



Establishing the basis for a school bus emergency evacuation time standard



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ABSTRACT

Though it is commonly accepted that transporting children by school bus is the safest way to move them to and from school, the frequency of events causing full or partial evacuations each year is relatively unknown. As research demonstrates that the interior of a bus can be completely burned-out in as few as three minutes, it raises the question as to why there is not a federal school bus evacuation time standard in place. The objective of this paper was to present the need of a school bus evacuation time standard that can enhance post-accident school bus passenger safety. Passenger train and commercial aircraft evacuation standards were studied to identify how school bus evacuation standards compare to those of other modes of mass transportation. Considerations for the proposal of an evacuation time standard while focusing on the unique challenges associated with school buses are discussed.

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1. Introduction

Busing children to and from school in the United States is a staggering enterprise. There are approximately 480,000 school buses in service, each with an average life span of approximately 10 years,

meaning that about 10% of the bus fleet is being retired and replaced every year (NSTA, 2013). Each bus travels approximately 12,000 miles per school year, resulting in roughly 3.5 billion miles being driven annually to transport approximately 26 million students (Fahey, 2010; Burgoyne-Allen and O'Keefe, 2019). It has been estimated that

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there are an additional five million extracurricular trips beyond daily transport (FEMA, 2009). In nearly all cases this is done professionally and safely. Despite this enviable safety record, nearly 26,000 school bus accidents occur each year (CDE, 2020). The overwhelming majority of these are minor (at least to the bus occupants); nonetheless, there are numerous accidents involving serious injuries accompanied by approximately five to ten student fatalities in an average year (Toppo, 2015). A search for evacuation standards of mass transportation vehicles (airplanes, passenger trains, and buses) reveals that commercial airplanes are the only mode of mass transportation that has an emergency evacuation time standard (Pollard and Markos, 2013; Abulhassan et al., 2016). The purpose of this paper is to detail the case for the development and implementation of a National school bus emergency evacuation time standard, similar to that required of commercially flown aircraft in the United States.

2. School bus evacuation criteria and research

Schools in the United States are required to 'routinely' address evacuation training each school year, for both bus drivers and student passengers. This can be accomplished by several means, but often involves a 'simulated evacuation' where children perform an orderly and safe demonstration. Some schools record evacuation specifics (type of bus, number of seats, exit information, number of children, grades, ages, door(s) used, evacuation times, injuries, etc.) while others do not. It appears that each State/School District provides thoughtful consideration into what data if any will be recorded and/or analyzed from such training and demonstration events. Unlike the FAA mandated evacuation time standard, the school bus industry, the Federal Motor Carrier Safety Administration (FMCSA), and the National Highway Transportation Safety Administration (NHTSA) do not have uniform prescriptive requirements for evacuation times or a methodology for collecting, analyzing, and disseminating routinely performed evacuation data and information. Such data would be highly valuable for benchmarking, trend analysis, and continuous improvement purposes.

2.1. Rear emergency door and roof hatch flow rates

Although actual school bus evacuations are rare, events that may lead to an evacuation include: (1) serious accidents where the normal exit is impaired; (2) roll-overs following any number of events; (3) fire; (4) smoke; (5) leaking fuel; (6) bus stranded in area where it may be struck; and (7) entry into water, are some that immediately come to mind. Research on school bus emergency exit evacuations is sparse. In 1970, a series of experiments conducted by the University of Oklahoma Research Institute (OKRI) using plywood mock-ups, a group of 60 students in first through twelfth grade crawled through simulated hatch openings to assess evacuation flow rates via a 24 in. \times 40 in., and a 24 in. \times 24 in. hatches in light and dark conditions (Purswell et al., 1970). Later critiques on this study suggest that the results have little applicability to actual hatches as the subjects did not have to raise (pull) themselves up to gain access to the opening (Purswell et al., 1970). In 2018, evacuation flow rates of kindergarten through second grade children via an actual school bus roof hatch were published by Abulhassan, Davis, Sesek, Callendar, Schall, and Gallagher using a test apparatus constructed from a school bus roof section to accurately represent the geometric properties and operating mechanisms of an emergency escape hatch in a rolled-over school bus (Abulhassan et al., 2018a). Flow rates of kindergarten through second grade children via a typical 22 in. \times 22 in. emergency escape roof hatch opening were reported to be between 11 and 15 passengers per minute (PPM) (Abulhassan et al., 2018a). Similarly, flow rates of kindergarten through second grade children via a rear emergency door opening in a rolled-over school bus ranged between 11 and 16 PPM

