Evaluation of School Bus Emergency Evacuation Systems With Regard to Physical Capabilities of Young Children

by

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Chapter 1

Introduction

Motorized school buses have been used to transport children for over a century and are known to be the safest mode of transportation for students traveling to and from school [NASDPTS, 2000]. Between 2001 and 2008, only 1% of student fatalities during normal school travel hours were occupants of a school bus while 23% were occupants of a vehicle with an adult driver, and 58% were occupants of a vehicle with a teen driver [NHTSA, 2015]. Despite the small chance of encountering a school bus fatality, there are approximately 26,000 school bus accidents in the United States in a system that transports more than 23.5 million children annually [McCray and Brewer, 2005]. School bus rear emergency door and roof hatches are usually used in post-accident scenarios to evacuate passengers. For instance, on December 2^{nd}, 2014, a collision caused one school bus to overturn, as shown in Figure 1.1, killing two young children and injuring twelve others [Associated Press, 2014]. First responders evacuated students through the roof hatches because the front door was inaccessible. Currently, there are no federal standards regarding emergency response times for first responders [Ludwig, 2015]. However, individual counties usually set an emergency response time based on location and population [Ludwig, 2015]. In a study conducted by Blackwell and Kaufman (2002) a metropolitan county (population 620,000) requires emergency medical services (EMS) to meet a 90% fractile standard [Blackwell and Kaufman, 2002]. The standard requires emergency medical services to have a response time of 10:59 minutes 90% of the time in urban areas of the county [Blackwell and Kaufman, 2002]. School bus crash files revealed that 47% of crashes had an EMS response time of less than 10 minutes, 24% had a response time of 10-14 minutes, and 29% had a response time of greater than 15 minutes [Donoughe and Katz, 2015]. Therefore, occupants of a school bus may need to

Figure 1.1: Rolled Over School Bus with Roof Hatches Opened [Associated Press, 2014]

evacuate before the arrival of first responders in events such as fires or other life threatening emergencies.

School bus accident severity may be reduced by evaluating the operability of the emergency evacuation system. Emergency exit systems on school buses are regulated by FMVSS No. 217, Bus Emergency Exits and Window Retention and Release, 49 CFR §571.217, a standard promulgated by the US Department of Transportation and put into effect on September 1, 1973 [NHTSA, 2011]. The standard defines the maximum force required to operate the release mechanisms of a rear emergency door and roof hatch. The maximum forces defined in the standard are equivalent to the least force required to open an emergency exit, and **does not take into account individual differences, especially those between adults and children.** School buses primarily transport children whose strength capabilities are not fully developed. Measuring the strength capabilities of the youngest population riding school buses (kindergarten through second grade students), and their ability to evacuate through the emergency exits are important factors to be considered. This would help determine the usability of the emergency exits and children's dependency on adults in a post-accident scenario.

Another important factor to be considered in evaluating of the evacuation system is the expected evacuation time which is a function of moving to and opening an exit, the number and location of exits, and the flow rate of passengers via the exits. Although FMVSS No. 217 specifies the number of emergency exits required on a school bus (based on the maximum occupancy of the bus), there are no specifications on evacuation times. In comparison to a larger but similar system, aircraft in the United States with a seating capacity larger than 44 passengers are required to demonstrate a full-scale evacuation within 90 seconds under simulated emergency conditions, while using half the available exits [FAA, 1990]. Additionally, the Federal Aviation Administration (FAA) performs certification tests through research and empirical data to specify the number of passengers that can evacuate through the aircraft exits (flow rate) [Hall, 2000]. Emergency evacuation systems are ameliorators, therefore utilizing a system that is designed to facilitate rapid evacuation could save lives and reduce the overall severity of an accident [Federal Highway Administration, 2004].

1.1 Research Objectives

The literature, reported in Chapter Two of this dissertation, suggests a gap in the incorporation of child strength and anthropometry in the design of the emergency evacuation system on school buses. While Federal Motor Vehicle Safety Standards mandate the specifications for school bus emergency evacuation systems, they fail to represent the capabilities of children who are the primary occupants of school buses. Furthermore, the literature clearly addresses concerns with easily opening and keeping open the emergency exits on motorcoaches/buses, which are also regulated by FMVSS No. 217, particularly when the motorcoach/bus is not in the upright position [Hall, 1999]. Thus, the objective of this research is to bridge the gap between current school bus emergency exit standards and the physical strength capabilities of children. By identifying potential improvements in the school bus evacuation system through the measurement of strength and stature of children, their ability to evacuate a school bus without adult intervention, and generating preliminary school bus egress times could help improve the overall safety of school bus transportation.

