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Dynamic diurnal social taxonomy of urban environments using data from a geocoded time use activity-travel diary and point-based business establishment inventory

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ABSTRACT

In this paper, we explore the diurnal dynamics of joint activity participation in a small city in Pennsylvania, USA, using behavioral data and an inventory of business establishments. We account for the variation caused by the collective impact of social, temporal and spatial choices of individuals to produce predicted space–time visualizations of activity participation. The focus is on how social contexts of an activity impact the temporal and spatial decisions regarding the activity locations and how this impact varies depending on activity types. A comparison across activity types and social interaction types is made among spatial patterns during a day. The CentreSIM dataset, which is a household-based activity diary survey collected in Centre County (Pennsylvania, USA) in 2003, provides very detailed social interaction information enabling the analysis of social, spatial and temporal aspects of activity participation. In this paper we use this information to develop a spatio-temporal interpolation method and demonstration based on kriging. In this way, we extract the dynamic social taxonomy of places from the behavioral information in the dataset and suggest how urban and transportation models can be informed from the dynamics of places by observing "what is taking place" (activities being pursued in the context of this paper) combined with "what exists" (business establishments) or "what is available" (businesses that are open). The method here can also be used to improve the design of urban environments (e.g., filling gaps in desired activity locations), manage specific places (e.g., extending the opening and closing times of businesses), study transportation policies that are sensitive to time of day (e.g., pricing of parking to discourage crowding and traffic congestion), and modeling of spatio-temporal decisions of social activities in travel demand models (e.g., to guide the development of model specification and representation of the space in which behavioral models are applied).

1. Introduction

Urban environments transform in cyclical manner offering opportunities for activity engagement that change by time of day, day of week, month of year and so on. This variability results in multiple layers of dynamics that should be included in behavioral data collection (Goulias et al., 2013) and in activity-based travel demand simulators (Kitamura et al., 1997;

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Pendyala, 2004; Pendyala et al., 2005, 2012; Balmer et al., 2008; Roorda et al., 2008; Auld and Mohammadian, 2012; Goulias et al., 2012). At the heart of this cyclicity of activity engagement and travel is the interaction between a person and the built environment and the multiple interactions among persons. One way to take into account the built environment influence on behavior, is to develop models of opportunities and constraints that shape individual behavior and conceptualize action within the boundaries of a spatio-temporal three dimensional container (e.g., Hagerstrand's time–space prism, 1970, 1989). This idea was used to compute a variety of derivative indicators to account for different types of constraints, explain and predict travel behavior, and create visual representations of opportunities and movement paths (Burns, 1979; Kitamura et al., 1981, 2000; Kostyniuk and Kitamura, 1982; Kondo and Kitamura, 1987; Pendyala et al., 1991, 2002; Nishii and Kondo, 1992; Kwan, 1998, 1999a,b, 2000, 2004; Miller, 1999; Miller and Wu, 2000; Timmermans et al., 2002; Weber and Kwan, 2002; Kwan et al., 2003; Pendyala, 2003; Kwan and Lee, 2004; Yamamoto et al., 2004; Susilo and Kitamura, 2005; Shaw and Yu, 2009; Liao et al., 2013).

Activity participation, time allocation, and travel are all heavily influenced by human interactions and early activity-based methods recognized their importance (Kitamura, 1988; Jones, 1990; Bhat and Koppelman, 1999). Although these interactions motivate the collection of behavioral data using household surveys and the creation of models that aim at replicating household activity schedules (Bhat et al., 2013), activity participation and travel of people takes place in many social fields (or networks) that involve many persons outside the household that exert social influence (Bhat and Pendyala, 2005; Dugundji and Walker, 2005; Carrasco and Miller, 2006; Carrasco et al., 2008; Habib et al., 2008; Farber and Páez, 2009; Arentze and Timmermans, 2008; Timmermans and Zhang, 2009; Axsen, 2010; Goulias and Yoon, 2011; Walker et al., 2011; Deutsch and Goulias, 2013). This social influence and interactions are also place specific and it is informative to examine them employing the time–space prism (Schönfelder, 2006; Neutens et al., 2008; Yoon and Goulias, 2010).

