Transportation Research Part C 60 (2015) 52–76

Contents lists available at ScienceDirect

Transportation Research Part C

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

An integrated real-time traffic signal system for transit signal priority, incident detection and congestion management

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ARTICLE INFO

Article history:
Received 22 February 2015
Received in revised form 24 June 2015
Accepted 7 August 2015

Keywords:
Traffic signal control
Incident detection
Transit priority
Congestion management
Micro simulation
Urban traffic networks

ABSTRACT

This paper presents a traffic control system that can work standalone to handle various boundary conditions of the recurrent, non-recurrent congestion, transit signal priority and downstream blockage conditions to improve the overall traffic network vehicular productivity and efficiency. The control system uses field detectors' data to determine the boundary conditions of all incoming and exit links. The developed system is interfaced with CORSIM micro-simulation for rigorous evaluations with different types of signal phase settings. The comparative performance of this control logic is quite satisfactory for some of the most frequently used phase settings in the network with a high number of junctions under highly congested conditions.

1. Introduction

According to the 2012 Urban Mobility Report (Lomax et al., 2012), the delay endured by an average commuter has considerably increased and the cost of congestion amounted to $120 billion in the USA. Lomax et al. (2012) also highlights that congestion has even emerged as a big problem outside of the rush hours, as 40% of the delay occurs in the mid-day and overnight hours. Non-recurrent congestions are also major contributors to delay.

Developing real-time systems to manage congestion conditions; both recurrent and non-recurrent congestion, has been the focus of many researches over the past three decades. This was occasionally coupled with transit signal priority systems (TSP), which emerged for their potential contributions to significant reductions of transit users travel times. Another addition to the congestion and the transit priority capabilities, which was rarely addressed in relevant systems, is enhancing ability of such systems to detect and as such react through some built–in strategies to incident situations particularly in urban streets. This could lead to significant reductions of operational cost and increase in network throughputs. Throughout the remaining part of this section a critical review is conducted on the research initiatives of relevance to such capabilities in order to highlight the potentials and challenges of such systems development.

According to Stevanovic (2010), existing signal control systems can handle the recurrent congestions efficiently, but they do not have the ability to cope up with non-recurrent congestions and sudden fluctuations of the traffic demand levels within a short period of intervals. This, in turn, leads to the lower efficiency (and/or lower productivity) of the existing traffic control systems in these conditions. Therefore, to overcome these limitations, *Adaptive Traffic Control Systems* (ATCSs) emerged to adjust signal timing plans in real time based on the current traffic conditions, demand and system capacity.

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http://dx.doi.org/10.1016/j.trc.2015.08.004
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The ATCS needs broader surveillance and a communication infrastructure for the purpose of communication with the central and/or local controllers.

Typically, the objective of traffic signal control algorithms is to optimize (minimize) some disutility function, such as, travel time, delay or number of stops, or maximize a utility function such as network throughput (He et al., 2011). For example, OPAC (the Optimization Policies for Adaptive Control, Gartner, 1982) aims to minimize delay, UTOPIA (Urban Traffic Optimisation by Integrated Automation, Mauro and Di Taranto, 1990) aims to minimize stops and delay, SCATS aims to maximize capacity (Lowrie, 1982), SCOOT aims to minimize stops delay and congestion (Hunt et al., 1981), PRODYN (Programming Dynamic, Henry et al. (1983)) aims to minimize total delay and MOVA aims to minimize stops, delay and maximize capacity simultaneously (Vincent and Peirce, 1988). Among these ATCSs, UTOPIA, SCOOT and SCATS are primarily centralized, but others are regarded as distributed control systems.

The majority of these systems utilize field detectors as the source of on-line data to estimate the targeted objective functions. Most of these systems change the current signal settings (i.e. adjust cycle, green splits, off-set and green extension) for some pre-determined set of signal phases. Some of these control systems have the ability to incorporate the transit signal priority at the local control level, but none of these seem to have the ability to incorporate or explicitly account for the incident condition of the associated road network.

