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ANYTHING, ANYWHERE, ANYTIME? DEVELOPING INDICATORS TO ASSESS THE SPATIAL AND TEMPORAL FRAGMENTATION OF ACTIVITIES

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Abstract

Developments in transportation and information and communication technologies (ICTs) have facilitated the process labeled *activity fragmentation*. In this process, the weakened associations between activity, time, and place ICTs made possible facilitate the disintegration of activities into smaller subtasks, which can then be performed at different times and/or locations. However, until now discussion of the fragmentation of activity hypothesis has been limited to the theoretical domain and largely absent from the empirical domain. This paper connects both domains by a) developing a set of measures of activity fragmentation and b) applying them to study the fragmentation of the activity of paid work using combined activity, travel, and communication diary data collected in the Netherlands in 2007 in order to assess the performance of these indicators. The results show that the indicators developed in this paper differentiate between the multiple facets of activity fragmentation (such as the number, dispersion, and configuration of fragments). The preliminary analyses also suggest that, although the temporal fragmentation of activities appears to be or have become more common, spatial activity fragmentation is rather limited.

1 Introduction

Recent technological developments in transportation and Information and Communication Technologies (ICTs) have been hypothesised to enable a fragmentation of activities in both space and time (Couclelis, 2000, 2004). The fragmentation-of-activity hypothesis states that ICTs have weakened the associations between activity, place, and time, thereby facilitating the disintegration of activities into smaller sets of acts that can then be performed at different times and/or locations. As a result of this decoupling of activity and place, an individual's opportunities to undertake activities are said to increase significantly, supposedly altering post-industrial society from a place-based to a person-based one (Castells, 1996; Couclelis, 1998; Haythornthwaite and Wellman, 2002). Instead of the place dictating the activities that can be performed there, individuals are increasingly free to decide for themselves where and when to engage in activities.

Since most traditional land-use and transportation planning is built on a place-based view of society, the shift to a person-based view exemplified by the fragmentation of activities could have great consequences for urban society (Couclelis, 1998). The fragmentation of activity-travel patterns might reveal itself in a changing use of places (e.g. teleworking or e-shopping from home), travel time (whose utility might be increased by, say, working on a laptop while traveling) and more diversified activity and trip chains (with paid work, care-giving, and leisure activities alternating throughout the day, replacing the traditional 9-to-5 paid-work pattern). Activity fragmentation has furthermore been predicted to result in increased travel demand and, although traffic during conventional peak hours might be relieved, increased road congestion during what are now considered non-peak hours might ensue. More dynamic and fragmented activity-travel patterns may reflect changes in people's preferences resulting, for example, in new requirements for dwellings (with preferences possibly changing from living near the main employment location to living close to recreational facilities), workplaces (with flexible workstations), and public transportation (with broadband wireless Internet access in both train stations and the trains

themselves). Planners and designers would then have to respond to these changes when designing new buildings and infrastructures.

Although the activity-fragmentation hypothesis is intuitively sensible, it is difficult to grasp empirically. Some attempts have been made to collect empirical evidence for the notion of activity fragmentation (see for example Lenz and Nobis, 2007), but a clear framework for its measurement is still lacking. The aim of the current paper is, therefore, to develop a set of straightforward, user-friendly measures of activity fragmentation, and to assess their performance. Although this set of indicators could in principle be applied to study the fragmentation of any kind of activity, we confine our examination to the fragmentation of paid work. Paid work is an activity with the potential of becoming more person- than place-based since ICTs enable workers to extend or redistribute their paid-work activities to previously unconventional parts of the day (early morning, late evening or weekends) as well as unconventional work locations (the home, train, car, and so forth). Based on previous research on the structure and content of total activity patterns (Ettema et al, 2007; Golob, 1998; Hanson, 1982; Lu and Pas, 1999; Pas, 1984) and individuals' ICT usage, we can distinguish certain subgroups of the workforce who could be expected to have more fragmented paid-work patterns than others. Fulltime workers, for example, tend to have both spatially and temporally more diversified paid-work patterns than part-time workers. Similarly, the activity patterns of telecommuters have been shown to differ from those of stationary workers (Pendyala et al, 1991; Saxena and Moktharian, 1997). Our indicators could be considered satisfactory if they produced different results for different subgroups classified according to their ICT, employment, and sociodemographic characteristics, such that findings of theoretical and empirical studies reported in the literature are confirmed. Consequently, the indicators have been applied to combined activity, travel, and communication diary data collected in the Netherlands in 2007.

In the next section, we first describe the definition of activity fragmentation on which our research is based, and follow with a short description of the three dimensions of fragmentation that we distinguish. In section 3, we present the measures of fragmentation

and in section 4 we briefly describe the dataset that formed the basis of our analyses. These are described in section 5; the results of the analyses are tabulated according to groups of sociodemographic, ICT, and work-related variables. The paper concludes with a discussion of the main findings and some suggestions for future research.

2 Theoretical notions and the dimensions of activity fragmentation

2.1 The concept of activity fragmentation

The concept of activity fragmentation that underlies the current paper is inspired by Couclelis (2003, page 11) and reads as follows:

Fragmentation is a process whereby a certain activity is divided into several smaller pieces, which are performed at different times and/or locations.

We distinguish between two kinds of activity fragmentation: *temporal fragmentation* (episodes of an activity carried out at different times) and *spatial fragmentation* (episodes carried out at different locations). It is important to note that an activity consists of smaller subtasks, each of which can consist of several smaller episodes that can be performed at different locations. In general terms, a subtask can be defined as a bundle of actions in the material world undertaken to fulfill an arbitrarily specified goal; we use the term episode to denote a continuous time-span devoted to a particular subtask. Examples of subtasks of paid work can include attending a meeting about a given issue, reading a particular piece or browsing the Internet for information about a particular topic. Each of these subtasks can comprise multiple episodes. For instance, a person may browse the Internet for information about a given topic at her (primary) workplace in the morning, during the work-to-home commute and from home in the evening.

