Transportation Research Part C 81 (2017) 300–316

Contents lists available at ScienceDirect

Transportation Research Part C

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

Traffic guidance–perimeter control coupled method for the congestion in a macro network

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ARTICLE INFO

Article history:
Received 2 June 2016
Received in revised form 13 June 2017
Accepted 14 June 2017

Keywords:
Traffic congestion
Macroscopic fundamental diagram (MFD)
Traffic flow
Traffic guidance
Perimeter control

ABSTRACT

Macroscopic fundamental diagram (MFD) describes the macro relationship between a network vehicle density and a network space mean flow, without requiring the mastery of complex origin to destination data. Thus, MFD provides an opportunity for the macro control of urban road network. However, most of the existing MFD control methods ignore the active role of traffic guidance in solving congestion problems. This study presents a traffic guidance–perimeter control coupled (TGPCC) method to improve the performance of macroscopic traffic networks. The method considers the optimal cumulative volume of a network as the goal and establishes a programming function according to the network equilibrium rule of traffic flow amongst multiple MFD sub-regions, which regards the minimum delay of network, as the objective. The Logit model for the compliance rate of driver route guidance is established by the stated preference survey. Moreover, the perimeter control (PC) method is proposed for adjusting the phase split of intersections. Finally, three schemes, namely, the TGPCC, PC and the method without PC and guidance are tested on a network with four well-defined MFD sub-regions. Results show that the TGPCC addresses the issue of congestion and decreases the total delay accordingly.

1. Introduction

Regional traffic congestion has an adverse effect on resident travel. Although many methods, such as toll, odd–even vehicle prohibition scheme and no entry signs, have been applied to solve this problem, related practice has proven that traffic guidance and signal control remain to be the key measures to solving the problem without constraints. Therefore, the coupled method of traffic guidance and signal control for addressing traffic congestion is worth exploring.

Traditional single-point, arterial and area coordination control methods cannot deal with regional traffic congestion specifically. Agent technology has been used to coordinate the signal time of regional networks because of the development of the artificial intelligence technology (Wiering et al., 2004; Li and Zhao, 2008). Subsequently, traffic guidance has become the key development field. Several scholars have attempted to solve traffic problems through signal control and guidance systems, including emphasis coordination (Shimizu et al., 1996), iterative coordination (Bell et al., 1995) and global optimal coordination (Yang and Yagar, 1995). Nevertheless, these methods focus on specific links or intersections in congestion areas, and the traffic flow into the congestion area has no limit.

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http://dx.doi.org/10.1016/j.trc.2017.06.010
0968-090X/

Considering that the macroscopic fundamental diagram (MFD) simplifies the modelling of the traffic flow dynamics for large-scale urban networks and provides a unimodal, low-scatter relationship between network vehicle density (veh/km) and network space mean outflow (veh/s) for a roughly homogeneous regional network, many researchers have utilised MFD to control the traffic inflow and outflow of regions. The MFD was first proposed by Godfrey (1969). However, it was not verified until Daganzo and Geroliminis (2008) and Gonzales et al. (2009) used the floating car data of Yokohama and Nairobi. Subsequently, other scholars have described the main characteristics, inherent properties and influence factors of the MFD, which provide a theoretical basis for the classification of regional traffic flow status, rank division and traffic control of congested areas (Geroliminis and Daganzo, 2008; Buisson and Ladier, 2009; Geroliminis and Sun, 2011; Gayah and Daganzo, 2011). The MFD can also be utilised to introduce simple perimeter flow control policies to improve mobility in homogeneous networks (Daganzo, 2007; Haddad and Geroliminis, 2012; Keyvan-Ekbatani et al., 2012; Aboudolas and Geroliminis, 2013; Geroliminis et al., 2013; Haddad et al., 2013; Knoop et al., 2013; Zhang et al., 2013; Hajiahmadi et al., 2015). Boundary control strategies, i.e. manipulating the transfer flows at the borders of urban regional entrances and utilising the MFD concept, have been introduced for application to a single region by Daganzo (2007), Zhang et al. (2010) and Keyvan-Ekbatani et al. (2012) and to multiple sub-regions by Haddad and Geroliminis (2012), Aboudolas and Geroliminis (2013) and Geroliminis et al. (2013).

