation (Monday-Sunday)

	Students etc.			House-wife etc.			Pensioner			Worker		
	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F
Intercept	26.9	0.6	<.0001	37.4	1.2	<.0001	39.8	1.0	<.0001	35.3	0.9	<.0001
Gender	-19.3	0.8	<.0001	-19.0	2.0	<.0001	-16.1	1.2	<.0001	-17.9	1.2	<.0001
H_Sing_NChild				-17.7	2.8	<.0001	-23.9	1.8	<.0001	-7.9	1.5	<.0001
Age25_55	12.3	2.1	<.0001				13.4	6.3	0.036			
License	3.1	1.0	0.003									
N	113			90			104			389		
F value	203.86			68.37			97.6			127.80		
DF	112			89			103			388		
Model Fit statistics (Pr>F)	<.0001			<.0001			<.0001			<.0001		

Table 26: Regression analysis for intrapersonal variability (WPSS) of individuals' daily activity sequence (Monday-Friday)

	Students etc.			House-wife etc.			Pensioner			Worker		
	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F
Intercept	26.0	0.6	<.0001	37.3	1.5	<.0001	43.1	1.1	<.0001	36.5	1.0	<.0001
Gender	-18.4	0.9	<.0001	-20.0	2.3	<.0001	-20.4	1.4	<.0001	-19.2	1.3	<.0001
Age25_55	13.5	2.3	<.0001									
Age55_65				5.4	2.3	0.023						
H_Sing_NChild				-18.7	3.1	<.0001	-24	2	<.0001	-7.3	1.6	<.0001
License	3.4	1.1	0.003									
N	113			90			104			389		
F value	162.70			44.44			150.69			118.84		
DF	112			89			103			388		
Model Fit statistics (Pr>F)	<.0001			<.0001			<.0001			<.0001		

Table 27: Model comparison for the regression analysis of individuals' daily activity sequence (Monday-Friday)

Models<	All	Students etc. (1)	House-wife etc. (2)	Pensioner (3)	Worker (4)
Number of variable	23	18	18	18	23
LnL	-2633.3	-328.3	-329.91	-344.2	-1529.0
Likelihood ratio test	model 1+ model 2+model 3+model 4 - model all				
LR	101.79				
df	54				
p-value<	<0.0001				

Table 28: Regression analysis for intrapersonal variability (WPSS) of individuals' daily activity sequence (Monday-Sunday)

	Students etc.			House-wife etc.			Pensioner			Worker		
	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F
Intercept	99.3	2.4	<.0001	142.3	5.9	<.0001	164.9	4.4	<.0001	139.1	3.8	<.0001
Gender	-70.5	3.4	<.0001	-76.6	8.8	<.0001	-77.7	5.3	<.0001	-73.3	4.9	<.0001
Age25_55	52.2	8.9	<.0001									
Age55_65				21.2	8.9	0.02						
H_Sing_NChild				-71.2	11.9	<.0001	-92.1	7.7	<.0001	-27.3	6.2	<.0001
License	12.7	4.3	0.004									
N	113			90			104			389		
F value	161.84			44.49			150.44			117.43		
DF	112			89			103			388		
Model Fit statistics (Pr>F)	<.0001			<.0001			<.0001			<.0001		

Annex 2: Core stops analysis based on four-attribute characteristics of trips

Table 29: The quantiles of arrival time at activity destination (by hour from midnight)

	Home	Work	School	Shopping	Personal business	Social-recreation
Quantile	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate
100% Max	24.0	22.9	22.8	23.8	23.5	23.8
99%	23.6	20.8	18.9	19.6	20.5	23.1
95%	22.3	16.6	18.0	18.3	19.3	21.1
90%	21.0	14.1	16.0	17.7	18.3	20.2
75% Q3	18.5	11.8	12.9	15.9	16.1	18.7
50% Median	16.7	8.6	8.4	12.9	13.4	15.7
25% Q1	12.4	7.9	8.2	10.3	10.2	12.5
10%	9.8	7.3	8.0	9.2	9.0	10.4
5%	8.3	6.4	7.8	8.6	8.6	9.2
1%	0.5	4.6	7.5	7.5	8.1	2.0
0% Min	0.0	0.8	7.0	0.4	6.0	0.0

