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Establishing school bus baseline emergency evacuation times for elementary school students

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ABSTRACT

Emergency evacuation systems are critical to mass transportation vehicles such as school buses. Previous bus fire propagation tests indicate that the available time for successful evacuation is approximately 3–5 min. Many school districts in the United States utilize school bus routes that exclusively transport children in kindergarten through second/third grade where the bus driver is the only adult onboard. Currently, no standards specify the maximum allowable evacuation time for school buses. Full-scale evacuation trials were performed to measure front door, rear door, and both door (simultaneous) evacuation flow rates for kindergarten through third grade students. The evacuation trials indicated that the grade level of school bus passengers, and available evacuation routes have a significant effect on flow rate ($p < 0.05$). For evacuation trials with driver's assistance mean flow rate through the front door was 29 children/min, 21 children/min for the rear emergency door, and 36 children/min for evacuations using both doors simultaneously.

1. Introduction

Emergency evacuation training and measurement of evacuation times is critical to ascertaining the effectiveness of an emergency evacuation system in any transportation scenario (plane, train, bus, etc.). The Federal Aviation Administration (FAA) **mandates** that all aircraft with a seating capacity of 44 or more passengers demonstrate that the aircraft can be evacuated using half the exits with full occupancy in 90 s or less (FAA, 1990). Full-scale emergency evacuation demonstrations include subjects (evacuees) of certain age, gender, and body mass index specifications in addition to dolls replicating the weight of two year old children (Bahrami, 2012). Furthermore, many airlines in the United States outline specific requirements for passengers to be seated in emergency exits. For instance, Delta Airlines specifies that passengers must meet the following qualifications to be seated in an emergency exit row: (i) Must be over 15 years of age and be able to comprehend instructions for operating an emergency exit; (ii) Must be physically able to open an exit door and to lift and stow a 31–52 lb window exit; and (iii) Must be able to quickly activate the evacuation slide and assist others to exit (Delta Airlines, 2016). A school bus and an aircraft are fundamentally very similar (long, narrow metallic containers used to transport closely-packed occupants). However, no similar standards exist for school buses in the United States.

A case study conducted by the National Transportation Safety Board used surveillance cameras to study the evacuation process of a lap-belt equipped school bus following impact with a truck-tractor semitrailer (Poland et al., 2015). The school bus was carrying 30 (5–11 year old) students and the evacuation process lasted 3.5 min. Nineteen students self-evacuated through the front door (18 students evacuated in one minute or less), four were assisted out the rear emergency door, but seven remained on the bus at the end of the video recording (Poland et al., 2015). Previous bus fire propagation tests indicate that the available time for successful evacuation is approximately 200–300 s (~3–5 min) (Matolcsy, 2010).

The National Highway Transportation Administration (NHTSA) funded studies in 1970 and 1972 to measure school bus egress times (Purswell et al., 1970; Sliepcevich et al., 1972). A series of evacuation trials were conducted by Purswell et al. (1970). Two groups of 60 kindergarten through twelfth grade students from a laboratory school operated by the University of Oklahoma College of Education were recruited for the school bus evacuation study (Purswell et al., 1970). One group performed trials with a Superior Coach Corporation Model 69-1099 school bus in the upright

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Table 1
Upright orientation evacuation times (seconds) ($N = 60$) (Purswell et al., 1970).

Evacuation trial	Daylight	Simulated darkness
(A) Rear exit and side windows	41	48 (49)[a]
(B) Rear emergency exit, front exit, and side windows	32	32 (35)[a]
(C) Left side windows and the rear emergency exit	50	44 (49)[b]
(D) Rear exit and side windows	41	41
(E) Side windows, rear emergency exit, and left side exit	34	Did not conduct

[a] Conducted with 59 subjects, number in parenthesis is extrapolated time for 60 subjects.
[b] Conducted with 58 subjects, number in parenthesis is extrapolated time for 60 subjects.

Table 2
Rolled-over school bus evacuation times (seconds) ($N = 60$) (Purswell et al., 1970).