(Abulhassan et al., 2018b). While the opening of a school bus rear emergency door (646 in²) is 133% larger than that of a roof hatch opening (484 in²), the last row of seats in many school bus configurations obstruct up to 44% of the available opening area (Abulhassan et al., 2018b). Federal Motor Vehicle Safety Standard (FMVSS) No. 217 requires a parallelepiped (45 in. high, 24 in. wide, and 12 in. deep) to pass through the rear emergency door by keeping the 45 in. dimension vertical and the 24 in. dimension parallel to the opening (NHTSA, 2011). Similarly, FMVSS No. 217 requires school bus emergency escape roof hatches to have a minimum opening of 16 in. \times 16 in. (NHTSA, 2002).

2.2. Full-scale school bus evacuation times

The first reports of full-scale school bus evacuation times are dated back to the studies performed at OKRI in 1970 (Purswell et al., 1970). Upright school bus evacuations trials were conducted in various exit availability scenarios: 1. Rear emergency door and side windows; 2. Front door, rear emergency exit, and side windows; 3. Only windows on the left side of the bus and rear emergency exit; 4. Side windows, rear emergency exit and a side emergency exit. (Purswell et al., 1970). Evacuation times in daylight conditions were reported to range between 32 s for the trial using the front door, rear emergency exit, and side; to 50 s in the trial where windows on the left side of the bus and rear emergency exit were the only available egress routes. In the United States, it is common for many school districts to have routes dedicated to students in the same school levels (i.e. elementary school, middle school, and high school). Hence, no actual evacuation studies were performed by school aged children in the same school level using representative equipment (exits) until the study published by Abulhassan et al. (2016), the first study to establish baseline times upon which to measure evacuation performances. The authors conducted numerous evacuations via the front door (only), rear emergency door (only), and both doors (simultaneously) with and without driver direction, for kindergarten through third grade students. In total, 475 students participated. Results indicated that for this age group mean flow rates of trials without driver direction were 28 PPM via the front door, 18 PPM via the rear emergency door, and 35 PPM via both doors simultaneously (Abulhassan et al., 2016). The results of the study suggested that younger students required significantly more time to evacuate, and evacuation through the rear emergency door was impeded due to the elevation drop from the opening of the rear door to the ground (Abulhassan et al., 2016). One major suggestion from early bus evacuation studies was the need for a maximum evacuation time standard for buses (Purswell et al., 1978). If we accept the FAA evacuation time of 90 s or less as the required time to evacuate a school bus under ideal conditions, only those students in the third grade were capable of achieving this time, and then only when both doors were employed simultaneously (Abulhassan et al., 2016).

Based on school bus literature and crash observations, it is estimated that school bus interiors can **completely** burnout in as few as three minutes (Matolcsy, 2009). With Class C buses capable of seating up to 72 children, and Class D buses up to 90 children, it is important to realize that at the published flow rates for school bus exits, not every child might successfully evacuate (Abulhassan et al., 2016). One of the primary purposes for setting a baseline evacuation time under 'ideal conditions' is to benchmark against this time for the propagation of fire and smoke to promulgate throughout the bus, and ultimately predict survivability. Once a baseline time is established, simulation models can be used to study the impact of other events including the final orientation of the bus (Lin and Hsu, 2019). Evacuation models exist for airplane and cruise ship evacuation, airEXODUS (Galea, 2006) and maritimeEXODUS (Galea et al., 2003) respectively, however no similar model(s) exist(s) for bus evacuation.

