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Expressway Network Model Construction and Road Section Impedance Estimation Based on Mixed Data

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Abstract: The acquisition of high-speed road network information and traffic environment information is of great significance for traffic management and planning, and at the same time, an accurate and efficient road network model is also the basis for the acquisition and application of traffic parameters. In order to quickly obtain high-speed road network information and road section traffic state information, this paper takes Chongqing Highway as an example, analyzes the traffic condition and characteristics of the highway network, and establishes the topology of the high-speed road network using network data and actual high-speed toll data from the graph theory and complex network theory. At the same time, based on the topology theory, fully exploiting the high-speed toll data, a more accurate estimate of different time periods, vehicles in the high-speed road section of the travel time, for highway traffic analysis to provide data reference, to improve the traffic planning program to enhance the efficiency of traffic management, to promote traffic planning and decision-making, as well as to enrich the theoretical basis of transportation research is of great significance.

Keywords: Traffic Network; Toll Station; Vehicle Speed Estimation; Topology Model.

1. Introduction

The construction of the current highway network and the acquisition of current traffic parameters of highway sections play an important role in high-speed traffic prediction, traffic management and optimization [1]. Zhang [2] et al. used mileage stations as the minimum granularity for road network modeling division, which improved the degree of refinement of the road network. Chen et al. [3] proposed the "ramp + entrance and exit" road network topology based on project data. Based on the road network, traffic speed is an important indicator for traffic status evaluation and can better reflect the traffic congestion status of the road network [4]. Lee [5] et al. proposed a travel speed estimation method based on pattern classification based on floating vehicle positioning data; He Zhaocheng et al. [6] proposed an adaptive estimation model to estimate the average speed of highway intervals based on previous work; Tang Keshuang et al. [7] This method uses floating car data to estimate the average speed of the interval and proposes certain improvement strategies. In addition, scholars have also explored road network traffic speed prediction driven by deep neural networks [8,9].

Road network model construction and traffic parameter acquisition usually rely on comprehensive traffic flow sensors and monitoring systems, which are costly to build and have limited coverage. This article is based on the toll station location and station entry and exit planning data information obtained by AutoNavi API, combined with the highway toll data, to quickly establish an accurate highway network topology model, and use this to estimate the average speed of the highway main road and quickly estimate the traffic on the road section. state.

Table 1. Path planning sample data set

Origin	Destination	Paths	Distance	Duration
105.47,29.40	105.49,29.36	1	7.9km	8min
105.49,29.36	105.40,29.49	1	58.6km	37min
......	......	......	......	......
105.40,29.49	105.53,29.49	1	41km	27min

2. Network Topology Construction

2.1. Site Relationships and Edge Attributes

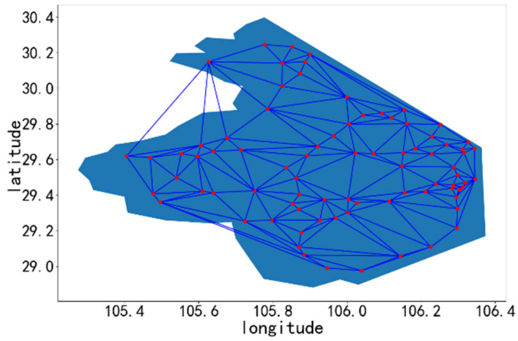

Figure 1. Distribution of toll stations and Delaunay triangulation

As the national highway charging method is adjusted from shortest path charging to actual driving route charging, it can accurately reflect the effective paths between toll stations and contain a large amount of road network information, thereby more accurately reflecting the actual road network and traffic conditions. [10]. This study takes the expressway network within the Chongqing Expressway Chengdu-Chongqing Expressway as the research background. Obtain current toll station information through python and the geographic information service of the Amap API open platform, including the name and geographical coordinates of each toll station and the road where it is located. Considering the duplication of toll station names and the interference of entering and exiting toll stations, the toll station data Perform clustering processing. Obtain route, time and distance information of the specified starting point and end point through the platform route planning service. Taking into account the platform data limitations and data stability, the Delaunay triangulation geometry algorithm is used to generate a graph that does not contain intersecting edges as the starting and end points for obtaining data. In the end, a total of 101 toll station data were screened out, and the route planning data was denoised, resulting in a total of 4689 screened data, as shown in Table 1.

The data acquisition time of AutoNavi API is highly discrete. As the data acquisition time is different, the path time cost also changes. Each path includes three parts: a highway section, a section entering the highway ramp, and a section leaving the highway ramp. This data has great limitations in information density and timeliness, but it can obtain the current road network information within a period of time relatively accurately. Therefore, this data is suitable for building topology models.

