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Bus bunching along a corridor served by two lines

Jan-Dirk Schmöcker[a,*], Wenzhe Sun[a], Achille Fonzone[b], Ronghui Liu[c]

[a] Department of Urban Management, Kyoto University, Japan
[b] Transport Research Institute, Edinburgh Napier University, U.K
[c] Institute for Transport Studies, University of Leeds, U.K.

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ABSTRACT

Headway fluctuations and “bus bunching” are well known phenomena on many bus routes where an initial delay to one service can disturb the whole schedule due to resulting differences in dwell times of subsequent buses at stops. This paper deals with the influence of a frequent but so far largely neglected characteristic of bus networks on bus bunching, that is the presence of overtaking and common lines. A set of discrete state equations is implemented to obtain the departure times of a group of buses following the occurrence of an exogenous delay to one bus at a bus stop. Two models are distinguished depending on whether overtaking at stops is possible or not. If two buses board simultaneously and overtaking is not possible, passengers will board the front bus. If overtaking is possible, passengers form equilibrium queues in order to minimise their waiting times. Conditions for equilibrium queues among passengers with different choice sets are formulated. With a case study we then illustrate that, if overtaking is not allowed, the presence of common lines worsens the service regularity along the corridor. Conversely, common lines have positive effects when overtaking is possible. We suggest hence that appropriate network design is important to reduce the negative effects of delay-prone lines on the overall network performance.

1. Introduction

The lack of bus service reliability is a major problem for bus passengers and service operators. A key feature of an unreliable service is the irregular arrivals of buses at stops. The effect of two successive services of a single line arriving at stops with shorter than designed headways is generally defined bus bunching. Bus bunching is undesirable for passengers because it reduces the predictability of bus arrival times and leads to on average increased waiting times at stops. This is particularly important sine studies have shown that passengers value their time waiting at bus stops more than they do to on-board travel time. For example, Hollander and Liu (2008) found that the value of service reliability to bus passengers is four times higher than that of mean travel time.

Bus bunching may be caused by the first service being delayed due to unforeseen traffic congestion en-route or unplanned high demand at previous stops. A further contributing factor is the differences in bus driver behaviour. If for any of these reasons a bus is delayed, the subsequent service then has fewer passengers to pick up at that stop and departs earlier than scheduled. At downstream stops the effect is emphasised as the (small) delay to the first vehicle and the (slight) early

* Corresponding author.
E-mail addresses: schmoecker@trans.kuciv.kyoto-u.ac.jp (J.-D. Schmöcker), wz.sun@trans.kuciv.kyoto-u.ac.jp (W. Sun), a.fonzone@napier.ac.uk (A. Fonzone), r.liu@its.leeds.ac.uk (R. Liu).

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arrival of the second vehicle result in increasingly longer dwell times for the first bus and increasingly shorter dwell times for the second bus.

The bus bunching effect on a single line of service was first described in a seminal work by Newell and Potts (1964). They studied an idealised corridor with evenly spaced bus stops, identical travel times between stops, and constant passenger loads at bus stops. Given a small delay of the first bus at a stop, Newell and Potts provide an analytical formulation of the deviation of bus arrival time to schedule for all buses and at all subsequent stops. They show that adjacent buses alternate between behind and ahead of schedule, leading to bus bunching. The scale of the bunching effect and the stability of the bus system is affected not only by the size of the original delay to the first bus, but also by the ratio (referred to as the k value later) between passenger arrival rate and loading rate. They show that if $1/2 < k < 1$, instability occurs. In practice, however, one would expect the passenger arrival rate to be much smaller than the loading rate, i.e. $0 < k < 1/2$. In this case, Newell and Potts show that the system can recover from the original perturbation and return to schedule. Potts and Tamlin (1964) offered some empirical support, based on experimental investigations of bus bunching in Adelaide, Australia. They showed that the pairing of buses is in part due to the variations in passenger loading time. The analytical expression of Newell and Potts is in terms of the time a bus leaves a stop (see full description in Section 3). Chapman and Michel (1978) provided a different expression, in the form of the time between the departure of one bus from a stop and the arrival of the next. It is a more direct measure for bus pairing, and they used the method to identify the bus stop where bunching occurs. Since these earlier papers on bus bunching, much of the research has been to design and test means to control irregularities in bus operations so to reduce the bunching effect. In particular holding strategies for headway keeping and/or schedule-adherence have been analysed and shown to be successfully applied in literature. The holding objectives are different for low- and high-frequency services. For low-frequency systems, loosely defined as those that run at a headway of 10 min or longer (Jolliffe and Hutchinson, 2001), holding strategies are implemented through building slacks in the schedule at key timing points and holding buses at these points to keep them to schedule (e.g. Osuna and Newell, 1972; Newell, 1974; Cats et al, 2012). For high-frequency systems, however, the holding strategies aim to maintain regularity in headways (e.g. Eberlein et al., 2001; Hickman, 2001). Due to the complexity of the problem, most of these early studies involve solving just one controlled timing point. Using a simulation approach, Hickman (2001) derived a set of static holding solutions, which do not respond to dynamical changes in the actual bus performances on the day. Eberlein et al (2001) proposed a model for dynamical bus holding which takes real-time information on bus headways into consideration and strives to minimise passenger waiting time. Liu and Sinha (2007) showed a clear correlation between headway regularity and passenger wait time delays.

