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Study on some bus transport networks in China with considering spatial characteristics

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ABSTRACT

Many real-world networks are embedded in spaces. Recent studies have found that spatial characteristics are closely related to network features. Bus transport networks (BTNs) are typical spatially embedded networks, but their spatial characteristics are commonly disregarded in previous researches. In this paper, we propose a new spatial representation model for BTNs with information on the geographical location of bus stations and routes, for which we named as the ES model. The new model aids in the study of real-world BTNs. By performing a statistical study with the new representation model on three typical BTNs in China, namely the Beijing, Shanghai and Hangzhou BTNs, we identify some network features that are consistent with those revealed by previous studies, as well as some new features such as high clustering of short-distance station pairs (SSPs) and small average number of bus routes in a path. The result shows that the existence of SSPs can significantly influence the characteristics of BTNs. Besides, with the help of the ES model, we designed a new transfer algorithm for BTNs.

1. Introduction

We are surrounded by a variety of networks (Bullmore and Sporns, 2009; Schweitzer et al., 2009; Traud et al., 2012). These networks are closely related to us. A new research field known as the Network Science has recently emerged with the goal of analyzing, predicting, controlling, optimizing, or designing networks (Chen et al., 2012; Mirzasoleiman et al., 2012; Zhou et al., 2010) through relative basic studies (Liu et al., 2011; Nadakuditi and Newman, 2012; Watts and Strogatz, 1998). Public transport networks (PTNs) (Song and Wang, 2011; Yang et al., 2011) such as road networks, bus networks, train networks, airline networks are among the most widely used networks in our daily lives. Recently, studies on PTNs have drawn considerable interest from researchers along with the development of the Network Science researches, which shed new light on the traditional public transport system researches. Related studies cover the range of statistical analysis on PTNs' network properties (Chen et al., 2009; Cui et al., 2013; von Ferber et al., 2009), transfer (or routing) algorithm design (Roca-Riu et al., 2012; Song and Wang, 2011), network optimization (Chen et al., 2012; Yang et al., 2011), and so on.

Spatially embedded networks (SENs), such as road networks, power grid networks, are networks whose nodes and edges are disposed in spaces which can be characterized by spatial metrics (Barthélemy, 2011), such as the Earth's surface. Their

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structures and behaviors are highly coupled with the embedding spaces. No doubt SENs are a significant class of networks, as they commonly serve crucial roles in a wide range of fields in real-world situations. The studies on SENs have become an important part of the Network Science researches nowadays. Recent studies show that spatial characteristics can shape the features of a network in a great way, and further, useful applications utilizing these spatial characteristics can been developed. One can refer to the review paper (Barthélemy, 2011) for more details about SENs. PTNs also belong to the category of SENs because of their close blending with city infrastructures. However, for reasons such as difficulties in data acquisition, the spatial characteristics of PTNs have been less studied by researchers in previous years. Situations have been improved recently due to the advances of related fields and easier big-data accessibility. For instance, in Song and Wang (2011) the authors utilized the spatial clustering features of road networks and proposed an efficient routing algorithm for large road networks, and the algorithm was tested and verified on the real-world New York road network; in Wang et al. (2012) the authors analyzed the traffic flow distribution and visualized the road usage for two large real-world PTNs; in Austwick et al. (2013) the authors studied the community structure of the constructed spatial networks for public bicycle sharing systems of several cities.

In this paper, we focus on a specific type of PTNs: the bus transport networks (BTNs). BTNs are crucial networks for transferring large amount of people place to place in cities. Several studies on the network feature of BTNs have been previously conducted (Chen et al., 2007; Sui et al., 2012; von Ferber et al., 2009; Xu et al., 2007). For example, in von Ferber et al. (2009), the authors analyzed several BTNs in Poland and revealed some common features of BTNs such as the exponential degree distribution, large clustering coefficient and small average transfer times, and further based on lattice network they proposed an evolving model for BTNs which can reproduce similar features of real-world BTNs. In Zou et al. (2010), the authors discussed the relationship between the degree distributions in different representation networks of BTNs. In Yang et al. (2011), the authors analyzed some BTNs in China and proposed a diameter (maximum transfer times) optimization method for BTNs. As we find that, most of the previous studies were focused on the topology features of BTNs, they commonly dismissed the spatial characteristics of BTNs and only used un-weighted un-directed networks to represent and study BTNs. A few studies have taken into account of some spatial characteristics of BTNs. For example in von Ferber et al. (2009), the authors studied the geographical path length and the harness of bus routes in real-world BTNs. We notice that, there are still some intrinsic spatial characteristics of BTNs need to be considered in further studies, such as the ones induced by the directed and geographical edges connecting stations brought by routes, and more importantly the ones induced by the virtual edges connecting stations brought by short-distance walking between stations. Especially, the virtual edges brought by short-distance walking between stations are rarely considered but they exit abundantly in real-world situations. In fact, these virtual short-range edges may connect bus routes or stations which appear nonadjacent in the topology without considering short-distance walking, and thus may improve the entire performance of BTNs.

Taking into account of these factors, in this paper we propose a new network representation model of BTNs which is named as the ES model. Based on this model, we perform a statistical study on some network features of three typical BTNs in China, namely the Beijing, Shanghai and Hangzhou BTNs. We implement two modifications to fit the traditional Space-L (P) representation model into the ES model. The first modification is on the short-distance station pairs (SSPs) which consist of two geographically close stations that can reach each other through short-distance walking. The second modification is on the directions and the geographical distances among edges. The statistical result on the three BTNs shows some consistent common features of BTNs that have been revealed in previous studies, and also some new features such as the high clustering of SSPs and the common form of the geographical edge length distributions. We reveal that SSPs can have a huge influence on BTNs, especially they can decrease the transfer times between stations in a great way. Besides statistical analysis, we design a transfer algorithm based on the ES model which can provides multiple "shortest" paths (namely the minimum cost transfer plans) between two stations in BTNs, and the influence of the threshold of the short-distance walking distance on the geographical path length and the transfer times of a path in BTNs is studied.

The remainder of this paper is organized as follows: Section 2 presents the new BTN representation model, namely the ES model. Section 3 details the statistical analysis on three typical BTNs in China. Section 4 depicts the new transfer algorithm for BTN based on the ES model. And Section 5 states the conclusion and some discussion.

2. New representation model of BTNs

BTNs consist of bus stations and routes. Traditionally, the Space-L (P) representation model (Sen et al., 2003) is widely used in the analyzing of the network properties of BTNs. In the model, a BTN is represented by two networks: the Space-L network (which reflects the direct topology) and the Space-P network (which reflects the transfer topology). In the Space-L network, nodes represent bus stations, and two bus stations are connected by an edge when these two stations are adjacent in at least one common bus route. In the Space-P network, nodes also represent bus stations, two bus stations are connected by an edge when these two stations are contained in at least one common bus route. An illustration of the Space-L (P) representation model is presented in Fig. 1. The original structure of a BTN is shown in Fig. 1(a) and Fig. 1(b) illustrates the Space-L network, and Fig. 1(c) illustrates the Space-P network.

To incorporate the spatial characteristics, we modify the Space-L (P) representation model and propose a new representation model named as the Extended-Space (ES) model. The ES model comprises three networks: the ESL, ESP, and ESW networks.