Since path selection is end-to-end restricted, in order to avoid missing paths or data loss between some toll stations due to different quality of returned data and limitations of the acquisition algorithm, high-speed statistics need to be introduced for analysis. At the same time, the distance and time used by AutoNavi API data usually include two ramps and road section distances that are not the same as the highway operating distance, so the mileage information in some highway toll data is introduced as a supplement and correction.

After de-weighting, correcting and filtering the high-speed toll station data, the data were obtained as shown in Table 2, totaling 159252 items.

Table 2. Highway toll data sample data set

Entrance	Entry time	Exit	Exit time	Male(m)
Shuitu	7:36:05	Dianjiang	9:07:24	140.9
Qianjiangxi	8:47:35	Heixi	9:07:53	19.9
Liangjiang	8:59:24	Sansheng	9:07:44	15.1
......	......	......	......	......

In terms of mileage, there is a certain deviation between the actual highway toll distance and the distance in the route planning. This value is added to the road network topology as the road network attribute and serves as a constraint for the subsequent estimation of the high-speed loss time.

The corrected mileage is used as the weight, and the general maximum degree of highway interconnection is 4 as the partition. The minimum spanning tree is calculated, and then the minimum spanning trees are merged to obtain an undirected road network topology model with distance as the weight attribute.

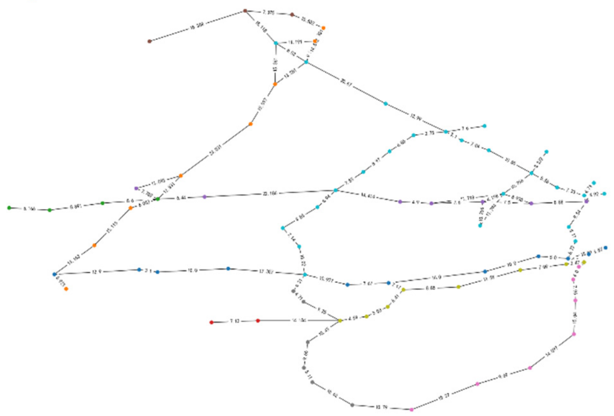

Figure 2. Road network model

In this way, a highway network topology model with road segment attributes and node attributes is obtained. Road segment attributes include journey distance and toll distance attributes, and node attributes include toll station coordinates, estimated distance to toll station and attributed route attributes.

2.2. Toll Sites and Node Attributes

The distance traveled by vehicles on the highway includes entrance ramps (enM, enN), exit ramps (exL, exM), highway main lines (L, M, N), and the distance between the same entrance and exit (p1, p2), as shown in the figure. In the past, highway period research usually required information such as toll station traffic, toll mode, ramp length, speed, etc. This article is based on real toll data and uses the difference-by-difference method to quickly estimate the travel time of vehicles on and off the expressway.

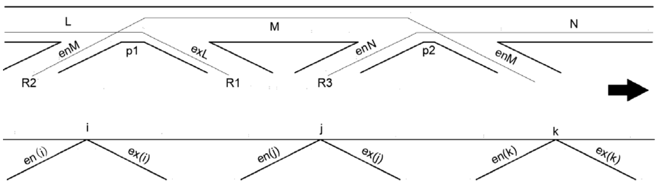

Figure 3. Analysis diagram of highway section composition

Assuming that the distances between the entrances and exits of different toll stations on the main line are the same and have small distances, the entrances and exits can be simplified.

$$T_{i,j} = T_{en(i)} + T_{main(i,j)} + T_{ex(i)} \quad (1)$$

The time it takes for a vehicle to go from toll station i to toll station j is $T_{i,j}$, where the time for the upper main road to pass through toll station i and the connecting ramp is recorded as $T_{en(i)}$, and the time for the lower road to pass through toll station j and The connecting ramp is denoted as $T_{ex(i)}$.

Travel time between two toll stations using high-speed data.

$$T_{i,j} = t_{en(i)} - t_{ex(j)} \quad (2)$$

It is assumed that the entrance and exit of the same toll station have the same traffic environment and the length of the connecting ramp is similar. Through actual data, it is possible to estimate the travel time on the expressway (including acceleration at the toll station, passing the ramp, and the main line acceleration process), and the travel time on the lower expressway (including deceleration on the main line, passing the ramp, decelerating at the toll station, and passing the toll station).

$$T_{en(j)} = [T_{i,k} - (T_{i,j} + T_{j,k})] \times \frac{q_{en(j)}}{Q_{(j)}} \quad (3)$$

$$T_{ex(j)} = [T_{i,k} - (T_{i,j} + T_{j,k})] \times \frac{q_{ex(j)}}{Q_{(j)}} \quad (4)$$

The time to enter toll station j is $t_{en(j)}$; the time to leave toll station j is $t_{ex(j)}$ the travel time of a vehicle entering from upstream toll station i and leaving toll station j is $T_{i,j}$; the travel time of a vehicle entering from j toll station and leaving downstream toll station k is $T_{j,k}$; the travel time of a vehicle entering from upstream toll station i and leaving downstream toll station k is $T_{i,k}$; toll collection The total traffic volume in and out of the station is $Q_{(j)}$; the traffic volume in and out of the toll station is $q_{en(j)}$, $q_{ex(j)}$respectively.

