Physica A 465 (2017) 347–357

Contents lists available at ScienceDirect

Physica A

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

Assigning on-ramp flows to maximize capacity of highway with two on-ramps and one off-ramp in between

Jing Chen [a,b], Lan Lin [b,c], Rui Jiang [a,b,*]

[a] MOE Key Laboratory for Urban Transportation Complex Systems Theory and Technology, Beijing Jiaotong University, Beijing, 100044, China

[b] School of Engineering Science, University of Science and Technology of China, Hefei, 230026, China

[c] Newland Technology Group Co., Ltd, Fuzhou, 350000, China

HIGHLIGHTS

- Eight regions are observed in the phase diagrams and the optimal assignment can be performed only in region I.
- Two critical values of the off-ramp flow ratio have been observed.
- The formulas to calculate the critical values and the system capacity are given.

ARTICLE INFO

Article history:
Received 12 May 2016
Received in revised form 10 August 2016
Available online 22 August 2016

Keywords:
Multiple ramps system
Flow capacity optimization
NS model
Traffic flow

ABSTRACT

In this paper, we study the capacity of a highway with two on-ramps and one off-ramp in between by using a cellular automaton traffic flow model. We investigate how to maximize the system capacity by assigning proper traffic flow to the two on-ramps. The system phase diagram is presented and eight different regions are observed under different conditions. It is shown that in region I, in which both on-ramps are in free flow and the main road upstream of the upstream on-ramp is in congestion, assigning proper proportion of the demand to two on-ramps could maximize the system capacity. Two critical values of the off-ramp flow ratio p_{off} have been observed. When $p_{off} < p_{off,c1}$ ($p_{off,c1} < p_{off} < p_{off,c2}$), a higher (smaller) proportion of the demand should be assigned to the upstream on-ramp. When $p_{off} > p_{off,c2}$, no demand should be assigned to the upstream on-ramp. An analytical investigation has been performed to calculate the critical values. The analytical results are in good agreement with the simulation ones.

© 2016 Elsevier B.V. All rights reserved.

1. Introduction

In the last few decades, the physics of traffic congestion has attracted the wide interests of scientists [1–4]. This is because, on the one hand, how to alleviate congestion is practically important. On the other hand, traffic flow systems exhibit many interesting nonlinear phenomena.

Traffic congestion is usually induced by bottlenecks. In urban traffic network, the bottlenecks are usually located at intersections including signalized [5,6] and unsignalized ones [7], roundabouts [8], and so on. For uninterrupted traffic flow

* Corresponding author at: MOE Key Laboratory for Urban Transportation Complex Systems Theory and Technology, Beijing Jiaotong University, Beijing, 100044, China.

E-mail address: jiangrui@bjtu.edu.cn (R. Jiang).

http://dx.doi.org/10.1016/j.physa.2016.08.053
0378-4371/© 2016 Elsevier B.V. All rights reserved.

on highways or expressways, bottlenecks are usually located at on-ramps, off-ramps, lane closures, speed limits, and so on [9–12].

The on-ramps play an important role in the real traffic and the corresponding physics is widely studied. Kerner [13] discussed the freeway capacity at an on-ramp bottleneck based on the three-phase traffic flow theory. Lee et al. [14] studied the phase diagram of the continuum traffic flow model equation in the presence of an on-ramp. Tang et al. [15] used the car following model to explore the impacts of on-ramp on the vehicle fuel consumption. Meanwhile, the ramp metering method has been applied to enhance system capacity [16]. For example, Carlson et al. [17] proposed the mainstream traffic flow control method based on the variable speed limits and the coordinated ramp metering actions and stated that this tool favors to reduce the congestion. Sheu et al. [18] investigated an integrated freeway traffic management system, which coordinates both dynamic toll pricing and ramp control strategies for the purpose of dynamic freeway congestion management.

Since there usually exist more than one isolated on-ramp on real highways, Kerner and Klenov [19] pointed out interaction between the successive bottlenecks has a nontrivial influence on traffic flow. Davis [20] and Wang et al. [21] have analyzed how to apportion demand between two on-ramps to reduce the congestion and found that a larger proportion of the demand should be assigned to the upstream on-ramp. This conclusion is consistent with the findings of Zhang and Recker [22], and has later been extended to the highway with more on-ramps [23].