1.2 Research and Dissertation Organization

The chapters of this dissertation are organized according to the Auburn University dissertation guide [Auburn University, 2015]. The dissertation is comprised of six chapters. Chapter One provides a traditional introduction. Chapter Two is a comprehensive literature review on current standards and regulations for school bus emergency evacuation system design, and strength and anthropometry of children. Each of the remaining chapters is a stand-alone manuscript describing the purpose, methods, results and discussion of an experiment. The experiment described in Chapter Three measured the force five (5) to seven (7) year old children could exert on the handle of an emergency exit door, and their ability operate the release mechanism in a rolled over orientation. Chapter Four reports on the ability of children to operate the release mechanism on a roof hatch and evacuate through the hatch while the bus is in a rolled over orientation. Additionally, anthropometric measurements of the children are compared to the size, shape, and location of the roof hatch to determine sufficiency. Chapter Five reports the evacuation time of school buses with occupants divided by grade level from kindergarten to the third grade using the front door, an emergency exit door, and both door evacuation scenarios. The limitations of the experiments, study recommendations, and overall conclusions are discussed in Chapter Six. The appendices contain details outlining the recruitment and participation of human subjects, approved internal review board consent forms, summaries of the collected data, and other information to support the results presented in the chapter manuscripts.

1.3 Closing Statement

While school buses remain the safest mode of transportation, school bus accidents and motor vehicle fatalities occur on a daily basis in the United States. As school districts operate exclusive kindergarten through second grade routes in rural areas, the ability of young children to evacuate through the emergency exits in a post-accident scenario may be the difference between life and death. Quantifying the strength and stature of the youngest group of children riding school buses would be the first step in evaluating the effectiveness of emergency exits present in school buses. Therefore, the purpose of this research is to determine if school bus emergency exit standards adequately represent the ability of children to evacuate a school bus using the current setup.

Chapter 2

Review of the Literature

2.1 Problem Statement

Kindergarten through second grade (K-2) routes are common in many school districts in the United States. For instance, in 2012, the Auburn City Schools in Auburn, AL utilized 18 routes exclusively for kindergarten through second grade and 16 kindergarten through fifth grade (K-5) routes [Ingram, 2013]. Kindergarten through second grade routes encompass 528 miles per day transporting 545 children, and kindergarten through fifth grade routes transport 667 children over 546 miles per day in Auburn, AL [Ingram, 2013]. Children in kindergarten through fifth grade are physically developing and do not have the same physical capabilities and stature of adults. For example grip strength, a common measure of physical performance, of a 6-7 year old male is approximately 35% of a 18-19 year old male [Mathiowetz et al., 1986]. Therefore, it may not be acceptable to expect the same physical capabilities from children that would be expected from adults. Studying the stature and strength capabilities of children would help estimate the probability of successful evacuation from a school bus rollover accident, and identify any potential improvements in current emergency exit systems. Additionally, determining the required (standard) time to evacuate a school bus using available exits could provide a benchmark that school districts can use to compare their performance against for training effectiveness.

2.2 School Bus Emergency Evacuation System Force Requirements

The design of school bus emergency exit systems is regulated by FMVSS No. 217 [NHTSA, 2011]. This standard specifies the type of motion and the maximum force required to open the rear emergency exit, roof hatches, and window exits on a school bus. The term "maximum force" is equivalent to the minimum force a person is required to exert to open an emergency exit. Emergency exit areas on school buses are defined as either high force or low force access regions [NHTSA, 2011]. The motion required to open a side emergency exit and rear emergency exit must be upward for school buses with a gross vehicle weight rating (GVWR) of 10,000 pounds or greater and an upward or pull-type motion for a school buses with a GVWR of 10,000 pounds or less [NHTSA, 2011]. The location of the rear emergency exit release mechanism falls in the high force region and therefore the maximum force required to open the exit cannot exceed 178 Newtons (40 pounds) [NHTSA, 2011]. Roof hatches can have one release mechanism with two force applications to release the exit, or two release mechanisms, each requiring one application to release the exit [NHTSA, 2011]. A rotary or straight motion can be used to operate a roof hatch located in the low force region with a maximum force of no greater than 89 Newtons (20 pounds)[NHTSA, 2011]. Roof hatch operating mechanisms located within the high force region are required to have a motion that is straight and perpendicular to the undisturbed surface with a maximum force not exceeding 178 Newtons (40 pounds) [NHTSA, 2011].