A crucial question when studying the fragmentation of activities is how to define an activity and/or a subtask. This is all the more important as some subtasks lend themselves better than others to performance at unconventional times and places. As Couclelis (2004, page 48) notes about the tasks that constitute the activity of shopping, “[s]ome (notably, paying for the purchase) can only involve one location per purchase while others may involve several locations (gathering information, searching, comparing prices, etc.)”. How an activity or a subtask is defined depends on the research question at hand. If the purpose is to find out whether female telecommuters’ paid work is more often alternated with household activities than male telecommuters’, a more general classification of paid and maintenance activities will suffice. However, if one attempts to determine whether a secretary’s paid work are more or less fragmented than that of a college professor, one needs more detailed information on the subtasks that can be distinguished for both professions and the extent to which it is feasible to fragment them spatially and/or temporally.

Furthermore, there are some concepts that are intimately associated with the concept of activity fragmentation, but should be distinguished from it: multitasking and spatial diversification. With temporal activity fragmentation, the emphasis is on how a single activity is performed at multiple times. *Multitasking* on the other hand concerns how, at a single moment in time, multiple types of activity are performed more or less simultaneously and has largely to do with the fragmentation of time below the level of temporal resolution of the data. The basic assumptions behind fragmentation and multitasking are thus different. Although activity fragmentation is also closely aligned with the notion of *spatial diversification* put forward by Hanson (1980; see also Hanson and Huff, 1988; Huff and Hanson, 1986), the concepts are used to address different questions. By looking at the variability in the locations people visit for a certain activity during a five-week period, Hanson aimed to establish whether it was appropriate to use only one- or two-day activity diaries to study people’s activity schedules, since these schedules might be highly variable in the longer run (week, month, and so on). However, the spatial diversification concept ignores the possible division of these broader activities into smaller

subtasks and the ICT-enabled spatial and temporal relocation of these tasks. The importance of spatial diversification lies for our purposes in its emphasis on the level of repetition and variability in an individual's daily behavior. So not only can episodes of a certain activity be relocated over the day, but this relocation can also appear to be more or less routinized when viewed over a longer period in that the same fragmented activity pattern might repeat itself every week. For the sake of brevity, the relationships between the concepts of multitasking and spatial diversification and activity fragmentation are left to future studies.

Another field of research that bears resemblance to the investigation of activity fragmentation is the work done on describing the spatial dispersion of human activities using models stemming from physics or ecological sciences (e.g. González et al., 2008). Basically, this work aims to establish models and regularities that describe patterns of human activity on an aggregate level. While some of the applied metrics in that work are similar to the metrics employed in this paper, there is a fundamental difference between the approaches. The work by González et al. (2008) is concerned with aggregate patterns of all human activities. In fact, the approach deals with geographic data about locations, ignoring the functional characteristics of activities and places. The work on fragmentation aims to provide individual-level measures of activity fragmentation for specific activities, which is inherently linked to the locations and their functionalities available to an individual.

2.2 Dimensions of fragmentation

The definition of fragmentation above provides a first idea of what the concept entails. The definition does not, however, provide a clear indication of when a certain activity can be considered to be fragmented. This can be assessed using the three dimensions below. They were derived from the field of ecology, which has a vast literature on the fragmentation of forests (Rutledge, 2003); the dimensions were first applied in activity research by Hubers and colleagues (Hubers et al, 2008).

2.2.1 Number of fragments

In ecology, three basic dimensions of fragmentation are usually discerned. The first is the *number* of fragments an activity is divided into. As Rutledge (2003, page 7) explains: “A plate that is broken into 100 pieces is more fragmented than a plate broken into 10 pieces.” For example, if we look at the images under the heading of number of activity episodes in Figures 1 and 2, the left images (with only three episodes/locations) can be considered less fragmented than the right images (with six episodes/locations at which the activity or subtask is performed). Let us suppose the plate resembles paid labor: if it is made up of more activity episodes and performed at more different locations, it is more fragmented.

[Insert Figure 1 about here]

[Insert Figure 2 about here]

2.2.2 Distribution of fragment sizes

Although the first dimension would imply that all plates broken into equal amounts of fragments are equally fragmented, according to Rutledge there is another distinguishing factor; it concerns the *distribution of the sizes* of the fragments (second dimension). Continuing the example above, Routledge (2003, page 7) suggests that “a plate broken into 10 pieces of equal size is more fragmented than a plate broken into 10 pieces, one of which is 90 percent of the original plate”. This is also expressed in Figures 1 and 2 under the heading of distribution of sizes and can be illustrated with an example about activity participation: if paid labor consists of one big 8-hour activity episode at the office and one smaller episode of 30 minutes at home, the fragmentation is less than if one works 4 hours and 15 minutes both at work and at home.

2.2.3 Configuration of fragments

This dimension provides valuable insights into the spatial and temporal patterns formed by the different activity locations and episodes. Because the temporal distances between episodes can be visualized in a single dimension while distances in physical space require two dimensions, we need one sub-dimension to describe the configuration in time, but two for configuration in space. That is why, in addition to the sub-dimension that describes the dispersion of the fragments that is relevant for both temporal and spatial activity patterns, we have distinguished an extra sub-dimension for the shape and orientation of the spatial configuration of fragments.

Dispersion of fragments

When describing the dispersion of fragments across space and time, it is important to draw a distinction between global and local clustering and special cases of clustering where a cluster of a single episode or location occurs, which we would define as an *outlier*. Global clustering indicates whether the fragments at the level of the total pattern are located relatively nearby or far away (visualized in images A in Figures 1 and 2). Global clustering is thus indicative of the distribution of episodes throughout the day (temporal configuration) and the size of a person's activity space (spatial configuration). However, the extent of clustering at the level of the total activity pattern may mask significant differences within parts of that activity pattern (for example, a certain period of the day or a particular sector of a person's activity space). We therefore also consider whether local clusters can be identified. Local clusters are subsets of fragments within the temporal pattern or activity space that are located at a certain temporal or spatial distance from one another (see images B, C and D, Figures 1 and 2). Single fragments that are separated relatively far in time or space from the other fragments (that is, outliers) can be considered special cases of local clustering; they have been visualized in images C and D of Figures 1 and 2.

