

Accessibility and User Performance Modeling for Inclusive Transit Bus Design

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ABSTRACT

The purpose of this paper is to demonstrate the impact of low-floor bus seating configuration, passenger load factor (PLF) and passenger characteristics on individual boarding and disembarking (B-D) times -a key component of vehicle dwell time and overall transit system performance. A laboratory study was conducted using a static full-scale mock-up of a low-floor bus. Users of wheeled mobility devices (n=48) and walking aids (n=22), and visually impaired (n=17) and able-bodied (n=17) users evaluated three bus layout configurations at two PLF levels yielding information on B-D performance.

Statistical regression models of B-D times helped quantify relative contributions of layout, PLF, and user characteristics viz., impairment type, power grip strength, and speed of ambulation or wheelchair propulsion. Wheeled mobility device users, and individuals with lower grip strength and slower speed were impacted greater by vehicle design resulting in increased dwell time.

To ensure safe, efficient and equitable access to the diverse spectrum of transit riders, transit system design needs approaches that transcend existing minimum federal accessibility design standards. This study improves our understanding of the relationship between vehicle design and the functional abilities of users. The need for research and design to achieve inclusive and space- and time-efficient transit systems is discussed.

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INTRODUCTION

Public transit (PT) systems are integral and necessary to realizing mobility and community participation for a broad diversity of users [1, 2, 3]. Designing for safety, usability and access in public transportation is increasingly important due to a general push towards sustainable transportation, changes in passenger demographics (due to aging, obesity), greater passenger expectations in the level of service, and the increasing complexity of features in the transit environment. Further many cities in the U.S. and internationally are investing heavily in public transportation infrastructure in response to growing demand [4] and urban congestion. It is important that these systems be designed to meet the needs, abilities and priorities of an increasingly diverse ridership.

An increased demand for accessible and equitable transportation options has also resulted from older adults and individuals with disabilities being more independent and active socially through employment, education and recreation. Enforcement of federal accessibility legislation such as the Americans with Disabilities Act (which requires public transportation operators to make their vehicles accessible to people with disabilities) [5], better quality and access to

medical care, increased trauma survival, and improved assistive device technologies have all contributed positively to increased expectations of accessible and equitable transportation options.

Unmet needs remain in physical design and access to transit systems for people with impaired mobility, including users of walking aids, wheeled mobility devices, and vision and cognitive impairments [2,6,7,8]. For instance, Frost and Bertocci [9] highlight the need for improved usability and safety on transit vehicles due to high incidence rates of injuries and fatalities among mobility impaired passengers in bus boarding and disembarking.

Improving usability and access in fixed-route transit also has economic benefits. Demand and costs of providing paratransit services to people with disabilities and older adults are escalating [10]. Reducing dependence on paratransit services and shifting riders to fixed-route by improving the accessibility and usability of fixed route public transit can lead to substantial financial savings for transit operators.

The benefits of improving the usability, safety and accessibility of transit systems are limited not just to persons with functional impairments, but extend to the elderly, users with large items like luggage and push strollers, children, and the general able-bodied user population. Eliminating design barriers increases the proportion of people that are potential passengers.

The impact of passenger safety, B-D efficiency and dwell time implications, make transit agencies important stakeholders in vehicle design. Most agencies produce their own specifications for manufacturers when ordering new vehicles or retrofitting existing vehicle interiors. These specifications are based on individual agencies experiences and needs combined with the particular floor plans available from manufacturers.

Accessibility provisions rely primarily on federal standards [5, 11] and industry recommended guidelines [12]. No coordinated effort exists to evaluate combinations of bus design features for usability and safety. As a result, vastly different interior seating configurations for buses have resulted across transit agencies and bus manufacturers over time.

The long-term goals of this research are to generate knowledge and design requirements for future inclusive transportation systems. One aspect of this approach requires understanding the relationship between design features in the transit environment and peoples' abilities in relation to safety, efficiency and preference in the design environment.

The aim of this study was to determine the impact of interior seating configuration in low-floor buses on B-D times of mobility impaired passengers. The study focused on statistical regression to model effects of seating configuration, social factors (i.e., low vs. high PLF) and person-dependent variables (e.g., mobility device type, power grip strength and speed of ambulation or wheelchair propulsion) on B-D times.

