Topology Structure Improvement Strategy for Urban Road Networks

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ABSTRACT

To improve the average travel efficiency of the urban road networks, we propose a topology structure improvement strategy which aims to connect the nodes with smallest and the second smallest degree values around the node with the biggest degree value by edges. Finally, the road networks of Deyang city are taken as an example for simulation. The results show that the topology structure improvement strategy can improve the average travel efficiency greatly with the increase of the number of the edges added to the network.

KEYWORDS

Urban road networks, topology structure improvement, travel efficiency.

INTRODUCTION

Urban road network is composed by road intersections interconnected together, and the network capacity and network structures are closely related. Therefore, the reconstruction of road network connection status is an effective method to improve the efficiency of network transport. But for the actual urban road network, how to improve the network structure to enhance the capacity of the entire road network to carry more traffic? Ref.[1,2] pointed out that removing the edge connected to the node having highest betweenness can increase the transmission efficiency of the network. Ref.[3,4] pointed out that the method of adding nodes or edges can improve network operation performance. Because of the cost of adding edges is much larger than the cost of closing edges, so adding edge is not as simple as closing edges. Therefore, the studies of adding edge strategy of the urban road network have important guiding significance to the road network planning and design. In this paper, we will propose a topology structure improvement strategy by adding edges to the urban road networks. The validity of the strategy is verified by the comparison simulation results before and after structure adjustment.

MODELING URBAN ROAD NETWORKS

There are two main approaches to model the urban road networks, and they are primary approach and dual approach[5]. In the primary approach, the road intersections are abstracted to nodes, and the intersections are abstracted to roads, and can reflect the spatial properties of the original graph. But in the dual method, the roads are abstracted as nodes, then connected relationship among the roads are abstracted into the edges. In the model with dual approach of the road network, a road is a combination of a number of successive sections according to certain rules.
TRAVEL EFFICIENCY INDICES

In this paper, we assume the traveler travels along the path which have the biggest residual capacity. That is

\[
z = \max\left( \frac{C_j - q_j(\tau)}{\sum_{v \in \xi_i, v \neq path(i,s)} (C_v - q_v(\tau))} \right) \quad \forall j \in \xi, \ j \in \text{path}(i,s) \tag{1}
\]

Where \( q_j(\tau) \) represents the traffic flow of node \( j \) at time \( \tau \); \( \xi \) represents for a set of all adjacent nodes of node \( i \); \( \text{path}(i,s) \) represents for a set of all nodes in the minimum path length from a node \( j \) to the destination node \( s \). \( q_j(\tau) = (1 + r) \tilde{q}_j \) \((r \in [-f, +f], f \geq 0)\), where \( f \) is the traffic fluctuation parameter; \( r \) is generated in the parameter.

The average travel cost is chosen to be a measure of the efficiency of travel. Assuming that the average number of edges to walk for all travelers as \( \text{edges} \), the average walking steps as, then we define the average cost of travel as

\[
\text{cost} = \text{edges} \times \text{steps} \tag{2}
\]

Where \( \text{edges} \) is the number of the roads the traveler walking from the starting point to destination, reflecting the travel economy. \( \text{steps} \) reflects the waiting conditions when travelers are in the traffic jams, which shows the traveling timeliness. \( \text{cost} \) takes into account the travel economy and timeliness.

TOPOLOGY STRUCTURE IMPROVEMENT STRATEGY

Generally, the nodes with bigger degree values in the network will attract more traffic. To alleviate the traffic pressure of the node, we can directly connect the two nodes with the lower degree around the core node. Therefore, we propose a topology structure improvement strategy based on node degree. The steps are as follows:

S1: For the urban road networks modeled with the primal approach, the node importance in the urban road networks is determined by the multi-attribute evaluation method of node importance based on the information entropy;

S2: Set a value of \( \theta \). Sort the node degree by descending order, and the collection of nodes is \( V = \{v_{a1}, v_{a2}, \ldots, v_{an}\} \). \( k = 1 \).

S3: If \( k > \theta \), the calculation ends. If \( k \leq \theta \), find the node \( i \) and \( j \) around node \( v_{ak} \), which meets \( \mu = I_i + I_j \). If there is no edge which connect node \( i \) and \( j \) directly, use an edge to connect the node \( i \) and \( j \). If node \( i \) and \( j \) is connected directly, \( k = k + 1 \). Repeat S3.

S4: Transfer the urban road network modeling with the primal approach to the urban road network modeling with the dual approach according to the name method. Calculate the travel efficiency indices \( \text{cost} \). Output the results.
SIMULATIONS

Until 2013, according to the traffic road map in the Deyang City, we get Deyang city road network topology using the primary approach to model the road network shown in Figure 1. It contains 95 nodes, 176 edges that corresponds to 95 roads intersection and 176 edges and the average value of degree is 3.705.

Use the node degree to evaluate and sort nodes of the Deyang road network. Set $\theta=5$. The results of the top five most important nodes are 86, 65, 85, 73 and 61.

In this section, we analyze the relationship of the minimum of the average travel efficiency and the flow fluctuation range parameter $f$ is analyzed based on the topology structure improvement strategy. The results are shown in Fig.1-Fig.3.

Figure 1. Relationship of $edges$ and $f$ under the topology structure improvement strategy.

Figure 2. Relationship of $steps$ and $f$ under the topology structure improvement strategy.

Figure 3. Relationship of $cost$ and $f$ under the topology structure improvement strategy.
As can be seen, with the increase in the number of network edges, the average travel efficiency of the travelers has been improved substantially. Especially when the first three edges are added, the effect is quite obvious. This is because before adding the edges, the road network in Deyang City modeling with the primal approach belongs to a heterogeneous network. The number of adding edges makes the network increasingly a homogeneous network, and the characteristic path length of the network is getting smaller and smaller. Thus, the more number of edges added, the less of the average number of traveled edges. Thus the average travel cost are less naturally.

SUMMARY

In this paper, we have proposed a topology structure improvement strategy. The core idea of this strategy is to connect the nodes with the smallest and second smallest degree values around the node with the biggest degree values by edges. Then, we have transferred the network which has been added edges to the road network modeling with the dual approach, and the relationship of the average travel efficiency and the flow fluctuation range parameter was analyzed after adding different numbers of edges. Finally, the road networks of Deyang city was taken as an example for simulation. The results show that the proposed strategy can improve the average travel efficiency greatly with the increase in the number of edges added to the network. Thus this strategy can provide a theoretical basis for the urban road network planning.

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