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Double-layer ramp-metering model for incident congestion on expressway

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Abstract: In order to ensure stable traffic capacity and avoid incident congestion, a double-layer ramp metering model is proposed in this paper, based on coordination control theory, to predict and control the traffic flow at each on-ramp, when there is incident congestion on the expressway. The function of the lower model is to recognize where the incident congestion exists, based on an adaptive neural network with inputs of traffic flow, velocity and density. The outputs of the lower model are the number of section where the congestion occurs, the number of ramp which should be controlled, and real-time traffic flow information. These outputs should be transmitted to the upper model. The function of the upper model is to design the ramp-metering strategy based on nonlinear theory. The outputs of the upper model are a ramp-metering rate and traffic-flow state after ramp controlling on the expressway. The results of the simulation show that the double-layer ramp metering model could shorten the delay by about 25%, and the variance of the model results is 0.002, which could certify the control strategy is equitable.

Key words: traffic engineering; double-layer model; incident congestion; ramp metering; urban expressway

1 Introduction

Some traffic congestion is induced by traffic accidents, we call this "incident congestion". It is random and accidental, and impossible to predict where and when it might happen. As a result, it is difficult to disperse incident congestion. If it not dispersed in time, it can lead to paralysis of the road network (Liang 2005). In order to alleviate traffic jams and to elevate road capacity with sufficient service, many ramp-metering

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measures are used on the urban expressway. These are classified mainly into three: on-ramp metering, masterstroke control, and passageway control.

On-ramp metering is the most widely applied control measure, the objective of which is to control the number of vehicles entering the expressway, so as to keep the expressway working at a maximum traffic capacity (Papamichai and Papageorgiou 2008). When occasional jams occur on a certain section of the expressway, for instance, lanes are occupied as a result of a traffic accident, causing traffic capacity decline or jam, the congested sections should be controlled by taking effective measures to avoid the congestion spreading on a larger scale. Currently, the research on ramp metering has about 4 stages: local ramp metering; ramp-coordination metering; dynamic traffic assignment; and traffic channel integration control. The control method could be classified as: masterstroke control, line guide control, speed-limit control, and so on (Ghods et al. 2007).

Of these, local ramp metering is a static or dynamic control method for single on-ramp on freeway. For instance, a local feedback control law (ALINEA), advanced by Papageorgiou, is a typical feedback method for local ramp metering, and could disperse part of the congestion, but may induce congestion drifting. The road section that is moving maybe become a newly congested section (Kotsialos et al. 2004; Kotsialos et al. 2002). Ramp-coordination metering is a static or dynamic control strategy for nearby on-ramps on the freeway, which could carry out a static control method, based on linear plan theory, or carry out linear secondary feedback control, and nonlinear optimal control, based on dynamic optimal control theory (Kotsialos et al. 1999).

The calculation rule of these control methods is simple and cost is low, but it cannot cope with traffic incidents and disturbance. So, the control results are not so good (Yuan et al. 2009). Some researchers have analyzed how to implement ramp-linkage metering, such as Payne, Papageorgiou, and so on. These models could reflect the traffic flow state and optimize the whole road network. However, the results of ramp-linkage metering maybe mean that the waiting time for some drivers, waiting on a controlled on-ramp, is too long to endure, or the queue length is too long, which may disturb the well-balanced traffic flow state for intersected roads (Bellemans et al. 2006; Papageorgiou and Kotsialos 2002).

Ramp-channel metering is a territorial, integrated-control method. By combining ramp metering on the freeway and urban traffic information regional control, a selected control index could achieve the best. The purpose of it is to compensate the delay time on the controlled ramp by decreasing the traveltime on the freeway (Jang and Han 1994). By doing this, the whole travel time for the traffic system could decrease. So the effects of this method depend on the traffic-flow state of the freeway and alternative routes, and whether drivers would choose the alternative routes (Ma 1999).

In this paper, a double-layer ramp metering model is advanced, based on coordination control theory. The function of the lower model is to recognize where the incident congestion is based on the adaptive neural network, whose inputs are traffic flow, velocity and density. The outputs of the lower model are the number of section where the congestion occurs, the number of ramp which should be controlled, and the real-time traffic flow information. These outputs should be transmitted to the upper model. The function of the upper model is to design the ramp-metering strategy, based on nonlinear theory. The outputs of the upper model are the ramp-metering rate and the real-time traffic flow state after ramp controlling on the expressway.

2 Basic idea of ramp-metering for incident congestion on urban expressway

Considering that incident congestion is random and accidental, the required ramp-metering number is also random and accidental (Han and Jiang 2007). So the occurrence time and place of the incident congestion must be identified first, then it is possible to control and disperse them. On account of the purpose, a double-layer ramp-metering model is advanced, based on coordination control theory. The basic ideal of the model is shown in Fig. 1. This double-layer model should identify the congestion, and design a control strategy quickly and accurately. The final outputs of