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A Study on Road Traffic Performance Index

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Abstract: In recent years, using road traffic performance index turns to be ever-increasing popular in Chinese cities, in which it is adopted to assist in decision-making in traffic management and public travel services. This paper first summarizes the essence of traffic congestion and traffic performance index, as well as the difference of various types of traffic performance index. The paper then discusses a number of critical limitations about the existing traffic performance index, including raw data collection and indicator selection process. Finally, the paper provides corresponding improvements: 1) enhance traffic assessment model; 2) develop forecasting model and publication mechanism; 3) strength data collection technology; and 4) propose a synthesized traffic performance index. **DOI:** 10.13813/j.cn11-5141/u.2019.0211-en

Keywords: traffic management; traffic performance index; percentage of congestion mileage; travel time ratio

0 Introduction

Along with the rapid development of economy and urbanization, individual motorized travel is growing rapidly. Over their development process, international developed cities have experienced or are still suffering from traffic congestion problems. Cities such as New York, London, Paris, Tokyo, and Seoul experienced traffic congestion in the 1940s to 1990s. In recent years, the number of motor vehicles in Beijing, Shanghai, Guangzhou, Chengdu, Hangzhou, Shenzhen and other cities has grown rapidly and exceeded one million successively. Traffic congestion first appeared in several megacities such as Beijing, Shanghai, Guangzhou and Shenzhen and quickly spread to cities with a population of more than one million in a few years. Even some small and medium-sized cities also suffered from traffic congestion.

The root cause of traffic congestion is the mismatch of traffic supply or transportation services with the rapid growth of traffic demand. From a certain perspective, traffic congestion does not occur accidentally. It is a comprehensive outcome of the imbalance in traffic supply and traffic demand caused by rapid economic development. How should we assess or quantify urban road traffic congestion? In order to quantify traffic congestion through a single indicator and comprehensively reflect the traffic conditions of the road network, some cities have developed road traffic performance indexes in line with their local conditions. However, there are still some shortcomings when using the road traffic performance index to evaluate the urban traffic operation. For example, using the GPS data of public vehicles as the basic data has some problems: The data collection is not comprehensive (such as incomplete coverage of vehicle categories, insufficient vehicle samples passing through a specific road section and incomprehensive coverage of drivers' behavioral tendency). The evaluation and analysis of the index is not systematic (e.g., the traffic performance index adopted in Beijing fails to reflect the evaluation and analysis of uncongested road sections, and the calculations of Shenzhen's traffic performance index are different at different locations due to different travel experience of the public and different expected speeds) and so on.

1 Connotation of traffic congestion and the traffic congestion index

1.1 Connotation of traffic congestion

Traffic congestion is caused by excessive traffic demand at a certain road section, which exceeds this road section's traffic capacity. It leads to the slow moving of vehicles, which propagates upstream to form traffic stagnant with the development trend of "point→line→area". The fundamental reason is the imbalance between traffic demand and facility supply. The definition of traffic congestion in different countries and cities does not have a strict and unified quantitative standard, and different people have distinct individual

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differences in their perception of congestion at different time, too. At present, the main criteria are based on queuing theory, travel time theory (including travel speed and delay) and traffic density theory. The United States defines that when the road speed is less than 24 km/h or the vehicle density per kilometer is greater than 42 passenger cars, it is considered as traffic congestion. Germany defines traffic congestion as a situation in which the vehicle density is greater than 40 passenger cars per kilometer. In Japan, it is considered as traffic congestion when the speed is less than 20 km/h on ordinary roads or less than 40 km/h on freeways [1–2]. In China, the *Urban Road Traffic Management Evaluation System* (Doc NO. GJG[2008] 262) was jointly issued by the Traffic Management Bureau of the Ministry of Public Security and the Urban Construction Department of the Ministry of Housing and Urban-Rural Development, China. It defines that when the average travel speed of motor vehicles on urban roads is less than 20 km/h, it is considered as traffic congestion, and it is considered as serious traffic congestion if less than 10 km/h. *Road Traffic Congestion Degree and Evaluation Method* (GA115-1995) defines that when a vehicle fails to pass an intersection within three signal cycles, it is considered as traffic congestion and it is considered as serious congestion when a vehicle fails to pass within five signal cycles.

