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# Constructing human activity spaces: A new approach incorporating complex urban activity-travel

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ABSTRACT

Activity space represents an important concept for understanding human activity-travel. The existing activity space delineation approaches are limited in fully characterizing real-world travel behaviors. To address the issue, this research proposes a new time geography based approach to more accurately portray activity spaces of urban travelers. The proposed approach takes into account the full complexity of real-world travel and underlying urban structures. Results of an empirical study are presented based on the 2008 Add-on National Household Travel Survey conducted in Tucson, Arizona. Activity spaces of 1164 sample travelers are delineated and analyzed. Results show the effectiveness of the new approach in more realistically depicting urban activity-travel.


## 1. Introduction

Understanding individuals' travel behavior is important for various urban and transportation planning applications. Among others, constructing activity spaces provides an important way to describe where and how individuals' travel takes place (Schönfelder and Axhausen, 2004; Buliung and Kanaroglou, 2006a; Järv et al., 2014). Different from concepts that focus on travel potential or accessibility (e.g., space-time prisms, action spaces, perceptual spaces, mental maps), activity spaces are constructed based on locations that individuals have personally visited (Schönfelder, 2006), thereby providing important insights into individuals' movement dynamics in space-time. Over the past few decades, research on activity spaces has drawn interest from a range of disciplines, including transportation, urban studies, geography, sociology, and public health (Dijst, 1999; Järv et al., 2014; Harding et al., 2013; Parthasarathi et al., 2014; Buliung and Kanaroglou, 2006a, 2006b; Wong and Shaw, 2011; Jones and Pebley, 2014; Hieronimo et al., 2014; Sherman et al., 2005).

A number of approaches have been developed to portray activity spaces with varied emphases. One commonly used approach has been focused on development of certain geometric shapes (e.g. the standard deviational ellipse (SDE) or minimum convex polygon (MCP)) to describe the spatial dispersion of activity locations. Studies have also incorporated the time geography framework into the activity space delineation design (Newsome et al., 1998; Dijst, 1999; Saxena and Mokhtarian, 1997). Time geography based approaches have a unique capability to delineate activity spaces by also integrating individuals' travel behavior in space and time. However, all these measures are limited in accurately representing individuals' activity-travel (Wong and Shaw, 2011; Rai et al., 2007; Sherman et al., 2005; Patterson and Farber, 2015). For example, those approaches may overestimate the actual extent of travel due to the overlooking of the underlying urban structures. Another issue lies in the inability to account for complex urban travel. For example, most geometry based approaches such as SDE or MCP measures pay more attention to the spatial distribution of activity locations but ignore other important aspects of activity-travel, such as activities along a trip chain. Current time geography based approaches are also limited with a main focus on commuting trip and the associated activities between home and workplace. However, empirical studies (Lockwood and Demesky, 1994; Mcguckin and Murakami, 1999; Strathman and Dueker, 1995; Jou and Mahmassani, 1997; Mcguckin et al., 2005; Primerano et al., 2008) have shown that urban travel is more complex that goes beyond commuting trips.

To the best of our knowledge, little effort has been made to address the aforementioned issues associated with the activity space measures. Motived by these research needs, in this study we develop a more realistic, time geography based approach to account for complex urban activity-travel as well as underlying urban structures. In particular, building on the work by Newsome et al. (1998), we propose a new activity space model to allow for more complex trip cases, such as non-commuting trips (either home-based or workplace-based) and simple trips with no additional stops made. To address the problem of delineating these more realistic network-based activity spaces, we introduce a GIS-based delineation algorithm.

This paper is organized as follows. The next session provides a review of the literature on activity space and urban travel behavior. This is followed by a methodology section describing our new activity

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space measure. Then the empirical study is presented. Discussion and conclusions are given in the final two sections.

## 2. Literature review

A number of approaches have been proposed to describe people's movements. In general, these approaches have been focused on either travel potential or observed/realized travel.

The time geography approach (Hägerstrand, 1970; Lenntorp, 1976) has been recognized as the pioneer work in studying travel potential. Under this framework, an individual's movement can be captured within a 3-dimentional (3-D) space-time prism (Lenntorp, 1976), which contains all locations that the individual can visit given his/her time constraints. In the past two decades, geographic information systems (GIS) have been highly integrated in constructing space-time prisms and analyzing travel potential (Miller, 1991; Kwan, 1998, 1999; Wang and Cheng, 2001; Kwan et al., 2003; Frihida et al., 2004). In particular, by projecting the potential path space in the 3-D space-time prism to a 2-D geographical space, Kwan (1998) and Kim and Kwan (2003) demonstrated that the projected geographical area delimits the spatial extent that an individual can reach, also known as the potential path area (PPA). Schönfelder and Axhausen (2004) provided a summary of other approaches used to describe individuals' travel potential, including cognitive or mental map (Lynch, 1960), perceptual space (Dürr, 1979), action space (Horton and Reynolds, 1971) and awareness space (Brown and Moore, 1970). Overall, space-time prisms, along with other approaches, mostly focus on individual travel potential and whether actual travel will be realized in the described space is not addressed.

