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Observing individual dynamic choices of activity chains from location-based crowdsourced data ☆

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A B S T R A C T

The existing efforts on studying human mobility and activity using location-based crowdsourced data mainly focus on obtaining the activity chain pattern in a region at an aggregate level. To observe individual dynamic choices of activity chains, this paper presents a data-driven approach to estimating individual-specific activity chain set and corresponding choice probabilities for a given person over a 24-h period using crowdsourced data from location-based service apps. We detect an individual-specific stochastic activity set using a contextual-parcel data analysis. Based on the time geography theory, we refine a space-time bicone concept to construct an activity-travel space-time-state network from the stochastic activity set. These space-time bicone constraints define a set of potential activity choices to reduce the search space of activity location and duration choices. We construct an activity state transition graph from the space-time-state network and calculate a Markov matrix for activity choice probabilities. Furthermore, we calculate the probabilities of activity chain choices using the Markov matrix. We also visualize individual-specific activity chain set in a space-time-state network to show the dynamic choices of individual daily mobility and activity. We demonstrate the proposed approach through conducting numerical analyses using crowdsourced data from location-based service apps - Foursquare and Twitter to construct individual-specific activity choice sets and corresponding choice probabilities.

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1. Introduction

To obtain data for studying human mobility and activity, traditional travel survey methods are cost and time intensive. Crowdsourced data from location-based service (LBS) apps (e.g. Foursquare, Facebook, Twitter, and Instagram) or mobile phones contain information about anonymous users' activity locations and times over many days (e.g. several months or years), which can be used to estimate activity sequences. A rich body of literature from various communities including transportation engineering, computer science, and social science have adopted data-driven approaches to capturing human mobility and activity patterns using location-based crowdsourced data. The existing efforts mainly focus on mining human aggregate travel activities in a region using mobile phone data (Schneider et al., 2013; Alexander et al., 2015; Toole et al., 2015a, 2015b; Widhalm et al., 2015) or social networking service data (Wang et al., 2010, 2014; Cheng et al., 2011; Long

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et al., 2012; Cranshaw et al., 2012; Zhang et al., 2014), which provide a supplement to travel survey data for travel demand modeling.

This paper aims to observe individual dynamic choices of activity chains from location-based crowdsourced data. However, the location-based crowdsourced data include many infrequent check-ins and discontinuous records, which will pose issues to construct a complete activity chain choice set. To address these issues, we propose a novel data-driven approach to estimating activity locations and durations. The data-driven approach uses probability distribution information of check-in location and duration through a contextual-parcel analysis from all the check-in records of individual users. The probability distribution of check-in location and duration is defined as a stochastic activity set. Using a refined space-time bicone concept, we estimate missing activity locations and durations in a reduced search space and construct an activity-travel space-time-state network from the stochastic activity set. From the space-time-state network that contains choice probabilities of each activity location and duration, we estimate a complete set of activity chains with choice probabilities through constructing an activity state transition graph based on a Markov decision process. The resulting activity chain set and choice probabilities of individual users can be used to develop and calibrate activity-based travel demand models, as well as to better understand human movement during a day. In this section, we will first review relevant literature and then present an overview and our contributions in this area.

1.1. Literature review

Crowdsourced data is a type of data that contains information extracted from an undefined network of people who are volunteered to undertake a task that proposed by a group of individuals (company, institution, or non-profit organization) via an open call. The crowdsourced data from LBS users have been used in emergency response and urban evacuation. Goodchild and Glennon (2010), Elwood et al. (2012), and Gao et al. (2011) discuss the advantages and disadvantages of applying crowdsourced data into disaster relief, resource distribution and human activity pattern analysis. Yin et al. (2012) propose an emergency response system that extracts emergency warnings, notification of incidents, and incidents' impact from crowdsourced texts. Goetz and Zipf (2012) simulate two different evacuation strategies using crowdsourced data with geo-location information. People use LBS apps to explore local business services, check weather conditions, and share locations with their friends. Noulas et al. (2011), Cho et al. (2011), Preoţiuc-Pietro and Cohn (2013), Silva et al. (2013), Hasan et al. (2013), and Hasan and Ukkusuri (2014) try to extract individual trajectories from these location-based crowdsourced data sources to construct an aggregate mobility pattern across all the LBS users in a region, or conduct statistical analyses for activity pattern classification. Mobile phone data have also inspired research on human mobility patterns. Wang et al. (2010), Schneider et al. (2013), and Alexander et al. (2015) use cell phone data to estimate trajectories and analyze human activity pattern, in which they filter out incomplete phone call records. Caceres et al. (2007) and Toole et al. (2015a, 2015b) use cell phone records to do origin-destination generation and validation in the trip level. Chen et al. (2014) estimate activity location from passive cell phone data using a logistic regression model. Some reviews about using cell phone data in travel behavior studies are in Chen et al. (2014).

However, these crowdsourced users who are willing to use the services may not always report their activities over an entire day. As a result, incomplete within-day and discontinuous day-to-day trajectories from the crowdsourced check-ins produce uncertainty for users' activity choices. This poses a challenge to use these crowdsourced data to construct an individual-specific activity chain pattern. As such, a data-driven estimation method is needed to generate activity chain choice sets. Li and Lee (2014) present a probability method to estimate the distribution of daily activity patterns using household travel survey data. Hasan and Ukkusuri (2015) propose a probability model to estimate activity choices that can be used to reveal individual life-style patterns using Foursquare check-in data. Jiang et al. (2016) estimate a flexible choice of individual activities and generate individual mobility patterns that contains activity durations, inferred activity types, and number of visited locations within a day using phone call data. To the best of our knowledge, the existing studies mainly focus on aggregate activity and mobility pattern analyses and exclude incomplete information from individual observations. Also, most of the current works on individual activity patterns estimate activity and mobility patterns using a simplified activity rather than observe the dynamic decision making process of individuals in both space and time dimensions based on historical observations.

To cope with the challenge resulted from the partial information of location-based crowdsourced data, we need to find a way to fill in the stochastic activities in individual activity chains with space-time constraints. As a classical tool to show individuals' possible behavior in time and space dimensions, space-time prism has attracted intensive research in transportation and urban planning communities. Based on Hägerstrand's (1970) seminal time geography theory, individual activity location choices are confined by spatial availability and time windows. In particular, the space-time prism concept in the time geography theory imposes constraints on individual mobility and activity, since it captures the set of all points that can be reached by an individual from a starting point to an ending point. To investigate the accessibility problem, Miller (1991) mathematically defines the space-time prism concept to construct potential path spaces (PPS) in a space-time bicone. In light of the time geography theory and the space-time prism concept, Kitamura et al. (1995), Kitamura and Fujii (1998), and Pendyala et al. (1997) develop the Activity-Mobility Simulator (AMOS). Raubal et al. (2004) refine the space-time prism concept using LBS data. Kwan (1998) and Kim and Kwan (2003) introduce this concept to individual accessibility analysis. Furthermore, Song and Miller (2012, 2014) illustrate the potential to analyze traffic flow patterns using space-time cubes and simulate visit probability distribution.

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