In spite of all these advancements, a gap is left in the development and testing of a method that produces time varying spatial distributions of activity participation propensity that can be used for multiple purposes. Developing these dynamic spatial distributions is our ultimate objective in this research and this paper is the first attempt. Our motivation also stems from the following simple issue. Neither behavioral data nor business establishment databases can answer the question of what will a person do at a specific location at a specific time of day with high spatial and temporal resolution. Even when one employs sophisticated urban simulators the activity location is either a traffic analysis zone (i.e., comparable to a large city block) or some other kind of spatial summary of points. For this reason post-processing of simulated data is required to position (geolocate) each activity and each person at a specific business establishment and a specific period of a day (Tang et al., 2013). Instead of ad hoc geolocation algorithms we could use a spatio-temporal distribution. Developing this type of distribution for activity participation requires first understanding how urban space is used and possibly interpolate data in a way that produces a high resolution distribution of the propensity to participate in activities by the residents and visitors of a place. It is also important to use these distributions to identify urban policies that will guide people to behave in an environmentally responsible manner and to build simulation models that create policy scenarios.

There are some complications as we attempt to do all this. One of the complicating issues is due to the standardized system of business classification (International Harmonized and SIC/NAICS see Pierce and Schott, 2012), which is not sufficient for understanding how each business establishment is used. For example, consider a business establishment classified as restaurant. A person may go there to have a breakfast meeting with a business customer at 8:00 am, have lunch with his coworkers at 12:00 noon, meet with a friend for coffee at 3:00 pm, have dinner with his family at 6:00 pm and come back at 11:00 pm to listen to live music and have a drink. This restaurant changes in terms of the activity engaged and the interaction of the people involved. In response to the opportunities offered by built environments, individuals and their groups choose to populate certain places that satisfy their need to pursue certain activities at specific times in a day, and engage in activities alone or with other people. This choice is an outcome of many other events and offers regularity that we can exploit in spatial prediction. Spatio-temporal patterns of activity engagement are constrained by the dynamic patterns of attraction that are a function of the demand for services but also dictated by regulations as well as the availability of other persons that are involved in the activity. To develop the method in this paper we follow a vein of development that started 40 years ago.

Behavioral dynamics were discussed as one of the important aspects of urban environments in "what time is this place?" by Lynch (1972). Lynch stated that human activities are as important as or even of greater importance than the permanent physical artifacts to the quality of a place. Time of day and timing are important ingredients in understanding the role places play in the life of people and the places themselves. In fact, for human behavior the temporal aspects are as important as the spatial aspects. This is also a major focus of Chapin's analysis (1974), and received attention as early as the first georeferenced time-use study in Halifax was made available (Harvey, 1993; Janelle and Goodchild, 1983; Goodchild et al., 1993). Spatio-temporal patterns of activities in Halifax in these studies are shown as the presence of people at different parts of the city at different times in a day, and these same dynamic patterns are analyzed for different socio-demographic groups. These daily dynamics of a place have been represented mostly as variability of available opportunities by considering opening and closing hours of businesses (Weber and Kwan, 2002; Kim and Kwan, 2003; Chen et al., 2011; Yoon et al., 2012). All these models focus on what exists and what is available at a place at a given time point with personal trajectories added within the Hagerstrand time–space prism and related aquarium. In this paper, we combine the ideas from the Halifax study with the focus more on the temporal patterns of activities taking place to describe the dynamic change of a place especially as it relates to social interaction, adding information about social networks accessing each location by time of day. With inspiration from the probability fields in Beckmann et al. (1983a,b), we derive, using data, time varying spatial distributions of activities that are informed by social influence, capture the dynamics of activities focusing on social interaction taking place