As opposed to the travel potential-oriented approaches, activity spaces are indicators of observed or realized travel. Activity spaces focus on the actual usage of space. They provide a micro-geographic depiction of the observed travel range and locational choices of travelers (Rai et al., 2007). The concept of activity space was introduced in the 1960s and 1970s (see Golledge and Stimson (1997) for a detailed discussion). Despite minor variations as the concept has been applied in different disciplines (Sherman et al., 2005), a generally accepted definition is that activity space is a 2-D space consisting of all (local) places that are frequented by an individual over a certain period of time (Rai et al., 2007; Schönfelder, 2006). The concept has also been distinguished from *action space* (Horton and Reynolds, 1971), in which second-hand experiences are considered as well.

Activity spaces have been broadly adopted and studied in a range of fields. In transportation, various factors influencing activity spaces have been examined, including mode of transportation (Harding et al., 2013), street-network structures (Parthasarathi et al., 2014), and travel behavior patterns (Järv et al., 2014). In social science, Jones and Pebley (2014) used activity spaces to compare social characteristic variations in multiple residential neighborhoods. Wong and Shaw (2011) proposed an activity space based exposure approach to evaluate residential segregation. In public health, activity spaces have been used to link the spatial-temporal occurrence of plague in Western Tanzania (Hieronimo and Gulinck, 2014) and evaluate utilization of health services (Nemet and Bailey, 2000). In urban studies, the spatial extent of travel described in activity spaces provides substantive insights into how people interact with the built environment, including urban forms (Buliung and Kanaroglou, 2006b) and neighborhood effects (Jones and Pebley, 2014). Interested readers are also referred to Patterson and Farber (2015) for a comprehensive review of previous applications of activity space.

Using geometric shapes to describe individuals' activity spaces represents one of the widely used strategies (Ren, in press). For example, the standard deviational ellipse (SDE) (Yuill, 1971) is drawn to encompass the smallest area that contains a set of activity sites. The minimum convex polygon (MCP) measure has also been used to delineate activity spaces (Hirsch et al., 2014; Buliung and Kanaroglou, 2006a, 2006b). Rai et al. (2007) examined a number of more complex geometric shapes used to draw activity spaces, including superellipse, cassini oval and bean curve. A common characteristic of these geometry-based approaches is that they focus on the spatial dispersion of activity locations, little or no attention has been paid to the underlying program of indiviuduals' activity-travel, such as trip types, travel sequences, trip chaining, etc.

Another strategy for delineating activity spaces is built on the time geography paradigm (Ahas et al., 2007; Ren, in press). The activity space approach offered in Newsome et al. (1998) is the first attempt to incorporate the time geography into the construction of activity spaces (Ahas et al., 2007; Schönfelder, 2006). Unlike the geometry based approaches that primarily examine the spatial distribution of activities, the time geography based strategy gives a better depiction of travelers' activity-travel in space and time, including trip types, trip chaining and the associated activities. Anchor points of daily life travel, such as home and workplace, are considered as foci of the ellipse. The boundary of the activity space is determined by the furthest activity chained on the commuting trip that has the largest total distance to the foci assuming that the time budget allowed for the performed furthest activity is fixed. The idea inherently differs from simply finding the area that encloses observed activity locations as has been conceived in the geometric activity space approaches (e.g. SDE, MCP). In addition, compared to the 2-D potential path area (PPA) projected from the 3-D space-time prism (Hägerstrand, 1970) whose size is solely determined by the space-time budget, the measure introduced in Newsome et al. (1998) takes into account the observed travel behavior of an individual. Therefore, it provides a better understanding of an individual's activity-travel.

Although the approach introduced in Newsome et al. (1998) has been considered as a useful tool for modeling activity spaces, some issues exist in its implementation. Wong and Shaw (2011) noted that it may be difficult to derive ellipses for some less common but realistic cases, such as when locations visited are in a straight line, or sites visited are too few to meet the geometric requirement for defining an ellipse. In addition, a common issue of the existing activity space measures relates to the tendency of overestimating the actual extent of travel, as a rather large and generalized area is included (Sherman et al., 2005; Wong and Shaw, 2011; Patterson and Farber, 2015). Such an area may sometimes cover places where no activity opportunity exists, such as “no-go” areas (Rai et al., 2007; Schönfelder and Axhausen, 2004). As suggested by Sherman et al. (2005), with the rapid advance of GIS and growing computational capabilities, new approaches are needed to enhance the capabilities of activity space approaches for a more realistic depiction of spatial travel behavior.

A major problem with the approach described in Newsome et al. (1998) is its inability to fully address the complexity of real-world travel behaviors. Their approach is built upon commuting trips (home-to-work and work-to-home trips) and assumes all other activities are chained to these trips. To some extent, the focus on commuting can be justified by the importance of work trips in daily lives (Golledge and Stimson, 1997). However, as noted by Primerano et al. (2008), work trips do not reflect the activities undertaken by many population subgroups (e.g., non-workers, the unemployed, retirees).

Over the years, an increasing number of empirical studies have indicated that other types of trips can be as important as commuting trips. In particular, home-based non-commuting trips (home-to-home tours) have been found to account for a significant portion of all trips made by individuals (or households). For example, based on the 1995 National Personal Transportation Survey Mcguckin and Murakami (1999) found that most trips were completed as home-based trips. After examining the personal travel data in San Francisco, Adiv (1983) reported that the majority of daily activities were independent from commuting trips. Strathman and Dueker (1995) also estimated that commuting related trips only accounted for 30% of all personal trips, compared to 70% home-based non-