METHODOLOGY

Passenger performance during B-D was systematically assessed using a static full-scale mock-up of a low-floor bus featuring reconfigurable seating configurations and positioning of ramp-equipped doorways at the front and rear in relation to the wheeled mobility securement areas (WMSAs). The apparatus modeled the front two-thirds (i.e., the low floor section between the front and rear axle) of a 40-foot low-floor transit bus (Fig. 1). The WMSA had longitudinal fold-up seats to accommodate ambulatory seated passengers when not occupied by a wheeled mobility device. A static mock-up was deemed adequate since the primary focus was on B-D tasks occurring when the bus is typically stationary. Each participant separately evaluated three bus interior configurations at two levels of PLF [13, 14].

Study Participants

The study enrolled a convenience sample of 104 individuals (female: 56, male: 48) between the ages of 18-80 years for participation. The sample comprised manual wheelchair users (n=18; age mean, std. deviation: 46.7, 7.9 yrs.), powered wheelchair users (n=21; age: 50.4, 10.8 yrs.), scooter users (n=9; age: 56.8, 12.1 yrs.), cane users (n=12; age: 53.3, 11.5 yrs.), walker users (n=10; age: 62.6, 11.2 yrs.), visually impaired users (n=17; age: 49.4, 12.3 yrs.), and able-bodied users without no mobility impairment (n=17; age: 43.4, 9.4 yrs.). Participants were recruited through the general public and multiple local organizations such as an Independent Living Center, Geriatric Center, and the Veterans Affairs Medical Center. The university's institutional review board approved the study and all the participants provided written informed consent prior to participation.

Apparatus

Following a review of transit buses operating in the U.S., three bus interior configurations that were substantially different from each other were identified for testing (Fig. 1).

- Layout 1 had an entry/exit ramp in the front doorway, a floor mounted fare payment device adjacent to the driver's seat, two WMSAs immediately behind the front wheel-wells, and transverse seats through the remainder of the bus interior.
- Layout 2 had an entry ramp at the rear doorway, a wall-mounted fare payment box near the rear doorway, longitudinal seats on either sides of the bus interior (i.e. perimeter seating), two WMSAs along the curb side of the bus, and an exit ramp in the front doorway.
- Layout 3 had an entry/exit ramp at the rear doorway, a smart-card reader mounted near the rear doorway on the left, a WMSA on either side of the bus immediately to the right of the rear doorway, and transverse seats through the remainder of the bus interior.

The layout designs complied with federal accessibility requirements [11] and dimensional clearances recommended by the U.S. bus industry [12].

Clothed inflatable adult-size mannequins were positioned in pre-defined seat locations depicted in Figure 1 simulating levels of low (shown in red) and high (shown in red and gray) PLF. Only one pair of vacant seats (for ambulatory study participants) or one WMSA (for participants using a wheeled mobility device) was available in conditions of high PLF. Half the number of vacant seats and both WMSAs were available for participant use in conditions of low PLF. Mannequin locations were kept constant within each test condition to avoid potential confounding.

