Transportation Research Part B 104 (2017) 376–397

Contents lists available at ScienceDirect

Transportation Research Part B

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

Group-based hierarchical adaptive traffic-signal control Part II: Implementation

Seunghyeon Lee[a,*], S.C. Wong[b], Pravin Varaiya[c]

[a] Department of Civil and Natural Resources Engineering, University of Canterbury, Christchurch, New Zealand
[b] Department of Civil Engineering, The University of Hong Kong, Pokfulam Road, Hong Kong, China
[c] Department of Electrical Engineering and Computer Sciences, University of California, Berkeley, CA, 94720-1722, USA

ARTICLE INFO

Article history:
Received 1 February 2017
Revised 11 August 2017
Accepted 13 August 2017

Keywords:
Global proactive-optimization scheme
Local reactive-control policy
Simulation platform
Mathematical programming approach
Rolling-horizon approach

ABSTRACT

In part I of this study (Lee et al., 2017), the formulation of a theoretical framework for a group-based adaptive traffic-control method for isolated signalized junctions is presented, which includes tactical and local levels of signal timing optimization. The global level control aims to determine the time-varying cycle structure, with a resolution of cycles, and the real-time adjustment of the green phase, with a resolution of seconds, based on longer-term traffic information observed by traffic detectors. Overall, the purpose of the study is to actualize a multi-resolution strategy for a group-based adaptive signal-control method and establish a microscopic simulation platform to implement the proposed methodology and test its effectiveness. To actualize the global proactive-optimization scheme, in this paper, a rolling-horizon approach to the temporal and spatial variables, signal structures for four-arm intersections, and discrete directional search methods is applied using the developed mathematical framework. The formulation of the group-based max-pressure policy is realized using the logical form of the local reactive-control policy at a typical directional three-lane, four-arm approach to an isolated intersection. The integrated group-based adaptive traffic-signal control is actualized using VISSIM, Fortran, and VBA based on the developed tactical and local levels of signal timing optimization. The results of the computer simulations and the case study presented in this paper show that the integrated group-based adaptive traffic-signal-control logic outperforms the other methods over a wide range of traffic conditions, from free-flowing traffic to extreme congestion. Moreover, the proposed models perform much better than the existing fixed-signal plan and the actuated signal-control in asymmetric traffic conditions.

1. Introduction

In this paper, a multi-resolution strategy for the development of a group-based adaptive control method is proposed, in which a hierarchical structure consisting of two levels of signal control is designed, one for the global and one for the local level of signal timing optimization presented in Lee et al. (2017). The global level control aims to determine the time-varying cycle structure, with a resolution of cycles, and the real-time adjustment of the green phase, with a resolution of seconds, based on longer-term traffic information as observed by traffic detectors. The global level uses a group-based optimization

* Corresponding author.
E-mail address: snghynyi@connect.hku.hk (S. Lee).

http://dx.doi.org/10.1016/j.trb.2017.08.009
0191-2615/

method to determine the cycle-structure based on the traffic information from the previous cycles with a resolution of minutes. Finally, the local level uses a reactive local-control logic to update the stage-switching times based on local traffic information with a resolution of seconds. The proposed multi-resolution strategy serves to simultaneously determine the global signal settings and update the local signal parameters in a unified and systematic framework that can help improve the performance of signalized isolated junctions effectively and efficiently. The objective of the papers is to actualize a multi-resolution strategy for a group-based adaptive signal-control method and establish a microscopic simulation platform to implement the proposed methodology and test its effectiveness.

