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The impact of a public bicycle-sharing system on urban public transport networks

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A R T I C L E I N F O

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A B S T R A C T

As a healthy and environment-friendly trip mode, public bicycle-sharing systems, which have so far been built in hundreds of cities around the world, have been developing rapidly recently. The public bicycle-sharing systems, which are usually spatially embedded where original urban bus transport networks are located, comprise the new urban public transport system together with the bus transport networks. Therefore, studying the impact of the public bicycle-sharing systems on the original urban public transport networks is an important research subject. In this study, using the real spatial location data of the public bicycle-sharing systems of Hangzhou and Ningbo in China, we propose a multi-layer coupling spatial network model that considers the geographical information on bus stations, bus routes, and public bicycle stations by studying the urban public transport networks. The spatial network model consists of bus subnets, short-distance bicycle subnets, and short-distance walk subnets which are interdependent rather than independent. We apply the model to study the influence of bicycling between the short-distance bicycle station pairs (SDB) and walking between the short-distance bus station pairs (SDW) on the performance of the urban public transport networks. Results show that SDB and SDW can significantly reduce the average transfer times, the average path length of passengers' trips and the Gini coefficient of an urban public transport network. Therefore, the public bicycle-sharing systems can decrease the average trip time of passengers and increase the efficiency of an urban public transport network, as well as effectively improve the uneven level of traffic flow spatial distribution of an urban public transport network and will be helpful to smoothening the traffic flow and alleviating traffic congestion.

1. Introduction

The number of public bicycle-sharing systems, which are cheap, healthy, and environment-friendly trip modes, has been increasing rapidly. Thus far, hundreds of cities around the world have built the public bicycle-sharing systems (DeMaio and Meddin, 2016). The implementation of the public bicycle-sharing systems is so flexible that it complements the original urban public transport pattern, such as the bus and subway. A passenger can borrow a bicycle from an arbitrary self-help bicycle station and then return it to another arbitrary station after the trip. Research on public bicycle-sharing systems' performance and optimization methods have been

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drawing increased attention at present. For example, de Chardon and Caruso (2015) estimated bike-share trips using station level data. Gosse and Clarens (2014) based their estimation on sparse data in temporally and spatially continuous bicycle volumes. Winters et al. (2013) proposed a method to find the most appropriate areas for a public bicycle-sharing system through statistics. Frade and Ribeiro (2015) proposed a maximal covering location approach for a public bicycle-sharing system's stations. Chen et al. (2015) judged the number and locations of stations and optimized route options. Chow and Sayarshad (2014) proposed a framework which is applied to formulate a symbiotic bike-sharing network design problem in the presence of a coexisting transit system as a departure-time-elastic multicommodity flow problem. We also observe that, in the public transport networks with a public bicycle-sharing system, passengers often achieve flexible transfer by way of short-distance walking. For example, de Jonge and Teunter (2013) proposed optimizing itineraries in public transportation with walks between rides. Buehler and Hamre (2015) studied American adults' trip modes including driving, walking, bicycling, and public transportation.

A public bicycle-sharing system is usually embedded in the space of original bus public transport network and complements it to form the new urban public transport system. An urban public transport network is a type of spatial network (Barthélemy, 2011; Silva et al., 2015) that is one kind of complex networks with spatial characteristics. The networks are embedded in their specific spaces, where every node and edge has its own spatial (geographical) position whose restriction plays an important role in the network characteristic. In the real world, many networks related to geographical positions belong to spatial networks, such as the Internet (Huang and Tang, 2015; Choi et al., 2015), power grid networks (Pei et al., 2015; Dewenter and Hartmann, 2015; Bai et al., 2016), airline networks (Ryerson and Kim, 2013; Dobruszkes, 2013), and road networks (Austwick et al., 2013; Peng et al., 2014; Zheng et al., 2015; Ruan et al., 2015; Gao et al., 2016). An urban public transport network is a kind of typical spatial networks because its nodes and edges have spatial positions (Zhang et al., 2016; Louf et al., 2013). In addition, new public transport networks often consist of the public bicycle-sharing system subnets, bus subnets, and subway subnets, which are interdependent rather than independent. So they belong to typical coupling spatial networks (Yang et al., 2014; Morris and Barthelemy, 2012).

Studying the influence of a new public bicycle-sharing system on an urban public transport network is the topic of this paper. We propose a new multi-layer coupling spatial network model that consists of bicycle subnets, walk subnets, and bus subnets to represent the whole public transport system, where bus and bicycle-sharing stations have their geographical positions and edges are directed-weighted (weight is the path length between two stations). We studied the features of urban public transport networks with public bicycle-sharing systems on the basis of real public transport network data of Hangzhou and Ningbo in China. We discovered that bicycling between short-distance bicycle station pairs (SDB) and walking between short-distance bus station pairs (SDW) can not only significantly improve the performance of urban public transport networks but also smoothen traffic flow and alleviate traffic congestion.

This paper is organized as follows. In Section 2, we propose the multi-layer coupling spatial network model of the urban public transport system. In Section 3, we study the influence of SDB and SDW on the performance of an urban public transport network. In Section 4, we describe the performance of an urban public transport network under the conditions of feasible major short-distance bicycling and walking thresholds. In Section 5, we design a transfer algorithm on the basis of the proposed three-layer coupling spatial network model. Finally, our conclusion and discussion are given in Section 6.

2. Three-layer coupling spatial network model of urban public transport systems

A public transport network is composed of stations and routes. In recent years, researcher often used the Space-L and Space-P network models to study the network properties of urban public transport networks (Sen et al., 2002). In the Space-L network model, a node represents a bus station, there is an edge between two bus stations when they are adjacent in one bus route. In the Space-P network model, a node denotes a bus station, there exists an edge between two bus stations when they are contained in at least one common bus route. The Space-L model reflects connection status of adjacent bus stations in a bus transport network, while the Space-P model denotes the transfer topology and often is used to study the transfer feature of a bus transport network.

To represent the spatial geographic location factors of an urban public transport network, we extend the Space-L and Space-P networks and propose two new models which are named as Spatial Space-L Network Model and Spatial Space-P Network Model. For

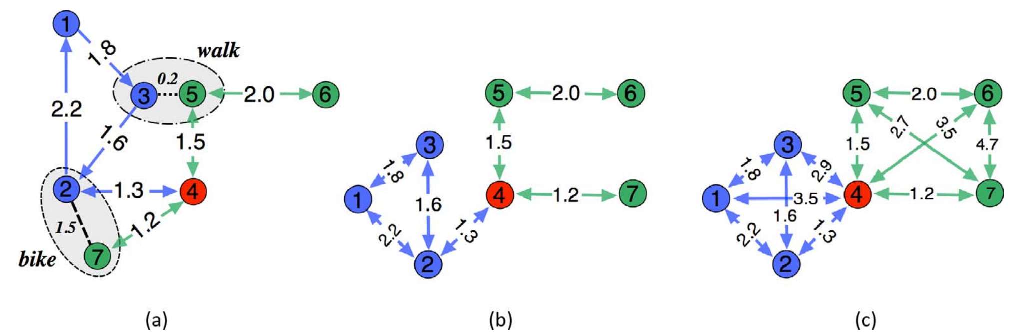

Fig. 1. (a) A public transport network consists of two bus routes. Different edge colors represent different bus routes, and arrows denotes the bus route directions. The weights of edges represent the path length of bus routes (km). The red Station 4 represents the common station of the two bus routes. (b) represents Spatial Space-L Network Model, and (c) represents Spatial Space-P Network Model.