1.2 Connotation of the road traffic performance index

In order to quantify the traffic operation of urban road, several indexes have been proposed in overseas countries to assess road traffic operations, such as Road Congestion Index (RCI) [3], Lane Kilometer Duration Index (LKDI) [4], Travel Time Index (TTI) [5], and Congestion Severity Index (CSI) [6]. In China, road traffic performance index models suitable for local cities are mainly constructed from normalized evaluation indexes such as the proportion of serious congestion mileage, travel time ratio and delay time ratio.

The road traffic performance index is an indicator that comprehensively reflects the traffic operation status of the road network, which is also a comprehensive and simplified description of the characteristics of traffic congestion in space, time, intensity and other aspects. The basic principle is to dynamically obtain floating vehicle data through the wireless communication network from GPS-equipped vehicles (including taxis, buses and one or more types of other public vehicles, with taxis as the majority in general) on various road sections of a city and in each time interval. It calculates the weighted travel speed according to the weight and clustering characteristics of the road network, based on which the proportion of congestion mileage, congestion time ratio or delay time ratio of the road network are calculated and the road traffic performance index is finally obtained after normalization. The calculation methods of the road traffic performance index adopted by different cities are generally similar but slightly different. However, they are all expressed by a single value. Generally, the larger value can lead to the more congested road traffic, while the smaller value can result in the smoother traffic.

According to *Urban Road Traffic Performance Index* (DB11/T 785-2011) of Beijing and *Urban Road Traffic Operation Evaluation Index System* (DBJ440100/T-2013) of Guangzhou, Beijing and Guangzhou mainly calculate the road traffic performance index based on the proportion of seriously congested mileage, and the calculation methods of these two cities are similar. In other words, the travel speed and the weight of the road network are mainly used to calculate the proportion of congestion mileage of each road section class, each road and each road network. Then, according to the relationship between the proportion of seriously congested mileage and the road traffic performance index, normalization and conversion are conducted (namely that the proportions of congestion mileage of different road networks are converted into different road traffic performance index values). The road operation status is divided into five levels: smooth, basically smooth, slightly congested, moderately congested and severely congested. The value range is [0, 10], and the traffic performance index values of different classes of roads are different. For example, the traffic performance index intervals for the five levels of operation status are both [0, 2), [2, 4), [4, 6), [6, 8), [8, 10), 10 in Beijing and Guangzhou, but the corresponding proportions of congestion mileage are respectively [0%, 5%), [5%, 8%), [8%, 11%), [11%, 14%), [14, 24%), ≥ 24% and [0%, 2%), [2%, 9%), [9%, 15%), [15%, 18%), [18%, 33%), ≥ 33%.

According to the *Evaluation Index System for Shanghai Urban Road Traffic Status* (DB31/T 997-2016), the vehicle travel speed calculated based on the GPS data collected in real time from various road sections is taken as the basic input. And it is weighted and standardized according to geometric characteristics, capacities and other parameters of different sections to generate a comprehensive traffic performance index. The operation status is divided into four levels of "smooth, basically smooth, congested and blocked", and the value range is from 0 to 100. Shenzhen uses the floating car data to calculate the travel speed and combines different road classes to calculate the travel time ratio (the ratio of the actual travel time of a road section or the road network to the expected travel time, indicating the severity of the delay in the current road condition compared with the expected travel speed). The road traffic performance index is calibrated through a large number of field surveys and inquiries, and the operation status is divided into five levels of "smooth, basically smooth, slow, relatively congested and congested", and the value range is (0, 10) [7].

At the national level, based on the *Road Traffic Information Service: Traffic Condition Description* (GB/T 29107-2012) and the experience and achievements of relevant cities, the *Specification for Urban Traffic Performance Evaluation* (GB/T 33171-2016) was issued. It comprehensively proposed three evaluation methods, namely, the relationship between the proportion of seriously congested mileage of the road network and the traffic performance index, the relationship between the travel time ratio of the road network and the traffic performance index, and the relationship between the delay time ratio of the road network and the traffic performance index. This specification is an integration and extension of the road traffic performance index models adopted by the four cities of Beijing, Shanghai, Guangzhou and Shenzhen, whose characteristics are summarized in Table 1.

