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The improved degree of urban road traffic network: A case study of Xiamen, China

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HIGHLIGHTS

- A method to quantify the interaction between nodes in the traffic network is proposed.
- The direction and odd or even classifications of degree need to be analyzed specifically.
- Hierarchical values of the improved degree conform to the power-law distribution.
- Correlation of the new measure exhibits significant segmentation in the urban street network.

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ABSTRACT

The complex network theory is applied to the study of urban road traffic network topology, and we constructed a new measure to characterize an urban road network. It is inspiring to quantify the interaction more appropriately between nodes in complex networks, especially in the field of traffic. The measure takes into account properties of lanes (e.g. number of lanes, width, traffic direction). As much, it is a more comprehensive measure in comparison to previous network measures. It can be used to grasp the features of urban street network more clearly. We applied this measure to the road network in Xiamen, China. Based on a standard method from statistical physics, we examined in more detail the distribution of this new measure and found that (1) due to the limitation of space geographic attributes, traditional research conclusions acquired by using the original definition of degree to study the primal approach modeled urban street network are not very persuasive; (2) both of the direction of the network connection and the degree's odd or even classifications need to be analyzed specifically; (3) the improved degree distribution presents obvious hierarchy, and hierarchical values conform to the power-law distribution, and correlation of our new measure shows some significant segmentation of the urban road network.

1. Introduction

Research on topological characteristics of urban road traffic network, on the basis of which to analyze the relation between the structure and function is of great significance. In order to study urban street network topological features, many existing researches selected only one area of the specific road network for statistics of complex network's original indicators. On the one hand, it's hard to grasp the characteristics of the whole network; on the other hand, the selection of original

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indexes is not quite appropriate in the field of transportation. Therefore, due to the shortcomings and limitations mentioned above, this kind of statistical conclusion is difficult to truly reflect the characteristics of real traffic network. Meanwhile there has been little done on the study of Chinese cities which have experienced specific historical stage of development and planning, and they may have distinct characteristics with comparison to other cities of the world which have been studied much more. In particular, during the 13th Five-Year Plan period of China, the government suggests that cities should draw lessons from foreign experience and puts forward the urban planning idea of "narrow road, dense network" for structure optimization of block networks. The research on China's urban road traffic network topology characteristics in this new period should be paid more attention.

Overall, scholars have studied much more in highway networks [1–3], public transit systems [4–6], aviation networks [2,7,8] etc., but little has been done on topology characteristics of urban road traffic networks. And their fundamental idea is to analyze network properties by original indicators in the complex network theory. For example, Jiang et al. [9] used the dual approach to model an urban street network, and found that city street network did not have power-law property. Lämmer et al. [10] analyzed urban road networks of 20 major cities in German, and found that traffic concentrated on a small fraction of the roads, and its flow distribution obeyed a power-law indicating a clear hierarchical order of the roads. Porta et al. [11] found that most of the considered networks had a broad degree distribution typical of scale-free networks and exhibited small-world properties as well after the authors addressed a study of six urban road traffic networks (1 sq. mile) characterized by different patterns and historical roots. Crucitti et al. [12] studied centrality in urban street patterns of different world cities and found self-organized cities exhibited scale-free properties. Wu et al. [13] compared the different types of networks' congestion and efficiency characteristics by experiment simulation, and the result exhibited the scale-free networks can support the largest flows. Gao et al. [14] investigated the urban road network based on the GIS technology, and thought it was a scale-free network with small-world characteristic. Sun et al. [15] found strong community structure can improve the network performance and is effective to resist the propagation of the traffic congestion. In addition to the description and analysis on urban road network topology characteristics, many scholars have also begun to investigate the influential factors of road network evolution. For example, Wu et al. [16] analyzed the influence of topological structure on traffic network design, and thought small-world network had better performance. Zhao et al. [17] proposed a road network growing model with the consideration of population and central business district attraction.

Primal and dual approaches are main two modeling methods in real networks. The dual approach, opposite of the primal one, regards an edge as a node, and a node as an edge. The method can show something from a different perspective, but it loses the space geographic attributes when it comes to the urban road traffic network. Once urban street network does not have the practical constraints of geographical boundaries, it will be difficult to be objective, comprehensive and realistic for the network analysis on urban street systems [18]. So the primal approach should be a better choice for topology structure research. In this paper we look in detail at one specific network, particularly concentrating on its spatial form. Our network is the city traffic road network of Xiamen Island, China, in which the vertices represent intersections, termination points of segments, and the edges represent links. Vertex positions and edges were extracted from GIS databases. For data from the year 2014 the network has 1379 vertices and 2521 edges (see Fig. 1). And data collection which mainly includes positions and lane properties is accomplished with the help of Google Map and Baidu Street View. Xiamen is one of typical first-tier cities in China, which has good economic base, convenient transportation and unique charm. The city has a population of 3.86 million, and the number of cars is up to 0.9 million in 2015.

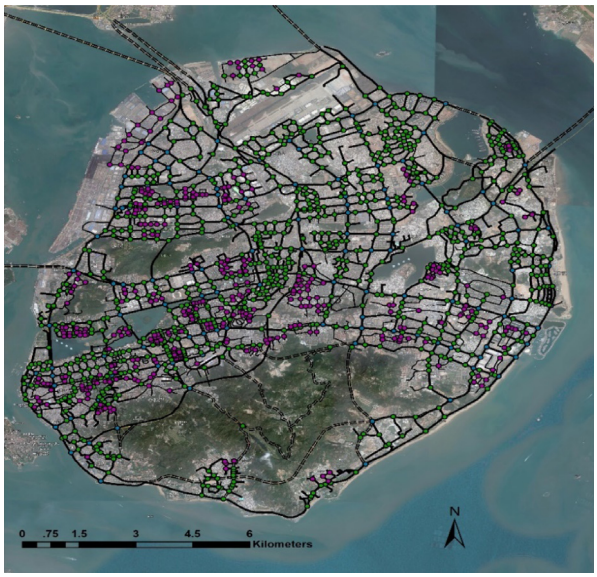

Fig. 1. (Color online) The street network of Xiamen Island China.