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A model of bus bunching under reliability-based passenger arrival patterns ☆

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ABSTRACT

If bus service departure times are not completely unknown to the passengers, non-uniform passenger arrival patterns can be expected. We propose that passengers decide their arrival time at stops based on a continuous logit model that considers the risk of missing services. Expected passenger waiting times are derived in a bus system that allows also for overtaking between bus services. We then propose an algorithm to derive the dwell time of subsequent buses serving a stop in order to illustrate when bus bunching might occur. We show that non-uniform arrival patterns can significantly influence the bus bunching process. With case studies we find that, even without exogenous delay, bunching can arise when the boarding rate is insufficient given the level of overall demand. Further, in case of exogenous delay, non-uniform arrivals can either worsen or improve the bunching conditions, depending on the level of delay. We conclude that therefore such effects should be considered when service control measures are discussed.

1. Introduction

Service irregularities increase passenger waiting times, decreasing the attractiveness of public transport. The more the passengers can trust the service schedule, the better they can time their arrival at stops. Whereas under completely random service arrivals the passengers can also do no better than "randomly" arrive at stops, in many cases at least some coherence of the actual arrivals with the service schedule might be expected. Therefore, even if the schedule might not be known to all passengers and uncertainties in the access time to the stop are considered, non-uniform passenger arrival patterns can be expected. With a few exceptions, the effect of such non-uniformity on bus loads has been largely ignored in the literature and is the topic of this contribution.

We propose a "mixed behaviour": Passengers consider the likely service departure times and leave some safety margins in order to ensure that they do not have to wait too long for a bus but also minimise the chances of missing a service. Such a behaviour seems reasonable for passengers in cities with fairly good bus services. As a motivating example familiar to the authors, consider the bus stop in front of Kyoto University. The stop is close to the office buildings and the most frequent service arrives around every 15 min during the evening hours. Some passengers, possibly those without knowledge of the schedule, will arrive randomly though the bulk of passengers will time their arrival to 2–3 min before scheduled service

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arrival. Some "risky" passengers, or those delayed by for example waiting times at the elevator, will arrive even closer to the scheduled departure.

In general, it is well known that passenger arrival is influenced by service characteristics, such as average value of headways and headway deviations. In particular, it is commonly accepted that passengers tend to arrive closer to the scheduled departure time (i.e., their arrivals are not uniform) when the headways are large. This behaviour is often termed as scheduled-based arrival behaviour. Bowman and Turnquist (1981) provide a model of passenger arrival behaviour, which links the arrival distribution to the characteristics of the service, including its reliability.

Therefore a good understanding of arrival patterns is the foundation to modelling boarding demand. Deriving bus loads is important to estimate potential capacity bottlenecks and possibly revenue splits among bus operators. Furthermore, bus loads and bus service dwell times at stops are closely correlated, and unexpected high loads can lead to the well-known "bus bunching" process. The seminal work of Newell and Potts (1964) presents a simplified model of the phenomenon, which casts light on some causes. However, their model does not provide a realistic representation of bunching as they neglect aspects such as en-route service perturbations, transport operator policies concerning holding and overtaking as well as complex network features such as the presence of "common lines" among which some of the passengers at a stop might choose. Some of these issues have been dealt with in later literature as reviewed in more detail in the next section.

Newell and Potts further assume uniform passenger arrival. In the above Kyoto bus stop example this might overestimate the bunching phenomena as only a few additional passengers arrive in the time interval between the scheduled and actual service departure and hence delayed buses have to board fewer additional passengers than predicted with uniform arrival. Furthermore, Newell and Potts do not capture the effect of severe bunching where buses might be overtaken.

The contributions of this paper are twofold. Firstly, a model of passenger arrival extending the approach of Bowman and Turnquist (1981) to allow for overtaking between buses at a stop. We refer to our model as the "reliability-based arrival pattern model" in line with the above example. Secondly, we include these passenger arrival patterns in a model of bus propagation, highlighting causes of bunching which are not identified by Newell and Potts.

In line with above discussion, our model will be mainly applicable to situations in which passengers consider timetables in deciding their arrival at stops. It is conventionally accepted that timetables influence passengers decisions for services with expected headways of more than 10 min and that, instead, if service headways are shorter, uniform passenger arrival patterns can be expected. Actually the threshold between schedule-dependent and uniform passenger arrival can be lower than the conventional one. A review of existing studies on the relation between service headway and passenger arrival at stops is provided by Luethi et al. (2007). Interestingly, this study finds that passengers consult schedules even when the headway is 5 min. We consider the topic discussed in this paper especially of topical importance due to the increasing presence of service schedule information to passengers before arrival at a stop even for passengers unfamiliar with the network due to online availability of journey planners. More and more cities now provide real-time information (RTI) for passengers. RTI changes the "visibility of the network" and hence passenger behaviour. For instance, it is reasonable to expect that ubiquitous RTI on departure time (accessed by internet and/or mobile phone apps) induces non-uniform passenger arrivals also for short headways and irregular services.

The reminder of this paper is organized as follows: Section 2 provides a more detailed review of the two key references for this paper, Newell and Potts (1964) and Bowman and Turnquist (1981) as well as further related and newer literature. Section 3 then introduces the notation that is utilized in later sections. Section 4 describes the passenger arrival model and Section 5 the bus propagation model. Section 6 illustrates both models through case study applications before Section 7 concludes this paper.

2. Literature review

Bus bunching is generally defined as the effect of two successive services of a single line arriving at stops with shorter than scheduled headways. The effect occurs by the first service being delayed at previous stops due to unplanned long boarding times, or being delayed en-route by unforeseen traffic congestion. The subsequent service then has to pick up fewer passengers at that stop and departs earlier than scheduled. At downstream stops, the effect is further emphasised as the initial delay to the first vehicle and the early arrival of the subsequent service result in increasingly longer dwell times for the first bus and increasingly shorter dwell times for the second bus.

Bus bunching has a direct negative impact on the passengers as it leads to, on average, longer dwell-times. Quarmby (1967) already found that transit passengers value their time waiting two to three times more than their time on board travelling. Subsequent literature has confirmed this, sometimes reporting even higher disutility associated with waiting. Using a stated-preference survey, Hollander and Liu (2008) found that bus passengers value service reliability four times higher than they do to mean travel time. Hollander et al. (2007) further demonstrate that bus unreliability has a significant impact on passengers' response in their departure-times.

Bus bunching is a common feature in urban public transport, and a long-standing problem facing the bus/transit service providers and academic researchers alike. The bunching effect on a single line has been first analytically described by Newell and Potts (1964). Assuming that travel times between stops are identical and that passenger loads are constant, Newell and Potts show that if the passenger arrival rate at a stop is larger than half the loading rate of buses the bunching effect occurs for small perturbations in the original schedule. If the ratio (referred to below as ρ-ratio) is smaller, the system can recover