Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-3 (2016) 377–382

A Traffic Light Signal Control System with Truck Priority*

Yanbo Zhao and Petros Ioannou

Department of Electrical Engineering, University of Southern California, Los Angeles, United States, CA 90089

Abstract: This paper proposed and evaluated a traffic light control system for signalized urban intersections that aims to benefit all traffic flows involved by giving priority to trucks. The problem is motivated from the observation that in some cases extending a green traffic signal to have a heavy truck cross an intersection instead of forcing it to stop and restart again may have benefits for all vehicles involved. The proposed traffic light control system uses a co-simulation optimization control approach to generate the traffic light sequence in a network of signalized intersections. The system has been evaluated using a road network simulator adjacent to the twin ports of Long Beach/Los Angeles. The evaluation results show consistent improvements in reducing the overall traffic delays, number of vehicle stops, fuel consumption and vehicle emissions.

Keywords: Signal Control, Truck, Signal Priority, Simulation, Optimization.

1. INTRODUCTION

The control of signalized intersections plays an important role in traffic efficiency and safety by reducing traffic delays and vehicle stop frequency. Most current traffic signal controllers treat all vehicles the same when generating signal sequences based on the detected traffic flows. However, heavy vehicles such as trucks have a detrimental impact on traffic flows due to their slow dynamics and large sizes, especially in urban areas where the truck volumes are relatively high. Truck need a longer time and distance to accelerate or decelerate when facing traffic signal changes (Garber and Hoel, 2008), which results in higher traffic delays and more air pollution. With new sensing, GPS and communication techniques, the traffic controllers could detect or be informed of the characteristics of approaching vehicles and use the detected vehicle information to make better decisions. In some cases, reducing the overall traffic delay further could be achieved by giving signal priority to heavy trucks in order to let them cross intersections other than going through a stop and go manoeuvre that may generate extra delays not only for trucks but also for passenger cars. Avoiding stop and go manoeuvres of heavy trucks could also lead to less fuel consumption, pollution emissions and road surface damages.[1]

There have been many research efforts on the design and analysis of traffic signal priority systems that support giving priority to special vehicles, including dedicated signal priority systems and adaptive signal control systems. Ma and Yang 2007 and Li et al., 2008 proposed bus priority approaches based on macroscopic traffic flow patterns by giving longer green light to directions having buses. In addition, active priority approaches requiring real time vehicle approaching detections have also been studied with the rapid developments of new sensing solutions and communications, such as the prototype truck detections using video sensors in Saunier et al., 2009, the priority system with GPS and wireless communication application in Liao and Davis, 2006 and Li, et al, 2008, as well as truck priority by using connected vehicle technology in Kari et al, 2014. Other approaches that can support signal priority include the LHOVRA (Peterson and Bergh, 1991), Optimized Policies for Adaptive Control (OPAC) (Liao, 1998 and Pooran, 2011), and Real-time Hierarchical Optimizing Distributed Effective System (RHODES) (Mirchandani and Head, 2001). Most of the previous signal priority systems are on basis of the Model Predictive Control (MPC) methodology. The traffic state is predicted by explicit mathematical models then the optimal signal is generated by minimizing a cost index that depends on the predicted traffic states. However, the mathematical models in MPC based approaches become less accurate in traffic network with multiple intersections due to the time-variant, nonlinear dynamical characteristics of traffic flows that are difficult to capture with simple mathematical equations. Furthermore, performance criteria such as traffic delay, frequency of vehicle stops, or environmental impact are not explicit functions of the traffic flows generated by mathematical models used for MPC. As a result, the MPC based approaches may be not able to assess a wide range of performance criteria, which are of interest as they are not part of the minimized objective cost function.

In this paper, we develop a new truck priority system that uses a co-simulation-based optimization control approach to find intersection signal sequences by using real time simulators for traffic state prediction instead of simple mathematical models. The advantages of the proposed approach are: 1) The simulator in approach integrates car following, lane changes, and driver models that captures most of the dynamical characteristics and complexity of the

[1] This work has been supported in part by the National Science Foundation under the CPS program and in part by the University Transportation Center METRANS at University of Southern California.

10.1016/j.ifacol.2016.07.063

network; therefore the traffic simulator predicts future traffic flows with higher accuracy than a simple mathematic model by using the expected traffic demand and the fast forwarding simulation in time; 2) The cost function values can be easily obtained and accurately computed from the simulation results. This co-simulation-based optimization approach is used to search for the optimal baseline signal sequences. Then the baseline signal sequences are adjusted by an active priority decision in response to real time truck priority requests. We developed a traffic test bed of an actual road network in the Long Beach/Los Angeles port area and evaluated the proposed system using microscopic simulations. The simulation results demonstrate that both the average travel delay and stop frequency of trucks have been reduced. The passenger vehicles also benefited by improvements on travel time as a result of elimination of truck stops. In addition the overall fuel consumption and vehicle emissions are reduced.

