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Revealing group travel behavior patterns with public transit smart card data

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ABSTRACT

Most analyses of travel patterns are based on the assumption of isolated individuals and ignore interpersonal relationships between travelers. In this paper, we develop a straightforward method to identify group travel behavior (GTB), defined as two or more persons intentionally traveling together from a single origin to a single destination, with public transit smart card data based on proxemics theory. We apply our method to Beijing to reveal the patterns of GTB, using all records generated by the subway system during a one-week period in 2010. Our data and method do not allow a reliable estimate of GTB share in overall travel, but do enable a description of the characteristics and the spatiotemporal pattern of GTB. The results reveal that the group size and GTB frequency follow a long tail distribution: far more people travel in small groups than in large groups and far more group travelers can be observed carrying out only one group trip than travelers making multiple group trips. Group trips tend to occur in weekends, in afternoons, and during public holidays. Furthermore, stations and lines serving leisure destinations show the highest GTB scores. We conclude that the GTB pattern is distinctly different from the pattern of individual travel in terms of both time and space, and is essentially influenced by urban land uses surrounding subway stations.

1. Introduction

Travel behavior is a well-developed research area with an extensive body of literature describing, explaining and predicting travel behaviors in various contexts (Handy, 1996; Golob, 2003; Ewing and Cervero, 2010). While traveling with other persons has been studied in the past, the typical starting point of most travel behavior studies is that persons travel on their own. The consequence is that there is limited understanding of what we call group travel behavior (GTB), which we define as two or more persons intentionally traveling together between a single origin and a single destination.[1] The aim of this paper is to develop a method to identify GTB with public transit smart card data, and to present some first empirical results about the patterns of GTB on the subway system in Beijing, China.

The paper is organized as follows. Following this introduction, we first present a brief review of studies that have addressed GTB (Section 2). We then present our smart card data based method (Section 3). Section 4 presents the study area and data set. In Section 5, we present the results for Beijing using smart card data of the subway system during a one-week period in 2010. We end with a brief conclusion and discussion about the potential applications of the proposed method across a range of contexts.

2. Literature review

While travel behavior research typically focuses on individual travel behavior, a number of strands of literature can be distinguished that directly or indirectly explore group travel behavior.

Group walking behavior may be the most well understood type of GTB. In line with most travel behavior research, early studies into walking behavior have treated pedestrians as isolated individuals, each having a desired speed and direction of motion (Moussaïd et al., 2010). More recently, GTB among pedestrians has received substantial attention (Moussaïd et al., 2010; Polzer, 2011; Vizzari et al., 2013; Zanlungo et al., 2014; Bruneau et al., 2015). Among these studies, identification of pedestrian groups is usually done manually using data collected by video recordings (Moussaïd et al., 2010; Polzer, 2011), but other methods have also been adopted, like interviews (Reuter et al., 2014), 3D laser range sensors (Zanlungo et al., 2014), and accelerometer sensors (Katevas et al., 2015). Besides identification and spatial

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[1] Note that this GTB definition does not include persons who travel together for part of their trip in this paper.

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formation analysis of pedestrian groups, some research focused on group-considered crowd simulation using approaches like social force modeling (Moussaïd et al., 2010; Xu and Duh, 2010), cellular automata (Sarmady et al., 2009) and agent-based modeling (Manenti et al., 2012; Vizzari et al., 2013, 2015). While these studies help us understand pedestrian behavior from a group perspective, group walking behavior has so far only been analyzed at a micro scale or in a relatively small area, like a commercial street, a shopping mall, or a metro station. To the best of our knowledge, this type of analysis has not been conducted at a macro or a city scale. In addition, most methods for data collection are relatively labor intensive, which implies that only a limited pedestrian data set can be analyzed. As a result, these approaches have not been able to provide an understanding of the characteristics of group walking behavior versus individual walking behavior at a larger spatial scale, such as a neighborhood, a city center, or an entire town or city.

Analysis of household travel behavior, somewhat related to GTB, emphasizes the household as the basic analysis unit, rather than the individual as is common in travel behavior research. Drawing on notions derived from time geography, various approaches have been developed to analyze an individual's travel behavior while accounting for the interaction and interdependency between household members. This focus on the household is typical for activity-based travel models, which have developed since at least the early 1990s (Axhausen and Gärling, 1992; Ettema and Timmermans, 1997; Timmermans and Zhang, 2009). For instance, one of the main functions of UrbanSim (Waddell, 2002) is to simulate household mobility. Buliung and Kanaroglou (2006) proposed a system designed to support exploration of household level activity and travel behavior. Chatman (2008) investigated the relationship between development density and household travel behavior. While these and other studies do address the interrelationship between individuals' travel behavior, and activity-based models could theoretically also account for GTB, studies along these lines hardly ever aim to reveal GTB as part of overall travel patterns. Exceptions include studies such as conducted by Kang and Scott (2008), who identified joint episodes in persons' activity and travel diaries using restrictive and flexible criteria, respectively. Restrictive criteria require that joint episodes have the same start/end time and same activity type/travel mode, while flexible criteria for joint travel allow for a 10-min difference in the start/end time. This study does provide some understanding of GTB pattern, but is limited in terms of the population covered and the relative coarse way for identifying joint travel patterns.