When FMVSS No. 217 was published, a torque limit of 20 inch-pounds was required for the actuation of rotary emergency exit releases [Toms, 1973]. However a petition received from Wayne Corporation deemed the standard impractical [Toms, 1973]. Furthermore, the Blue Bird Bus Company requested that the limit be raised to 225 inch-pounds in order to avoid inadvertent openings [Toms, 1973]. Based on these petitions, NHTSA eliminated this requirement because it decided that a maximum torque requirement is redundant since the force magnitude generally is limited in paragraph S5.3.2 to not more than 20 pounds [Toms, 1973].

High force and low force regions for the area surrounding the rear emergency exit and roof hatch are shown in Figure 2.1 and Figure 2.2. Accordingly, high force regions correspond to those in which an able-bodied person (not physically disabled) can exert maximum force

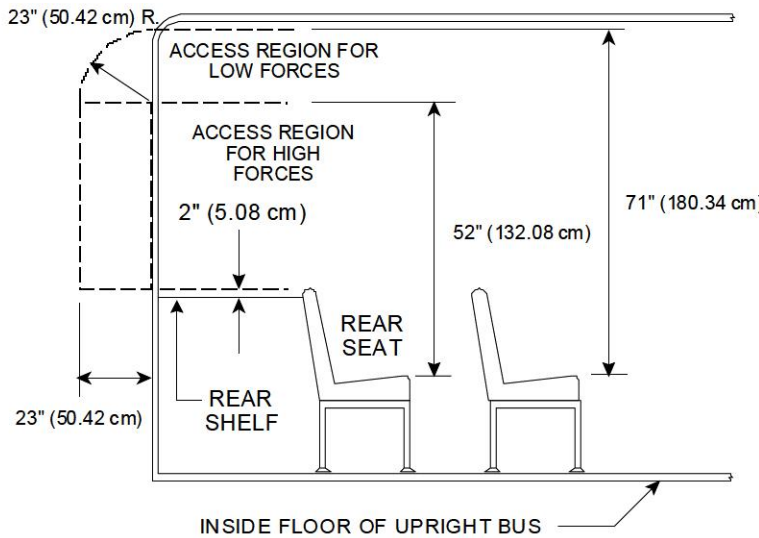

Figure 2.1: Access Regions for Rear Emergency Exit [NHTSA, 2011]

"relatively close to shoulder height of an average adult male" [Pollard and Markos, 2009]. Similarly, low force regions correspond to regions which require reaching well below or well above occupant shoulder height [Pollard and Markos, 2009]. While the access regions are shown for the bus in the upright position, paragraph S5.2.2.2 states that the rear emergency exit and roof emergency exit should meet those same requirements when a school bus with a GVWR of 10,000 pounds or more is overturned on either side, with the occupant facing the exit [NHTSA, 2011]. However, based on National Transportation Safety Board Recommendation H-99-9, there are concerns with easily opening and keeping open the emergency exits in an orientation that is not fully upright [Hall, 1999].

2.3 Emergency Exit System Size Specifications

The type and number of emergency exits on a school bus is dependent on the maximum occupancy of a school bus as shown in Table 2.1. Maximum occupancy is calculated by dividing the bench width in millimeters by 380, rounding to the nearest whole number, and multiplying that number by the number of benches on the school bus [NHTSA, 1993]. The "380" is based off of having enough space to accommodate an adult female at the 5th percentile

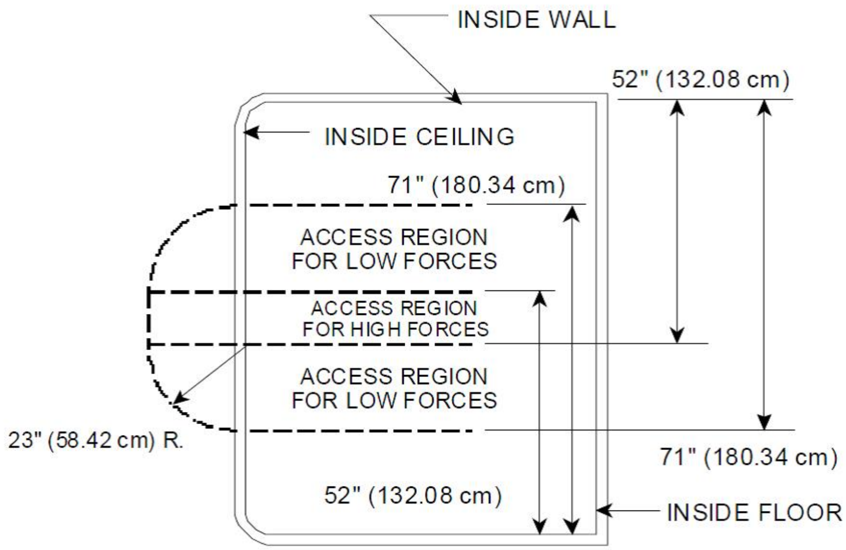

Figure 2.2: Access Regions for Roof Hatch [NHTSA, 2011]

[NHTSA, 2002]. Seat width is generally measured by hip and shoulder breadth in a sitting position [Pheasant, 1988]. The average hip and shoulder breadth of a five year old female is 210 millimeters and 270 millimeters, respectively [Pheasant, 1988]. Therefore, on a Blue Bird school bus with a 914 millimeters wide bench, it is possible to exceed the maximum capacity on kindergarten through second grade (K-2) routes. Type D school buses are the most common type of school bus and may have a maximum seating configuration of 90 passengers, but usually transport 50 to 60 passengers comfortably [Blue Bird Bus Corporation, 2014].