The paper is organized as follows: Our approach is presented in section 2. The evaluation results using a road network simulator with different volumes of trucks are presented in section 3. The conclusion is given in section 4.

2. PROBLEM FORMULATION

2.1 Proposed System Overview

The proposed truck signal control system provides priority to trucks using two integrated stages: baseline signal generation stage and active priority stage. In the first stage, the system tries to find an optimized signal sequence for controlled intersections based on observed traffic flows and predicted future traffic demands. The outputted signal sequence is used as the baseline signal for the second stage. In the second stage, the active priority module receives real time priority requests from approaching trucks and decides whether truck priority request should be granted. If yes, the active priority part will adjust the baseline signal by either extending the green light or starting the green earlier. The detailed design of each stage is presented in the following subsections.

2.2 Baseline Signal Generation Problem Formulation

We assume that traffic flow sensors are available at each signalized intersection to provide traffic flow information regarding the number of vehicles and their class entering and leaving the intersection. Let X_t be a vector of traffic volume and truck percentage of the link traffic flows on the road network at time t. Let D_t be the traffic demand of the road network at time t. The control input at time t i.e. the selected signal sequence for signalized intersections in the road network is denoted with the vector U_t. The traffic flows at next time step can be computed by a nonlinear dynamical equation.

$$X_{t+1} = f\left(X_t, D_t, U_t\right) \tag{1}$$

In previous systems, this nonlinear function in (1) is approximated using a mathematical model by ignoring many complex dynamical phenomena and complex interactions. In this paper we use a simulation model that captures most of the dynamical characteristics and complexity of the network in order to approximate the nonlinear function in (1).

Let C_t be the total cost for the traffic flows at time t. Then the cost C_{t+1} could be computed using the predicted traffic state X_{t+1} generated by the traffic simulator. The problem for selecting baseline signal over a given time horizon T can be formulated as problem (2).

$$\begin{aligned} &\min_{U_t} C\left(X_{t:t+T}, U_{t:t+T-1}\right) = \sum_{k=1}^{T} C_{t+k}\left(X_{t+k}\right) \\ s.t. \quad & X_{t+1} = f\left(X_t, D_t, U_t\right) \\ & \text{given } X_t \text{ and } \{D_t, D_{t+1}, \ldots, D_{t+T-1}\} \end{aligned} \tag{2}$$

We solve the problem (2) in an iterative manner as Fig. 1. During the iterations, the network simulation models generate the predicted traffic lows of the network using the detected current network traffic flows and the expected demands. The proposed co-simulation-based optimization approach starts with an initial signal sequence generated by any other method such as model based predictive approaches. Then the controller keeps searching for new feasible signal sequences that reduce the cost function further till any one of the stopping criteria are satisfied such as the reduction of costs is less than a threshold value or the maximum number of iterations is exceeded. The current best signal sequence will be outputted as the resulted baseline signal and applied to transportation network through the signal controller. Otherwise, the iteration process will continue until stopping criteria achieves.

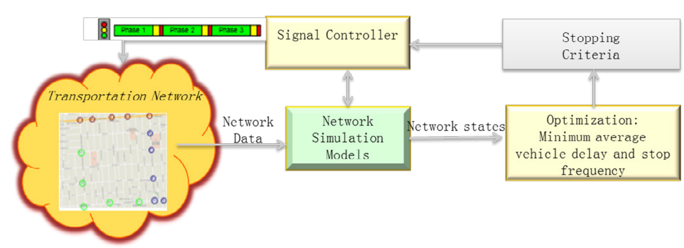

Fig. 1. Co-simulation-based optimization approach.

In the evaluation of this paper, the network simulation model is formulated with VISSIM, a microscopic and behaviour based simulation software. The microscopic simulation models could implement fast forward simulations for small and medium level of transportation networks. For the large scaled network, the macroscopic simulators based models are suggested in order to speed up the searching process.

The proposed approach can accommodate any quantifiable performance criteria that could be obtained or computed using simulations. They may include: 1) vehicle travel delay; the delay for one vehicle is the difference of the real travel time and the ideal travel time that could be achieved without any other vehicles, signal controls, and stops in its travel path. 2) Number of stops; the number of one vehicle is the number of the occasions when the vehicle comes to a standstill. 3) Environmental impact such as HC (hydrocarbon), CO_2 (carbon dioxide), NO_x (oxides of nitrogen), and vehicle fuel