On the control method for a single or two MFD sub-regions, Zhang et al. (2010) proposed the gridlock prevention control strategy for a single region to solve the traffic congestion problem in the core area by adjusting the green split of the border intersection, which has exhibited a certain development in the aspect of macroscopic boundary control. Haddad and Shraiber (2014) introduced a robust boundary control method with the design of a robust proportional integral controller to maintain the accurate range of the accumulated vehicles inside the region. Keyvan-Ekbatani et al. (2012) presented a feedback control method with multi-variable and integral feedback controllers, which could effectively control the cumulative traffic flow in a single region to reduce traffic delay. Haddad (2017) proposed a boundary optimization control method between two adjacent sub-regions based on the analysis of the vehicle queuing at the sub-region boundary. Ding et al. (2017) proposed an optimal control method for the boundary of sub-regions that is based on the optimal outflow rate of two adjacent sub-regions that was analysed. Due to the limited number of sub-regions, these methods do not consider traffic guidance appropriately amongst the sub-regions.

On the control method for multiple MFD sub-regions, Hajiahmadi et al. (2013a, 2013b) proposed a graded control strategy for feedback gate control based on the traffic critical point of the MFD region to relieve traffic congestion. Aboudolas and Geroliminis (2013) implemented boundary control by setting a multi-variable feedback controller. The two methods exhibit a certain development in solving the traffic problem of multiple MFD sub-regions. However, these methods do not consider the coordination control problem of multiple sub-regions. Keyvan-Ekbatani et al. (2015) considered the expanded status of congestion areas in multiple sub-regions and proposed a multi-layer feedback control method for the congestion area in the road networks with multiple sub-regions. Ramezani et al. (2015) implemented the boundary control of multiple sub-regions using the MFD model for networks with heterogeneous density. Hajiahmadi et al. (2015) applied a hybrid perimeter and switching plans control to an urban network composed of several sub-regions. Zhou et al. (2016) implemented a predictive control to balance the traffic demand of multiple sub-regions.

Considering the remarkable achievement of the MFD in the field of traffic control, experts have shifted MFD research to dynamic traffic guidance. For instance, Hajiahmadi et al. (2013a, 2013b) and Yildirimoglu et al. (2015) used dynamic traffic guidance to solve the problem of traffic congestion in multiple MFD sub-regions by obtaining the best MFD. Yildirimoglu and Geroliminis (2014) considered the effect of dynamic route guidance on large-scale urban road networks, used the traffic assignment mode to determine the influence of route choice on a MFD and investigated the optimal route selection of multiple sub-regions. However, they did not consider the effect of guidance success rate on the entire network and did not adjust the flow rate of boundary.

The aforementioned macroscopic traffic flow control and dynamic guidance methods provide a theoretical basis for solving the problem of traffic congestion. Nevertheless, several deficiencies remain. Firstly, sub-regions adjacent to the congestion area have different densities, and the coordination problems amongst those MFD regions should be considered in the entrance boundary control of the congestion area. Secondly, although dynamic guidance has been applied to adjust a network MFD, it neglects the different state characteristics of sub-regions and cannot exert further effort to solve the traffic congestion amongst the sub-regions using guidance. Thirdly, existing macroscopic traffic guidance and control methods are relatively isolated; they cannot solve the problem of regional traffic congestion by cooperative control. Sirmatel and Geroliminis (2017) combined traffic guidance with boundary control and proposed an optimization method, which aims to minimise total network delay. This method provides a solution to the traffic problem. However, it does not consider the influence of control method on network state transition, which may causes hysteresis of network or local gridlock in the optimal regulation rate of excessive flow.

This study proposes a TGPCC method according to the network state to solve traffic congestion based on a macroscopic road network with multiple MFD sub-regions. Through numerous guidance–control cycle operations, the average delay of vehicles amongst regions has been low. The remainder of this paper is organised as follows. Part 2 presents the theoretical basis of the sub-region division and traffic flow equilibrium equation. Part 3 introduces the macroscopic traffic guidance and PC methods. Part 4 proposes the TGPCC method and establishes an optimization model. Part 5 discusses the case analysis, and Part 6 presents the conclusions and future work.