The dimensions of school bus emergency exits are regulated by paragraph S5.4 of FMVSS No. 217 [NHTSA, 2011]. An opening of at least 41 centimeters (16 inches) high and 41 centimeters (16 in) wide is required for roof hatches [NHTSA, 2011]. The laboratory test procedures for FMVSS No. 217 specify that an ellipsoid with a minor axis of 33 centimeters (13 inches) and a major axis of 50 centimeters (19.7 inches) must be able to pass through the roof hatch while keeping a major axis horizontal at all times [NHTSA, 2002]. Moreover, paragraph S5.4 requires rear emergency doors to be large enough for a parallelpiped (45 inches high, 24 inches wide, and 12 inches deep) to pass through while keeping the 45 inches dimension vertical and the 24 inches dimension parallel to the opening [NHTSA, 2011].

While school bus emergency exits are not rated for the number of passengers that can evacuate through them per unit of time, they are assigned a capacity credit which is used to determine the combination of exits required for school buses with a seating capacity greater than 83 passengers as shown in Table 2.1 [NHTSA, 2011]. However, depending on the orientation of the school bus, the capacity credit rating could be less based on accessibility and usability of the exits. In a study conducted by Matolcsy (2010), the usability of exits were rated based on the orientation of a bus [Matolcsy, 2010]. As shown in Table 2.2 if a bus is rolled over on its roof, the roof hatches are unusable, and if a bus is rolled over on either side, the side emergency windows usability becomes very weak. Taking into account the usability of exits may help determine if the current minimum emergency exit requirement are adequate for the different rollover orientations.

Table 2.1: School Bus Emergency Exit Requirements [NHTSA, 2011]

Seating Capacity	**Emergency Exits Required**
1-57	None
58-74	1 right side exit door, or 2 exit windows
75-82	1 right side exit door or 2 exit windows, and 1 roof exit
83 and above	1 right side exit door or 2 exit windows, and 1 roof exit, and any combination of door (CC=16), window (CC=8), roof exit (CC=8) such that the total Capacity Credit (CC) specified plus 82 is greater than the capacity of the school bus

Table 2.2: Emergency Exit Usability based on Bus Orientation [Matolcsy, 2010]

Evacuation Path	**Standing on its Wheels**	**Rolled Over on its Roof**	**Rolled Over on Right Side**	**Rolled Over on Left Side**
Roof Hatch	Very Weak	Unusable	Very Good	Very Good
Rear Emergency Door	Good	Good	Good	Good
Side Wall Emergency Window	Good	Good	Very Weak	Very Weak

Flow rate of an emergency exit is important to determine the efficiency of the current egress system. In terms of emergency evacuations there are many similarities between aircraft and school buses, they are both metallic tubes used for transportation. While aircraft have more complex emergency evacuation systems, similar standards could be implemented on school buses to determine the effectiveness of their evacuation system. For instance, the FAA performs certification tests through research and empirical data to specify the passengers per minute flow rate of aircraft exits [Hall, 2000]. Similar testing could be done on school bus exits using children of different ages to determine the effects of age and size on emergency evacuations. Additionally, the FAA requires aircraft with a seating capacity of greater than 44 passengers to perform a full scale evacuation utilizing participants with demographics representative of the traveling public within 90 seconds, using only half the exits on the aircraft [Hall, 2000]. Gathering evacuation time data for school buses would be the first step towards promulgating a standard for acceptable egress times.