A proactive global-optimization procedure is developed for group-based signal settings at the global level of control. According to the real-time queue-length estimation process explained in Lee et al. (2015a), the prevalent arrival rates are obtained for the individual lanes approaching a signalized junction so that the patterns of arrival at the junction can be discerned. An arrival pattern is defined as the pattern of traffic that would arrive at the stop line at the end of a lane if the traffic were not impeded by the signals at the stop line. As shown in Wong (1995), the queue-formation pattern is classified into several types, based on the set of analytical expressions that are derived for estimating the derivatives of the queuing delay with respect to a change in the signal timing. The procedure for using queue-formation patterns is explored in Lee and Wong (2017a, 2017b). Using this procedure, the total delay at the junction for a given signal plan and its derivatives are estimated with respect to the changes in timings, which serve as the objective function and the gradient information for the formulation of a mathematical program for conducting the proactive global-optimization procedure, as developed in Lee et al. (2017). In this mathematical program, the group-based timing variables, i.e., the start and the duration of the green phase for each signal group and the successor functions between conflicting signal groups, are defined as control variables. The set of constraints includes the constraints on the duration of the green signal, the clearance time, the capacity, and the various other constraints that govern the additional safety and operational requirements specified by the users. The process of optimizing the application of these control and constraint variables is clarified in this paper.

The advantage of the group-based optimization method is that the most effective cycle structure (or the best overall pattern of signal stages) can be obtained automatically. The definitions of the stages, and the combinations, sequences, and structures of the inter-green periods between consecutive stages, do not need to be pre-specified. This freedom from pre-determined controls allows a high degree of flexibility in tactically identifying the optimized signal plan in response to the real-time-traffic information. However, despite these advantages, and given that the group-based optimization procedure is highly efficient (Wong, 1996, 1997), it is anticipated that a certain amount of computing time will still be required to obtain the optimized solution. Therefore, the global approach is used to compute the group-based solution during the current cycle and to implement this optimized solution in the next cycle, which helps to provide a window for the computational work. Nevertheless, the signal control in the current cycle is adjusted reactively in real time by the local level of control. The resolution of this global control level is in minutes because the cycle length and cycle-structures are allowed to vary from cycle to cycle.

Based on the global level of control, the cycle length and the cycle structure of the signal plan for a junction are obtained before the commencement of the current cycle. Nevertheless, traffic may still vary locally, and can deviate from the patterns used for computation at the global level. Therefore, a reactive local signal-control policy is developed to locally adjust the signal timings in response to the second-by-second variations in traffic patterns, as based on the max-pressure signal-control policy (Varaiya, 2013). From the global control plan, the group-based optimization procedure identifies the most appropriate cycle-structure according to the latest available information for which the number of stages, sequences, and durations have been generated automatically. At the local level of control, a transition zone is set before and after each switching time from one stage to the next (e.g., three seconds for each zone). During the real-time operation of the current cycle, the queuing information is monitored from the real-time, second-by-second queue-length estimation procedure, as developed in Lee et al. (2015a). The trigger switching then occurs in the next stage, when the criteria specified by the local control policy are met or when the time involved reaches the end of the transition zone. Therefore, the stage-switching time can occur before or after the time set by the global plan. The resolution of this local control level is in seconds, because changes to the signal features are decided second-by-second.

The use of a simulation platform is one of the possible alternatives for evaluating and verifying the performance of the newly developed traffic-control algorithms. The main advantage of this approach is that it helps to generate identical inputs for the evaluation of different algorithms, while avoiding the high installation and operational costs involved in a real-traffic system. This approach is also free from the safety concerns relating to tests that involve conflicting traffic movements during the development stage. Traffic, signal, and geometrical information is collected for the target intersection, and is implemented using the VISSIM (Verkehr In Staedten SIMulation) microscopic simulation platform. Fortran programming language is used to code the proactive global group-based signal-control algorithm to optimize the signal timings cycle-by-cycle at the global level. The visual basic application (VBA) is used to install the algorithm that performs the real-time group-based adjustments of each green phase second-by-second at the local level and sets the responsive time frames for the analysis and transition zones. VBA is also used to construct the synthetic framework that connects the microscopic simulation program, mathematical program, local adjustments, and algorithms for the temporal frames. The performance of the proposed methods is compared with those of the existing fixed-control and actuated-control methods to evaluate the effectiveness of the developed methodology.

In the following section, the integrated framework of the adaptive traffic-signal-control logic is introduced. The implementation of the global proactive-optimization method, including a rolling-horizon approach, the plan for the signal struc-