Table 1 Comparison of evaluation indicators and methods of traffic performance index in different cities

City	Definition method	Value range	Description of congestion level
Beijing	Proportion of congestion mileage	0–10	Smooth [0, 2) Basically smooth [2, 4) Slightly congested [4, 6) Moderately congested [6, 8) Severely congested [8, 10]
Shanghai	Travel speed and load	0–100	Smooth [0, 30) Basically smooth [30, 50) Congested [50, 70) Blocked [70, 100)
Guangzhou	Proportion of congestion mileage	0–10	Smooth [0, 2) Basically smooth [2, 4) Slightly congested [4, 6) Moderately congested [6, 8) Severely congested [8, 10]
Shenzhen	Travel time ratio	>0–<10	Smooth (0, 2) Basically smooth [2, 4) Slow [4, 6) Relatively congested [6, 8) Congested [8, 10)
China	Proportion of congestion mileage Travel time ratio Delay time ratio	0–10	Smooth [0, 2) Basically smooth [2, 4) Slightly congested [4, 6) Moderately congested [6, 8) Severely congested [8, 10]

2 The issues of the existing road traffic performance index

2.1 Incomprehensive raw data collection

At present, one of the basic parameters of the road traffic performance index in major cities is the travel speed. The travel speed of different road section classes or roads is mainly calculated based on the GPS data of public vehicles. In this context, three problems may arise:

1) Coverage

The collected data only includes floating vehicle data of public vehicles (such as taxis without private vehicles) and road section detection data. Since the trajectory of a public vehicle depends on the passenger's starting point and ending point, the data coverage is good along the roads with a lot of starting and ending points of passengers (the passenger flow is concentrated). On the other hand, some road sections have poor data coverage, such as road sections along which no passengers need to get on or off, or road sections that do not have popular destinations and are only accessed for uncommon reasons such as parking, going home, having meal, and going to the bathroom. Therefore, the travel speed cannot be calculated on some urban roads. According to statistics, in the peak period, the roads covered by taxis in Guangzhou account for 72% of the main road and expressway network in the central urban area (see Figure 1). In Shenzhen, the daily average proportion of roads covered by taxis is 36%, and this number increases to 77% after including ride-hailing vehicles and the data from the Baidu vehicle navigation App.

Table 2 Comparison on raw data collection of traffic performance index in different cities

City	Raw data
Beijing	Floating vehicle data (including buses and 66 000 taxis) throughout the city, as well as loop and radar speed data collected by automatic detection devices installed on important road sections
Shanghai	GPS data from about 20 000 taxis and 9 000 container trucks, as well as loop data from more than 4 000 sets of expressway loops and more than 10 000 sets of intersection loops
Guangzhou	GPS data from about 20 000 taxis running without fixed routes, which are transmitted every 15 seconds; GPS data from about 12 000 buses running along fixed routes, which are transmitted every 60 seconds; data from some other public vehicles.
Shenzhen	GPS data from taxis, buses, and "tour bus, fixed-route bus of Class 3 and above and hazardous vehicles", ride-hailing data, map navigation data, geomagnetic data, etc.

2) Sample imbalance

If there are more residential, commercial, entertainment and office lands along a road, this road would in theory has more taxis passing by, and vice versa. In addition, the taxi coverage is better in areas with a better road network structure, and vice versa. Due to the influence of the road network structure, the proportion of roads covered by taxis in Huangpu District of Guangzhou is more than 35% lower than that of other administrative districts in the central urban area. This is the important reason why the travel speed of major roads is relatively accurate when it is calculated based on the floating car data.

3) Driver's behavioral tendency

A taxi driver usually cruises at a low speed when the taxi is vacant in order to find passengers and always drives at a high speed when the taxi is occupied in order to increase the turnover rate. This characteristic leads to deviations in the calculation of the road travel speed, and the evaluation result is not accurate enough. According to statistics, the travel speed of occupied taxis is 4% higher than that of private vehicles on the same road sections in Shenzhen, and the travel speed of vehicles using map navigations is 4% lower than that of all private vehicles.

2.2 Non-systematic evaluation and analysis of indexes

The existing road traffic performance index cannot systematically and comprehensively reflect the operation of urban traffic. The traffic performance indexes adopted by Beijing and Guangzhou are essentially converted from the proportion of seriously congested mileage in the road network. They are

Figure 1 Taxi road coverage of Guangzhou

more sensitive in reflecting the changes of serious traffic congestion in the road network, but they do not directly reflect the evaluation and analysis of road sections with operation levels below the level of severe congestion. Therefore, this type of traffic performance index can only indicate whether the road network is congested and the degree of congestion (more sensitive to the change of the traffic congestion status in a road network), and it cannot reflect whether the road network is smooth and the degree of smoothness. From this point of view, it is inaccurate to call the road traffic performance index as the road traffic congestion index. In other words, it is a misleading of the evaluation standard.