Shape and orientation of configuration of fragments

Although the title of this paper may suggest otherwise, some locations in physical space are more suitable for undertaken a given activity than others, and existing transportation and communication infrastructures continue to affect what real-time and virtual locations can be visited. Space is not a Euclidean plane or container waiting to be filled by human activity but striated, offering different opportunities for movement and activity participation. It is, among others, structured by transport and communication infrastructures which bend, shrivel and shrink space differentially in different directions from any one location. As a result, differences can emerge in the space constituted by the locations where activity episodes have been performed. A more thorough investigation of the spatial patterns formed by fragmented activity is thus warranted. When describing spatial patterns, it is common to include an indication of their shape (Ebdon, 1985). The most basic shapes a pattern can take are a line, ellipse or circle, but polygons are also possible. The pattern of locations of person A in Figure 2, for example, has a roughly circular shape, while person B's image can more readily be described as having an ellipsoid or even linear form. The orientation of the fragments might be relevant as well. For instance, the orientation can reveal whether a person's activity patterns are gravitating towards major urban centres, or how activity fragmentation is affected by the configuration of transport and communication infrastructures or a person's commute (home-to-work) axis. The significance of the commute axis is evident from the activity-based travel demand literature, which suggest that the combination of home and primary workplace structures how and where people engage in non-work activities (Damm, 1979; Nishii and Kondo, 1992; Schwanen and Dijst, 2003). In short, the orientation provides important information as to how the fragmentation of activities is affected by the existing urban fabric.

3 Operationalisation of fragmentation measures

This section introduces the measures developed for fragmentation based on the dimensions of activity fragmentation discussed in Section 2. The specification and interpretation of each temporal and spatial fragmentation measure are presented below. As mentioned in Section 1, the specification of measures for activity fragmentation focuses on paid work. In addition, in the current paper we only consider multiple episodes rather than subtasks. Although fragmentation of activities is a process, we will limit our analysis to an examination of the temporal and spatial patterns of paid work episodes. The focus on episodes is justified given that our aim is to investigate spatial and temporal fragmentation rather than functional fragmentation. An episode is defined as the time span used for a more or less uniform and coherent set of actions (e.g. reading e-mail, attending a meeting), suggesting that spatial and temporal fixity or flexibility can be well defined at the episode level. It therefore is a logical measurement unit when investigating spatial and temporal fragmentation. In this paper we apply the measures to the time scale of the day, because this time frame is commonly used in the analysis of activity/travel patterns. However, it should be appreciated that the proposed measures can be used to evaluate activity fragmentation on multiple time scales (days, weeks, and so forth). An overview of the measures is given in Tables 1 and 2.

[Insert Table 1 about here]

[Insert Table 2 about here]

3.1 Measures for the number of the fragments

The first dimension is operationalized through two measures: the number of episodes and the number of locations. The number of episodes can be quantified by counting the different episodes of a certain activity. As before, an episode is defined as an uninterrupted stretch of time devoted to a paid work subtask. Similarly, the number of locations is

measured by counting the number of locations where a particular type of activity – here paid work – is conducted on a given day.

$$E = \sum_{i=1}^n e_i \text{ and } L = \sum_{j=1}^n l_j \quad (1)$$

where E is the total number of activity episodes on a given day and e_i is the i^{th} paid-work episode; L is the total number of work locations and l_j is the j^{th} work location. The interpretation of these measures is straightforward: greater numbers indicate more fragmentation. If we look at Figure 1, we see that the right image is more fragmented ($E=7$) than the left image ($E=3$).

3.2 Measures for the distribution of fragment sizes

The distribution of the fragment sizes is measured by the *time index* and the *spatial index*. The time index is based on the number of minutes allocated to a certain episode; the spatial index describes how the time spent on the episodes is distributed across different locations. The distribution of time can be represented as:

$$\text{Across different episodes: } T = (t_{e1}, t_{e2}, \dots, t_{eE}) \quad (2a)$$

$$\text{Across different locations: } T = (t_{l1}, t_{l2}, \dots, t_{lL}) \quad (2b)$$

where T is the total time spent on work activities on a given day; $t_{e1}, t_{e2}, \dots, t_{eE}$ is the time spent at the 1st, 2nd ... and E^{th} episodes; $t_{l1}, t_{l2}, \dots, t_{lL}$ is the time spent at the 1st, 2nd ... and L^{th} locations.

The time index is obtained in three steps. First, we divide the duration of each episode by the total time spent on paid work on a given day, take the square of each fraction and sum these across episodes. Second, we subtract that sum from 1 so that greater values are indicative of more fragmentation. Finally, we control for the differences in the number of

episodes by dividing the intermediate outcome by $1 - (1/E)$ if $E > 1$. More formally, the time index can be defined as:

$$T_index = \frac{1 - \sum_{i=1}^E \left(\frac{t_{ei}}{T} \right)^2}{1 - (1/E)} \quad \text{if } E > 1$$

$$0 \quad \text{if } E = 1$$
(3a).

The spatial index (S_index) is defined in an analogous manner:

$$S_index = \frac{1 - \sum_{j=1}^L \left(\frac{t_{lj}}{T} \right)^2}{1 - (1/L)} \quad \text{if } L > 1$$

$$0 \quad \text{if } L = 1$$
(3b).

3.3 Measures for the configuration of the fragments

Two measures have been developed to represent the configuration of the fragments dimension of the temporal fragmentation; five measures are used to describe the configuration of the fragments of spatial fragmentation. We start with the specification of measures for temporal fragmentation and then proceed with the description of measures for the configuration of the spatial fragmentation.

