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RESEARCH PAPER

Reviewing Traffic Reliability Research

WANG Dianhai[1,2,*], QI Hongsheng[1], XU Cheng[1]

1 College of Traffic and Transportation, Jilin University, Changchun 130025, China
2 College of Civil Engineering and Architecture, Zhejiang University, Hangzhou 310058, China

Abstract: Multi-dimension, stochastic, and dynamic are essential nature of urban traffic operation. Traffic reliability introduces the idea of reliability into traffic research and is an important field of cause analysis of traffic problems. Considerable researches have been conducted on traffic reliability, covering from theory to practice, and from model to algorithm. There already exists a framework for reliability analysis. However, few comprehensive review literatures can be obtained. The goal of this paper is to fill this blank from describing of development of traffic reliability research. Basic definitions, theory, and methods are depicted accompanied with the application to traffic optimization. In the last section, the future development of traffic reliability research is concerned.

Key Words: traffic engineering; traffic operation; reliability; traveler behavior

1 Introduction

Urban traffic system serves as the lifeline of modern cities, which implies the importance of a stable, high-efficiency road traffic system. Reliable urban traffic state is not only the premise of realization of travelers' purpose, but the ultimate aims of traffic managers. During daily operation, however, traffic system is influenced by many factors such as earthquake, flood, bad weather, traffic incidents, and accidents ect.[1] These factors enhance the uncertainty of trip and decrease road capacity, which makes the realization of purpose difficult and operational state unstable. Because there is rare consideration of such influence in traditional framework, traffic system under this condition is difficult to explore[2], and no effective measures could be proposed accordingly.

The concept of reliability comes from the discipline of reliability engineering[3] which is relatively mature. Reliability has been used extensively in communication network design and management. In recent years, this concept is introduced into transportation area due to the increasingly worsen traffic state, denoted by the discrepancy from the expectation of people, which makes researchers treat transportation system from a higher point. A series of achievements have been completed, which involves not only theoretic researcher, but also practitioners. Till now, four international conferences have been held. In 1991, transportation network reliability seminar was held in Australia, the focus of which was connotation and content of transportation network reliability. In 2001, the first International Symposium on Transportation Network Reliability (INSTR) took place in Tokyo, Japan. The second INSTR was held in 2004, New Zealand and forty papers were presented. The third INSTR was held in 2007, Delft, Holland. The coverage was even more extensive than before. These conferences have greatly improved the research of traffic reliability. During the researches, people found that traffic supply and demand are influenced by outside factors all the time; there is also inner-system fluctuation due to the uncertainty of travel behavior. The two parts overlap and make the dynamic network state complex and stochastic. Recognition of the nature and consideration of it during management and control are premises for a stable, high-efficient state.

2 Current researches

Generally, traffic system could not reach its design performance due to various stochastic factors. Real capacity of its constituents (such as roads or intersections) is lower than its expectation. Focused on modeling of traffic system, some researchers proposed the concept of degradable transportation system (DTS) and its analysis framework. Chen *et al*.[7]

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*Corresponding author. E-mail: wangdianhai@sohu.com

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summarized the stochastic factors into four types: road capacity fluctuation, demand fluctuation, perception errors of route choice, and road travel time fluctuation. Nicholson and Du[6] analyzed the interaction between traffic supply and demand before and after traffic incidents and constructed traffic reliability equilibrium analysis framework shown in Fig. 1(a): the traffic state is formed by the interaction of traffic supply and demand under stochastic influence. Suppose $h(D)$ and $g(C)$ are distributions of traffic demand and supply, overlapped area in Fig. 1(b) denotes conditions when congestions happen. This framework was then used extensively[1,8–11]. Under the consideration of the difficulty for obtaining real data, demand, supply or traffic index are assumed to obey some specific distribution. The distribution for traffic supply (such as road capacity) is a general uniform distribution[1,6,12,13]; the distribution for demand is usually a normal distribution[11]; the distribution for traffic time includes normal distribution[12], Weibull distribution[8], exponential distribution[14], and so on. Some distribution functions are fitted using real data. Brilon[15] defined road capacity through traffic demand: traffic is uncongested when supply exceeds demand; else the congestion occurs, which implies the capacity is stochastic. Xiong[16] concluded that the travel time of morning and moon is normally distributed while the evening peak is a beta distribution.