3. Similarities and differences between passenger trains, airplanes, and school buses

The various modes of mass transportation, school buses, passenger trains, and aircraft are similar in terms of geometric shape, passenger seating, and the availability of exits that permit passengers to evacuate in an emergency. As discussed in further detail in Section 4, commercial airplanes are the only known mode of mass transportation that are required to demonstrate the ability to meet a maximum evacuation time by performing a full-scale evacuation with specific conditions and criteria. From an emergency evacuation perspective, taking into consideration post-accident conditions to specify the maximum time available for safe egress is necessary to determine the number and type of exits required. Therefore, a detailed comparison of evacuation criteria between commercial airplanes and school buses is presented in Sections 3.1-3.5.

The effectiveness of a school bus evacuation system is currently addressed by the number and location of exits available. FMVSS No. 217 specifies the number and types of emergency exits required on a school bus based on the passenger capacity of the school bus, and the availability of either a rear emergency door, or a left side emergency door (NHTSA, 2011). School buses with a rear emergency door and a passenger capacity greater than 70 passengers may use a combination of exits to meet a capacity credit rating as shown in Table 1.

Similar to school buses, passenger rail cars do not have an emergency evacuation time standard (Pollard and Markos, 2013). Passenger rail cars are required to demonstrate an effective evacuation system by complying with the American Public Transit Association APTA PR-PS-S-003-98 (APTA, 2004). While this standard does not specify a maximum evacuation time, it requires manufacturers and operators to have a combination of emergency exits that satisfy a minimum number of “emergency evacuation units” (EEU) equal to or greater than the “capacity exit factor” (CXF) or “usable exit path” (UXP) of a rail car (APTA, 2004). The CXF is determined by dividing the number of passengers in a rail car by 17 and rounding up to the nearest whole number; and UXP is the “number of emergency windows and exit doors that can be used by passengers after an incident that requires emergency egress from the vehicle” (APTA, 2004). Table 2 shows that number of EEU to be designated to each exit type, and the number of exits required on passenger rail cars.

3.1. Geometric shape

In general terms, airplane geometry can be described as an elongated cylindrical tube designed to transport closely seated rows of passengers between two locations. Only a small amount of actual travel time is spent at the gate, or in taxi between takeoff and landing, when the actual emergency exit systems would functionally be of use. Likewise, a school bus is a geometric elongated rectangular tube designed to transport closely seated rows of passengers between two locations as visualized in Fig. 1. Unlike an airplane, it remains in constant contact with the ground, and the emergency exit systems can be readily used without the need to land.

Table 1
School bus emergency exit requirements (NHTSA, 2011).

Seating capacity	Emergency Exits Required
1–45	None
46–62	1 left side exit door or 2 exit windows
63–70	1 left side exit door or 2 exit windows, and 1 roof exit
≥ 71	1 left side exit door or 2 exit windows, and 1 roof exit, and any combination of door (CC = 16), roof exit (CC = 8), or windows (CC = 8) such that the total capacity credit (CC) for these exits, plus 70, is greater than the seating capacity of the bus

Table 2
Minimum passenger rail car exit requirements (DOT, 2008).

Exit Type	Number of EEU	Required Number of Exits
Emergency exit window	1	2 per car level, per side
Each door leaf (≥30 in. width)	2	–

3.2. Personnel

Airplanes have flight deck (pilots, flight engineers) and cabin crew (flight attendants) members whose primary responsibility is passenger safety, including cabin evacuation. Some school districts may require bus monitors, but most do not require an additional adult to be onboard beyond the driver. Therefore, in many aspects the school bus driver functions as both pilot and flight attendant, particularly when evacuation is required.