The Volpe Center is a federal agency under the U.S Department of Transportation and has 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 and "hold open" mechanisms were used to keep the emergency exit windows open after they have been unlatched [Pollard and Markos, 2009]. Results for egress times and flow rates for each egress path are shown in Table 2.3. Participants in the study were the staff of the Volpe Center and had sufficient knowledge of the evacuation system on the motorcoach [Pollard and Markos, 2009]. Therefore egress times are likely to be considerably higher for children on a school bus. Factors that could lead to increased emergency evacuation times include no "hold open" mechanisms, an incapacitated driver that cannot assist passengers, injured passengers, passengers with little to no experience using the emergency exits, passengers lacking the agility and strength to use the emergency exits, and emergency exits not staying open [Pollard and Markos, 2009]. The largest exit on school buses is the rear emergency exit door that has a weight of 90 approximately pounds. The "hold open" mechanism on the rear emergency door is not activated unless the door is in a fully open position. This could be an issue if the school bus is rolled over on its left side (facing forward) with the door hinges on top. If the door was unlatched and could be partially swung open, gravity would pull the door shut, slowing down or even preventing egress. In comparison with the front door, the flow rate of adults out of roof hatches is approximately a third when compared to the front door due to the size of exit opening and agility required to evacuate through the roof hatch.

Table 2.3: Volpe Center 56 Passenger Motorcoach Egress Times [Pollard and Markos, 2009]

Egress Path Used	**Number of Exits Used**	**Opening Time (min)**	**Flow Rate (exit/ppm)**	**Egress (min)**	**Total (min)**
Front Door	1	0.05	36	1.56	1.61
Windows	6	0.2	9	1	1.20
Wheelchair Access Door	1	0.2	25	2.24	2.44
Roof Hatches	2	0.1	12	2.33	2.43

2.4 School Bus Evacuation Times

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, J.L., Dorris, A., and Stephens, R. in 1970 [Purswell et al., 1970]. Two groups of 60 students each from kindergarten through twelfth grade 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 participated in evacuation trials performed on a Superior Coach Corporation Model 69-1099 school bus in the upright orientation, 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 evacuation trials were performed for each orientation;

a set of evacuation trials in daylight, and a 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 second in 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 [Purswell et al., 1970]. 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 Table 2.4 and Table 2.5. 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.

Table 2.4: 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] Trial conducted with 59 subjects, number in parenthesis is calculated time for 60 subjects.

[B] Trial conducted with 58 subjects, number in parenthesis is calculated time for 60 subjects.

Table 2.5: 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

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 2.6 [Sliepcevich et al., 1972]. While these evacuation times may be acceptable, many school districts utilize school bus routes that transport children in similar age groups. 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 higher on these routes because of children's developing cognitive and strength capabilities to open and evacuate through the exits especially in a rolled-over orientation or if the school bus driver is unable to assist in the evacuation process. Studies have identified that students with no prior experience operating emergency exits are unable to open emergency exits requiring coordinated action to open, and the uses of these exits were unsatisfactory in panic emergency situations [Sliepcevich et al., 1972, Purswell et al., 1970].

Table 2.6: School Bus Egress Times [Sliepcevich et al., 1972]

Trial Description	**No. of Participants**	**Egress Time (Seconds)**
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

2.5 History and Revisions of FMVSS No. 217

Since the proposal of FMVSS No. 217 in 1970 there has been some significant proposals and amendments related to the evacuation system on school buses. The timeline shown in 2.3 summarizes some of the main school bus evacuation systems milestones related FMVSS No. 217 [Pollard and Markos, 2009]. Recently, the Federal Register Proposed Rules (2014) has express concern over the operability of the emergency exits after a rollover accident and the impact of inoperable exits to emergency evacuations [NHTSA, 2014]. Moreover, the operability of the emergency exits in a rolled over orientation has been questioned if it meets the requirements of exits in the upright orientation [NHTSA, 2014].