3.3.1 Temporal fragmentation

The first measure for the configuration of the fragments in the temporal domain is the *average inter-episode duration (AID)*. The average inter-episode duration indicates the global clustering/dispersion of episodes for the day as a whole. Suppose a certain number

of work episodes is given. Let $S_{e1}, S_{e2}, S_{e3} \dots S_{E-1}, S_{Ei}$ and $F_{e1}, F_{e2}, F_{e3} \dots F_{E-1}, F_E$ be the start and end times of each episode. The inter-episode duration can then be defined as:

$$d_i = S_{ei} - F_{ei-1} \quad (4),$$

where d_i is the duration between i^{th} and $i-1^{\text{th}}$ episodes, S_{ei} is the starting time of the i^{th} episode, and F_{ei-1} is the ending time of the $i-1^{\text{th}}$ episode. The mean distance between episodes is then:

$$AID = \frac{\sum_{i=1}^{E-1} d_i}{E-1} \quad (5).$$

The second measure for the configuration of the fragments is the *inter-episode duration index (ID_index)*. This indicates the local clustering of episodes along the time axis and indicates whether the time spans between episodes have a similar duration, as shown in Figure 1. The specification of this measure resembles the *T_index* but is based on the between-episode time duration (time spent on non-work activities). The *ID_index* is defined as:

$$ID_Index = \begin{cases} \frac{1 - \sum_{i=1}^{E-1} \left(\frac{d_i}{D} \right)^2}{1 - (1/(E-1))} & \text{if } E > 2 \\ 0 & \text{if } E = 2 \end{cases} \quad (6),$$

where D is the sum of interval between episodes and $D > 1$. Values close to 0 indicate that all activity episodes follow each other immediately, except one that takes place at another time of day. Values closer to 1 imply that the intervals between episodes are of equal duration, and that no local clustering of episodes (in time) takes place. As a set the *AID* and *ID_index* measures provide an indication of how a person's paid work is spread more or less evenly across the day.

3.3.2 Spatial fragmentation

As noted above, the spatial configuration of the fragments is reflected by five measures: the area index, cluster index, distance, orientation index and shape index. We have chosen these measures, because they provide a clear indication of the pattern, direction, shape, and extent of the fragmentation of an activity. The first three measures represent the dispersion of the fragments, while the last two measures describe the shape and orientation of configuration of the fragments.

The area index, which describes the global clustering/dispersion of activity locations, is associated with the standard deviational ellipse (SDE), first developed by Furfey (1927) and Lefever (1926) and has been widely used in spatial analysis to describe the spatial configuration of a set of locations. The SDE is less sensitive to outliers than the standard distance SD (Buliung and Kanaroglou, 2006). The SD is defined as the standard deviation of the distance between any location and the mean center of a point pattern (see Bachi, 1962, for details). The concept of the SDE is described as follows: the SDE is centered on the mean center of the activity locations; the long axis of the ellipse represents the maximum dispersion of the locations, while the short axis of the ellipse is perpendicular to the long axis at the mean center and shows the minimum dispersion of the activity locations. The respective standard deviations along these two axes define the SDE. Note that the long (x') and short (y') axis of the SDE are rotated relative to the x and y axis of the coordinate system with an angle θ . The standard deviations of the fragments (locations) along the x' and y' axes are calculated as:

$$\sigma_{x'} = \sqrt{\frac{\sum_{j=1}^L (\tilde{x}_j \cos \theta + \tilde{y}_j \sin \theta)^2}{L}}, \quad \sigma_{y'} = \sqrt{\frac{\sum_{j=1}^L (\tilde{x}_j \sin \theta - \tilde{y}_j \cos \theta)^2}{L}} \quad (7),$$

where $\sigma_{y'}$ is the standard deviation of the locations along the y' axis; $\sigma_{x'}$ is the standard deviation of the locations along the x' axis, \tilde{x} and \tilde{y} are the deviations of the x, y coordinates from the mean center $MC = \{\bar{X}, \bar{Y}\}$ and $\cos \theta$ and $\sin \theta$ are the *cosine* and *sine* of angle θ , which is defined below in equation 12. The *area index* (A) is calculated as:

$$A = \pi \cdot a \cdot b \quad (8),$$

where A is the area index, a is the semi-major axis of the SDE ($a = \sigma_{x'}$), and b is the semi-minor axis of the SDE ($b = \sigma_{y'}$). The interpretation of this measure is straightforward: a greater value indicates more fragmentation.

The cluster index indicates whether the activity locations form clusters or are spread more evenly across space and is thus a measure of the degree of both global and local clustering. It is related to the nearest neighbor distance:

$$NND = \frac{\sum_{j=1}^L NND_j}{L} \quad (9)$$

where NND_j is the nearest neighbor distance for each activity location j , and L is the total number of activity locations. As the NND is sensitive to both the number of locations L and the area covered by the locations, we standardize it by comparing it with the completely random point pattern NND_s . NND_s is defined as:

$$NND_s = \frac{1}{2\sqrt{L/A}} \quad (10),$$

where A is the area of the circle with the standard distance SD (Bachi, 1962) as radius, such that $A = \pi \cdot SD^2$. Then the cluster index is obtained by calculating the ratio between NND and NND_s :

$$R = \frac{NND}{NND_s} \quad (11),$$

where R is the cluster index of fragments ($0 < R < 2.15$). High values for the cluster index suggest that locations are evenly spread and low values that there are multiple local clusters; intermediate values are indicate of one or several clusters in combination with outliers.

The area and cluster indices are only meaningful for $L > 2$; if there are only two activity locations, the area index and nearest neighbor distance resolve to the straight-line distance between the locations. We use the *distance* (D) between the two locations as an indicator of spatial dispersion for the special case of $L=2$.

