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Discrete Optimization

Microscopic modeling and control logic for incident-responsive automatic vehicle movements in single-automated-lane highway systems

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Abstract

Automatic response to lane-blocking incidents is a critical issue in the field of automated highway systems (AHS). Accordingly, this paper presents a microscopic vehicular control methodology for automatic-control (AC) vehicular movements in response to lane-blocking incidents in the AHS environment. The embedded traffic control logic is based on the basic safety requirements for automatic-control lane traffic maneuvers responding to lane-blocking incidents in the single-automated-lane AHS environment. Accordingly, respective automated vehicular control models are proposed to deal with AC vehicles moving in three corresponding sequential phases, i.e., (1) AC platoon approaching the incident site from the blocked lane, (2) mandatory lane changing and mixed car following in the adjacent lane, and (3) AC platoon reforming downstream from the incident site in the blocked automated lane. Using a microscopic simulation model which embeds these proposed models, preliminary tests are conducted to investigate the relative performance of the proposed method in various traffic flow and control scenarios. The resulting numerical results, including simplified sensitivity analyses, indicate that the proposed microscopic traffic control logic permits regulating automatic-control vehicular movements in response to the effects of lane-blocking incidents on traffic flows either in control-free lanes or in the automatic-control lanes. Implications of the results and some findings are discussed for further research.

Keywords: Traffic; Microscopic modeling; Automatic-control vehicles; Incident-responsive

1. Introduction

Prompt response to lane-blocking incidents is a critical issue in the development of advanced automated highway systems (AHS) although all the limited existing AHS technologies are on trial. In this paper, a lane-blocking incident in AHS refers to any lane blockage in either the automated-control lanes or the

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adjacent control-free lanes on AHS freeways. Such a lane-blocking incident may be caused by any unusual event, e.g., malfunction of automatic control systems in automated vehicles, or abnormal traffic conflicts resulting from the traffic flows in adjacent lanes in either the single-automated-lane or multi-automated-lane AHS environment. The significance of this issue can be perceived from three aspects. First, the phenomena of incident-induced lane traffic maneuvers, including mandatory lane changing and queue overflowing, actually remain ambiguous in numerous related study fields, e.g., traffic theory, incident management, and traffic control. Other relevant discussions can be readily found in our previous literature (Sheu et al., 2001; Sheu and Ritchie, 2001b; Sheu, 2002, 2003a,b). Second, the traffic maneuvers of automatic-control (AC) vehicles are different from those of AC-free vehicles, which rely primarily on human factors. Consequently, the effects of incidents on the mixed traffic flows are more complex than those on the existing fully AC-free traffic flows, given the exclusive AHS lanes existing in the normal freeway systems. Thirdly, the variety of incident characteristics (e.g., incident duration and location) coupled with incident impacts (e.g., delays and queue lengths) in both the temporal domain and the spatial domain have led to the invalidation of the existing traffic control and management strategies, which may further contribute to the uncertainty surrounding the system performance of AHS. One might argue that the aforementioned reasoning may not hold in the case of fully AC traffic flows where each vehicle is supposed to be ideally controlled. Nevertheless, the incident-responsive strategies remain unknown in the above ideal scenario.

Although recent years have seen growing advances in investigating AHS traffic flow problems and the corresponding control logic rules, investigation of the corresponding AHS lane traffic maneuvers and respective control logic to address the issues of AHS under anomalous operational conditions appear to warrant more research effort. Some typical examples are illustrated below for further discussion.

The control system architecture and corresponding functionality of intelligent vehicle/highway systems were amplified in Varaiya (1993), which provides an elaborate overview of AHS. According to the description in Broucke and Varaiya (1996), vehicles in the AHS environment might be under automatic control in terms of the corresponding traffic maneuvers, e.g., the vehicular headways in a given platoon, the spacing between two sequential platoons, platoon-based speeds, and the route from entry into the highway to exit. All the aforementioned traffic attributes should be determined automatically by specific control logic, e.g., optimal control. Given the fully automatic control condition, Hall and Lotspeich (1996) proposed a linear programming model to deal with the lane traffic assignment problem on an automated highway with the goal of maximizing the total throughput. However, the assumptions in terms of vehicular lane changing and corresponding formulas coupled with lane-changing coefficients may not hold true in lane-blocking incident cases. Similar problems are also found in Li and Wang (2002), which investigated a simplified automated lane-changing control model based on the concept of fairly distributing lane densities. Although the problems of bottlenecking at ramps of an AHS freeway have been investigated by some researchers (Ran et al., 1996; Zhang, 1996), their solution strategies appear to be inapplicable for mainline lane-blocking incident cases; and furthermore, the characterization of AHS traffic flows at bottlenecks remained vague in the literature. Efforts of other researchers devoted to controlling AHS platoons against longitudinal and lateral collisions via novel control technologies, e.g., fuzzy logic control and hierarchical hybrid control, can also be found in the literature (Godbole, 1994; Hessburg, 1994; Seto and Inoue, 1999). Nevertheless, the applicability of these methods in incident scenarios still remains problematic. In addition, several specific simulators which embed AHS traffic flow models were proposed to analyze the traffic dynamics of AHS in various traffic scenarios (Eskafi et al., 1995; Haddon, 1997; Gollu and Varaiya, 1998). However, there are limited numerical results to verify the validity of these resulting AHS traffic simulation models under lane-blocking incident conditions.

In addition, the resulting AHS emergency management maneuvers and related simulation experimental design have also raised increasing research interests (Ioannou, 1998; Lygeros et al., 2000; Yi et al., 2001; Toy et al., 2002). For instance, considering the issues of safety and human factors existing in the scenario of automated vehicle movements mixed with manually-driven vehicles, scenario design and evaluation via simulation were conducted in Ioannou (1998), which concludes that several safety concerns may still remain in the interaction of fully automated vehicles with manually-driven ones due to unpredictable maneuvers of drivers of those manual vehicles. Extended from the control hierarchy of Varaiya (1993), a fault tolerant control framework, which includes several control layers, is proposed in Lygeros et al. (2000) to deal with the operations of AHS under diverse faulty conditions, e.g., vehicular malfunction, infrastructure failure, and