The traffic performance index adopted by Shenzhen is essentially converted from the travel time ratio of a road network, which represents the ratio of the actual travel time to the expected travel time. It can reflect the travel experience realistically. However, its description on the traffic congestion of the road network is less sensitive to the road traffic performance index adopted by Beijing and Guangzhou. For example, the Dongfeng Road in Guangzhou is a fast east-west corridor with good road conditions (two-way 8–12 lanes), but the large traffic volume in the peak period leads to a travel speed of 25.8 km/h. On the other hand, as an east-west secondary trunk road in Guangzhou, the Zhongshan Road has 2–4 lanes for both directions and has relatively small traffic volume in the peak period, resulting in a travel speed of 25.1 km/h. These two roads have different road classes but similar speeds due to different traffic volumes. For two road sections of the same length, the one on the Dongfeng Road has better road conditions and a smaller expected travel time or free-flow travel time, and the one on the Zhongshan Road has a larger expected travel time. According to the definition of Shenzhen's road traffic performance index, the traffic performance index of the Dongfeng Road is 2, and the traffic performance index of the Zhongshan Road is 1. In other words, for a road with a better location and road conditions, it would have a higher expected speed or a shorter expected travel time, resulting in a higher traffic performance index. On the contrary, for a road with the same road class but poor geometrical conditions, it would have a lower expected speed or a longer expected travel time, resulting in a lower traffic performance index.

3 Thoughts and suggestions

3.1 Further improvement of evaluation model for traffic performance index

The evaluation models of road traffic performance adopted by Beijing, Shanghai, Guangzhou, Shenzhen and other cities are basically based on the floating vehicle data from public vehicles, the loop data and the geomagnetic data. The collected data is used to calculate basic indicators (such as travel speed, travel time, weighted average speed and weighted travel time) and characteristic indicators (such as proportion of congestion mileage, travel time ratio and delay time). During this calculation process, calculation deviations of comprehensive or decision-making indexes (the road traffic performance index) could occur due to the settings of some parameters, such as weight, public perception and expected values. For example, in the process from the average speed to the weighted average speed, Beijing and Guangzhou adopt the Vehicle Kilometers Traveled (VKT) as the weight, which should have been dynamically adjusted according to the length distribution of different road classes and the accumulated Passenger Car Equivalent (PCE) traffic volumes. Therefore, relying on existing multi-source data and deep learning techniques, the model parameters and algorithms should be dynamically modified to further improve the accuracy and scientificity of the assessment of the road traffic performance index. Literature [8] used the floating vehicle data and other traffic multi-source data to build a dynamic traffic flow discrete model and proposed a method to estimate the probability of traffic congestion, which made up for the shortcomings of existing evaluation methods of traffic operation.

3.2 Development of the forecasting model and publication mechanism for the traffic performance index

The existing road traffic performance index focuses more on the evaluation of the existing traffic conditions and lacks effective traffic forecasting mechanisms. It plays a relatively weak role in the planning and guidance of citizens' travels. Therefore, it is suggested to build a forecasting model of the urban road traffic performance index. This model should consider the impacts of weather, holidays, major events and other factors on traffic, as well as macroscopic rules on traffic changes, so as to realize the medium and short term forecasting and publication mechanism of the traffic performance index.

Based on the analysis of the overall change pattern of the traffic performance index of urban roads, Guangzhou comprehensively consideres the influence of weather, holidays and major activities on traffic and constructs a prediction model of traffic performance index. This model can forecast the 5-min traffic performance index for the next three hours and the 2nd day. Based on the index prediction and analysis system, the traffic operation performance in the previous week is regularly released on a weekly basis through newspapers, the internet and other print media. The traffic performance index changes and the distribution of congested road sections during major holidays are predicted, and traffic guidance is issued to guide citizens to travel [9–10].