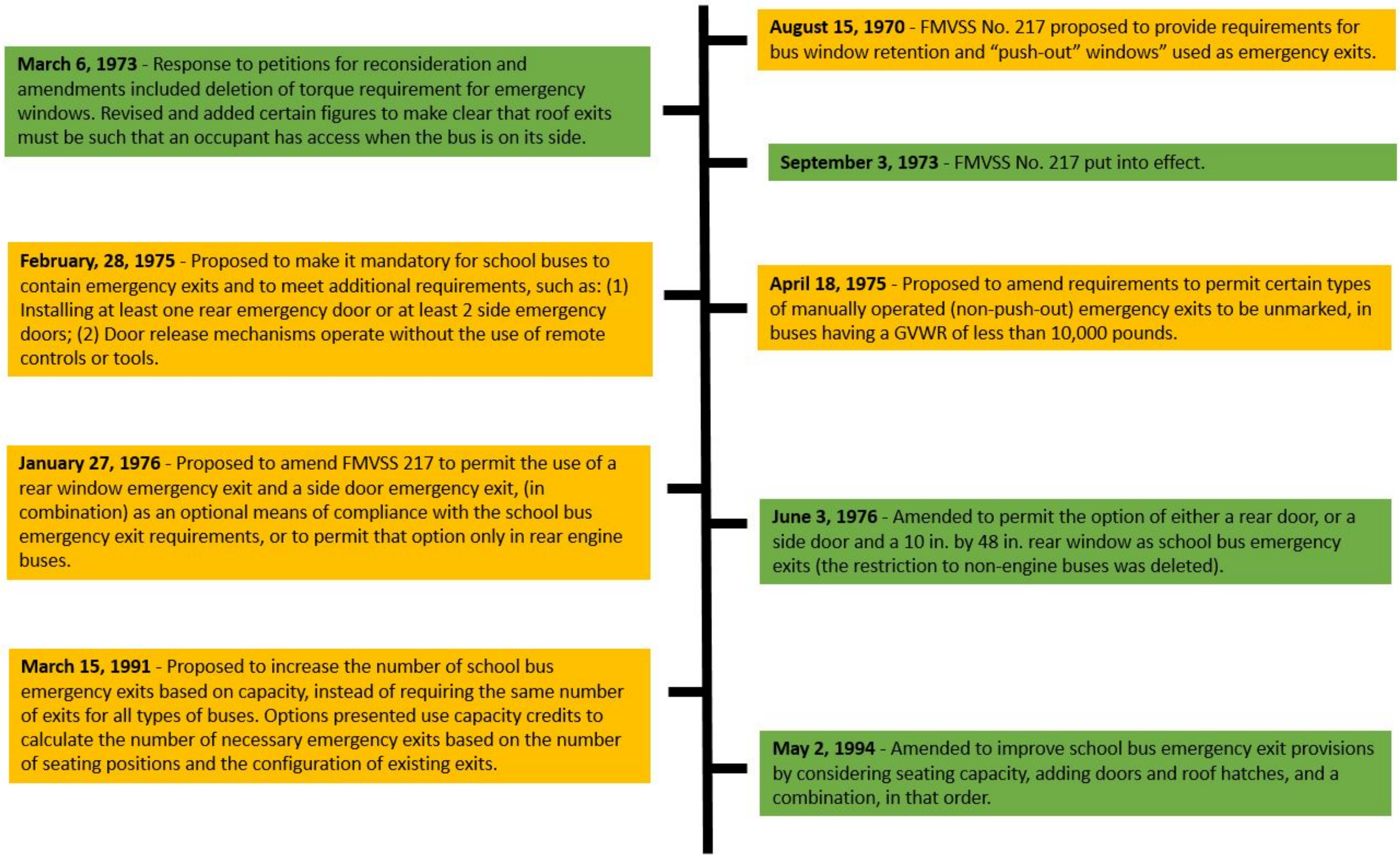

Figure 2.3: Timeline of Proposals and Amendments to FMVSS No. 217 [Pollard and Markos, 2009]

Figure 2.4: School Bus Roof Hatch

2.6 Roof Hatch Operating Instructions and Cognitive Abilities of Children

Unlike the rear emergency door, operation of roof hatches on school buses take longer to open compared to other emergency exits, and could be challenging from a cognitive standpoint [Cook and Southall, 2000]. This is primarily because roof hatches are infrequently used (if ever by children), whereas the rear emergency door is sometimes used in evacuation training and in non-emergency situations to load sporting gear on school buses, etc. Furthermore, roof hatches are required to have one release mechanism with two force applications to release the exit or two release mechanisms, each requiring one force application to release the exit [NHTSA, 2011]. Due to these requirements roof hatches often have instructions indicating the operation required to release the roof hatch. A common type of roof hatch used on Blue Bird school buses operated by Auburn City Schools Transportation Department in Auburn, AL is the Transpec 1970 Series Standard Safety Vent shown in Figure 2.4. To release the roof hatch, the passenger must turn the red knob from the "latched" position to the "to exit" position, push sharply upward on the red knob to partially open the hatch, and then push on the roof hatch to open it all the way [Blue Bird Bus Corporation, 2008].

