Based on Urban Resident Travel Behavior Characteristics Modeling

1 Introduction

In today’s fast-paced world, many transportation infrastructures nearly reach their service limits along with the increasing travel demand. Road traffic jam and traffic pollution become a ubiquitously serious problem in big cities all over the world. There are two approaches to deal with the traffic problem. One is by building more roads, and the other is through improving the service efficiency and service standard of traffic supply. Transportation Demand Management (TDM) seeks to provide a solution to congested thoroughfares by utilizing existing roads more efficiently through the adjustment of urban resident travel behavior [1]. How to evaluate road network reliability, identify the congestion bottlenecks, and realize traffic optimization, which are based on the current road network and its traffic conditions, are the key issues of Intelligent Transportation System (ITS).

Road network reliability originates from decision-making problem about whether to continue accomplishing transportation function or not when emergency happens, such as natural calamities, traffic accidents and traffic jam, etc [2]. Therefore, road network reliability is the basis of road network planning, optimization, road rebuilt and traffic flow organization, and it can provide decision-making to prevent and manage the traffic emergency or large events. There are five popular methods to evaluate road network reliability both at home and abroad for the present. Some of them are just applied to evaluate a sort of specialized evaluating indicators, such as terminal reliability and Markov chain method. Some methods can be used for multifarious evaluating indicators, such as the Game Theory, Monte Carlo and microcosmic traffic simulation. Various kinds of evaluation methods have both advantages and disadvantages [3, 4].

Terminal reliability evaluation can only be employed to calculate connectivity, which is based on graph theory. After calculating road sections reliability, the road network reliability can be figured out. The advantages of this method are that only a few data are needed to calculate road network reliability directly and its influence factors are less than others, only place restrictions on topology structure of road network. However, because the road network is broken into series and parallel network in the calculation process, for enormous road network, it is difficult to do evaluation. What is worse, the calculated quantities also grow with exponent [5]. The Game Theory can be used to analyze network
performance in the case of severe damage. It gives full consideration to the traveler’s route choice behavior and road network capacity constraints. However, it can only give boundary value of road network reliability. Monte Carlo method is based on statistics and probability theory. It can simulate the random acts of independent variables to identify the random acts of dependent variables. This means that this method needs a lot of data, and when volume is too small, it is inapplicable. Markov chain method is mainly used to calculate encounter reliability. It can distinguish encountering road section decline travelers from who never encounter in the course of an OD trip. Because it is not necessary to differentiate strictly whether the path is a complete jam or partial jam, the travel time reliability and travel expenses reliability cannot be figured out. Microcosmic traffic simulation model also requires large amounts of data in terms of road network building, model calibration and model inputs, which make the accuracy of model lie in real-time data.

2 Road Network Reliability Evaluation Methods

2.1 Data Source

Due to growing traffic density on road systems new methods have to be developed to generate up-to-date traffic and safety information. The FCD concept is a promising approach to generate and collect traffic related data. The operator of traffic information service is making increasing efforts to supplement the acquisition of traffic information with traffic data acquired by vehicles equipped with GPS receivers that ‘float’ with the traffic, which are called FCD. Especially, with the continuous development of Intelligent Transportation System, the FCD is used more and more as an advanced method to get traffic information of the roads. The FCD technique is based on the exchange of information between a fleet of floating cars traveling on a road network and a central data system. Therefore, the FCD is the basic data source in this paper.

2.2 Traffic Analysis with GIS

GIS is a computer-assisted system for acquisition, storage, analysis and display of geographic data. It is one of the fastest growing technologies in the world. Its ability to analyze spatial data and provide answers to many spatial problems is impressive. GIS is being more widely used in digital city and other related research area with its powerful spatial analysis and data processing functions, combination of GIS and traffic analysis is one direction of transportation planning development. Spatial data are the backbone of GIS analysis, and based on FCD, GIS is the very perfect tool to analyze urban resident travel behavior characteristics.

Traffic spatial analysis can be used to explore the relationship between travel behavior and urban space. Through GIS, traffic spatial analysis can be done by traffic survey with social attributes, spatial attributes, and spatial behavior. From the perspective of spatial structure of residential and industrial land use, and based on GIS traffic analysis method, the travel behavior characteristics are analyzed, which uses taxi FCD as traffic survey samples. The traffic zones are divided ahead of time according to some rules. In this paper, the travel behavior characteristics include Original-Destination (O-D) distribution between two different traffic zones, individual travel trajectory, the traffic flow distribution and the travel speed distribution.

2.3 Travel Behavior Modeling

Urban resident travel behavior can reflect urban traffic demand characteristics, travel behavior regularity and traffic flow distributing, and provide decision-making for transportation planning. As a main mode of non-daily traveling, taxi plays an important role in urban public traffic system. Its driving characteristics can partly reflect the travel behavior of urban residents.

The FCD of taxi includes its current GPS and driving status data, such as location (longitude and latitude), speed, direction, date and time, car ID number and capacity state (loaded or vacant), etc. If we can get large volume and high-quality temporal-spatial urban travel data, then we can model and analyze urban resident travel behavior characteristics.

According to the division of administrative regions and the blocks, traffic zones have been divided in Shenzhen city of China, and then O-D modeling is constructed, as shown in Fig. 2. Through O-D modeling, spatial structure of residential and industrial land use are realized. And on the basis of travel speed modeling and traffic flow modeling of urban resident travel behavior characteristics, the key road junctions and road sections which often cause traffic jam can be found out. If the speed is too slow that it is below critical value of congestion, or the traffic flow is too heavy that it exceeds capacity in some road sections, then the road is considered to be congested and regarded as weak jam or partial jam, the travel time reliability and travel expenses reliability cannot be figured out. Microcosmic traffic simulation model also requires large amounts of data in terms of road network building, model calibration and model inputs, which make the accuracy of model lie in real-time data.