Table 30: Frequency table of number of trips which are core stops (4 attributes) per person per week: Home

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	156	21.76	156	21.76
3	144	20.08	300	41.84
4	119	16.6	419	58.44
5	63	8.79	482	67.22
6	51	7.11	533	74.34
7	65	9.07	598	83.4
8	33	4.6	631	88.01
9	32	4.46	663	92.47
10	25	3.49	688	95.96
11	9	1.26	697	97.21
12	7	0.98	704	98.19
13	5	0.7	709	98.88
14	1	0.14	710	99.02
15	3	0.42	713	99.44
16	1	0.14	714	99.58
17	1	0.14	715	99.72
18	1	0.14	716	99.86
19	1	0.14	717	100

Table 31: Frequency table of number of trips which are core stops (4 attributes) per person per week: Work

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	145	35.71	145	35.71
3	92	22.66	237	58.37
4	83	20.44	320	78.82
5	63	15.52	383	94.33
6	7	1.72	390	96.06
7	3	0.74	393	96.8
8	7	1.72	400	98.52
9	2	0.49	402	99.01
10	2	0.49	404	99.51
11	1	0.25	405	99.75
14	1	0.25	406	100

Table 32: Frequency table of number of trips which are core stops (4 attributes) per person per week: School

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	103	55.38	103	55.38
3	24	12.9	127	68.28
4	20	10.75	147	79.03
5	31	16.67	178	95.7
6	3	1.61	181	97.31
8	3	1.61	184	98.92
9	2	1.08	186	100

Table 33: Frequency table of number of trips which are core stops (4 attributes) per person per week: Shopping

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	572	91.23	572	91.23
3	31	4.94	603	96.17
4	11	1.75	614	97.93
5	3	0.48	617	98.41
6	5	0.8	622	99.2
7	2	0.32	624	99.52
8	1	0.16	625	99.68
10	2	0.32	627	100

Table 34: Frequency table of number of trips which are core stops (4 attributes) per person per week: Personal business

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	366	99.46	366	99.46
3	2	0.54	368	100

Table 35: Frequency table of number of trips which are core stops (4 attributes) per person per week: Social-recreation

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	603	88.16	603	88.16
3	43	6.29	646	94.44
4	17	2.49	663	96.93
5	7	1.02	670	97.95
6	2	0.29	672	98.25
7	2	0.29	674	98.54
8	3	0.44	677	98.98
11	1	0.15	678	99.12
12	2	0.29	680	99.42
13	1	0.15	681	99.56
14	1	0.15	682	99.71
15	1	0.15	683	99.85
20	1	0.15	684	100

Table 36: Frequency table of number of trips which are core stops (4 attributes) per person per week: Other activities

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	431	81.63	431	81.63
3	35	6.63	466	88.26
4	14	2.65	480	90.91
5	16	3.03	496	93.94
6	5	0.95	501	94.89
7	2	0.38	503	95.27
8	9	1.7	512	96.97
9	1	0.19	513	97.16
10	7	1.33	520	98.48
11	2	0.38	522	98.86
12	1	0.19	523	99.05
13	3	0.57	526	99.62
15	1	0.19	527	99.81
16	1	0.19	528	100

Annex 3: Core stops analysis based on three-attribute characteristics of trips

Table 37: Frequency table of number of trips which are core stops (3 attributes) per person per week: Home

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	22	3.07	22	3.07
3	19	2.65	41	5.72
4	52	7.25	93	12.97
5	60	8.37	153	21.34
6	78	10.88	231	32.22
7	78	10.88	309	43.1
8	68	9.48	377	52.58
9	71	9.9	448	62.48
10	63	8.79	511	71.27
11	59	8.23	570	79.5
12	47	6.56	617	86.05
13	16	2.23	633	88.28
14	27	3.77	660	92.05
15	14	1.95	674	94
16	14	1.95	688	95.96
17	7	0.98	695	96.93
18	8	1.12	703	98.05
19	6	0.84	709	98.88
20	4	0.56	713	99.44
21	1	0.14	714	99.58
22	2	0.28	716	99.86
23	1	0.14	717	100

Table 38: Frequency table of number of trips which are core stops (3 attributes) per person per week: Work