3.3. Emergency exit operation requirements

The FAA states the following regarding passenger exit row seating qualifications (FAA, 2006):

“(b) No certificate holder may seat a person in a seat affected by this section if it is likely that the person would be unable to perform one or more of the applicable functions listed in paragraph (d) of this section because-

1. The person lacks sufficient mobility, strength, or dexterity in both arms and hands, and both legs;
 - i. To reach upward, sideways, and downward to the location of emergency exit and emergency slide operating mechanisms;
 - ii. To grasp and push, pull, turn, or otherwise manipulate those mechanisms;
 - iii. To push, shove, pull, or otherwise open the emergency exits;
 - iv. To lift out, hold, deposit on nearby seats, or maneuver over the seatbacks to the next row objects the size and weight of over-wing exit doors;
 - v. To remove obstructions of size and weight similar to over-wing exit doors;
 - vi. To reach the emergency exit expeditiously;
 - vii. To maintain balance while removing obstacles;
 - viii. To exit expeditiously;
 - ix. To stabilize and escape slide after deployment; or
 - x. To assist others in getting off an escape slide;
1. **The person is less than 15 years of age** or lacks the capacity to perform one or more of the applicable functions listed in paragraph (d) of this section without the assistance of an adult companion, parent, or other relative;
2. The person lacks the ability to read and understand instructions required by this section and related to emergency evacuation provided by the certificate holder in printed or graphic form or the ability to understand oral crew commands;
3. The person lacks sufficient visual capacity to perform one or more of the applicable functions in paragraph (d) of this section without the assistance of visual aids beyond contact lenses or eyeglasses.”

When compared to FAA regulations for passenger exit row seating qualifications, **there are no regulations that specify passenger qualifications to be seated near emergency exits on school buses.** Recent studies suggest that the heavy weight of a school bus rear emergency (100 lb), and associated force requirements to operate the exit exceed the strength capabilities of many young children especially when the bus is in a rolled-over post-accident orientation (Gunter et al., 2020a). Furthermore, the operating mechanisms of school bus



Fig. 1. Geometric tubes of closely seated passengers.

emergency exits may overlook the physical capabilities and stature of young children, as the force requirements to operate school bus emergency exits are designed to accommodate average adult males (Pollard and Markos, 2009).

3.4. Passenger qualifications

Some commercial airlines require additional qualifications for passengers to be seated in close proximity. For instance, Delta Air Lines excludes passengers from sitting in an emergency exit row if they: 1. Lack sufficient hearing or vision to perform emergency exit functions or be able to communicate information orally during an emergency; 2. Require a wheelchair or other assist device; 3. Require the use of a seatbelt extension, supplemental oxygen, or portable oxygen concentrator; 4. Traveling with a small child that can interfere with their ability to perform emergency functions; 5. Traveling with an emotional support or service animal (Delta Air Lines, 2021).

3.5. Passenger acknowledgement and training

Many airlines require each passenger who selects exit row seating to specifically acknowledge by checking a box during the reservation process to affirm that they are aware of the exit row seating requirements and are willing to render assistance if needed. At the start of each flight, during taxi to the runway, a video (or audio recording) is played portraying aspects of the safety features of the aircraft and flight attendants demonstrate the various aspects of the safety equipment and evacuation systems, and are willing to answer questions that may come up pertaining to the briefing. All passengers are encouraged to look at the passenger safety cards located in the seat back in front of each passenger. Exit rows passengers are given an additional safety brief, and are required to verbally acknowledge that they are sitting in an exit row, and are willing and able to assist if required.

Though airplanes that seat more than 44 passengers and spend little time on the ground are required to have this level of safety rigor designed in by the manufacturers, operationalized by the airlines, and enforced by the FAA, school buses that can hold up to twice as many small children, and essentially spend virtually all their time

where the exit systems could be used, require none of these additional safety requirements. One must ask oneself why this is the case? With the exception of the school bus driver, young children are the only passengers on many school bus routes. School bus evacuation training varies significantly between school districts as there are no specific regulations for training school bus passengers on the operation of emergency exits. While some school districts require students to participate in actual evacuation trials annually, other districts may only inform students about the availability of the exits, but don't perform evacuation trials due to the risk of injury. The developing cognitive abilities of children paired with the complexity of emergency instructions could be disastrous in instances where prompt evacuation is necessary. In a study where the ability of kindergarten through second grade children to follow emergency escape roof hatches instructions was evaluated, very few participants were able to apply the instructions to disengage the operating mechanism on the hatch (Abulhassan et al., 2018a).