The final two indicators describe the shape and orientation of the spatial configuration; both can be derived from the SDE. The *orientation index* (θ) describes the orientation of the activity locations and is equivalent to the angle between the long axis of the SDE and the x -axis, as noted before. It can be obtained by using \tilde{x}_j and \tilde{y}_j :

$$\tan \theta = \frac{-A \pm \sqrt{A^2 + 4B^2}}{2B} \quad (12)$$

where $A = \sum_j \tilde{x}_j^2 - \sum_j \tilde{y}_j^2$; $B = \sum_j \tilde{x}_j \tilde{y}_j$. Values of the measure describe the orientation of activity locations. The value of 0, for instance, indicates that activity locations are oriented along the east-west direction. Angles can be standardized along any arbitrary axis. The *shape index* (τ) describes the shape in which activity locations are fragmented: for example, a circular or a linear shape. The shape index is described as the ratio of the minor and major axes of the SDE:

$$\tau = \frac{a}{b} \quad (13)$$

where a is the minor axis of the SDE $a = \sigma_y$, and b is the major axis of the SDE $b = \sigma_x$.

The value of the shape index ranges from 0 to 1: a value of 1 indicates a perfectly circular shape, the minimum value of 0 a linear shape, and values between 0 and 1 an ellipsoid shape. Note that this measure is similar to the anisotropy ratio applied by González et al. (2008). However, whereas the shape index is applied to locations visited for work purposes by a single individual in our study, González et al. (2008) apply the measure to describe the aggregated locations of individuals in a population irrespective of activity. While the shape index can only be used for $L > 2$, it is possible to employ the orientation index for $L = 2$.

4 Research design

4.1 Data

The data we have used consists of 2-day activity-travel diaries collected from single- and dual-earner households residing in the Utrecht-Amersfoort-Hilversum region in 2007. The data was collected in the following stages. First, selection questionnaires were sent to about 13,500 respondents living in various neighborhoods in the research area. Addresses within each neighborhood were selected randomly using digital files containing all street addresses. Households were sent a selection questionnaire about general household characteristics (gender, age, employment status, and so forth), possession of ICT devices, and in addition whether they would like to participate in the main survey. This main survey provided more detailed information about sociodemographics and ICT availability and usage and included a two-day activity-travel diary. In total, the main questionnaire was completed by approximately 740 respondents, either online or in a mail-out/mail-back paper-and-pencil format; the activity and travel diary was completed by 662 respondents (paper-and-pencil format only).

We selected this dataset because it allowed us to test the set of fragmentation measures developed. In the diary, the respondents were asked to report the activities in which they

were engaged, at what location, for how long, and with whom. For paid work, respondents were asked to report various subtasks (see section 4.2), enabling the calculation of fragmentation measures for the work activity. With regard to travel, the respondents were asked to report what transport mode they had used, with whom they traveled, for how long, and what other activities (reading, working, listening to music, sleeping, and so forth) they engaged in while traveling. They were also asked to provide details about their electronic communication (duration, purpose, type of communication mode, and with whom they communicated) at stationary locations and when traveling. Further information about the data is available in Tillema et al (2010).

The raw data was further screened to examine the fragmentation of paid work. As the measures developed in section 3 are sensitive to the total work duration, we only selected full-time workers who worked between 7 and 10 hours on the given diary day for the empirical analysis. In the descriptive analyses of measures for the number of fragments and the distribution of fragment sizes dimension, we used 407 person days of 321 individuals. This sample is not representative of the Dutch population. Table 3 shows that our sample is characterized by an over-representation of high-level professionals (47.7 percent) and highly educated people. We deliberately oversampled these people, because we expected them to be more likely to fragment their paid-labor activity.

[Insert Table 3 about here]

The distribution of autonomy over employment times indicates that about one-fifth of the respondents experience no autonomy, which may be interpreted as circumstantial evidence that most people fragment paid work at least to some extent because they chose to do so. About 11 percent of the respondents work at home for at least one day a week. The shares of men and women in the sample are 54 percent and 46 percent respectively. Only 11 percent of the total sample reported that they had a PDA and 25 percent had a laptop computer. Excluding time spent on emailing, in chat-rooms or on instant messaging services, almost 36 percent of the respondents use the Internet for at least 5 hours per week.

4.2 Defining paid work activities

In the current study, a paid work activity is defined as comprising one of the following subtasks: work-meeting, work-emailing, work-internet browsing, working-on-the-road and work-other (reading articles, writing reports, and so forth). It should be noted that work-related emailing only includes the reading of emails and not their composition. Besides the general activity and travel sections, the diary had a separate section for recording electronic communications. The writing of emails was part of the separate electronic communications section, because we wanted to know to whom work-related e-mails were sent (in the context of another research project). To lower respondent burden, we decided not to ask participants to provide information about the persons from whom they received e-mails . Because of this choice, we could include the reading of work-related emails in the general activity section rather than section on electronic communications. Pre-tests with the diary suggests that this distinction worked well for study participants. We also reduced respondent burden by asking respondents only about the duration of electronic communication episodes and not about start and ending times. Not knowing the exact start and ending times of the communication episodes made it impossible to determine whether the writing of work-related emails took place during work or non-work activities. Consequently, if the writing of work-related emails took place during another paid labor subtask, this would result in an overestimation of the actual time devoted to paid labor. This is why we opted not to take them into consideration in our analyses. The start and end times of paid work undertaken while traveling were derived in the following way. The respondents reported whether they engaged in work activities while traveling. For the travel episodes, they only provided the departure and end times of the trip. Thus, based on this information, we inferred the start and end times of work activities on the road. Most respondents who worked while traveling used a multi-trip mode with the train as their main mode. Krygsman and colleagues (2004) found that about 20 to 50 percent of the duration of multi-modal trips in the Netherlands was spent on access and egress travel. Based on this

finding, we assumed that people spent only 50 percent of the time during the multi-mode trip on paid work.

