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ScienceDirect
Procedia - Social and Behavioral Sciences 138 (2014) 259 – 268
Procedia Social and Behavioral Sciences

The 9th International Conference on Traffic & Transportation Studies (ICTTS'2014)

Exploring the Influence of the Congested Downstream on Traffic Flow at Its Upstream Bottlenecks

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Abstract

With the rapid increase of the private cars, urban road congestion is getting worse. As known, when the downstream section is free flow, the congestion for every bottleneck section starts from the bottleneck cell, and then gradually propagates towards its upstream. Many studies about bottlenecks are based on the assumption that the downstream of each bottleneck is free flow. In this paper, we have investigated ramp systems with the congested downstream. Based on the cell transmission model, a tri-cell ramp system with two bottlenecks is used as an example to explore what the convergence state of the bottleneck section is under the congested downstream section. Three cases have been studied: free-flow downstream, middle-state downstream, and the most congested downstream, and the different convergence states. The results show that 1) if the downstream of the bottleneck is the most congested, the upstream bottleneck section converges to the most congested state no matter what the initial state is; 2) if the downstream is congested, the upstream section converges to congested states, and the degree of congestion in the upstream section increases with; 3) the larger the density in the congested downstream is, the more congested the final state of the ramp system is.

Peer-review under responsibility of Beijing Jiaotong University(BJU), Systems Engineering Society of China (SESC).

Keywords: Bottleneck; Cell transmission model; Congestion; Convergence state; Stationary demand.

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Peer-review under responsibility of Beijing Jiaotong University(BJU), Systems Engineering Society of China (SESC).
doi:10.1016/j.sbspro.2014.07.203

1. Introduction

Recently, private cars increase rapidly and urban road congestion is getting worse. Congestion wastes travelers' travel cost, leads to an increase of traffic accidents, exhaust of emissions and energy consumption. For example, the cost of congestion in Beijing increased from 12,557 million in 2005 to 105,600 million in 2011. In 2011 there were 210,812 traffic accidents causing that a total of 62,387 people were killed in China. The carbon dioxide emission of transportation in China increased at an average annual growth rate of 15.6%. Therefore, how to alleviate urban traffic congestion has become an important issue for urban traffic.

As a typical bottleneck in traffic system, the ramp system always causes congestion. Thus, ramp control has become one of the most effective methods to alleviate congestion in urban traffic. Li et al. (2012) analysed the characteristics of traffic congestion, then put forward the idea of flexible capacity and solved the problem of its reasonable allocation for ramp coordinated metering, and finally evaluated the efficiency and the equity of the flexible capacity by modifying the length of control cycle. A nonlinear model-predictive hierarchical control approach for coordinated ramps of freeway network was presented by Papamichail et al. (2010), and the results showed that metering of all on-ramps with sufficient ramp storage space might optimize the utilization of the available infrastructure. Bhouri et al. (2013) proposed a coordinated control strategy based on heuristic algorithm, and pointed out that the coordinated strategy was more efficient than the isolated strategy in terms of the reliability of travel time. A speed control of entrance ramp was presented by Liu et al. (2011). This method can reduce the network, ramp average delay and the average parking times, and improve the main downstream average speed. Yang et al. (2008) also proposed a ramp control method which can shift the control from the entrance ramp to the side-road and its nearby intersection. The method can simplify the complexity of the coordinated strategy, and it is more suitable to control urban expressway in China.

To understand congestion mechanism of ramp system and design the effective control method, many traffic flow models have been developed. Among them, Daganzo (1994) have proposed a macroscopic traffic flow model—Cell Transmission Model (CTM), where a freeway is divided into lots of cells, and in each cell the vehicle number, the inflow and outflow rate are used to describe the discipline of traffic flow. CTM is widely used and extended to analyse a variety of traffic problems, due to its very low computation memory requirements, easily extending to networks, and its capability of applying to issues of traffic assignment, signalized intersections, and ramp metering, e.g. a switching-mode model (Muñoz et al. 2003), a variable cell transmission model (Hu et al., 2010), and a stochastic cell transmission model (Sumalee et al., 2011) etc. Also CTM and its extended models have been applied to real traffic issues, e.g. the recovery time of traffic accidents (Ji et al., 2009), dynamic traffic around the bottlenecks (Chen et al., 2010), the evolution mechanism of regional traffic congestion (Dong et al., 2012) and the influence of variable speed limit on bottleneck capacity (Hadiuzzaman and Qiu, 2013), and estimation of the travel time and evaluation of the reliability (Sumalee et al., 2013) etc. Traffic congestion in ramp system is a major concern in urban traffic. Gomes and Horowite (2006) used asymmetric cell transmission model (ACTM) to optimize freeway ramp, and the results showed that the queue delay could be reduced about 17.3%. Furthermore, by using nonlinear dynamic method, they studied the characteristics of convergence equilibrium in the CTM under a stationary demand, and then applied these findings in the issue of ramp metering. Gomes et al. (2008) theoretically proved that under feasible demand the equilibrium states might be far away different (e.g. uncongested, or congested, or others), although the final equilibrium flows are the same. And then they proposed ramp metering methods under the infeasible demand to alleviate traffic congestion.

Gomes et al. (2008) theoretically proved that under feasible demand the final equilibrium flows are the same. The ramp system is divided into several bottleneck sections according to the location of bottlenecks, and in every bottleneck section congestion starts in the bottleneck cell, and then gradually propagates towards the upstream if the downstream section is free flow. But there are no studies on what the convergence state of the bottleneck section is if the downstream of the bottleneck section is congested. In this paper, a tri-cell ramp system with two bottlenecks is used as an example to explore what the convergence state is if the downstream is congested.

This paper briefly describes a ternary-cell ramp system, the CTM and its convergent characteristics in section 2. Then in section 3, simulation on the tri-cell ramp system could tell the influence of the congested downstream. Finally, conclusion is summarized in section 4.