4. Airframe evacuation standards

Emergency evacuation is taken very seriously by the Federal Aviation Administration (FAA) and the aviation industry as a whole. Manufacturers and airlines must conform to numerous safety standards in the design, operation, and maintenance of all commercial aircraft. One of the most rigorous requirements is the evacuation demonstration specified in Code of Federal Regulation (CFR) 14 – Aeronautics and Space, §121.291 – Demonstration of Emergency Evacuation Procedures (FAA, 2011). This regulation states that operators must conduct an emergency evacuation demonstration for any aircraft having more than 44 passenger seats. The purpose of the demonstration is to test: (1) The operator's emergency training program; (2) Crewmember competency; (3) The operator's emergency evacuation procedures; and (4) The reliability and capability of the emergency equipment on the aircraft. The operator must show that the aircraft, emergency equipment, and emergency procedures allow the evacuation of the aircraft at full seating capacity, including crewmembers, in 90 s or less. For this full-scale evacuation, a representative 'normal passenger complement'

must be employed. Before conducting the demonstration, the operator must ensure that the participants meet the appropriate criteria shown in Table 3 (FAA, 2006).

The operator (company) may not practice, rehearse, or describe the demonstration for the passengers, nor may any participant have taken part in this type of demonstration within the preceding six months (FAA, 2006). The operator should provide safety personnel at strategic locations around the aircraft to protect passengers, and may not assist crewmembers or otherwise participate in the evacuation (FAA, 2006). Safety personnel are used only to prevent passenger injury. To summarize, there are comprehensive evacuation time standards and criterion that must be met by both manufacturers and operators to ensure that **all credible risk** has been addressed and **minimized** for the safety of the Nation's flying public.

5. Considerations for proposing a school bus evacuation time standard

Maintaining a safe school bus transportation agenda is a multi-organizational effort which includes the National Highway Traffic Administration (NHTSA), school bus manufacturers, state transportation directors, and school bus district coordinators. It is recommended that a task force led by NHTSA, and a joint effort between school bus manufacturers, evacuation experts, and the National Association of State Directors of Pupil Transportation Services (NASDPTS) establish the basis of a school bus emergency evacuation time standard. A systematic approach for identifying the availability and operation of emergency exits in post-accident scenarios, evacuation time limiting factors (i.e. material burn rates, fire, smoke, etc.), and design constraints of modifying existing emergency exit systems would be warranted to have a feasible yet effective evacuation time standard.

The purpose of this paper is not to address all the issues that need to be considered for establishing a school bus evacuation time standard, but to elevate this issue to the national level by initiating the debate of whether a national school bus emergency evacuation time standard is appropriate; and serve as a reference for recognized concerns and recommendations to develop such a standard. Such recognized concerns and recommendations that should be taken into consideration include:

1. Post-accident orientation(s) of a school bus play a significant role in the availability and usability of emergency exits for evacuation (Matolcsy, 2009). Therefore, school bus orientation should be considered when proposing an evacuation time standard.
2. Physical and cognitive capabilities of school bus passengers play a significant role in the operation of emergency exits (Abulhassan et al., 2018a, 2018b). Establishing an evacuation time standard for school buses could positively influence design change recommendations that reduce the gap between operating requirements and passenger capabilities (Gunter et al., 2020a). The establishment of passenger qualification criteria to be seated near an emergency exit (similar to the requirements required by the FAA for passengers seated in an emergency exit row) could potentially address this issue (FAA, 2006).

Table 3
Participant criteria of evacuation demonstration (FAA, 2006).