As indicated in our data, paid work was performed at two generic types of location: stationary and mobile locations. The identification of a stationary location was straightforward, based on street addresses. Mobile locations were identified as follows: all trips on a given day between the same two street addresses (origin and destination) were considered to constitute one unique location. If a person worked on commute trips while traveling both from and to home, both work episodes were considered to be performed at the same location. Work activities performed on trips with different origin and/or destinations were considered to be conducted at different locations.

4.3 Explanatory factors

Based on past studies, we expected fragmentation to vary systematically with a person's ICT ownership and use, employment situation and sociodemographic background (Hjorthol, 2002; Hubers et al, 2008; Kakihara and Sørensen, 2004; Lenz and Nobis, 2007). More specifically, those using portable devices such as PDAs and laptops and using the Internet more extensively on a weekly basis were hypothesized to have more temporally and spatially fragmented work patterns. We also expected that people who have more time autonomy over employment times and who work at home more often would have more work episodes and/or would engage in paid labor on more locations. Occupation type might also be relevant, with managers and (higher) professionals having more fragmented work patterns than clerical staff, service workers and skilled workers. Women could also be expected to have more fragmented work patterns than men. This is because they face more space-time constraints due to the unequal division of housework and childcare between men and women spouses and are more likely to schedule paid-labor activities around domestic commitments than are men (Kwan, 2000; Schwanen, 2007). Furthermore, as urban areas offer a greater variety of facilities, we expect people living in urbanized areas

to exhibit temporally and spatially more fragmented paid work patterns than people residing in less urbanized areas.

The above expectations are tested below using bivariate statistical analysis. The purpose of that analysis is to explore the characteristics and behavior of the proposed indicators and not so much to establish which factors are *ceteris paribus* most strongly related with variations in activity fragmentation. That is why we use bivariate rather than multivariate statistical tests.

5. Empirical results

5.1 Paid work in space and time

The distribution of paid work episodes across different locations is presented in Figure 3. It shows that work activities are not only performed at work locations. The vast majority (85 percent) of paid work activities are conducted at employment locations, but 7 percent are undertaken elsewhere and 6 percent of work activities are performed at home. The lowest share of work activities (2 percent) was performed on the road. In terms of which subtasks respondents undertake at various locations, Figure 4 shows that *e-mail* and *Internet browsing* are undertaken relatively often at home and the primary workplace. Most *meetings* take place elsewhere. Yet, the subtask *other* dominates at all location types.

[Insert Figure 3 about here]

[Insert Figure 4 about here]

With regard to the duration of activity episodes, we see that those belonging to the other category last the longest with 145.0 minutes on average. As expected, e-mail episodes consume the least time (39.1 minutes on average). The average durations for *meeting* and *Internet browsing* episodes are 66.2 and 61.4 minutes, respectively.

5.2 Number of fragments

With regard to the first fragmentation dimension, Table 4 shows that the individuals in our sample have on average 7.47 paid work episodes and work at 1.42 locations on a given day, indicating that most people engage in paid labor at the primary work location. There are, however, considerable differences in the number of fragments according to ICT ownership and use, employment situation and sociodemographic background. With regard to temporal fragmentation, the analysis indicates that individuals with a PDA, who use the Internet in general more extensively, who work in managerial, high-level professional occupations (scientific, technical, health care, ICT, and so forth), who have complete or partial autonomy over their employment times or who regularly work from home have, on average, more paid work episodes than others. These findings are consistent with our expectations reported in Section 4.3. Contrary to expectations, we see that the difference between men and women is not statistically significant. This is presumably because many part-time workers, a majority of whom are female in the Netherlands (Van Wel and Knijn, 2007), have been excluded from our analysis. We expected activity fragmentation to be a means for women to fulfill work and caring responsibilities, which would result in more temporal fragmentation. This, however, does not seem to hold for women working fulltime.

[Insert Table 4 about here]

As far as the number of locations is concerned, the results indicate that managers, workers who have complete autonomy over their employment times, workers who sometimes work from home, and men work at more different locations than individuals who work in other occupations, workers who do not have time autonomy, workers who never work from home, and women. That men's paid work is spatially more fragmented than women's is not consistent with expectations and the results for temporal fragmentation. This might reflect differences in type of occupation and job specification; future research using multivariate statistical methods might shed light on this issue. There are also statistically significant differences in spatial fragmentation according to urbanization degree, but this relationship

is clearly non-systematic. This suggests that the effect is caused by one or more third-party factors whose values vary spatially. Exploring the nature of those third-party factors is, however, beyond the scope of the current paper. With respect to the ICT factors, only PDA possession and overall weekly Internet use are positively correlated with the level of temporal fragmentation of paid work, but the effects are very weak not statistically significant ($p < 0.10$).

On the whole, the outcomes for the first dimension of fragmentation concur with most of our *a priori* expectations. Nonetheless, employment factors are more clearly related to the number of fragments than ICT and sociodemographic factors.

5.3 Distribution of fragment sizes

With respect to the second dimension of fragmentation, Table 5 indicates that the average values of the *T_index* and *S_index* are 0.37 and 0.11 respectively, suggesting that the time spent on paid work is more evenly distributed across different episodes than across locations. This inference reflects the dominance of the traditional workplace (Figure 3), even when time is more evenly spread across various subtasks. Furthermore, the table indicates that the durations of paid work episodes are more equal to one another for individuals with a laptop; other differences are too small to be statistically significant ($p < 0.10$). Concerning spatial fragmentation, we see that the time spent on paid work is more evenly distributed across different locations for managers, high-level professionals, for workers who sometimes or at least once per week work from home, and for men than for those in lower level occupations, who ever work from home and women. The average is also rather high for skilled workers, but this seems to reflect the small number of respondents ($n=9$) in this category rather than a robust result. Finally, the distribution of sizes is also more equal as respondents have more autonomy over their employment times.