Carpooling is a specific form of GTB in which persons who either differ in terms of their origin or destination travel together in a car for at least part of the trip. Carpooling has been well studied, covering issues like the rise and fall of carpooling in the US (Ferguson, 1997), the emergence of the carpooling club model (Correia and Viegas, 2011), and carpooling patterns in different countries (Wang, 2011; Ciari and Zurich, 2012). Paraphrasing group walking behavior, carpooling could be seen as group driving behavior, and thus as a distinct form of GTB. Yet, most studies into carpooling have sought to explain the decision to carpool or not, and seldom to compare the carpooling pattern with the spatial and temporal pattern of drivers traveling alone in their vehicles. It is precisely this comparison which we take up in this paper.

3. Methodology

3.1. Theoretical background

Proxemics is the study of human use of space and the effects that population density has on behavior, communication, and social interaction (Hall, 1959, 1966). Hall (1966) identified four interpersonal distances (or zones) within public space: intimate, personal, social and public distances. Generally, intimate distance (0–0.46 m) is reserved for close interpersonal interactions, and kept by two or more people having a strong bond, like family members and close friends; personal distance (0.46–1.22 m) is kept by casual friends or people with close social contacts, like friendly acquaintances and co-workers; social distance (1.22–3.66 m) is maintained by people who are somewhat acquainted but do not really know each another and who come together for a common purpose, like friends of friends and casual acquaintances; and public distance (3.66–7.62 m) is used by people whose only association is being in the same place at the same time (Thompson, 2013). In public situations, individuals usually prefer to keep close to familiar persons. If strangers come too close, uncomfortable feelings, like stress, can be caused. As a result, individuals might engage in compensatory behavior, such as avoiding eye contacting or moving away. Proxemics suggests that persons traveling in groups will tend to maintain a small distance between each other during large parts of a trip.

Referring to the theory of proxemics, we define group distance as the distance that is typical for communication between persons with emotional ties, i.e., between members of 'group'. Group distance thus encompasses intimate and personal distances. Similar definitions of group distance can be found in the literature. For example, Manenti et al. (2012) use the term proxemic distance to refer to the preferred distance pedestrians maintain with other group members. When interpersonal distance of group members exceeds their group distance, they will move closer to each other, making sure their maximum distance is below the group distance again. Thus, it is possible to distinguish between groups and non-groups based on particular values of interpersonal distances. In what follows, we will build on this understanding to identify persons engaging in GTB from among all users of Beijing's metro system.

3.2. A smart card data based method

Against the theoretical background presented in the previous section, in what follows we propose a straightforward method to identify GTB by utilizing public transit smart card data.

Smart card data, generated by automatic fare collection systems, provide detailed onboard and outboard transactions of each cardholder and thus give a (near) complete listing of all public transit trips in an area. Clearly, the availability of smart card data provides enormous opportunities for public transport research (see Pelletier et al., 2011 for a broad review). Much of the existing literature has sought to propose various methods to investigate travel behavior using smart card data (Morency et al., 2007; Chu and Chapleau, 2010; Ma et al., 2013; Zhou et al., 2014; Kusakabe and Asakura, 2014; Langlois et al., 2016; Tao et al., 2016; Kerkman et al., 2015). However, most of these smart card data-related travel behavior analyses do not make an explicit distinction between individual travel behavior and GTB. One exception is the study by Sun et al. (2013), who identified familiar strangers, understood as individuals who are recognized because of regular encounters in the (semi-) public sphere (i.e., public transport vehicles), but with whom one does not interact. To some extent, we can say ties exist among familiar strangers, but they are not what we have defined as group travelers.

Generally speaking, smart card data contain the basic attributes of public transit trips. Depending on the exact smart card system that is used in a particular country or city, this may include data on entrance and exit time, entrance and exit stations or stops, the ID of train, subway or bus line, card ID, etc. Furthermore, both the proxemics theory briefly discusses above and previous psychological studies (Cheyne and Efran, 1972; Polzer, 2011) suggest that group travelers have a preference to tap their cards shortly after one another, while strangers usually try to avoid tapping cards between members of a group. Based on this, we develop our smart card data-based identification method for the case in which travelers tap their smart cards when entering and exiting the transit system and each transit line has separate entrance and exit points (at least in terms of smart card technology).

The basic idea of our identification method is as follows. We consider the time between two persons tapping their smart cards to enter or