Passenger	Age	Percentage
Adult Females ¹	12–60	30% minimum
Adult Males ¹	12–60	50% to 60%
Adult Males & Females (Proportional mix)	Over 60	5% minimum
Children (Prorated by age)	3–11	5% to 10%
Life-sized Dolls (Carried by passengers)	2 or younger	Three dolls

¹ For Evacuation, FAA considers age 12 and up to be an adult.

3. It is recognized that school bus evacuation research has primarily focused on younger age group passengers (K-3) due to the limited physical and cognitive capabilities of this age group (Abulhassan et al., 2016, 2018a, 2018b; Gunter et al., 2020a, 2020b). However, it is also acknowledged that older school bus passengers body size (middle school and high school students) could impede the evacuation process through smaller exits such as roof hatches (Gunter et al., 2020b). Hence, the proposal of a school bus evacuation time standard should consider the challenges associated with younger and older school bus passengers.
4. Unlike commercial aircraft transportation, where the majority of the population is assumed to be adults with an aptitude to make rational decisions in an emergency; it is typical to have school bus routes that are kindergarten and kindergarten through second grade (K-2) exclusive routes. Baseline school bus evacuation times suggest that school bus driver assistance in an evacuation can reduce evacuation time in younger passenger groups (Abulhassan et al., 2016). Recent evacuation research also suggests that overcrowded emergency exits, running, pushing, and other physical interactions between passengers is typical in evacuations involving children (Chen et al., 2020). The addition of a school bus monitor to school bus routes that primarily transport kindergarten and K-2 children would be desirable to facilitate safe and timely evacuations as well as the benefits of having an additional adult present.
5. Highway Safety Program Guideline No. 17 requires school bus passengers to participate in supervised and emergency evacuation drills at least once per semester, however, no details are provided on the exits to be used in an evacuation drill or the maximum time for a successful evacuation drill (NHTSA, 2007). Individual states may have additional training procedures and requirements that extend beyond the federal guidelines. For instance, the State of Indiana requires school districts, non-public schools, and contractors to perform a school bus evacuation drill within 45 school days of the beginning of each semester (IAC, 2014). Per 575 Indiana Administrative Code 1-10-2, school bus evacuation drills should be completed in two minutes or less using emergency exits doors and the service door, and one of the drills to be completed without the direction of the school bus driver (IAC, 2014). The Commonwealth of Kentucky driver training instruction manual acknowledges “a school bus can be fully engulfed in smoke and fire in 3–5 min,” and requires emergency evacuation drills to also be completed in two minutes or less (Kentucky Department of Education, 2019). However, per 702 KAR 5:030 – Pupil Transportation, school districts in Kentucky are required to perform four evacuation drills in a school year: “the first full week of school; the first full week of the second semester; and the other two (2) drills within the school year, preferably one in the late fall and one in the early spring.” (KAR, 2021). Based on the current evacuation drill training requirements by states that mandate a maximum evacuation time, a **two-minute** evacuation time standard could be used as an initial proposal of the maximum allowable time to evacuate a school bus.

6. Conclusion

An inaccessible emergency exit and a weak evacuation system were attributed as major contributors to the severity of one of the deadliest drunk driving accidents in the history of the United States, where 27 passengers including 24 children were killed when a school bus experienced a head on collision with a drunk driver of a pickup truck (Keneally, 2018). It can be argued that the additional passenger safety requirements for airplanes are necessary due to the highly flammable fuel load the airplane carries for extended flights. However, on an airplane, we are primarily dealing with adults, and those that sit in emergency exit rows have more stringent levels of qualifications to adhere to. It is a credible scenario that a school bus could be in a serious accident that may bring its own fuel load into consideration, as well as that

of other large vehicles potentially involved in the accident. In contrast to the airplane, relatively few of the children are 15 years or older, and on bus routes serving younger children, kindergarten exclusive, kindergarten through second grade, etc., the lack of an additional bus monitor (adult), is somewhat disturbing if the need for an evacuation arises. Taking all aspects of this discussion into consideration, the need for discussion, development and implementation of a National School Bus Evacuation Standard should be self-evident.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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