Transportation Research Part C 36 (2013) 381–393

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Computer-aided analysis and evaluation on ramp spacing along urban expressways

Shao-kuan Chen [a,b,c,*], Bao-hua Mao [a,b,c], Shuang Liu [b,c], Quan-xin Sun [c], Wei Wei [c], Lin-xia Zhan [c]

[a] The MOE Key Laboratory for Transportation Complex Systems Theory and Technology, School of Traffic & Transportation, Beijing Jiaotong University, Beijing 100044, China
[b] Integrated Transport Research Centre of China, Beijing Jiaotong University, Beijing 100044, China
[c] School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, China

ARTICLE INFO

Article history:
Received 10 December 2012
Received in revised form 18 September 2013
Accepted 18 September 2013

Keywords:
Ramp
Urban expressway
Computer-aided simulation
Data envelopment analysis
Analytic hierarchy process

ABSTRACT

High traffic efficiency on urban expressways and their ramps is the crucial requirement to ensure the optimum design and reliable operation of urban traffic networks in large cities. The mismatch between ramp configurations and spacing can lead to the dramatic drop of traffic capacity and efficiency. The traffic performance in different scenarios for four typical configurations along urban expressways is simulated after the calibration of simulation model. The results are then evaluated through the data envelopment analysis (DEA) and analytic hierarchy process (AHP). The traffic simulation software VISSIM is employed to calculate the critical variables and parameters able to represent traffic performance of urban expressways and their ramps in terms of traffic practice. To carry preferable multi-criteria evaluations from simulation process, the DEA and AHP method are used together to find the appropriate spacing between ramps and evaluate the effects from the different design speeds of frontage roads and opening time of ramps. The proposed method also gives the ranking of different scenarios for four configurations. The applicability and effectiveness of the proposed evaluation methods are demonstrated in case studies where some critical parameters for traffic designs and operations about ramps are practically given through field survey. The results show that the proposed methodology is vitally important for traffic planners and designers to assure an effective evaluation and decision support on complex transportation systems.

1. Introduction

Urban expressways have played an instrumental role in traffic systems of many modern large cities since the outburst of motorization. Urban expressways are necessary arterials in traffic networks and are nearly undertaking the major load of urban traffic. For instance, the skeleton of urban traffic system in Beijing is composed of ring-shaped expressways (from the second to fifth rings) and radial expressways connecting with the freeways to surrounding cities. The traffic volume on the second, third and fourth ring expressways in Beijing nearly exceeded 200,000 vehicles per day, and even that on the north section of the fourth ring expressway approached 346,000 vehicles per day (BJTRC, 2011). The average travel speeds on urban expressways during morning and evening peak hours within the fifth ring expressway are only 35.1 km/h and 30.2 km/h respectively according to the survey from floating vehicles (BJTRC, 2011), which are greatly lower than

* Corresponding author at: The MOE Key Laboratory for Transportation Complex Systems Theory and Technology, School of Traffic & Transportation, Beijing Jiaotong University, Beijing 100044, China. Tel.: +86 1051688695.

E-mail addresses: shkchen@bjtu.edu.cn (S.-k. Chen), bhmao@bjtu.edu.cn (B.-h. Mao), liushuang@bjtu.edu.cn (S. Liu), qxsun@bjtu.edu.cn (Q.-x. Sun), 11121009@bjtu.edu.cn (W. Wei), lxzhan@bjtu.edu.cn (L.-x. Zhan).