[Insert Table 5 about here]

Overall there are fewer differences not only in the T_index than in the S_index but also in the distribution of fragment sizes than in the number of fragments. These variations seem to reflect the nature of the activity type considered rather than the measures used. At least for the respondents in our study, paid work is for the most part undertaken at the (first) workplace in relatively large, continuous blocks of time (see Section 5.1).

5.4 Temporal configuration of fragments

Table 6 shows that there are often sizable gaps between paid work episodes: the average inter-episode duration (AID) is 23.2 minutes and the mean score for the inter-episode duration index (ID_index) is 0.37. The difference in the mean AID are not statistically significant ($p < 0.10$) for the ICT-related factors. Regarding the ID_index , we see that the paid work episodes of people without a PDA are more equally distributed across the time between the first and last episode than are those of people who do own a PDA. The paid-work patterns of the latter are more likely to take the form of several successive episodes and a single outlier, possibly reflecting the fact that the PDA allows them to perform some paid labor in the evening outside traditional office hours. This finding was expected, since we expected that a PDA would result in more temporal fragmentation.

[Insert Table 6 about here]

With regard to the employment-related factors, the AID shows us that the paid labor activities of workers who can choose their own start and end times or who regularly work from home tend to be more dispersed across the day than those of their counterparts. As indicated by the ID_index , the intervals between episodes are also more evenly distributed. Thus, the paid work of individuals with more autonomy over employment time and who regularly work from home are more temporally fragmentation, which concurs with expectations. Somewhat contrary to expectations, we see that men's intervals between paid work episodes are also more equal to one another, suggesting that their paid work is more temporally fragmented than that of women. There is also a statistically significant

difference in the inter-episodes duration index by urbanization degree although this relationship is again not systematic and presumably caused by third-party variables whose values vary spatially.

5.5 Spatial configuration of fragments

From section 5.1 we know that most of our respondents undertake paid work at a low number of locations. This has at least two ramifications for our analysis. The number of respondents for whom the area index (A), cluster index (R) and shape index (τ) and to a lesser degree the distance (D) and orientation index (θ) can be calculated is rather limited. Additionally, the results for the orientation index in particular will be sensitive to the number of locations where paid work is undertaken (L). Therefore, the results for the orientation index are given separately for $L=2$ and $L\geq 3$ in Table 7.

[Insert Table 7 about here]

The first conclusion to be drawn from that table is that there are very few statistically significant differences ($p<0.10$) in the spatial configuration of fragments according to ICT ownership and use, employment situation and sociodemographic background. For the global dispersion measures, A and D , there are three significant relations. Among the respondents who perform paid work at two locations, those possessing a PDA and men tend to have greater distances between those locations than those without a PDA and women. Both results concur with our expectations. A statistically significant difference is also observed for the area index among those who never, sometimes or at least once per week work from home. The relationship is, however, non-systematic, presumably due to the low number of respondents engaging in paid labor at three or more locations. With regard to the shape and orientation of the spatial configuration, there is only one factor significantly related to the orientation of the locations vis-à-vis the commute axis: for respondents with a PDA the spatial pattern of locations is more perpendicular to the commute axis than for those who do not own a PDA. For the shape index we find no statistically significant

differences, which is at least in part a consequence of the low number of respondents conducting paid work at three or more locations.

Most of our spatial configuration measures become particularly informative as activity participation is distributed across a greater number of locations. Because of the very small number of days on which respondents engaged in paid labor at four or more different locations, we can only explore the behavior of our measures in a qualitative manner. Therefore, we have selected three people with different employment characteristics and visualized the spatial fragmentation of their work activities (Figure 5).

[Insert Figure 5 about here]

Regarding the dispersion of fragments, Figure 5 shows that individual 1 (managing director, horticulture) has the highest score on the area and cluster indices ($A=102.9\text{km}^2$; $R=2.04$). His/her locations most dispersed and more evenly spread than those of the other two individuals. Individual 2 (manager, cleaning agency) works at five locations, which are less dispersed ($A=71.4\text{ km}^2$). The pattern can be classified as globally clustered but with outliers ($R=1.66$). Individual 3 (lawyer) has the lowest scores on the cluster and indices ($A=19.3\text{km}^2$; $R=1.23$). His work locations are the most clustered, representing less spatial fragmentation with a pattern including multiple local clusters. One cluster is situated around his primary workplace and the other around his home.

With respect to the shape of fragments, the set of locations tends to have an elliptical shape for individual 1 ($\tau=0.22$) and especially individual 3 ($\tau=0.37$), whose locations constitute an almost perfect ellipse. For individual two the shape is more linear ($\tau=0.17$), primarily because of the location close to Zoetermeer depicted in Figure 5. This indicates that the shape index is rather sensitive to outliers when the number of locations is rather limited and should preferably be used if there are many locations where episodes are conducted. Finally, in terms of the orientation of the set of locations vis-à-vis the commute (home-to-work) axis, there are marked differences between the three individuals. Individual 1's

locations are oriented rather strongly along the home-work axis ($\theta=118.3$), which is on contrast with individual 2 ($\theta=45.4$) and especially individual 3 ($\theta=113.1$). However, if the length of the home-work axis relative to the ellipse is too short, as it is for individual 1, there is no strongly structured ellipse. This suggests that the home-to-work axis is only a meaningful benchmark for the orientation of the spatial configuration of fragments if it is of considerable length.

6. Conclusion

The literature on activity fragmentation has as yet been mainly conceptual and a clear framework for its measurement is lacking. In this study, we have developed a set of indicators for activity fragmentation and tested their performance empirically. These indicators have been based on the three dimensions of fragmentation proposed by Hubers and colleagues (2008): the number of fragments; the distribution of fragment sizes, and the configuration of the fragments. Although the empirical application of the measures in this paper was restricted to paid work, the newly-developed measures could be applied to study the fragmentation of any kind of activity.