3.3 Application of new technologies to promote more comprehensive data collection and more scientific index evaluation

In recent years, Chongqing, Xiamen, Lanzhou, Nanjing, Yinchuan and other cities in China have actively tried to apply vehicle Electronic Registration Identification (ERI)①. In particular, the Ministry of Public Security, China has taken the lead in formulating relevant technical standards such as *Safety Technical Requirements for Electronic Registration Identification* and *General Technical Specifications for Electronic Registration Identification*. The draft was issued for comments in December 2014 and the standard was officially released in December 2017, which had been implemented on July 1, 2018. In 2015, Wuxi, Shenzhen and Beijing were included as pilot cities for ERI. In January 2016, Wuxi and Shenzhen began piloting ERI. The ETC technology② has been widely used in freeway management in the context of "one freeway network" promoted by the nation. According to statistics, there are 7 185 freeway toll lanes in the province of Guangdong, among which 1 720 are ETC lanes, accounting for 23.9% of the total toll lanes. For the toll stations on the mainlines, ETC lane coverage is as high as 100% [11]. As mentioned above, the raw data collection is not comprehensive when floating car GPS data is used to calculate the travel speed, which is the basic parameter of the traffic performance index. With regard to this issue, if the ERI promoted by the Ministry of Public Security is rapidly developed and is oriented to all motor vehicles, and if the database sharing is realized among cities, regions, or even at the national level, the collected data would cover not only public vehicles but all vehicles including private vehicles. Then, the vehicle samples and vehicle types will be more balanced and comprehensive, and the drivers' behaviors will be more realistic. In addition, the integration with other traffic management data may be considered, such as existing freeway flow data, high-definition license plate identification data and GPS data, so as to analyze the road travel speed more comprehensively, scientifically and objectively.

3.4 Development of a comprehensive traffic performance index after systematical and comprehensive considerations of influencing factors

Because the traffic volumes on different road sections cannot be collected in real time or the data collection workload is heavy, the existing model algorithms basically do not consider traffic volume as an indicator. However, traffic volume is an important factor that can reflect the three elements of traffic flow and can be used to calculate traffic flow density. Therefore, combined with speed data and the classification of road section weights, it is recommended to make full use of traffic big data to improve the prediction accuracy and timeliness of traffic models and to assist in the collection and prediction of traffic volume through big data or refined traffic models. It is also recommended that when constructing a comprehensive road traffic performance index which should cover different factors (including speed, flow, density, time and travel experience) and different vehicle categories (including buses, coaches, cars, etc.), we should consider the carrying capacity of each passenger transportation mode and its dynamic occupancy of road resources. This would reflect the return to the essence of transportation, which is to realize the movement of people and goods and reflect the shift of the evaluation idea from "car-oriented" to "people-oriented" and from "focus on efficiency" to "balance fairness and efficiency". It can lead to a more comprehensive and objective assessment of the road traffic performance.

4 Conclusions

Evaluation of road traffic performance is an overall evaluation on the operations of urban roads by the government and the public. With the rapid development of new transportation service modes, urban transportation is undergoing a development process from "supply and demand" to "supply, demand and service" and from simple relations to complicated relations. Therefore, it is incomplete and one-sided to evaluate the traffic operation status only through the road traffic performance index. It would be more comprehensive to evaluate the operation of road traffic through comprehensive indicators such as residents' travel time and travel accessibility. By sorting out the differences of the road traffic performance index in major cities in China, this paper analyzes the deficiencies of this index and puts forward suggestions from the following aspects: improving the evaluation model, developing a prediction model, actively searching for data sources and collection methods, and developing a comprehensive traffic performance index or a comprehensive travel index.

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① Electronic Registration Identification (ERI), commonly known as electronic license plate, is also called electronic identity card for motor vehicles. It is essentially an electronic tag that can be identified through wireless communication. Its working principle is to install a chip on a vehicle as the carrier of vehicle information. The information such as the vehicle license plate number, color, type, vehicle attributes, owner, annual inspection information, insurance information, and violation records is stored in the corresponding area of the chip. When a vehicle equipped with ERI passes a road section with authorized RFID readers or handheld RFID read-write devices, the data on the electronic license plate will be collected or will be read/written to achieve the purpose of comprehensive traffic management.

② ETC technology: Through the microwave-specific short-range communication between the electronic tag mounted on the windshield of the vehicle and the microwave antenna on the ETC lane of the toll station, the computer network technology is used to perform background settlement processing with the bank, so that the vehicle can be charged without stopping. The ETC technology is an attempt of the RFID technology in vehicle management. According to the existing national standard, the On-board Unit (OBU) in the ETC system requires connection to a power supply.