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	97	23.89	97	23.89
3	62	15.27	159	39.16
4	94	23.15	253	62.32
5	89	21.92	342	84.24
6	26	6.4	368	90.64
7	17	4.19	385	94.83
8	8	1.97	393	96.8
9	6	1.48	399	98.28
10	4	0.99	403	99.26
15	2	0.49	405	99.75
17	1	0.25	406	100

Table 39: Frequency table of number of trips which are core stops (3 attributes) per person per week: School

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	86	46.24	86	46.24
3	18	9.68	104	55.91
4	24	12.9	128	68.82
5	43	23.12	171	91.94
6	7	3.76	178	95.7
7	2	1.08	180	96.77
8	2	1.08	182	97.85
9	3	1.61	185	99.46
11	1	0.54	186	100

Table 40: Frequency table of number of trips which are core stops (3 attributes) per person per week: Shopping

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	500	79.74	500	79.74
3	47	7.5	547	87.24
4	26	4.15	573	91.39
5	23	3.67	596	95.06
6	10	1.59	606	96.65
7	10	1.59	616	98.25
8	1	0.16	617	98.41
9	3	0.48	620	98.88
10	2	0.32	622	99.2
11	1	0.16	623	99.36
13	3	0.48	626	99.84
16	1	0.16	627	100

Table 41: Frequency table of number of trips which are core stops (3 attributes) per person per week: Personal business

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	355	96.47	355	96.47
3	9	2.45	364	98.91
4	4	1.09	368	100

Table 42: Frequency table of number of trips which are core stops (3 attributes) per person per week: Social recreation

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	513	75	513	75
3	59	8.63	572	83.63
4	41	5.99	613	89.62
5	25	3.65	638	93.27
6	9	1.32	647	94.59
7	12	1.75	659	96.35
8	6	0.88	665	97.22
9	4	0.58	669	97.81
10	3	0.44	672	98.25
11	2	0.29	674	98.54
12	1	0.15	675	98.68
13	1	0.15	676	98.83
14	1	0.15	677	98.98
15	2	0.29	679	99.27
16	1	0.15	680	99.42
17	2	0.29	682	99.71
18	1	0.15	683	99.85
21	1	0.15	684	100

Table 43: Frequency table of number of trips which are core stops (3 attributes) per person per week: Other activities

number of trips which are core stops	Frequency	Percent	Cumulative Frequency	Cumulative Percent
0	376	71.21	376	71.21
3	35	6.63	411	77.84
4	29	5.49	440	83.33
5	21	3.98	461	87.31
6	14	2.65	475	89.96
7	6	1.14	481	91.1
8	10	1.89	491	92.99
9	9	1.7	500	94.7
10	8	1.52	508	96.21
11	4	0.76	512	96.97
12	3	0.57	515	97.54
13	6	1.14	521	98.67
14	3	0.57	524	99.24
16	1	0.19	525	99.43
18	2	0.38	527	99.81
22	1	0.19	528	100

Table 44: Regression analysis of average percentage of core stops of a week for workers and non-workers (four-attribute characteristics of trips)

	Workers			Non-workers		
	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F
Intercept	33.1	1.2	<.0001	22.3	3.2	<.0001
Gender				5.6	2.2	0.011
Children_12				8.7	3.0	0.004
Couple				7.6	3.0	0.011
License				-10.9	2.3	<.0001
Dur_work_21h	-11.0	2.0	<.0001	NA	NA	NA
Dur_work_41h	10.2	2.0	<.0001	NA	NA	NA
N of individuals	389			307		
F value	42.12			11.72		
DF	388			306		
Model Fit statistics (Pr>F)	<.0001			<.0001		

Table 45: Regression analysis of average percentage of core stops of a week for workers and non-workers (based on three-attribute characteristics of trips)

	Workers			Non-workers		
	Coef.	S.E.	Pr>F	Coef.	S.E.	Pr>F
Intercept	56.2	1.1	<.0001	47.9	1.7	<.0001
Gender				5.9	2.3	0.010
Children_12				8.6	3.1	0.006
H_Sing_NChild				-12.3	4.0	0.003
Dur_work_21h	-5.2	1.9	0.006	NA	NA	NA
Dur_work_41h	8.0	1.8	<.0001	NA	NA	NA
N of individuals	389			307		
F value	20.05			8.43		
DF	388			306		
Model Fit statistics (Pr>F)	<.0001			<.0001		