Overall, the study has shown that the newly-developed measures were able to distinguish between less and more fragmented patterns of paid work and reveal systematic differences in the fragmentation of paid work according to ICT ownership and use, employment situation and sociodemographic background. Summarizing the outcomes of the bivariate statistical analysis (Table 8), we see that employment-related factors are most directly and often associated with differences in the number of fragments, the distribution of fragment sizes and the configuration of fragments. ICT ownership and use are associated more directly with temporal than with spatial fragmentation, at least when the effects of confounding factors are not taken into consideration. The opposite seems to hold for the sociodemographic factor of gender, although we did not find women's paid work to be more fragmented than men's. This might suggest that fragmenting paid work is not a

strategy women frequently employ to reconcile the competing demands on their space-time resources by employment and family life. However, these preliminary finding needs to be explored with more advanced statistical methods in future research.

[Insert Table 8 about here]

Whether or not the proposed measures adequately express fragmentation is difficult to ascertain. Fragmentation has to date been described primarily as a technologically-induced development (activities becoming less temporally and spatially fixed due to the use of ICTs), and although the implications for activities have been the subject of speculation, they have not been empirically verified. However, since the proposed fragmentation measures reflect the hypothesized impacts of ICT ownership and use and employment situation on the fragmentation of paid work rather well, we believe that they are useful tools for the study of activity fragmentation. At the same time, the fact that we had to develop several measures to assess fragmentation indicates that it is a multidimensional concept with many different meanings. In many cases, researchers may wish to focus on a particular meaning of fragmentation depending on their study objectives; the application of fragmentation measures therefore requires an exact definition of the effects that are studied, leading to a choice of specific indicators. For instance, studying the impacts of ICT on work/life balance may require measures of the distribution of fragment sizes, such as the *T_Index*, whereas the impacts of ICT on mobility would be better studied with measure of the spatial configuration of fragments.

Our study of activity fragmentation can be improved in at least two ways in future research: improvement of the measures of fragmentation and the collection of more appropriate data. As we have seen, at this stage many of the spatial fragmentation measures are of limited value, because of the small number of respondents who engage in paid work at multiple locations. It is unclear, however, whether the spatial fragmentation of activities is not yet relevant or whether the limited results are the consequence of the relatively small number of respondents in the current study. Future studies should therefore use data from more

respondents and/or focus on time periods that exceed the diurnal cycle (e.g. the week or month). Another way of increasing data availability would be to address multitasking, which would require asking respondents also about secondary activities (which was not done in the diaries used for this analysis). By gathering information on possible secondary activities that were performed simultaneously, as is typical in time-use studies, a more complete representation of the activity under study would be obtained. What is more, more information should be collected on the purpose(s) served by a particular bundle of actions or sub-task. Here we have used only four sub-tasks but it is evident that more refined classification schemes could have been employed, which would also have resulted in the identification of more episodes. However, the use of more elaborate categorizations of sub-tasks should be traded against the extra respondent burden imposed on study participants. More experimentation is required in future studies as to what constitutes appropriate categorizations of sub-tasks for paid work and other activity types.

Regarding the measures of fragmentation, the current spatial fragmentation indicators are limited by their inability to include activities that are performed while being on the move, and the neglect of virtual activity locations. Because of the small number of respondents who apparently work while traveling, we expect that the suboptimal assessment of the spatial fragmentation of activities performed at non-stationary locations did not influence our results significantly. Nonetheless, activities-on-the-move should be considered differently in future studies. Data gathered via continuous GPS tracking of respondents' whereabouts, for example, could be analyzed using spatiotemporal GIS (Asakura and Hato, 2004; Miller, 2005; Shaw, 2000). An even more challenging task will be to incorporate non-stationary localities (e.g. a train) into measures of spatial fragmentation as developed in this paper. Additionally, information is also needed on the spatial characteristics of locations affected in some way by virtual activities. The notion of the *contact set*, which is defined as "the set of geographic locations that are contacted either physically or digitally for the purpose of initiating a physical or digital transfer" by an individual within a certain time span (Couclelis, 2000, page 348) is of relevance here. Even though one's physical action space might be confined to the municipality in which one lives, by trading products

or exchanging information on the Internet with people from across the world, one's virtual or digital action space might encompass the entire world. That is not to say, however, that the contact set size of Internet users automatically has a worldwide coverage since, for example, most of the products purchased on the Internet are bought from national retailers. The contact set size thus forms the most comprehensive assessment of the spatial fragmentation of one's activities.

Further, while we have developed measures for temporal and spatial fragmentation separately in this paper, it would be interesting to develop combined spatiotemporal indicators in future research. Miller's (2005) measurement theory for time-geography might be a useful point of departure for the development of such indicators. Spatiotemporal indicators would allow us to analyze the temporal order in which different activity locations are visited and also to determine the relevance of activity locations for affording temporal fragmentation. These spatiotemporal measures can offer a more comprehensive characterization of the fragmentation of activities and might enhance the relevance and the cohesion between the fragmentation indices proposed in this paper.

We foresee several interesting applications of the proposed fragmentation measures in future research. Following the work of Hanson on spatial diversification, the first would be to study fragmentation on a longer time-scale than the diurnal cycle. This would enable us to determine whether activity patterns that appear to be highly fragmented on the level of the day appear to be routinized when viewed over a longer period. The study of activity types other than paid work would also be of interest. Other promising research topics include the possible consequences of activity fragmentation for transportation and the built environment. Some studies have investigated whether the increased possibilities of working by means of ICTs have made train commuting more attractive (Lyons and Urry, 2005). Similarly, people who want to work from home might develop different demands for appropriate housing, since the house must enable working in a calm environment. A final issue concerns the way in which people experience the fragmentation of their activities. Although in general the increased opportunities ICTs offer to people to perform their

activities wherever and whenever they want appear to be beneficial, activity fragmentation might also increase the complexity of activity scheduling and thus make it more burdensome. The question is thus how much fragmentation a person can handle before it changes from being a benefit to a burden.

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