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How does a static measure influence passengers' boarding behaviors and bus dwell time? Simulated evidence from Nanjing bus stations

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ABSTRACT

Although various methods have been adopted to reliably predict bus stop dwell time, little research has explored how the adopted measures influence the efficiency of passenger boarding from the perspective of personal micro-scale behavior. Using the multi-agent concept, this study provides a simulation model based on the social force paradigm that can be applied to extract the movement characteristics of boarding passengers and calculate bus stop dwell time. For each passenger, the model incorporates five different forces that drive individual agents' boarding and alighting. Three statistical indicators (Doorway Flow Rate, Doorway Crowdedness and Waiting Entropy) are proposed to analyze the impact of static measures in different simulation scenarios. The simulation results illustrate that measures for enlarging platform areas and installing guide guardrails can observably reduce the variation in bus dwell times, but not the length of the time itself. This is because the boarding order in these measures requires a certain amount of time per passenger. However, the application of these two measures could improve the psychological experience of passenger boarding. Therefore, we recommend that transit operators in Nanjing should fully consider the gains and losses based on the implementation of the measures to make the best decision.

1. Introduction

The operational performance of service procedures at bus stops has been found to have a large effect on the estimation of the capacity of public transport (Bian et al., 2015). Bus dwell time is among the most important factors that determines transit capacity and service levels (Lin and Bertini, 2004; Blythe et al., 2010). In Chinese cities, for example, each bus line may have approximately twenty to thirty stations. Due to the boarding and alighting of passengers, the station dwell time of buses at a station can range from 3 to 5 s to a maximum of 2 min. As these dwell times accumulate, a journey can take an additional 10 min or more, and it may take up to 1 h for a bus to complete a full journey. Although the Chinese government has invested a tremendous amount of money and resources into improving the intelligence and information level of the public transport system, it remains difficult to obtain an accurate schedule of Chinese bus lines (PRC Ministry of Transport, 2016; Ji et al., 2017). Therefore, providing an effective method to calculate bus dwell time and to analyze its influencing factors is important in theory and practice for transit operators and passengers.

Traditional research defines bus dwell time as the time buses spend at a stop or station to serve passengers, including the time

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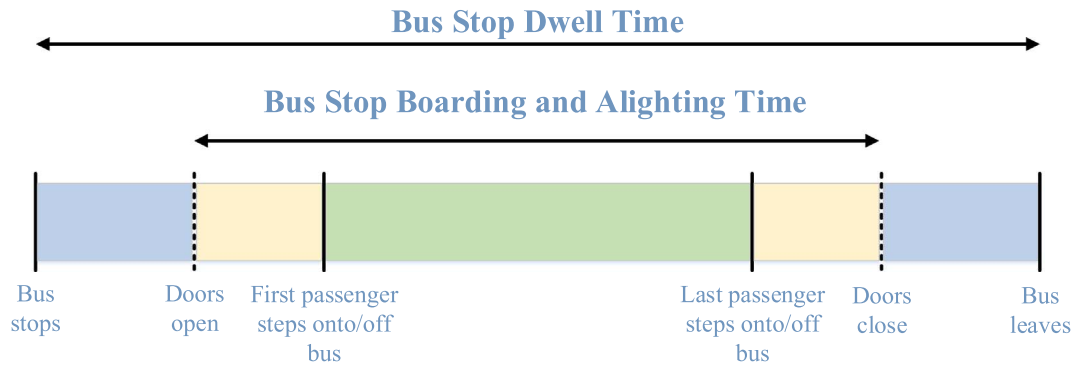

Fig. 1. Diagram of bus dwell time components.

required to open and close the doors (see in Fig. 1). Existing evidence shows that the dwell time at a given stop is directly related to the number of boarding passengers, the fare payment method, vehicle type and size, and in-vehicle circulation (KITTELSON ASSOCIATES, INC., 2013). Some previous studies have considered dwell time as a function of passenger volumes, headways, the designs of buses, and in-vehicle passenger congestion (Ashtiani and Iravani, 2002; Fernandez et al., 2015; Wang et al., 2016). However, little is known about how the boarding behaviors of passengers influence the estimation of bus stop dwell time from the perspective of dynamic analysis.

It is unclear which types of passenger behaviors on the platform increase or decrease bus dwell time. Do these behaviors contribute to the variation in bus dwell times? How does the layout of amenities at bus stops/stations (i.e., the platform area or leading guardrails) influence the platform behaviors of passengers and the time needed for bus stoppage? This paper aimed to answer these questions by collecting original data for transit users in Nanjing, China. Video surveys were used to record passengers' behaviors and the actual dwell time of each stopped bus. Furthermore, a modified simulation model based on the Social Force Model (SFM) was applied to examine how passengers' behaviors and the layout of amenities in stops/stations are related to bus dwell time.

2. Literature review

In the field of public transport, understanding passenger behavior and characterizing the factors that influence passengers' experiences are the keys to designing better facilities and improving service levels, thereby encouraging a greater number of citizens to use public transport (Lagune-Reulter et al., 2016; Ji et al., 2017). Recent studies analyzing passenger behavior have focused on the following topics:

- The functional evaluation of stop/station amenities

Evaluating the effects of stop/station amenities is often the foundational step to enhance the service quality of public transport and pull passengers towards the use of bus transit (Currie and Wallis, 2008). Data related to this issue have been extracted from the travel diaries or stated preference surveys (Hensher and Rose, 2007; Chica-Olmo et al., 2017; Abenoza et al., 2017) as well as by considering the platform behaviors (i.e., chatting, using mobile phones, listening to music) as one type of scenario data to explore how to improve citizens' perceptions of public transport systems (Lagune-Reulter et al., 2016; Fan et al., 2016; Ji et al., 2017). Other valuable articles, such as Chawla's research (2017), have focused on the relationships between transit vehicle accessibility, boarding technologies and the behaviors of passengers with reduced mobility.

- Safety analysis of the public transport system

Safety analysis is another important research topic related to public transport that involves personal behaviors. Research in this area involves the safety evaluation of transit operations (Cafiso et al., 2013; Li et al., 2015), station or vehicle design (Lam et al., 1999; Cox et al., 2006; Schelenz et al., 2013), and passenger flow analysis and evacuation in emergency situations (Hoogendoorn et al., 2007; Liu et al., 2013; Anvari et al., 2017). The characteristic data for such passenger behaviors were collected mainly from observations, surveys and laboratory experiments. The results of these studies illustrate that at both the macro and the micro level, passenger behavior is an indispensable factor in public transport research.

- Dwell time calculation

The travel time of public transport, for both bus operators and passengers, is believed to be influenced unreliably by highly variable stop dwell times (Furth, 2000). A better method of calculating dwell time may be the use of tactical and operational planning of transit scheduling to improve the service level to benefit both public transport operators and passengers (Strathman and Hopper, 1993; Yin et al., 2004; Chen et al., 2009; Wang et al., 2016). Furthermore, understanding the effect of boarding/alighting behaviors is