Transportation Research Part A 87 (2016) 51–58

Contents lists available at ScienceDirect

Transportation Research Part A

journal homepage: www.elsevier.com/locate/tra

A study of human mobility behavior dynamics: A perspective of a single vehicle with taxi

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ARTICLE INFO

Article history:
Received 9 December 2014
Received in revised form 11 September 2015
Accepted 7 March 2016
Available online 22 March 2016

Keywords:
Single vehicle
Mobility distance
Power-law distribution
Exponential distribution

ABSTRACT

In this paper, we first research on the distance distribution of human mobility with single vehicle based on the driving data from a taxi company in South China. Different from conventional exponential distribution, we discover the mobility distance with taxi follows power-law distribution. Further, we proposed a model which may explain the mechanism for the power-law distribution: mobility distance is constrained by time and fare. Specifically, the relationship between fare and mobility distance follows piecewise function, and responds to individual sensitivity; the relationship between time and mobility distance follows significant logarithmic relationship. These two factors, especially the logarithmic relationship between time and mobility distance, may contribute to a power-law distribution instead of an exponential one. Finally, with a simulation model, we verify the significant power-law distribution of human mobility behavioral distance with a single vehicle, by supplementing factors of waiting time and fare.

1. Introduction

The most direct way to research human behavior dynamics is to study traffic flow: temporal and spatial mobility of human evolve into various complex flow phenomena in traffic networks. Only when human beings understand spatial mobility regularities, they could properly plan traffic infrastructures, prevent and control traffic congestions.

In fact, the topic of human mobility inside and between cities has been researched in traffic engineering, and for a long time, engineers have collected data of citizens' daily mobility by surveying, modeling and predicting with the data (Meyer and Miller, 2001). However, this conventional method tends to be costly and thus it is unable to satisfy the large-scale and long-time observations of human mobility behavior. Owning to advancement of modern electronic technology, more methods, like GPSONE and GPS, are available for data collection of human spatial mobility, therefore they provide ground for the research on human mobility behavior with statistical models. From 2006, a series of works about human spatial mobility behavior on top journals like *Nature* and *Science* has been pointed out toward a new realm for human dynamics.

The work (Jiang et al., 2009) was the first empirical study using statistical physics to characterize human mobility behavior, and it also critically illuminated statistical modeling for following research on human mobility behavior.

Among various data of research on human mobility behavior, global position system (GPS) is generally regarded as a direct method for data collection of human mobility behavior. Reviewing amounts of empirical research these years, they concentrated on various vehicles and characteristics of population mobility. From the perspective of human mobility patterns with single vehicle, they focused on mobility patterns of taxi, private car and fright passengers with GPS data (Jiang

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http://dx.doi.org/10.1016/j.tra.2016.03.005
0965-8564/

et al., 2009; Liang et al., 2012; Peng et al., 2012; Rambaldi et al., 2007; Bazzani et al., 2010; Riccardo et al., 2012), and mobility patterns of subway and bus passengers with Passenger Flow Record (Roth et al., 2011; Wang et al., 2012).

We reviewed these works and found that conventional researches support the exponential distribution of mobility distance with single vehicle, regardless of competition of other vehicles and the waiting time. This paper proposes the power-law distribution of mobility distance with GPS data of a taxi company in South China, and argues that the conventional exponential distribution of mobility distance may be undermined by various constrains in reality.

2. Literature review

Studies of characteristics of human mobility behavior based on GPS data and statistical physics are summarized as below.

The work (Jiang et al., 2009) analyzed GPS data of 50 taxis for 6 months in 4 cities in Sweden, and proposed that mobility distance of taxi passengers follows a double power-law distribution: within a mobility distance of 3–23 km, the distance distribution follows power-law with the exponent 2.5; with a mobility distance greater than 23 km, the distance distribution follows power-law with the exponent 4.5, and that distribution curve seems to be better fitted with exponential function.

The literature (Liang et al., 2012) collected GPS data over 10,000 taxis for 3 months in Beijing City, analyzed the characteristics of mobility distance, and further found the distance distribution follows exponential distribution. Similar exponential-distribution mobility distribution of passengers with GPS data of taxis in Shanghai was noted in literature (Peng et al., 2012). These discoveries argued that as to the distance distribution for taxi passengers, exponential distribution probably tended to be more universal than power-law distribution.

Beside taxi, studies also focused on other vehicles. By analyzing the mobility behavior of private drivers in Rome, Bologna, Senigallia and Florence (Rambaldi et al., 2007; Bazzani et al., 2010; Riccardo et al., 2012), results demonstrated that the driving distances of 3 cities approximately follow exponential distribution (Rambaldi et al., 2007). Since the distribution did not change over time, it also suggested that as for private driving groups, regularities of exponential distribution for driving distance are relatively universal and stable.

The work (Roth et al., 2011) collected IC cards record of over 2 million passengers of London Metro, and found the mobility distance of subway passengers follows neither power-law distribution nor exponential distribution, but approximate negative binomial distribution. Literature (Wang et al., 2012) analyzed the passengers' record data of buses in Shijiazhuang City, and found it similar to those of subway passengers, following negative binomial distribution with peak value and exponential tail.

In literatures (Zhou et al., 2013), Tao Zhou et al. pointed out that the peak values of these two distributions approximately approaching 5 km, which was generally the limit of walking mobility. Meanwhile, the downside trend within 5 km probably resulted from the competition between mobility by walking and mobility by bus or subway. However, beyond the limit distance of walking mobility, the distance distribution of bus passengers tended to follow exponential distribution, similar to other single vehicles passengers.

Specifically as to mobility behavior with a single vehicle, spatial mobility distribution tends to follow exponential distribution, regardless of competition from others vehicles. GPS data of taxis is a classical floating car data (FCD), which is one of the most popular research topics in intelligent transportation and data mining especially for the dynamic analysis of tempo-spatial human mobility. Yang et al. (2005) noted some surveys from 1986 to 2000 that taxi service had gradually accounted for 25% of the overall traffic mix in urban areas of Hong Kong; additionally taxis even form as high as 50–60% of the traffic volume in some specific areas. Owing to the efficient, convenient and flexible services of taxi, taxis have become an important part of urban public transportation and hence GPS data of taxi has been utilized to reveal the global characteristics of urban transportation. Based on GPS data of taxis, Li et al. (2011) studied passenger-finding strategies of taxi, and concluded that a hunting strategy would harvest more passengers than a waiting strategy. Liu et al. (2010) focused on the factors of higher earnings by comparing driving behaviors of top drivers and average drivers, and they found a higher average driving speed and passenger load factor. With the information of passenger load of taxis, Phithakkitnukoon et al. (2010) inferred the amount of unloaded taxis in specific time and place by means of Bayesian classification algorithm. Pan et al. (2013) worked on urban land-use classification using taxi GPS traces, and found pick-up/set-down dynamics exhibited clear patterns corresponding to the land-use classes of these regions. Xin et al. (2008) analyzed the characteristics of tempo-spatial distribution of road networks with floating car data. Tang et al. (2011) proposed an optimization algorithm of public travel route based on ant colony optimization algorithm and taxi GPS data.

3. Power-law distribution of mobility distance

3.1. Data description

The data we analyze come from a data collection of taxi mobility with passengers on September 1st 2010 from a taxi company, with a total mobility 6,850,756 records. Each one contains the ID, record time of GPS, longitude and latitude of GPS, taxi speed, direction and the number of passengers. We have filtered and deleted the mobility record of empty taxi with two clues: first one is waiting time recognition; second one is mobility distance between two waiting time calculated by speed, longitude and latitude (see Fig. 1).