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Weighted complex network analysis of travel routes on the Singapore public transportation system

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ABSTRACT

The structure and properties of public transportation networks have great implications for urban planning, public policies and infectious disease control. We contribute a complex weighted network analysis of travel routes on the Singapore rail and bus transportation systems. We study the two networks using both topological and dynamical analyses. Our results provide additional evidence that a dynamical study adds to the information gained by traditional topological analysis, providing a richer view of complex weighted networks. For example, while initial topological measures showed that the rail network is almost fully connected, dynamical measures highlighted hub nodes that experience disproportionately large traffic. The dynamical assortativity of the bus networks also differed from its topological counterpart. In addition, inspection of the weighted eigenvector centralities highlighted a significant difference in traffic flows for both networks during weekdays and weekends, suggesting the importance of adding a temporal perspective missing from many previous studies.

1. Introduction

Because the structure of a network often affects its function [1], deciphering the topology and dynamics of the underlying networks is a prerequisite to a full understanding of connected, interacting systems. For the past half century, research on networked structures has focussed primarily on Erdös and Rényi (ER) random graphs, the canonical description of complex networks. However, ER random networks are theoretical constructs and may only represent a small subset of real-world systems.

The problem of real-world network analysis is that of complexity. Interesting real-world networks can consist of millions of nodes connected by a complicated set of edges, making them difficult to unravel. Fortunately, advances in complex network theory, measurement techniques and computational power have greatly improved our ability to analyze such structures. In the past few years, we have made fascinating discoveries on the nature of a diverse set of complex systems from the neural network of the nematode *Elegans* [2] to the World Wide Web (WWW) [3].

In this paper, we contribute a *complex network analysis of passenger travel routes* on the rail and bus public transport systems in the island nation of Singapore. The bus network studied in this work is among the largest studied to date, with more than 4130 nodes. Moreover, the Singapore Land Transport Authority uses an integrated distance-based fare

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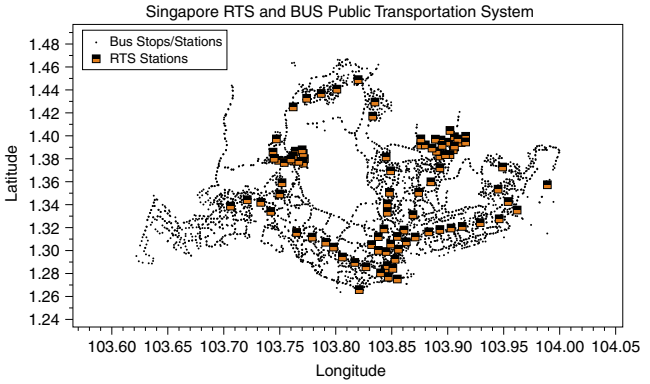

Fig. 1. The Singapore public transportation system, comprising the RTS and BUS systems.

system, which captures data *both* when commuters *board* and *alight* busses through the use of smart card readers. Alighting information on bus networks is usually unavailable or based on estimation in other urban transport information systems (e.g. London, Paris and New York). As a result, the public transport data captured through the Singapore public transport ticketing system is one of the most comprehensive in the world.

We compare its characteristics to previously studied transportation systems such as the Boston subway [4], the Indian railway [5], Chinese railway [6], the world-wide airport network [7] and the public transportation system in [8]. In addition to a topological study, we also investigate the dynamical properties of the networks by incorporating the magnitude of interactions [9–14]. We find that the Singaporean transport systems share several similar (but not identical) dynamical features with the world-wide air transportation network [10] and the German and Indian railway networks [15]. Furthermore, we extend previous analysis into the temporal domain by considering the differences in properties over weekdays and the weekend.

In the next section, we will set the stage by describing the Singapore Public Transportation system and the dataset provided by the Land Transport Authority. In Section 3, we report on the degree, strength, clustering, assortativity and eigenvector centrality characteristics of the transportation networks. In brief, our study highlights the importance of studying both the topological and dynamical properties of networks. For example, from a topological perspective, the Singapore rail network appears similar to a highly connected ER random graph (indicating travel between almost all districts in Singapore). However, a dynamical analysis reveals a more complex scale-free system in which certain regions enjoy substantially greater traffic. Furthermore, an eigenvector analysis (in Section 3.5) shows that the traffic can differ significantly depending on the day of the week, suggesting the importance of temporal effects. We believe that our results will have an impact on future modelling and simulation studies, for example in epidemiology, where static (rather than dynamic) networks are the norm. We elaborate upon these aspects as well as avenues for future work in Section 4, which concludes our paper.

2. Case study: the public transportation system in Singapore

Singapore is an island nation at the southern tip of the Malay Peninsula in South East Asia. Home to approximately 4.86 million people but with a land area of only 710.2 km^2, Singapore is the third densest country in the world [16]. Singapore has experienced tremendous economic growth since its independence in 1965; the International Monetary Fund now ranks Singapore as the fifth wealthiest country in the world in terms of Gross Domestic Product per capita [17]. Part of its rapid economic progress can be attributed to an efficient transportation system.

Pre-World War II, the human-powered trishaw was the main means of public transportation in Singapore. Today, the land-based public transportation system in Singapore is comprised of two efficient, sophisticated networks: (1) the rail or Rapid Transit System (RTS) and (2) the bus system (BUS), shown in Fig. 1. The RTS network in 2008 consisted of 93 stations (grouped into three mass-rapid transit (MRT) lines and three light-rail (LRT) lines), connecting all major districts across the island. The public BUS network is larger, with more than 4000 bus stops covering almost all populated regions. In 2007, approximately 4.5 million trips were made on the RTS and BUS systems daily.

The main payment method employed by the Singapore public transportation system is a contact-less smart card system called EZ-Link [18]. An individual taps his or her smart card once upon entry to the RTS station (or BUS) and once more upon exit (or alighting). In the case of the RTS, individuals can change trains at intermediate hub stations without exiting the RTS network. It is through the EZ-Link payment system that we are able to capture the traffic serviced by these transportation networks. Our datasets that are provided by the Land Transport Authority of Singapore (LTA) list the daily in and out traffic for each RTS station and bus stop to all other stations and stops. The data spans one week (Monday to Sunday) in January 2008, capturing 10.6 million RTS passenger rides and 19 million BUS passenger rides.