Employing real-time bus positioning data, now widely available, Daganzo (2009) explored a more systematic approach to the dynamical holding problem. The method is able to consider holding at multiple timing points, therefore providing opportunity for returning to schedule for long bus route. In addition, the model takes into account random effects in bus travel time, bus dwell time and passenger demand, making it resemble more closely to real-life situations. Daganzo and Pilachowski (2011) proposed an adaptive bus control scheme based on a two-way bus-to-bus cooperation, where a bus adjusts its speed to both its front and rear headways. They show that the scheme yields significant improvements in bus headways and bus travel time. Pilachowski (2009) proposed to use GPS data to counteract directly the cause of the bunching by allowing the buses to cooperate with each other and to determine their speed based on relative position. Bartholdi and Eisenstein (2012) formalised the method as a self-coordinating strategy to equalise bus headway. Recently, Hernández et al. (2015) developed an optimal holding strategy, for a common-line corridor where two bus lines serve the same sub-set of stops. They showed that the holding strategy significantly reduced the overall waiting time of the passengers as well as reduced bus headway variation, compare to a no control scenario. Sun and Schmöcker (2016) analysed the effect of different passenger distributions on bus bunching. They show that an “ad hoc control strategy” whereby passengers are asked to board a latter bus could reduce the bunching effect. Their analysis is though also limited to buses of the same line, i.e. ignoring common lines.

Despite these recent developments, most of the existing studies present an oversimplified model of the bus bunching phenomenon, notably with a single line of service (with the exception of the recent work of Hernández et al. (2015)), with fixed service frequency, uniformly distributed (in time and space) passenger flows, and no bus overtaking. They neglect important aspects of real-life bus systems, such as passenger behaviour, en-route service perturbation, transport operator policies such as holding and overtaking, and complex network features such as common lines. Newell and Potts (1964), for instance, assume fixed frequency, constant dwell times, equal-distance stops and equal-travel time between stops, and that buses cannot overtake. In real-life situations, busy urban corridors are often served by multiple lines of bus services, with different frequencies and different sequence of stops. Further, traffic congestion causes uncertainty in bus run time, buses overtake one another at bus stops. Boyd (1983) presented empirical evidence which demonstrated the impact of variability in bus journey time on bunching.

Another significant simplification in the existing studies is the assumption of random arrivals of passengers to bus stops, and the uniform passenger demand distribution over time and space. Bowman and Turnquist (1981) argue that passengers will, to some extent coordinate their arrivals to coincide with the scheduled service in an attempt to reduce their wait time, and that more reliable service would encourage such arrival behaviour. Using a passenger choice behaviour model, they demonstrate that passengers are more sensitive to schedule reliability than to service frequency. Nagatani (2001) shows a strong relationship between bus delay and the passenger number on-board, and proposed skipping a bus stop as a way of keeping to schedule. Liu and Sinha (2007) collected data on bus travel time, dwell time, and passenger boarding and