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Models of bus boarding and alighting dynamics

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ABSTRACT

Understanding the dynamics of boarding/alighting activities and its impact on bus dwell times is crucial to improving bus service levels. However, research is limited as conventional data collection methods are both time and labour intensive. In this paper, we present the first use of smart card data to study passenger boarding/alighting behaviour and its impact on bus dwell time. Given the nature of these data, we focus on passenger activity time and do not account for the time necessary to open and close doors. We study single decker, double decker and articulated buses and identify the specific effects of floor/entrance type, number of activities and occupancy on both boarding and alighting dynamics. A linear relationship between average boarding and alighting times and their respective standard deviations is also found, whereas the variability of boarding and alighting time decreases with the number of passengers boarding and alighting. After observing the cumulative boarding/alighting processes under different occupancy conditions, we propose a new model to estimate passenger activity time, by introducing critical occupancy – a parameter incorporating the friction between boarding/alighting and on-board passengers. We conduct regression analyses with the proposed and another popular model for simultaneous boarding/alighting processes, finding that the critical occupancy plays a significant role in determining the regime of boarding and alighting processes and the overall activity time. Our results provide potential implications for practice and policy, such as identifying optimal vehicle type for a particular route and modelling transit service reliability.

1. Introduction

The operating time of bus services comprises driving time between stops and dwell time at stops. Generally, driving time between successive stops depends on the speed profile of the bus, the length of the link, driver behaviour, availability of bus lanes, schedules and timetables, availability of active control strategies, and further factors such as signal control (Abkowitz and Engelstein, 1983). Dwell time is the time in which a public transport vehicle is stopped to transfer passengers, including the time necessary to open and close doors, plus any other time in which a bus has the doors open without passenger service. Dwell time starts with the opening and ends with the closing of bus doors, allowing passengers to board and alight. Dwell time may cover a great proportion of total travel time, which shows the significance of boarding and alighting processes on bus operation. For example, Levinson (1983) found, for US operations observed from 1957–1980 in many cities, that dwell

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time made up about 20% of total travel time within urban areas and increased to 26% in the CBD on average, and recently Tirachini (2013a) found in Sydney that dwell time is around 15% of total travel time with on-board fare payments.

An important issue that has received little attention in the literature is the estimation and analysis of the variability of bus dwell time, which has implications on bus operation and on the satisfaction of bus users, for whom it is valuable to have reliable public transport systems and predictable travel times. However, given the random nature of passenger turnover, dwell time is difficult to control even when the bus driver is experienced. Together with congestion and demand heterogeneity, the variation of dwell time is one of the major factors in the unreliability of bus operations, resulting in bus bunching and over-crowdedness (Newell et al., 1964; Strathman and Hopper, 1993). The dynamics of the boarding and alighting process also depend on various vehicle characteristics, such as the number and width of doors, the existence of steps to board and alight, the type of bus (single/double decker, rigid/articulated), the number of seats and space for standees, and the fare collection method (Guenthner and Hamat, 1988; York, 1993; Levine and Torng, 1994; TRB, 2000; Dorbritz et al., 2009; Fernández et al., 2010; Tirachini, 2013b; Fletcher and El-Geneidy, 2013). Therefore, to model and estimate dwell time accurately at bus stops becomes one of the main challenges involved in predicting bus travel time.

A high variability of bus dwell times is likely to produce unreliable travel times, with negative effects for both bus operators and users, because operators have to adjust the length of recovery times at terminals (Furth, 2000). Public transport users prefer reliable travel times (Bates et al., 2001; Hollander, 2006; Batley and Ibáñez, 2012), to the point that travel time variability influences users decisions on mode and route choice. Importantly, the social cost of unreliability in public transport might be significant, for instance, van Oort (2011) estimates a yearly cost of €12 million in the Hague, Netherlands, due to unreliable buses and trams. Therefore, a better understanding of travel time variability in all its components, including dwell time can be used in the operational and tactical planning of public transport operations and scheduling, and for the estimation of the economic and social benefits and costs of alternative systems of public transport service provision, benefiting both bus operators and users (Tirachini, 2013b).

In this paper, we analyse passenger boarding and alighting dynamics at a microscopic user-by-user level by using individual transactions generated from the smart card-based automated fare collection (AFC) system of Singapore, in which passengers are required to tap on at the front door and suggested to tap off at the rear door(s) (Lee et al., 2012). As summarised in (Pelletier et al., 2011), such data set provides new insights in reconstructing public transport operations at diverse scales, from strategic to tactical to operational management. To date, most studies utilising smart card data focus on macroscopic characteristics such as adjusting services, designing networks, understanding demand variation and user habits, and measuring service performance, while the microscopic level is generally neglected. By constructing detailed bus operation logs we present detailed models of passenger boarding and alighting behaviour under different occupancy levels and bus characteristics, and study their impact on bus dwell time. Note that such an operation log contains only passenger tapping-in/out activities, imposing an inherent limitation on our study: the time to open and close doors, which is also part of the dwell time, is unknown to us. Given the limitation of using smart card data as a proxy, we study the total passenger activity time between the first and the last tapping-in/out activities as a proxy which is called passenger activity time throughout this paper.[1] The contributions of this paper are twofold: first, we characterise the boarding/alighting dynamics (behaviour) of users under different bus characteristics in a microscopic framework, allowing us to identify processes that have not been observed in previous dwell time studies. Second, we provide insights on the characterisation of the variability of passenger activity time, an issue that can be analysed in-depth with our smart card data. Implications for policy on bus service operation and planning follow in the conclusions.

The remainder of this paper is organised as follows: in Section 2, we review existing studies on bus dwell time; in Section 3 the data employed in this study is described; in Section 4, we reconstruct the boarding/alighting processes and identify the boarding/alighting interval patterns for different types of buses. After observing the time-stamped boarding/alighting processes, in Section 5 we propose a new passenger activity time model for bus services on which passengers are required to board at the front door and suggested to alight at the rear door; the performance of the proposed model is analysed in Section 6; and finally Section 7 summarises the main findings of the study and provides the outlook for future work.

2. Background

In exploring the determinants of bus dwell time, a number of studies have been conducted since 1970s (e.g. Kraft and Bergen, 1974; Levinson, 1983; York, 1993; Weidmann, 1994; Lehnhoff and Janssen, 2003; Dueker et al., 2004; Fernández et al., 2010; Currie et al., 2013). The common approach is the use of simple or multivariate regressions to relate dwell time to the number of passengers boarding and alighting, the number of passengers inside the vehicle, the number of doors and other variables. Most studies define dwell time as the time for boarding and alighting of passengers plus the time to open and close doors. Levinson (1983) modelled bus dwell time Dw as the sum of the passenger activity time (depends on total number of boarding and alighting passengers) and the time for door opening and closing:

$$Dw = t \times N + t_d, \tag{1}$$

[1] Note that our analysis does not capture passenger activity time fully because if we have N passengers boarding or alighting, only $N-1$ intervals are observed: the time for the first boarding passenger and for the last alighting passenger are not computed.