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Empirical study on a directed and weighted bus transport network in China

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HIGHLIGHTS

- The difference between uplink and downlink for BTN-H is analyzed.
- The directed-space P representation model for BTNs is proposed.
- The four empirical distributions of BTN-H are presented following the exponential law.
- The rich-club phenomenon is demonstrated in BTN-H.

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ABSTRACT

Bus transport networks are directed complex networks that consist of routes, stations, and passenger flow. In this study, the concept of duplication factor is introduced to analyze the differences between uplinks and downlinks for the bus transport network of Harbin (BTN-H). Further, a new representation model for BTNs is proposed, named as directed-space P. Two empirical characteristics of BTN-H are reported in this paper. First, the cumulative distributions of weighted degree, degree, number of routes that connect to each station, and node weight (peak-hour trips at a station) uniformly follow the exponential law. Meanwhile, the node weight shows positive correlations with the corresponding weighted degree, degree, and number of routes that connect to a station. Second, a new richness parameter of a node is explored by its node weight and the connectivity, weighted connectivity, average shortest path length and efficiency between rich nodes can be fitted by composite exponential functions to demonstrate the rich-club phenomenon.

1. Introduction

As an important facilitator of urban travel, the public transport system has always been a hot topic of transportation research. In recent years, public transportation networks have evolved into complex networks. This has allowed for new methods of research into the urban public transport system. Angeloudis and Fisk analyzed the world's twenty largest subway systems as complex networks [1]. Soh et al. analyzed travel routes on the Singapore public transportation system from a weighted complex networks perspective [2]. Previous empirical studies showed that urban public transport networks such as bus transport networks and subway transport networks are complex and are characterized by properties such as scale free and small world [3–5].

In previous research [6–8], three representation models for public transport networks were established: space P, space L, and space R. Their corresponding topology spaces can be regarded as projections of a bipartite graph [9–11]. Von Ferber

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Fig. 1. Uplink and downlink of bus route 2 in Harbin.

et al. analyzed the public transport networks of fourteen major cities of the world based on space L and space P [12]. Bi et al. proposed an improved space L (space S) to analyze urban rapid transit networks [13]. Yang et al. proposed an extended-space (ES) representation for bus transport networks based on space L (P), which comprised of ESL, ESP, and ESW networks [14]. Considerable empirical data have showed that degree distributions of public transport networks follow exponential law, rather than power law [1,6,9,15,16]. Xu et al. conducted an empirical study on the public transport networks of 330 cities in China based on space P, which showed that the degree distribution of all networks can be described by an exponential function [15]. Zhang et al. explored the topological characteristics of urban rail transit networks and discovered that the corresponding cumulative degree distribution can be fitted by exponential distribution [16].

In this paper, we focus on bus transport networks (BTNs). In the following, we summarize the findings of previous studies that investigated BTNs as complex networks. Two common points can be listed as follows:

(1) BTNs can be roughly described as undirected complex networks, in which the uplink and downlink are the same for each bus route. The road networks in old cities are constantly adjusted with expansions in the size of a city. Many road segments are transformed into single lanes to accommodate traffic growth. This sometimes results in uplinks and downlinks having different paths for same bus routes, in keeping with adjustments in the road network. This is relatively common in big cities (such as Harbin, Dalian in China). Fig. 1 shows bus route 2 with different uplink and downlink in Harbin.

In Fig. 1, the uplink is from Guoyuanxiaoqu to Youyigong, the downlink is in the opposite direction. Obviously, a considerable part of the paths and the stations are different between uplink and downlink.

(2) Previous studies suggest that BTNs are composed of routes and stations, and focus on topological properties of route networks or station networks. However, in reality, BTNs are complex systems that consist of routes, stations, and passenger flow. Routes and stations are external carriers, while the passenger flow is the essential body. That is, "no passengers, no BTNs" just as "no water, no fish". The topological structure of BTNs heavily depends on passenger flow.

To address the two aforementioned issues, we present an empirical study on the bus transport network of Harbin (BTN-H). The remainder of this paper is organized as follows: Section 2 analyzes the difference between uplink and downlink for BTN-H and proposes a new representation model for BTNs, namely directed-Space P. Section 3 presents the cumulative distributions of weighted degree, degree, number of routes that connect to each station and node weight, which uniformly follow the exponential law. Section 4 analyzes the connectivity, weighted connectivity, average shortest path length, and efficiency between rich nodes to demonstrate the rich-club phenomenon. Finally, Section 5 presents a brief conclusion.

2. The proposed representation model

The data in this paper are derived from an empirical investigation on the BTN-H in 2013, which included 132 bus routes (excluding two loop routes), 993 stations and peak-hour trips at each station. All the routes are divided into uplinks and downlinks. Peak-hour trips at each station are collected by counting the number of passengers who get on and off the bus at each station in a peak hour.

The issue of a bus route having different uplink and downlink in Harbin owing to single lanes and unidirectional passenger traffic has become common, and its proportion is more than 36%. In the following, the duplication factor of a bus route and