Evacuation trial	Daylight	Simulated darkness
(F) Windows, rear emergency door, and side door	82	154
(G) Windows, rear emergency door, and front windshield	47	83
(H) Rear emergency door only	107	161

Table 3
School bus egress times (Sliepcevich et al., 1972).

Trial description	No. of participants	Egress time (s)
Trial 1: Wore goggles, all exits except for front door were available for use	68	53
Trial 2: Same as trial 1, but rear exit was blocked	66	86
Trial 3: No goggles, all exits were used	68	31
Trial 4: Same as trial 1	68	57
Trial 5: Wore goggles, all exits were available for use	68	30

orientation (control), and the second group of students participated in evacuation trials with the school bus rolled-over on its right side (facing forward) (Purswell et al., 1970). Two sets of trials were performed for each orientation; a set of evacuation trials in daylight, and a second set of evacuation trials simulating a dark environment via the use of goggles. Five trials were conducted in the upright orientation (once in daylight and a second in simulated darkness): (A) Using the rear exit and side windows; (B) Using the rear emergency exit, front exit, and side windows; (C) Using left side windows and the rear emergency exit; (D) A replication of the first trial to study learning effects; and (E) Using side windows, rear emergency exit, and a special exit door on the left side of the bus. Platforms were placed on the side of the bus for subjects to land on when evacuating through the windows. Three trials were performed in the rolled-over orientation (in daylight and simulated darkness): (F) Evacuation through the windows, rear emergency door, and side door; (G) Evacuation through the windows, rear emergency door, and front windshield; (H) Evacuation through the rear emergency door only (Purswell et al., 1970). Reported evacuation times are provided in Tables 1 and 2. For the upright orientation evacuations, simulated darkness trials had comparable evacuation times to evacuation trials performed in daylight, but in the rolled-over orientation evacuation times were 50% longer for the trials simulating darkness (Purswell et al., 1970). Additionally, opening the emergency exits and keeping them open had a significant effect on evacuation times.

NHTSA performed another evacuation study in 1972 where five egress trials using all exits except the front door (side windows, emergency exit window, and a rear emergency door located on the side) were conducted with a group of 68 students in first grade through twelfth grade (Sliepcevich et al., 1972). Goggles were also used to simulate darkness for two of the evacuation trials, and the school bus driver did not provide assistance during the evacuation process (Sliepcevich et al., 1972). The reported egress times are presented in Table 3.

While these evacuation times might appear to be acceptable, many school districts utilize bus routes that transport children in homogeneous age groups (e.g. kindergarten through second grade). For instance, in 2012, Auburn City Schools in Auburn, AL utilized 18 routes exclusively for kindergarten through second grade (Ingram, 2013). Evacuation times may be much longer on such routes due to young children's still developing cognitive and strength capabilities to open and evacuate through the exits, especially in a rolled-over orientation or if the driver is unable to assist in the evacuation (Leach, 2004). Studies have identified that students with no prior experience operating emergency exits are unable to open emergency exits requiring coordinated actions to operate, and the uses of these exits were unsatisfactory in panic emergency situations (Sliepcevich et al., 1972; Purswell et al., 1970).

In the State of Alabama, some school transportation departments record school bus evacuation times when they perform their mandated semiannual evacuation training. However, these data are typically not obtained in a scientific manner (nor published). Additionally, no information on the number of occupants, nor emergency exits utilized is collected. School buses and motorcoaches share similar emergency evacuation systems, and they are both regulated by FMVSS No. 217 (NHTSA, 2011). There have been several studies evaluating the emergency exits on motorcoaches through evacuation trials. The Volpe Center, a federal agency under the U.S Department of Transportation, performed a study to generate preliminary egress times of a fully loaded 56 passenger motorcoach (Pollard and Markos, 2009). Egress trials using each category of exits separately were performed from the fully loaded motorcoach in daylight using "hold open" mechanisms to maintain the emergency exit windows in the open position after they had been unlatched. Employees of the Volpe Center with extensive knowledge of bus exits participated in the evacuation trials. Results for egress times and flow rates for each egress path are presented in Table 4.