As shown in Figure 2.5, the Blue Bird Bus Corporation drivers handbook provides instructions with images on how to operate the roof hatch. It would be safe to assume that the most of school bus passengers have not read a school bus driver handbook, and the instructions on the roof hatch itself is the only information available to them in the event of an accident. A concern with roof hatch instructions is that they may not be conspicuous or easily legible in a dark or smoke-filled environment [Pollard and Markos, 2009]. The second concern is that children may not have the cognitive abilities to comprehend the instructions provided. One of the measures of cognitive abilities is executive functioning which is the management of one's resources to achieve a goal using mental control skills [Cooper-Kahn and Dietzel, 2008]. Executive functioning is not fully developed in children and maintaining two separate goals stated at one time is difficult for children to do [Bayliss et al., 2003]. Therefore, the phrase used on the Transpec 1970 Series roof hatch is, "turn then push knob to open," may not be comprehended or followed by children in the first and second grade due to their reading abilities. The inability to understand how to use emergency exits would considerably increase egress times [Pollard and Markos, 2009]. The ease of use and speed of operating mechanisms on emergency exits are critical in evaluating the effectiveness of an emergency exit. As shown in Table 2.3, opening time of the emergency exits ranged from 3-12 seconds. However, this may be longer for children or adults who do not have prior experience operating the emergency exits. A study conducted by Cook and Southall (2000) found that operating mechanisms on emergency exits on public service vehicles are impaired by the location of the operating mechanism, misleading or poorly located instructions, and poorly designed safety devices aimed at avoiding misuse [Cook and Southall, 2000]. While the focus of this research is on the physical capabilities of children, it is important to address the cognitive limitations of children as it plays a major role in the evacuation procedure [Callender et al., 2014].

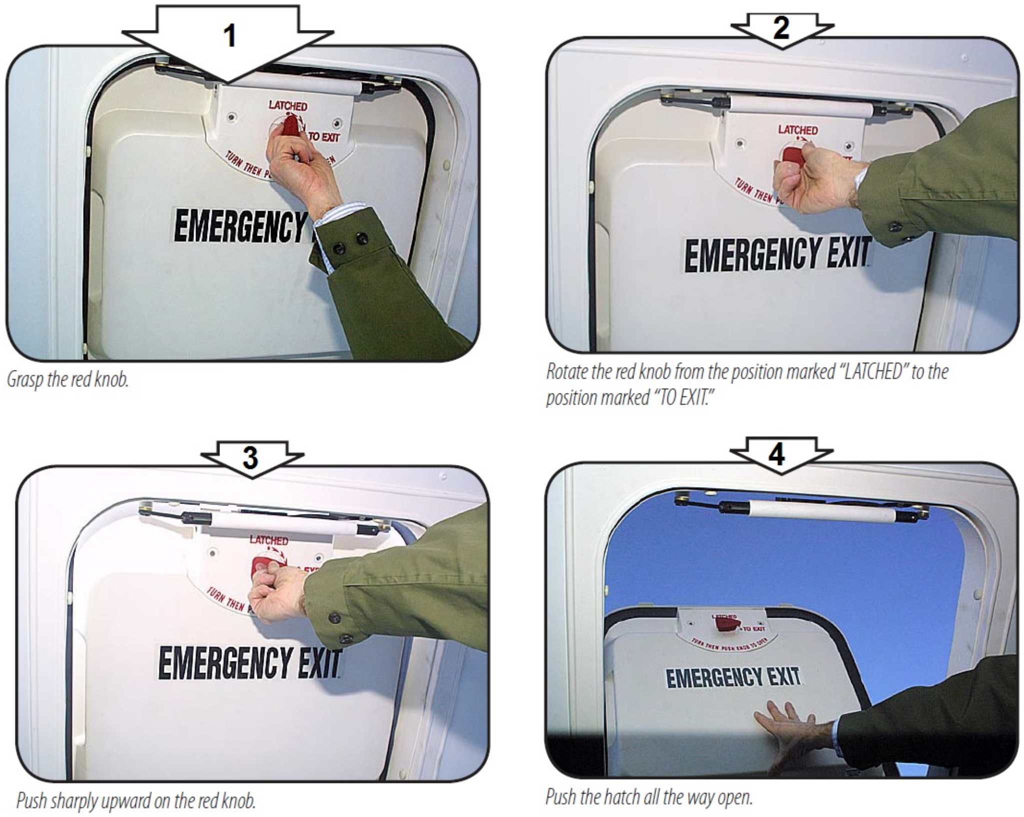

Figure 2.5: Roof Hatch Operation Instructions [Blue Bird Bus Corporation, 2008]

2.7 Strength and Physical Capabilities of Children

Currently, there are no studies to indicate if FMVSS No. 217 requirements provide an effective or balanced approach to emergency egress [Saul, 2007]. Measuring the strength and anthropometry of the youngest occupants utilizing school buses for daily transportation is a key factor in determining the probability of a successful egress. Several studies have been performed to measure pushing, twisting, grip, and pinch strength of children using different devices and protocols. However, information from existing sources is often not directly applicable to the design of consumer products including emergency evacuation systems [Pollard and Markos, 2009]. Information from existing literature can be used as a starting point to determine the likelihood of a child successfully operating the release mechanisms on roof hatches and the rear emergency door in upright and rolled over orientations.

