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Modelling bus bunching and holding control with vehicle overtaking and distributed passenger boarding behaviour

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ABSTRACT

Headway fluctuation and bus bunching are commonly observed in transit operations, while holding control is a proven strategy to reduce bus bunching and improve service reliability. A transit operator would benefit from an accurate forecast of bus propagation in order to effectively control the system. To this end, we propose an 'ad-hoc' bus propagation model taking into account vehicle overtaking and distributed passenger boarding (DPB) behaviour. The latter represents the dynamic passenger queue swapping among buses when bunching at bus stops occurs and where bus capacity constraints are explicitly considered. The enhanced bus propagation model is used to build the simulation environment where different holding control strategies are tested. A quasi first-depart-first-hold (FDFH) rule is applied to the design of schedule- and headway-based holding control allowing for overtaking, with the objective to minimise the deviation from the targeted headway. The effects of control strategies are tested in an idealised bus route under different operational setting and in a real bus route in Guangzhou. We show that when the combined overtaking and queue-swapping behaviour are considered, the control strategies can achieve better headway regularity, less waiting time and less on-board travel time than their respective versions without overtaking and DPB. The benefit is even greater when travel time variability is higher and headway is smaller, suggesting that the control strategies are preferably deployed in high-frequency service.

1. Introduction

The effectiveness of public transport system can be measured by its reliability. In uncontrolled bus systems, bus bunching is prevalent especially in the peak hours. Bus bunching occurs when two or more buses along the same route arrive at a designated stop simultaneously. This is undesirable for both passengers and transit operator since it leads to unexpectedly longer waiting times and degraded service reliability of public transport system (Hollander and Liu, 2008).

A series of factors contribute to bus bunching, such as stochastic running times and demand, vehicle capacity, driving manoeuvres, and passenger boarding behaviour. Among the driving manoeuvres, bus overtaking is one that is commonly observed in real life. Such phenomenon can take place between stops or at bus stops. The former is mainly due to stochastic travel times, whereas the latter often corresponds to scenarios whereby a late arrival bus departs earlier due to fewer queuing passengers. The performance of bus scheduling is closely related to both temporal and spatial distributions of pas-

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sengers and available fleet (Sorratini et al., 2008; Liu and Sinha, 2007). Intuitively, there are two processes going on during bus service at stops. One is passengers' boarding and alighting process, and the other is the bus arrival process which forms bus bunching at the stopping area (Bian et al., 2015). Accordingly, passengers would make their decisions as to which bus to board in response to bus arrival status at stops. When bus bunching occurs, passengers waiting at the stop may not always board the first arriving bus, instead they may autonomously swap queues over bus platoon to reduce their waiting time, assuming that the other bus also serves the same destinations. These microscopic behaviours are likely to have an impact on the performance of bus bunching and holding control.

To reduce bus bunching, a variety of corrective actions have been proposed in the literature. Within the family of dynamic control strategies, holding is the most commonly used. Holding control works by delaying buses at stops to regularise bus headway and reduce the overall passenger waiting time, possibly at the expense of extending on-board waiting time and total riding time. A well-designed holding strategy can improve the efficiency of a transit system by increasing its effective capacity and vehicle utilisation. However, if poorly designed, the overall bus frequency would be reduced and the efficiency of a transit system worsened. One of the greatest problems facing transit agencies is maintaining service reliability while achieving high efficiency. It is clearly beneficial to mitigate the negative effects of holding control. Since overtaking provides some flexibility for bus motion, more efficiency could be expected by allowing buses to overtake each other. At the same time, the passenger queue swapping behaviour can also balance the queue lengths and thus the load over buses. Most of the existing literature on bus propagation and holding control strategies presents simplified models without consideration of overtaking or passenger queue swapping behaviour. To increase the operational efficiency and behavioural realism, we set out in this paper to investigate bus propagation and holding control with these realistic characters.

Our primary objective in this paper is to identify possible measures that could help operators and decision makers to realise the full potential of holding control schemes, more specifically by including overtaking and passenger queue swapping behaviour in the design of the control strategies. We achieve this firstly by developing a new bus motion model which accounts explicitly for the stochastic attributes and overcrowding effect caused by vehicle capacity. Secondly, the new bus motion model is further extended to embed holding control rules. We develop the holding control strategies for both the schedule- and headway-based approaches. The holding control strategies are tested through case studies both for a hypothetic and a simulated real-life bus route. Our findings show that the inclusion of overtaking and passenger queue swapping behaviour can greatly increase the efficiency and accuracy of holding control strategies. We thus suggest that the performance of control policies can be improved in an ad-hoc manner, which provides managerial insights for bus operational control.

The remainder of this paper is organised as follows. In Section 2, we discuss the relevant literature. In Section 3, simulation frameworks for bus propagation are developed. In Section 4, holding control models are developed based on the new bus propagation model. In Section 5, a number of indicators are proposed. In Section 6, we verify the effectiveness of the proposed methods through an idealised bus line and a real bus line in Guangzhou, China. Finally, Section 7 draws conclusions of the study and discusses the practical implications on bus operational control.

2. Literature review

There is an extensive literature on bus control strategies for improving service reliability. The analysis of bus bunching was pioneered by Newell and Potts (1964) for a single bus line. They described how a small initial delay from a designated bus stop propagates along the bus route, and the conditions for service recovery. Fonzone et al. (2015) studied the impact of passengers' timetable behaviour on bus bunching. They showed that the bus bunching phenomenon is in part due to such passengers' timetable behaviour. Schmöcker et al. (2016) investigated the influence of common line stops on bus bunching, and they found that the presence of common lines have positive effects when overtaking is possible. Their analysis, however, ignores bus capacity constraints. Since the Newell and Potts' model, a variety of solutions has been proposed to improve bus service reliability. A sampling of control strategies includes: holding control (e.g., Wu et al., 2016; Hernandez et al., 2015; Dessouky et al., 1999; Daganzo, 2009; Hickman, 2001), boarding limits (Delgado et al., 2012), bus speed control (Daganzo and Pilachowski, 2011) and stop skipping (Sun and Hickman, 2005). Among them, bus holding control strategy is the most commonly adopted method. The design of a holding strategy is to determine whether a vehicle should be held and for how long at a given control point. The objective of holding control is to keep the sequence of vehicle headway regularity, or minimise the total passenger cost along the route.

The holding controlling approaches can be classified into three groups, namely, schedule-based control, headway-based control and optimisation-based control. The first two approaches are triggered by bus arrival time deviations and headway variations, respectively, while the third approach optimises holding times by formulating holding control as a mathematical programming problem where the objective function is cost or time based. They are implemented through building slacks in the schedule at designated time points, in which the slacks are predetermined and static for schedule-based control while in headway- and optimisation-based holding strategies the slacks are determined in real-time. Under schedule-based control policy, drivers are instructed to hold until scheduled departure time in case of early arrival, while late arriving buses leave the stop immediately after completing serving passengers (Wirasinghe and Liu, 1995). Osuna and Newell (1972) studied the holding problem at a single service point for an idealised cycle route, aiming at minimising the total waiting time of passengers over a long time. Hickman (2001) derived an analytical model to determine the optimal holding time at a control stop along a bus route considering the stochastic running time and the interaction between passengers and buses.