Figure 1. Travel behavior modeling based on FCD
reliability. Conversely, if the speed is fast, the road sections reliability can be considered as high. Through this method, road sections which are bottlenecks in the city can be obtained, which can provide decision-making for transportation planning, urban construction and management.

Figure 2. O-D modeling

2.4 Road Network Reliability Evaluation Methods

From macroscopically perspective of road network, the DNC can be calculated, which is based on the O-D modeling between two different traffic zones and individual travel trajectory modeling. DNC is a main index of measuring whether roads are convenient or not [17]. Traditional DNC only reflects the geometric properties of road networks, traffic flow is not considered. But in reality, traffic flow has a deep impact on road network reliability. Therefore, this paper presents a new method which loads traffic flow to calculate road network reliability.

Figure 3. Road network reliability evaluation with traffic flow loaded

As shown in Fig. 3, using the ratio of traffic flow at each road section as weight, we suppose the weight of road sections \( L_1, L_2, L_3, \) and \( L_4 \) were \( \omega_1, \omega_2, \omega_3, \) and \( \omega_4 \), then the actual distance between origin and destination (O-D) can be calculated as (1).

\[
L = \frac{\omega_1 \cdot L_1 + \omega_2 \cdot L_2 + \omega_3 \cdot L_3 + \omega_4 \cdot L_4}{\omega_1 + \omega_2 + \omega_3 + \omega_4}
\]  

(1)

In (1), the two points can be interpreted as the origin and destination of individual travel trajectory or different traffic zones.

On the assumption that the longitudes of origin and destination respectively are \( A_1, A_2 \) (East is positive, West is negative), the latitudes respectively are \( B_1, B_2 \) (North is positive, South is negative), let \( A_i = (A_i - A_0)/2 \), \( B_i = (B_i - B_0)/2 \)

\[
f = \sqrt{\sin B_1 \cdot \sin B_2 + \cos B_1 \cdot \cos B_2 \cdot \sin A_1 \cdot \sin A_2}
\]  

(2)

Then, its spatial straight line length (S) can be calculated as (3)

\[
S = 2 \cdot f \cdot R
\]  

(3)

In (3), \( R \) means earth radius.

Therefore, \( DNC = \frac{L}{S} \)  

(4)

3 Case Studies

We choose a region of Shenzhen city in China as the research site, shown in Fig. 4, and employ the taxi GPS data of a normal working day as traffic survey samples. The origin is the junction where Qiaocheng East road crosses Shennan road, and the destination is the junction where Liuxian road crosses Shahe west road.

Figure 4. Survey region of Shenzhen city in China

According to the number of vehicles in the road sections during a day, traffic flow modeling can be built. As the road data grades have been divided into three, it will be displayed at different scales under different road grades, so the modeling will show different levels of road traffic flow with the different scales. Because the one day traffic flow is too heavy, in this experiment, we mainly consider primary roads. On the basis of traffic flow, different colors stand for different grades, as shown in Fig. 5, green means expedite, yellow means slow and red means crowded.

Figure 5. Traffic flow model of the road network chosen

Here, the ratio of traffic flow at each road section in a
day as weight, the DNC can be calculated, as shown in Fig. 6. According to our calculation results, there are six route choices. The DNC of the road network chosen is about 1.89. For a public transportation route, if its DNC is no more than 1.41, it can be considered as convenient, otherwise as inconvenient. Generally speaking, DNC between 1.15~1.2 is the best \[17\]. From this perspective, the road network chosen is very inconvenient.

Figure 6. DNC of the road network chosen

Also, the speed of taxi has close relationship with time series and traffic flow, at the peak times; the speed is slower than other times. Moreover, there are many kinds of routes from origin to destination, and different route choice has different speed. Speed comparison of different route choices is as shown in Fig. 7.

Traffic flow model reflects traffic volume, speed model reflects average speed in a trip, and DNC reflects the quality of road network planning. Combining traffic flow model, speed model and DNC, the road network reliability can be evaluated.

Figure 7. Speed comparison of different route choice

4 Discussion and Conclusion

In this paper, a new method is proposed, which evaluates road network reliability based on urban resident travel behavior characteristics modeling. It includes O-D modeling, trajectory modeling, speed modeling and traffic flow modeling. Subsequently, the DNC loaded with traffic flow can be calculated. According to the comprehensive results of our experiment, the reliability of road network chosen is relatively poor. What is worse, the traffic flow of road network chosen is heavy. Therefore, it is necessary to build an auxiliary road from origin to destination which is labeled in Fig. 4.

At present, the road network reliability indicators and evaluation methods applied to the analysis of the transport network are still a prototype stage and not yet matured. There are some problems in existing reliability evaluation methods for evaluating the transportation system operating conditions. Although a variety of road network reliability evaluation indicators and methods have been proposed both at home and abroad, these methods have not been employed in actual road network in a wide range of applications. As a result, the approach which can resolve practical problems is an urgent need.

As we know, urban resident travel behavior can reflect urban traffic demand characteristics, travel behavior regularity and traffic flow distributing, therefore, the road network reliability evaluation method based on it conforms to philosophy of human-based. Moreover, with the development of advanced transportation technologies, such as ITS data collection and large-scale traffic simulation, the conditions of the road network reliability evaluation will be more convenient, and the road network reliability evaluation methods will be towards the direction of quantification, multi-index and synthesis.

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作者简介

陈会娟 作者简介见本期第13页。
朱定局 作者简介见本期封2页。
纪添 作者简介见本期第20页。
王倩男 作者简介见本期第20页。