0968-090X/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.trc.2013.09.011

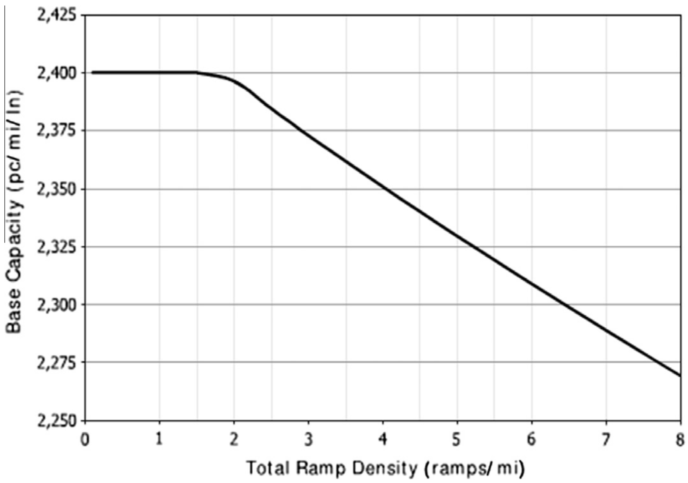

Fig. 1. Relationship between basic expressway capacity and ramp density from HCM (2010).

Table 1
Survey data on the spacing between entrances or exits ramps along an expressway in Beijing.

Spacing between contiguous ramps	Average spacing (km)	Shortest spacing (km)	Longest spacing (km)
Northbound	0.40	0.10	1.15
Southbound	0.33	0.09	1.15
Total	0.37	0.09	1.15

the common expressway design speed of 80 or 90 km/h due to large traffic volume. The design, operation and management of urban expressways should be paid much attention to in order to improve traffic efficiency and mitigate traffic congestion (Xing et al., 2010).

Urban expressways have some particular characteristics, such as short spacing between entrance/exit ramps, even only being thirty meters (Chen et al., 2010), various configurations and complex connections with frontage roads, which can influences travelers' route choice and traffic behavior (Abdel-Aty and Huang, 2004). The transportation performance of urban expressways and their frontage roads is closely related to the configuration and spacing of ramps (Hunter et al., 2001). For instance, the basic capacity of urban expressways is closely associated with the density of ramps which are the connecting infrastructures between urban expressways or urban expressways and their frontage roads. There is an approximately linear capacity drop of urban expressways as illustrated in Fig. 1 when the density of ramps is larger than two ramps per mile in terms of the 2010 Highway Capacity Manual (HCM, 2010). Moreover, the diverging and merging phenomena of traffic flow between urban expressways and their frontage roads frequently occurs because urban road networks have high road density, many crossing roads and short distance traffic flow. In practice, urban expressways in many large cities of China, such as Beijing, are aiming to the urgent challenge from the particular characteristics mentioned above. For example, the average spacing between ramps along an expressway in Beijing is only 370 m and even the shortest spacing is 90 m according to the field data in Table 1.

The mismatch configuration among urban expressways, their frontage roads and other connecting roads is one of important incentives that evoke serious traffic congestion (Sarvi et al., 2004; Huang, 2006) and vehicle crashes (Lord and Bonneson, 2005). Ramp merging phenomenon can lead to serious traffic congestion when traffic volume through ramps is large (Sarvi et al., 2004, 2007). Moreover, if the travel speed of vehicles through frontage roads is unmatched to that through urban expressways, ramp merging will be trapped into difficult and unsafe circumstances (Ahammed et al., 2008; Milanes et al., 2011). Thus, compatible ramp metering and reasonable design speed of frontage roads are much crucial to improve the traffic capacity and performance of urban expressways, their frontage roads and ramps (Zhang and Levinson, 2010).

2. Literature review

Although ramp spacing, metering and merging between urban expressways and their frontage roads are crucial issues in ramp problems, researchers tended to focus on the effects of ramp design, such as safety requirements (Lord and Bonneson, 2005; Chaudhary and Messer, 2002; Park et al., 2010), geometry layouts (Lederer et al., 2005) and signal placements (Wang, 2007). They also concentrated on the capacity evaluation (Lertworawanich and Elefteriadou, 2003) and length calculation of ramps (Wang et al., 2007), the type and configuration selection of ramps (Nassab et al., 2005) as well as the investigation of traffic behavior and volume in ramp systems through quantitative analysis methods (Li et al., 2007; Amin and Banks, 2005).