Under the reliability framework above, the academic field has explored reliability from many aspects which generally include reliability definition, the impact of reliability on traffic flow and optimization considering reliability.

2.1 Definition, index, and computation methods

2.2.1 Definition and index

There are various definitions and quantify methods for reliability. At the beginning, researchers were concerned with network connectivity proposed by Mine and Kawai[17] (or "terminal reliability"). Connectivity is used to describe the probability that a given OD pair is connected at a specific time. If there is at least one route between this OD pair, then it is connected. In this concept, road is either connected or disconnected, thus its capacity is irrelevant which imply that this type of reliability suits for extreme condition analysis such as earthquake rather than daily operation analysis. Nicholson and Du[6] pointed out that reliability analysis should not be confined in great disaster, but also extended to daily operation analysis. Because of the ineffectiveness of connectivity in describing real-time traffic flow, scholars proposed from system point of view and traveler point of view travel time reliability[19] and capacity reliability[7,20]. Travel time reliability is defined as the probability that a traveler reaches a destination in a given time interval[11,19] while capacity reliability is defined as the probability that maximum network capacity is greater than or equal to a required demand level when arc capacity is subject to random variations.

Many indexes are used to describe the same reliability. As for travel time reliability, indexes include buffer time[16,21], statistical indexes[21], probabilistic indexes[8], and so on. Buffer time is time reserved to assure punctuality. The bigger buffer time is reserved, the more unreliable the network is; statistical indexes include 90th or 95th percentile and suit for information provision rather than theoretical analysis; probabilistic indexes use the form of probability that travel time satisfy specific condition. Suppose C and C_0 denote network runs in normal condition and degradable condition, $u(C)$ and $u(C_0)$ denote travel time respectively and θ level of service, then travel time reliability could be defined as[7]:

$$\tau(\theta) = p(\frac{u(C)}{u(C_0)} \le \theta) \qquad (1)$$

If travel time in Eq. (1) is route travel time, then the output reliability is route travel time reliability. Similarly we have OD travel time reliability and network travel time reliability. For example, OD travel time can be defined as the mean value of all route travel time. For network travel time reliability, based on its definition it can be expressed as[7]:

$$R(\mu_r) = P(\mu \ge \mu_r) \qquad (2)$$

where μ_r denotes a given level of service. It is evident that network is absolutely reliable when demand is zero and absolutely unreliable when demand is infinite. Some researchers explored the relationship between travel time reliability and capacity reliability, considering that they are both descriptors of network state.

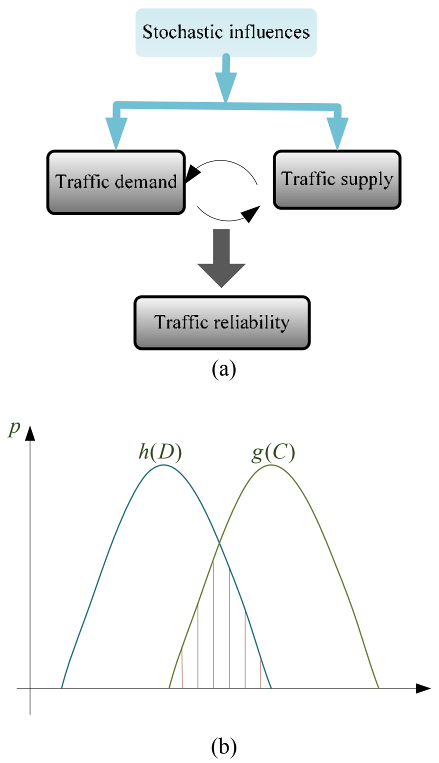

Fig. 1 Reliability framework