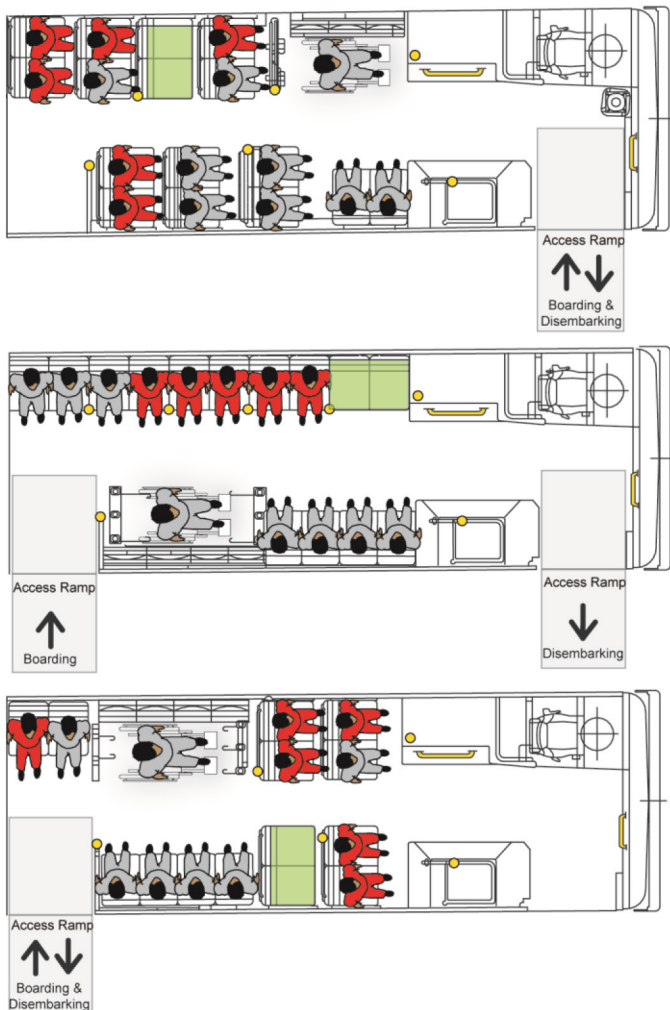


Figure 1. Graphical depiction of the 3 seating layouts evaluated across conditions of low passenger load (manikins shown in red) and high passenger load conditions (manikins in red and gray).

Experimental Procedure

Each participant was asked to perform the following tasks as independently as possible and as they normally would if travelling on a real bus. Bus driver (researcher) assistance could be requested when necessary. Movements during the BD attempts were recorded using conventional video cameras and subsequently analyzed to extract boarding (steps 1-4) and disembarking (steps 5-7) times across conditions and participants. The study did not investigate ramp deployment or use of wheelchair securement.

In conditions of low PL, the participant (1) boarded the bus using the assigned entry doorway and access ramp, (2) completed the fare payment transaction, either moved within the passenger compartment to (3a) any one of the vacant seats if ambulatory or (3b) one of two vacant WMSAs if using a wheeled mobility device, either (4a) sat down if ambulatory or (4b) folded up the seats and maneuvered into the WMSA facing forwards and locked or powered off the mobility device. Upon stop announcement from the bus driver, the participant either (5a) rose from the seat if ambulatory or (5b) unlocked or powered up the mobility device, (6) moved to the pre-assigned doorway depending on the layout design and (7) disembarked using the access ramp. In conditions of high PL, the participant had only one available seat or WMSA, with a manual wheelchair occupying the second WMSA.

Information about person-dependent attributes including type of mobility device used, power grip strength and speed of ambulation or wheelchair propulsion was recorded.

Power Grip Strength (PGS): provides a measure of upper extremity functional integrity impacting activities such as reaching, grasping, and wheelchair propulsion. PGS was recorded as the average of three measurements of maximum PGS taken on the dominant hand using a Jamar grip dynamometer in position 2 with the elbow flexed at 90 degrees with 2 minutes of rest in between measurements [15, 16].

10m Distance Travel Time (10MT): provides a standardized and easily obtainable measure of a person's comfortable ambulation or wheelchair propulsion capability [17]. Average time from 3 attempts of traversing a 10m distance in an unoccupied leveled-floor corridor was recorded.

Data Analysis

Hierarchical mixed effects regression [18] was used to model boarding time and disembarking time as a function of environmental conditions (i.e., layout), social factors (i.e., low vs. high PLF) and person-dependent variables (i.e., user group, PGS and 10MT). Separate regression models were developed for wheeled mobility users (manual, powered, scooter device users) and ambulatory users (cane, walker, visually impaired, able-bodied) due to differences in the interior circulation task resulting from use of the WMSA vs. sitting and rising. PGS and 10MT were coded as binary variables into a low vs. high-performing group values using a median-split as no specific relationship (linear vs. non-linear) between these variables and B-D times were hypothesized (Table 1). A 0.05 nominal significance level was used in the analyses, which were conducted using SPSS v.21.