The off-ramps sometimes also induce traffic congestion. For example, Kerner [24] showed that a free flow to jam phase transition can occur if the formation of synchronized flow is strongly hindered due to a non-homogeneity, in particular at a traffic split on a highway. Munoz et al. [25] found that the saturated off-ramps have pernicious effects on the freeway traffic flow. Newell [26] studied the effect of a queue from an off-ramp which spills back to the freeway and causes a partial blockage of the right lane. Ez-zahraouy et al. [27] studied the effect of the position of the off-ramp on the traffic flow phase transition. Spiliopoulou et al. [28] validated the traffic flow models in the congestion created by the saturated freeway off-ramps. Cassidy et al. [29] also studied the freeway traffic near an off-ramp and showed that the lengths of the exit queues were negatively correlated with the discharge flows. Jia et al. [30] investigated the off-ramps system on the highway with and without the exit lane using the cellular automaton model. It was shown that the exit lane favors to improve the flow capacity under certain situations.

The traffic flow induced by presence of on-ramps and off-ramps that are not far away has also been studied in the literature. For example, Diedrich et al. [31] reported results on the modeling of on- and off-ramps in cellular automata and showed that the ramps have effects similar to stationary defects. To control the traffic flow near on-ramps and off-ramps, Van Den Berg et al. [32] compared the on-ramp metering and off-ramp metering with respect to queue forming and total time spent. Huang et al. [33] investigated the ramp effects analytically in the scenario with both on-ramp and off-ramp. Nassab et al. [34] studied the effect of spacing between the on- and the off-ramps on a same periodic road that intersects with another road. Mhirech et al. [35] investigated the effect of one on-ramp and one off-ramp in a one dimensional cellular automaton traffic flow model with open boundary conditions. Davis has simulated how to mitigate congestion on a two-lane highway with an on-ramp and an off-ramp within the framework of three-phase traffic theory [36]. Geng et al. [37] has studied ramp systems on the Beijing 3rd ring road as double-cell ramp systems. It was found that the initial states have an important impact on the final convergence states of the ramp systems. Two demand adjustment strategies were proposed, and it was shown that the systems can converge to uncongested equilibriums after demand adjustment.

This paper generalizes our previous study on highway with two on-ramps [21] to that with two on-ramps and an off-ramp in between. The studied multiple ramps system is abstracted from one real traffic situation. We study the effect of off-ramp flow ratio and focus on how to maximize the system capacity by assigning proper traffic flow to the two on-ramps.

The paper is structured as follows. We present model of the system in Section 2. In Section 3, the simulation results are presented and discussed. Conclusions are given in Section 4.

2. Model

In this paper, we use the deterministic Nagel–Schreckenberg (NaSch) model to simulate the movement of cars as in previous works [21,23,38]. In the model, the road is divided into cells of length 7.5 m, and each car occupies one cell. The parallel update rules of the model are as follows:

(R1) Acceleration: $v_i \to \min(v_{\max}, v_i + 1)$;
(R2) Slowing down: $v_i \to \min(d_i, v_i)$;
(R3) Car motion: car i moves v_i cells.

Here v_i and d_i are the velocity of the ith car and the number of empty cells in front of it. One time step corresponds to 1 s and the maximum velocity is set to $v_{\max} = 5$.

Fig. 1(a) presents schematic diagram of the studied situation. In the scenario, there exist a highway and an ordinary road. The ordinary road has two on-ramps connecting the highway while the highway has an off-ramp between the two on-ramps. Vehicles on the ordinary road need to enter the highway via choosing one of the two on-ramps (vehicles from the ordinary road are assumed not to exit from the off-ramp). Therefore, the on-ramp flow assignment needs to be implemented at the diverge on the ordinary road to optimize the traffic capacity. Fig. 1(b) shows the abstracted system. As in previous works [21,23], both the main road and the ramps are assumed to be single-lane road and each ramp connects to the main road at one cell, C_0, D_0 and F_0, respectively. Although modeling vehicular traffic on multi-lane highways are more relevant

Download English Version:

https://daneshyari.com/en/article/7376805

Download Persian Version:

https://daneshyari.com/article/7376805

Daneshyari.com