JOURNAL OF TRAFFIC AND TRANSPORTATION ENGINEERING (ENGLISH EDITION) 2015; 2 (3): 167–178

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Review Article

Exploring the impact of a coordinated variable speed limit control on congestion distribution in freeway

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ARTICLE INFO

Article history:

Available online 31 March 2015

Keywords:

Active traffic demand management

Variable speed limit

Extended METANET model

Freeway queue

Congestion distribution

ABSTRACT

Over the past few decades, urban freeway congestion has been highly recognized as a serious and worsening traffic problem in the world. To relieve freeway congestion, several active traffic and demand management (ATDM) methods have been developed. Among them, variable speed limit (VSL) aims at regulating freeway mainline flow upstream to meet existing capacity and to harmonize vehicle speed. However, congestion may still be inevitable even with VSL implemented due to extremely high demand in actual practice. This study modified an existing VSL strategy by adding a new local constraint to suggest an achievable speed limit during the control period. As a queue is a product of the congestion phenomenon in freeway, the incentives of a queue build-up in the applied coordinated VSL control situation were analyzed. Considering a congestion occurrence (a queue build-up) characterized by a sudden and sharp speed drop, speed contours were utilized to demonstrate the congestion distribution over a whole freeway network in various scenarios. Finally, congestion distributions found in both VSL control and non-VS control situations for various scenarios were investigated to explore the impact of the applied coordinated VSL control on the congestion distribution. An authentic stretch of Whitemud Drive (WMD), an urban freeway corridor in Edmonton, Alberta, Canada, was employed to implement this modified coordinated VSL control strategy; and a calibrated micro-simulation VISSIM model (model functions) was applied as the substitute of the real-world traffic system to test the above mentioned performance. The exploration task in this study can lay the groundwork for future research on how to improve the presented VSL control strategy for achieving the congestion mitigation effect on freeway.

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Peer review under responsibility of Periodical Offices of Chang'an University.

http://dx.doi.org/10.1016/j.jtte.2015.03.005

1. Introduction

Traffic congestion on freeway is a critical social issue that we face every day. Some freeway locations recurrently experience congestion due to the existence of bottlenecks. From a safety perspective, as data from Persaud and Dzbik (1993) indicate, accident frequency during congested operation can be up to three times as high as that during uncongested operation at similar flow level. Over the past few decades, several dynamic control methods have been developed to address congestion problems. Active traffic and demand management (ATDM) strategies, such as variable speed limit (VSL), ramp metering (RM) and route guidance (RG) have been implemented in recent years to improve traffic freeway efficiency (mobility and/or safety). Among them, VSL operation has been presented in previous literature as a good solution. It is often based on the principle of speed homogenization over the freeway corridor, which is capable of improving freeway mainline capacity and reducing speed variability (Borrough, 1997). The VSL strategy adaptively controls the upstream traffic flow of a bottleneck by dynamically regulating the speed limit. The effectiveness of VSL control has been examined from various perspectives. In the first instance, VSL control performances were well reported to homogenize the traffic and improve safety. Despite the potential benefit of VSLs on safety, some studies have also evaluated the impact on mobility. The most frequently used way of demonstrating the impact of VSL on mobility is to calculate the numerical indicators of performance (the total travel time (TTT) on mainline or total time spent (TTS) for all vehicles in the network, etc.).

Although VSLs are capable of alleviating congestion and improving mobility in terms of TTT and/or TTS, congestions expressed by the form of queues may appear on mainline in VSL-implemented situations when facing heavy approaching demand flows. Few studies have explicitly evaluated the impact of a VSL control on congestion distribution. To bridge this gap, this study explored the impact of VSL on congestion distributions over a whole freeway network. It is a new visual angle for exploring the contribution of an implemented VSL control strategy. The incentives of queue build-up in the VSL scenario were also analyzed, since congestion was characterized by the existing queue.

Congestion will be aggravated with increased traffic demand regardless of whether VSLs are implemented or not. It has been demonstrated the limiting effect of VSL on congestion mitigating effect under excessively heavy demand flow level (Long et al., 2008; Mazzenga and Demetsky, 2009). Unfortunately, almost all metropolitan areas suffer from the rapidly increasing traffic demand on freeway. This study can be useful for improving the existing VSLs aiming at mitigating congestion even under extremely heavy traffic demand situation.

The existing VSL control strategy was proposed to improve the mobility on freeway (Hadiuzzaman et al., 2013). To address the dynamic traffic control problem, this existing VSL algorithm adopted a model predictive control (MPC) framework (Camacho and Bordons, 1995; García et al., 1989). Microscopic traffic simulation was found to be the most suitable and cost-effective tool for performing this study. Furthermore, a new local constraint more compatible with the field situation was added. The applied VSL control strategy was implemented in the VISSIM micro-simulation platform using a special-purpose software module developed in C++ with the Component Object Model (COM) interface.

The remainder of this paper is organized into five sections. Section 2 summarizes the literature reviews on the effect of VSL control. Section 3 presents a brief introduction on the applied VSL control strategy and discusses the queue formation in VSL control implemented scenario. Section 4 exhibits the simulation results in the studied freeway corridor. Section 5 summarizes the concluding remarks. Section 6 presents the on-going research work.

2. Literature review

Aiming at stabilizing traffic flow and mitigating traffic breakdowns to improve freeway traffic efficiency, VSL systems have been successfully implemented in many areas around the world. VSLs regulate the speed limit accommodating time-varying traffic conditions within the control period (Kang and Chang, 2006). It has been reported in previous literature that the main benefits of VSLs are improving network throughput, smoothing traffic flow, saving TTT, reducing speeding violations, and reducing crash potential (CP) (Abdel-Aty et al., 2005, 2006; Hegyi et al., 2005).

Tracing the development of VSL since 1990, many VSLs were targeted at improving traffic safety only. The effectiveness of real-world implemented VSLs in the United States and several European countries was summarized (Robinson, 2000). Evaluation results showed that it increased safety levels more significantly than it improved mobility. Several other simulation-based evaluations of freeway VSLs have also been conducted to explore the effect of VSLs on safety improvements. For example, Lee et al. (2006) assessed the safety benefits of VSL using PARAMICS. They selected an optimal speed limit based on several safety-related thresholds and found that CP decreased by 5%–17%, but travel time increased up to 10%. Abdel-Aty and Dhindsa (2007) concluded that, on a segment of I-4 in Orlando, Florida, changing speed limits by 5 mph increments produced best safety improvement results versus changing in 10 or 15 mph increments, which produced negative safety impacts. Beyond that VSL reduced the CP in non-congested conditions; Abdel-Aty et al. (2008) reported a 1% decrease in travel time during VSL control in non-congested conditions, but no significant improvement was found in congested conditions.

In spite of that the benefit of VSLs on safety has been well evidenced, it is still necessary to incorporate the traffic mobility. Several studies examined model predictive control (MPC)-based VSLs, wherein extended METANET models were employed to describe the traffic dynamics (Carlson et al., 2010; Hadiuzzaman et al., 2013; Hegyi et al., 2005, 2007; Long et al., 2008). They concluded VSLs were able to improve traffic mobility during congestion. Hegyi et al. (2005) evaluated VSL control with TTT as a mobility indicator; these authors