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Transit signal priority accommodating conflicting requests under Connected Vehicles technology

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ABSTRACT

In this research, a person-delay-based optimization method is proposed for an intelligent Transit Signal Priority (TSP) logic that resolves multiple conflicting TSP requests at an isolated intersection. This TSP with Connected Vehicles accommodating Conflicting Requests (TSPCV-CR) overcomes the challenge bore by the conventional "first come first serve" strategy and presents significant improvement on bus service performance. The feature of TSPCV-CR includes green time re-allocation, simultaneous multiple buses accommodation, and signal-transit coordination. These features help maximize the transit TSP service rate and minimize adverse effect on competing travel directions. The TSPCV-CR is also designed to be conditional. That is, TSP is granted only when the bus is behind schedule and the grant of TSP causes no extra total person delay. The optimization is formulated as a Binary Mixed Integer Linear Program (BMILP) which is solved by standard branch-and-bound routine. Minimizing per person delay is the objective of the optimization model.

The logic developed in this research is evaluated using both analytical and microscopic traffic simulation approaches. Both analytical tests and simulation evaluations compared three scenarios: without TSP (NTSP), conventional TSP (CTSP), and TSP with Connected Vehicles that resolves Conflicting Requests (TSPCV-CR). The measures of effectiveness used include bus delay and total travel time of all travelers. The performance of TSPCV-CR is compared against conventional TSP (CTSP) under four congestion levels and three different conflicting scenarios. The results show that the TSPCV-CR greatly reduces bus delay at signalized intersection for all congestion levels and conflicting scenarios considered. Simulation based evaluation results show that the TSPCV-CR logic reduces average bus delay between 5% and 48% compared to the conventional TSP. The range of improvement corresponding to the four different v/c ratios tested, which are 0.5, 0.7, 0.9 and 1.0, respectively. No statistically significant negative effects are observed.

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1. Introduction

Transit Signal Priority (TSP) is a traffic signal control technique that reduces transit buses' delay at the signalized intersections by adjusting signal timing plan according to bus arrivals. This technique has been widely applied to improve transit

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service quality and increase bus ridership. It has become one of the most important treatments of public transportation system in major cities, such as Seattle, USA, Los Angeles, USA, Beijing, China and Tokyo, Japan (Liao and Davis, 2007).

Conventional TSP is not perfect as it has potential adverse effect on other traffic users. It has been dragging the promotion of TSP. This shortcoming was first revealed by Salter and Shahi (1979) that the conventional TSP causes significant delay on competing travel directions and breaks traffic progression. The compromised progression could take hours to recover during peak hours (Shalaby et al., 2006). Since then, various new mechanisms have been proposed trying to overcome the adverse effect (Jacobson and Sheffi, 1981; Khasnabis et al., 1991; Chang and Messer, 1985; Garrow and Machemehl, 1997; Muthuswamy et al., 2007; Al-Sahili and Taylor, 1996; Pratt et al., 2000; He et al., 2014). Nevertheless, they all kept the same conventional signal strategies which are "green extension" and "red truncation" (Lee et al., 2005). This feature greatly impacts the effectiveness of their upgrades, since these conventional strategies by nature sacrifice the capacity of the competing travel direction.

Furthermore, the benefit of the conventional TSP is not usually noticeable by human drivers. It is because the conventional TSP only provides preference to a small percentage of the bus fleet. Only the buses that arrive during the green extension window could be accommodated. Even if the maximum green extension time (1/5 of cycle length (Chatila and Swenson, 2001)) is adopted, theoretically only up to 20% of buses could experience the travel time savings.

To address the shortcomings of conventional TSP, various new TSP strategies have been invented. For instance, "green time insertion" at all phase transitions (Balke et al., 2000), cycle extension during rush hours (Ekeila et al., 2009), TSP green time compensation, phase skipping, and TSP enabled adaptive signal control (Liao and Davis, 2007; Chang et al., 1996). Fundamentally, these newly developed TSP strategies have the same objective which is increasing the portion of buses that could receive TSP while, at the same time, reducing the sacrifice of the competing movement groups. This objective was advanced to its limit by the authors of this paper. A next generation TSP strategy was proposed using Connected Vehicles technology (TSPCV) (Hu et al., 2014) which increased the portion of TSP buses receiving the priority to the maximum and reduced the sacrifice of the competing movements to the minimum. The key features of the TSPCV are green time re-allocation and bus-signal coordination. Green time re-allocation divides and reassigns original green time as TSP green instead of adding extra green time. Therefore, no sacrifice is needed from the competing travel direction. The relocated TSP green time could start at any time corresponding to buses' arrivals. When green time re-allocation is not feasible due to minimum green time requirement, buses adjust their speed to avoid infeasible time window to coordinate with signal and receive TSP. As a result, portion of TSP buses is raised up to approximately 100%. This coordination between transit and signal control also allows TSP green to start when minimum progression interference is caused to the competing traffic direction. Therefore, the sacrifice from the competing street is reduced to the minimum. Evaluation results showed that the TSPCV reduces bus delay up to 84% compared to conventional TSP.

Like many other advanced TSP strategies (Liao and Davis, 2007; Balke et al., 2000; Chang et al., 1996; Ekeila et al., 2009), the TSPCV was developed for single bus scenario only. In case that multiple conflicting TSP requests were received, the system was designed to serve the first request only. However, it was discovered that the current "first come, first serve" way of solving conflicting priority requests not only does no benefit but also deteriorates the TSP system. A 13% extra bus delay was observed with first-come-first-serve strategy compared to no-TSP option (Zlatkovic et al., 2012). Therefore, it is important to upgrade the previously developed TSPCV strategy (Hu et al., 2014b) to be capable of accommodating multiple conflicting TSP requests.

Studies have been conducted to investigate the problem of resolving conflicting TSP requests. Ma et al. (2013) and Ma and Bai (2008) developed two methods accommodating multiple TSP requests. The first is a passive bus priority for exclusive bus lane that maximizes person capacity (Ma et al., 2014), and the other uses decision tree method to decide serving sequence (Ma and Bai, 2008). He et al. presented a heuristic algorithm which reduces up to 50% of the bus delay compared to the "first come first serve" policy (He et al., 2011). Zlatkovic et al. proposed a rule-based logic which always provides priority first to the direction with the green phase on (Zlatkovic et al., 2012). This algorithm shows a benefit of more than 30% reduction on bus delay.

The TSPCV strategy requires its own enhancement to accommodate conflicting TSP requests. Firstly, the aforementioned conflicting TSP resolving logic (Ma et al., 2014; Ma and Bai, 2008; He et al., 2011; Zlatkovic et al., 2012) were developed for the basic two conventional TSP strategies: "green extension" and "red truncation" (Lee et al., 2005). They are not applicable towards advanced TSP strategies like the green re-allocation. Secondly, and more importantly, with the transit-signal coordination feature, TSPCV could guide multiple buses to be discharged within one single TSP green time. This is a feature that could double benefit and has never been investigated before. Hence, the development of an enhanced TSPCV logic is essential and is a goal of this research.

This research also aims to improve the generalization of the TSPCV logic. The previously developed TSPCV logic was designed for a specific intersection in Charlottesville, VA. In order to make the logic applicable to any isolated intersections, the problem is formulated as a Binary Mixed Integer Linear Programs (BMILP) which is solvable by any standard branch-and-bound routine.

1.1. Research objective

Therefore, the purpose of this research is to further advance the TSPCV logic into an upgraded version which will have the following features: