Physica A 491 (2018) 471–479

Contents lists available at ScienceDirect

Physica A

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

Ring aggregation pattern of metro passenger trips: A study using smart card data

Ziyang Wang [a,*], Yuxin Hu [a], Peng Zhu [a], Yong Qin [b], Limin Jia [b]

[a] *School of Traffic and Transportation, Beijing Jiaotong University, Beijing, 100044, China*
[b] *State Key Laboratory of Railway Control and Safety, Beijing Jiaotong University, Beijing, 100044, China*

ARTICLE INFO

Article history:
Received 17 August 2016
Received in revised form 10 June 2017
Available online 20 September 2017

Keywords:
Ring aggregation
Linear relationship
Travel pattern
Smart card data

ABSTRACT

With the widespread implementation of smart cards and with more travel details being recorded, travel patterns can be studied more precisely and deeply. Although considerable attention has been paid to travel patterns, the relationship between travel patterns and the functional structure of a city is yet to be well understood. In this research, we study this relationship by analysing metro passenger trip data (in Beijing and Shenzhen in China and London in the United Kingdom), and we present two unprecedented findings. First, through averaging, a linear relationship is found to exist between individual travel distance and the distance between the origin and the city centre. The underlying mechanism is a travel pattern we call "ring aggregation", i.e., the daily movement of city passengers is aggregated into a ring (with approximately equal distances to the city centre). Then, for commuting trips, the daily travel pattern can be regarded as switching between the outer residential ring and the inner work ring. Second, this linear relationship and the ring aggregation pattern seem to be exclusive characteristics of metro systems (and may also fit other moderate- and long-distance transportation modes) but do not apply to short-distance transportation modes, such as bicycles and taxis. This finding implies that the ring aggregation pattern is a product of the relationship between travel patterns and the city functional structure at a large scope.

1. Introduction

A travel pattern, as a collective property of travel, is the common behaviour generated by various factors during travel. Understanding travel patterns is one of the core tasks for traffic planning, urban planning, marketing strategies making, and policy making. For example, identifying a preference for a transportation mode is a precondition for the transit authorities optimizing the ratios of different transportation modes [1]. Transit agencies need to know the loyalty of riders to specific transit modes to provide effective discounts to the riders [2]. Because of their wide applications in many fields, traffic patterns have been the focus of many studies. Some lines of research can be traced back to the 1940s [3]. However, due to the limitations of technology for data acquisition, many of the studies have been based on survey data, which have many shortcomings. Survey data is usually expensive or time consuming to obtain [1,4]. The accuracy of survey data can also be low. For example, after sampling, the pattern and characteristics may change from their original form [1,5]. Furthermore, errors can be introduced through mistakes made by the investigator during field investigations and questionnaire investigations [1,5].

* Corresponding author.
E-mail address: wzy_ustc@126.com (Z. Wang).

http://dx.doi.org/10.1016/j.physa.2017.08.105

Smart cards provide an efficient way to collect a large amount of detailed and specific data. With the maturing of certain technologies, smart cards have been widely used to collect travel data and to help improve public transit efficiency [6,7]. The researchers of [8,9] determined that network usage can be characterized if the trip information of each user is collected, which means that long-term network planning can benefit from smart card data. On the short-term side, transit authorities can provide frequently adjusted service, such as different schedules for each day, since the variations in travel can be detected from the smart card data [10].

Smart card data are also used to study travel patterns. However, although considerable attention has been paid to this field, most of the previous studies have primarily focused on the universal patterns of human travel, i.e., the universal trends of human mobility [11–14]. Using smart card data, researchers have determined that the displacement of human travels sometimes appears as a power distribution [15–17] or an exponential distribution [18–20]. Recently, researchers proposed that single modes of transportation will lead to an exponential distribution, while a power distribution may result from a mixture of different transportation modes [21]. Interestingly, [22] noted that the mixed displacement is due to the power distribution even though each individual moves irregularly. Recently, [23] proposed a general law to describe human mobility; existing models can be implemented as special cases of this model.

We benefit from abundant discussions on the universal trends of travel patterns [24]. Furthermore, travel patterns as a form of collective travel behaviour are closely related to the ways that people use land to satisfy their needs [25–27]. Specifically, with regard to a city, travel patterns tend to be closely affected by the functional structure of the city. From the viewpoint of complex systems, a city is a type of spatial network, with the functional spots being the nodes and the traffic roads being the links [28]. As the theory of "structure decides its function" indicates, the functional structure of a city tends to also influence human travel patterns significantly. At the same time, the characteristics of a city's functional structure should also be reflected in the travel paths of city passengers. The relationship between travel patterns within the city functional structure is often ignored in discussions, and only certain simple characteristics of city structure are linked to the study of travel patterns [29].

In this work, we investigate the relationship between the travel pattern and the functional structure of a city. To achieve this purpose, we concentrate our study on smart card data from the electrical ticket card of a metro system, for the following considerations. Typically, the network of a metro covers the city to provide the facility to the entire public, which means that a metro is closely interrelated to the functional structure of a city. A metro is a popular public transit option because of the low price and reliable travel time; thus, a large proportion of passengers will choose the metro, particularly during the peak hours, meaning that the metro is closely related the travel patterns of daily life. Thus, it is reasonable to hypothesize that metro data are suitable for this study.

In Section 2, a detailed investigation of the smart card data used in this study is described. To guarantee the generality of the results, several sets of smart card data are used to draw conclusions. Section 3 first presents a linear relationship between the mean travel distance of individuals with the distance from their original location to the city centre and then proposes a new travel pattern, the ring aggregation pattern of metro passengers to interpret the mechanism underlying the linear relationship. Section 4 discusses the output between different transportation modes by comparing corresponding data and presents some explanations. Section 5 summarizes the main conclusions of this research.

2. Data descriptions

To obtain the travel pattern of the metro passengers, we use the smart card data of the metro system from three cities: Beijing and Shenzhen in China and London in the United Kingdoms. These three cities have large populations; thus, the magnitudes of passenger flows are large. For example, nearly 600,000 passengers take the metro each weekday in Beijing. In all these cities, the metro networks are well developed with multiple lines built, and the networks cover most areas of the city. Thus, we can obtain the collective properties of how metro passengers travel within each city. To determine if certain properties are exclusive to metros, we compare collective properties of different transportation modes. Thus, we use two additional data sets, one for a bicycle system and one for a taxi system.

2.1. Beijing Metro system dataset

This dataset contains all passenger trips in the Beijing Metro system, which is composed of 17 railway lines and 218 stations, during one week in 2013. In total, 4,058,615 trips were recorded by the "Yikatong" card (a smart card system). The information for each trip includes the card number, the start and end stations, and the start and end times.

2.2. London Tube system dataset

The dataset contains 667,584 passenger trips, approximately 5% samples, of the London Tube system. These trips occurred over a week in November 2009 and were recorded by the Oyster card. The information for each trip includes the stations at which a journey started and ended. The dataset is available online at http://www.tfl.gov.uk/businessandpartners/syndication/.