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Bus control strategies in corridors with signalized intersections

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ABSTRACT

This paper proposes a new dynamic bus control strategy aimed at reducing the negative effects of time-headway variations on route performance, based on real-time bus tracking data at stops. In routes with high demand, any delay of a single vehicle ends up causing an unstable motion of buses and producing the bus bunching phenomena. This strategy controls the cruising speed of buses and considers the extension of the green phase of traffic lights at intersections, when a bus is significantly delayed. The performance of this strategy will be compared to the current static operation technique based on the provision of slack times at holding points. An operational model is presented in order to estimate the effects of each controlling strategy, taking into account the vehicle capacity constraint. Control strategies are assessed in terms of passenger total travel time, operating cost as well as on the coefficient of headway variation. The effects of controlling strategies are tested in an idealized bus route under different operational settings and in the bus route of highest demand in Barcelona by simulation. The results show that the proposed dynamic controlling strategy reduces total system cost (user and agency) by 15–40% as well as the coefficient of headway variation 53–78% regarding the uncontrolled case, providing a bus performance similar to the expected when time disturbance is not presented.

1. Introduction

The reliability of transit modes is an important issue to ensure their competitiveness against the extended use of private cars in major cities. However, in overall surface transit services with partial right of way, route travel times are highly dependent to transit demand and traffic states. There are several reasons in these systems that cause service disruptions such as illegal freight loading/unloading operations, taxi stops, use of bus lanes by slow vehicles (bikes, street sweepers) or car merging operations due to right turns. These facts, combined with transit demand fluctuations at stops and traffic light settings, make it difficult to maintain time-headway adherence and control the transit system performance. In bus routes with high demand, when a single bus is delayed from its schedule, the number of waiting passengers will increase at the following stops, resulting in a higher vehicle delay. This local disruption propagates to the whole fleet producing vehicle bunching, irregular vehicle arrivals at stops, unstable time-headways and higher user waiting times.

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Some research has been done to describe the dynamic performance of the bus system operations. Newell and Potts (1964) and Osuna and Newell (1972) were the first contributions that described the unstable performance of a cyclic bus fleet operation. In order to tackle the bus bunching problem, several control strategies are available. Traditionally, the bus pairing has been mitigated allocating slack times in bus schedules at determined stops (holding points) along the route (Barnett, 1974; Turnquist, 1981; Rossetti and Turitto, 1998). Slack times should compensate the delays of those buses experiencing random disruptions so that the schedule adherence would be still satisfied. Nevertheless, the obligation that all buses must remain a common slack time in a holding point represents a reduction of commercial speed. Indeed, it causes a significant inefficiency in the system's productivity. Moreover, this control strategy for maintaining the schedule of a single bus, does not take into account the real performance of the others. Therefore, some studies propose dynamic control strategies to monitor the response of the whole fleet to random disruptions in a short time horizon (Eberlein et al., 2001; Dessouky et al., 2003; Adamski and Turnau, 1998). These contributions determine the location of a holding point and a specific amount of slack time for each bus, based on suboptimal procedures and the dynamic bus performance data. Real-time information is supposed to be available, as Automated Vehicle Location (AVL) and Automatic Passenger Counter (APC) systems will be equipped in the vehicles. In Yu and Yang (2007) an improved holding-point optimization procedure is presented based on genetic algorithms to minimize total passenger costs. Other contributions develop optimization models based on holding points and stop skipping strategy, where the performance of the bus system is predicted over a rolling horizon. This prediction is made considering that all variables are deterministic and known in advance (Delgado et al., 2012) or even stochastic (Sáez et al., 2012; Cortés et al., 2010). Fonzone et al. (2015) proposed bus overtaking at stops in order to accommodate better the waiting passengers in buses that didn't reach its vehicle capacity constraint.

Although the previous contributions are generally based on short term predictions of the system behavior, other approaches propose adaptive strategies to the real performance of buses. They actuate over the system variables in the inter-station segments of a single bus route. Based on control theory principles, Daganzo (2009) defines an adaptive variable cruising speed patterns for public transportation vehicles. This control strategy may be conceived as dynamic holding times in a segment of the route: if a fast vehicle is catching up the vehicle ahead, the speed of the former vehicle is linearly reduced with regard to the difference between the target and the actual headway. The results provided by this method outperform the former static holding point strategies in terms of system productivity and regularity. Nevertheless, this procedure does not respond properly when the headway adherence is significantly poor. Daganzo and Pilachowski (2011) improved the determination of the cruising speed pattern when the time-headway variance is significant. In Xuan et al. (2011), a family of dynamic holding strategies are presented to improve both user and operating costs. This method improves the efficiency of existing control strategies since it minimizes the required slack times by 40% compared to conventional schedule-based methods. In Bartholdi and Eisenstein (2012), a method based on Markov-chains is presented where headways are dynamically self-equalized to a natural value. In addition to that, Argote-Cabanero et al. (2015) extends a dynamic control method for several interacting bus routes. The proposed method consists of a combination of dynamic holding and driver guidance that shows the proper cruising speed of buses along the route based on real-time data.

As is stated in Muñoz et al. (2013), previous contributions based on control theory assume that buses have infinite capacity to accommodate all the passengers waiting at stops. However, the scalable reduction of bus speeds in high transit demand corridors may lead to a problem of vehicle capacity. Experience shows that some users cannot get on overcrowded buses arriving at the stop and need to wait to the following transit vehicles. Indeed, both holding point and dynamic speed strategies are aimed to guarantee the time-headway adherence at the expense of losing commercial speed (in the whole fleet or passenger travel time) and increasing operating costs. Nevertheless, few contributions assessed the cost in which transit agencies will incur to deal with bus bunching. Indeed, transit agencies would take advantage of dynamic transit signal priority measures in order to minimize the reduction of the vehicle speed due to the time spent at holding points. In TRB (2013) there is an extended analysis of different techniques of transit vehicle actuated strategies that design off-line and on-line synchronization of traffic signals. The connection of buses to the transit control center (TCC) and the deployment of a coordinated Transit System Priority (TSP) system may significantly reduce the bus delay by 55–75% with regard to static transit priority systems (Hu et al., 2015).

To our knowledge, there are no contributions analyzing how traffic signal priority may help the system to maintain a good regularity. Therefore, this paper proposes an adaptive dynamic bus control strategy, based on active signal priority for buses. Taking into account real-time headway information and traffic signal variables, we propose an adaptive transit speed pattern combined with a signal offset modification at specific intersections, to avoid the bus bunching effect. The adaptive transit speed pattern has been adapted from the contributions of Daganzo (2009) and Daganzo and Pilachowski (2011). All stops are conceived as check points where the time-headway adherence control is estimated using AVL technologies. When the time-headway of one bus (with respect to the bus ahead) is larger than a targeted value, the green phase of downstream traffic lights may be extended (constrained to a maximum value) to allow the bus to pass through the signal without stopping. At the same time, the speed of buses showing smaller time-headways with regard to the target value with the vehicle ahead, will be reduced. However, in this paper, this speed reduction is lower than the presented in Daganzo and Pilachowski (2011). This strategy outperforms comparatively user costs and the coefficient of headway variation with regard to existing control procedures. Besides, it also improves the operating costs, since no additional vehicles are required in comparison to slack time strategies. Moreover, the modeling approach alleviates some of the drawbacks of the former contributions as stated in Muñoz et al. (2013): the occupancy of the vehicles is considered when activating the control criteria. However, it requires that APC systems should be deployed in vehicles to put in practice these control strategies.