3. Road Section Impedance Estimation

3.1. Estimation of Average Travel Time

Taking the Jiuyong Expressway section as an example, the road network topology model has been obtained in the previous chapter. According to the route attributes in the model nodes, the Jiuyong Expressway network model can be filtered out.

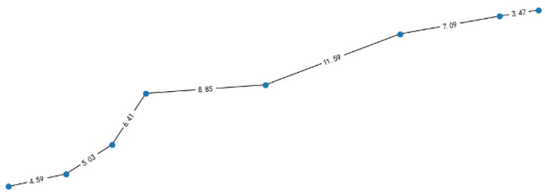

Figure 4. Jiuyong expressway network model

Based on the toll station loss time attributes of each node in the road network model, the mainline freeway travel time of passing vehicles is calculated. Considering the uncertainty of the traffic environment and the randomness of the traffic volume, the toll station loss time attributes of the nodes are adjusted according to the in and out flow of the toll station with 1 hour as the unit of calculation as shown in Table 3

Table 3. Average off-highway mainline elapsed time per hour

Time(s)	Rongchang	Shuangshi	Zouma	Bishan
0	87	139	69	83
1	60	158	58	73
......	......	......	......	......
18	34	193	62	57
19	32	140	81	67
......	......	......	......	......

The average high-speed mainline speed right t time travel time minus the non-mainline loss time at time t is found for a time period of t times with specified start and end times.

$$T^t_{main(i,j)} = T^t_{i,j} - T^t_{en(i)} - T^t_{ex(j)} \tag{5}$$

The average time-consuming attributes of main lines at each toll station obtained through statistics are shown in Table 4.

Table 4. Average highway mainlines elapsed time per hour

Time(s)	Yongchuang-Sanhe		Sanhe-Laifeng	
period	direction1	direction2	direction1	direction2
0	515	379	489	693
1	358	379	508	491
......	......	......	......	......
18	422	467	513	481
19	447	453	561	489
......	......	......	......	......

According to the distance attribute in the topology model, the average speed per hour of each road segment is obtained.

3.2. Experiment and Result

In order to verify the effectiveness of the road network topology model and road distance estimation, the internal travel flow within the study range was estimated. According to the data characteristics that the vehicle's actual high-speed main road journey is the toll distance, and the characteristic that the maximum four highway paths within a certain range are usually not selected [11], the shortest three path lengths between any toll stations in the topology model will be obtained. As another point, the toll distance in the high-speed toll data is Bluetoothed, the remaining travel time is divided into road segments according to the distance, and the result is finally put into the road segments. Find the distance of each road section as shown in Table 5.

Table 5. Hourly traffic volume of each road section

Section	Zouma-Bishan		Gaoxinnan-Zouma	
Period	direction1	direction2	direction1	direction2
0	158	102	197	211
1	90	53	135	132
......	......	......	......	......
7	413	467	638	756
8	728	765	873	798
......	......	......	......	......

Based on the average speed of the highway section obtained previously, the road impedance is visually displayed. Specifically, the slower the speed, the redder the color.

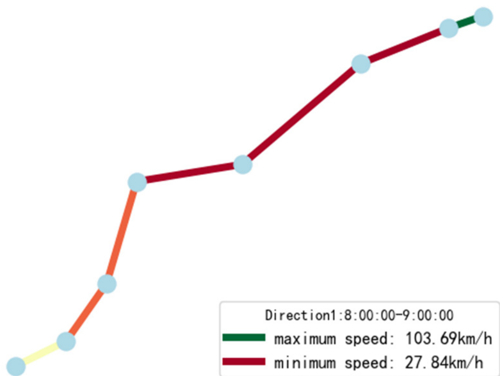

Figure 5. Speed Heatmap on Road Network

The relative speed distribution of Jiuyong Expressway heading towards the main city, that is, direction 1, from 8 a.m. to 9 a.m. is shown in Figure 1. Assuming that all sections of the Jiuyong Expressway adopt the same design, standards and ignore differences in road environment, the speed distribution and traffic volume distribution have the same trend.

4. Conclusion

In this paper, based on the high-speed toll station data combined with the route planning data obtained from Gaode API, a high-speed road network topology model with edge and node features including route attribution, high-speed mainline length, non-mainline loss time in different time periods, and in/out flow rate of the toll station is constructed from the graph theory and the theory of complex networks. And according to the topological model, the access time of the road sections in different time periods is successfully estimated. The topological model can improve the analysis efficiency of high-speed road network and quickly estimate the impedance of road sections, which provides an important reference for traffic planning and traffic management.

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