Kosonen (2003) indicated that there are many variable and possibly opposing objectives for an area-wide signal control. Among the most common objectives are minimizing the overall vehicular delays, avoiding/reducing stops on main streets, or improving the public transport mobility. In coordinated control systems, the smooth traffic flows cannot be guaranteed for all directions equally. The integration of the signal controller with a TSP usually induces more travel times for passenger vehicles. Most of the studies on the TSPs have concluded various degrees of improvements to the travel times of the transit vehicles along the tested corridors.

Smith et al. (2005) listed the typical objectives of the TSP as (a) improved schedule adherence, (b) improved transit efficiency and (c) a contribution to enhanced transit information and increased road network efficiency. They also indicated that typical active TSP priority measures are: (a) green extension: the extension of a current green phase for the approaching TSP equipped vehicle, (b) early green: earlier start of the green time phase for the approaching TSP-equipped vehicle, (c) actuated transit phase: when a transit vehicle is detected, an actuated transit phase is displayed, (d) phase insertion: special priority phase is inserted within the normal signal phase sequence, and (e) phase rotation: the order of the normal signal phases is rotated to provide TSP.

In the very initial methods of TSP, called passive TSP, the priority operates continuously based on knowledge of transit route and ridership patterns without detectors. Passive priority becomes effective with high transit vehicle frequencies, predictable transit travel times, and overall light or moderate traffic volumes (Vincent et al., 1978).

Active priority strategies mandate transit vehicles detection using sensors. Three known different categories of transit vehicles detection technologies exist. These are: “infrastructure equipment only”, “on-bus and local infrastructure”, and “on-bus and central infrastructure” (Hounsell et al., 2004). The active priority is classified into “with” and “without” condition. In case of unconditional active TSP, there are no conditions placed on the type or schedule of the transit vehicle requesting priority. The conditional active TSP only grants priority based on a set of conditions and rules, such as whether or not the transit vehicle is behind schedule. This conditional active priority may involve an Automated Vehicle Location (AVL) system for measuring schedule adherence and reliable Automated Passenger Counter (APC) systems for measuring transit vehicle occupancy.

The most comprehensive strategy is adaptive TSP, which considers the trade-offs between transit and traffic delay and allows adequate adjustments of signal timing. It can also consider some other inputs, such as the number of passengers on board. Zhou et al. (2007) stated that the basis of TSP with adaptive signal control systems is to provide priority while simultaneously trying to optimize some given traffic performance criteria. The control strategies are continuously adjusted with the continuous monitoring of traffic conditions. TSP can be improved using the Predictive Priority Strategies that depend on series of detectors to track the vehicle and allows a green signal for that vehicle on the intersections in accordance with the set of control logic.

A higher level TSP concept provides more sophisticated TSP control but requires more technologies and equipment than a lower level concept (Shalaby, 2006). The differentiating elements of the various TSP technologies are mainly related to the type of technologies and methodologies used, and application context, such as single intersection or multiple intersections.

Advances in TSP technologies include the use of multi-objective optimization process and embedded rule base such as the work by Dion and Hellinga (2002). Parallel genetic algorithms were used in Zhou et al. (2007) through adaptive TSP strategy to optimize the phase plan, cycle length, and green splits at isolated intersections. Muthuswamy et al. (2007) developed an adaptive TSP algorithm and investigated several issues including the optimization of signal timing, the impact of TSP on side street traffic and on heavily congested intersections. Stevanovic et al. (2008) used Genetic Algorithm based optimization tool. The study showed that optimization of the transit priority settings has significant impact on travelers’ delays in corridors with mixed traffic and transit operations. Ghanim et al. (2009) presented an integrated real-time traffic signal controller with a Genetic Algorithm based traffic signal timing optimization technique and an Artificial Neural Networks based TSP control. Typically, the optimization of transit priority is addressed with a localized focus on the subject intersection only. Mesbah et al. (2011) developed an optimum combination of exclusive transit lanes on a network basis.

TSP would be most effective under a traffic condition that has moderate-to-heavy bus approach volume, little or no turning movement hindering the bus movement, slight-to-moderate cross street v/c ratio, far-side bus stop, and signal