The main emergency exit on school buses is the rear emergency exit door. In the upright configuration, the door handle on the rear emergency door needs to be pulled upwards to unlatch the door, however, the location and release direction is different if the school bus is in a rolled over orientation. In 1972, a study titled *"Escape Worthiness of Vehicles for Occupancy Survival and Crashes"* was funded by NHTSA to evaluate the maximum pull force children can exert on the emergency exit door handle, and the push force on the rear emergency exit door of a 1971 Superior school bus [Sliepcevich et al., 1972]. Pull force on the emergency door hand was measured using two methods; pulling with the palm on the top of the handle, and pulling with the palm under the handle [Sliepcevich et al., 1972]. These force exertions are presented in Table 3.2

Table 2.7: Rear Emergency Door Force Exertions (Pounds)
[Sliepcevich et al., 1972]

Male	**Push Force**	**Mean Pull Force Palms Up**	**Mean Pull Force Palms Down**
6 Years	16.5	18.5	23.5
7 Years	19.7	26.0	36.7
8 Years	17.5	39.3	51.0
Female	**Push Force**	**Mean Pull Force Palms Up**	**Mean Pull Force Palms Down**
6 Years	20.5	21.7	31.0
7 Years	12.0	27.0	37.0
8 Years	19.0	41.3	52.7

A study funded by the Consumer and Competition Policy Directorate of the Department of Trade and Industry measured strength data of children and adults to provide designers with ergonomics data for use in the design of safer products [Department of Trade and Industry, 2000]. Peak pull force on a cylindrical bar (20 millimeters round and 300 millimeters long) smaller in size to the door handle on the rear emergency exit door (25 millimeters wide and 483 millimeters long) was measured by instructing the subjects to build up their maximum strength in the first few seconds and then maintain this for a few more seconds [Department of Trade and Industry, 2000].

The results are shown in Table 2.8 for children between the ages of 2 and 10 years old [Department of Trade and Industry, 2002]. While the height of the bar was adjusted to shoulder height of the subjects to be able to exert maximum force, the location of the door handle on the rear emergency door is fixed and may not be ideal for maximal exertion. Additionally, the seats may act as a barrier preventing the occupants from grasping the door handle comfortably, further impacting exertion force.

Table 2.8: Pull force on Horizontal Cylindrical Bar (Newtons) [Department of Trade and Industry, 2000]

Age	**Gender**	**No.**	**Mean**	**SD**	**Range**
2-5	Male	12	87.99	42.18	51.99 - 171.52
2-5	Female	9	43.22	34.62	35.41 - 114.60
6-10	Male	8	232.97	102.61	111.21 - 381.13
6-10	Female	11	175.09	75.65	88.21 - 365.30

Operation of the roof hatch requires the user to rotate the knob and push on it, exerting 89 Newtons of force to release locking mechanism. A second study was funded by the Consumer and Competition Policy Directorate of the Department of Trade and Industry to further measure strength data of children and adults for various tasks [Department of Trade and Industry, 2002]. Maximum push exertion using two or more fingers of a subjects dominant hand was measured on a (50 mm x 50 mm) plastic cube. Strength exertions were recorded for the subjects pushing forward on the plastic cube positioned at elbow height [Department of Trade and Industry, 2002]. Subjects were instructed to build up their maximum strength in the first few seconds and to maintain maximum strength for a few more seconds [Department of Trade and Industry, 2002]. The average push force using two or more fingers for children in the 2-5 year old and 6-10 year old age groups are shown in Table 2.9.

A similar push force study was conducted by Peebles and Norris (2003), but by exerting push force with a thumb and index finger on a circular force plate with a 20 mm diameter and 2 mm depth [Peebles and Norris, 2003]. The peak force was measured while the subjects

Table 2.9: Push Force with Two or More Fingers (Newtons) [Department of Trade and Industry, 2002]

Age	Gender	No.	Mean	SD	Range
2-5	Male	9	27.49	13.3	6.70 - 42.00
2-5	Female	8	20.80	9.93	6.10 - 34.70
6-10	Male	5	65.86	24.06	36.10 - 91.30
6-10	Female	8	78.04	29.89	47.20 - 124.70

were instructed to exert their maximum force for five seconds using their dominant hand [Peebles and Norris, 2003]. Results of this study are shown in Table 2.10 and Table 2.11 [Peebles and Norris, 2003]. Based on the three studies, pushing with a thumb resulted in higher average push force compared to pushing with the index finger or pushing with two or more fingers. However, the average push force in all three studies was lower than the 89 Newton threshold set by FMVSS No. 217 for roof hatch operation [NHTSA, 2011]. Furthermore, the push forces measured in these studies are likely to be higher than what can be exerted on a roof hatch knob. The first reason is that the there is less surface area to exert a force on with a roof hatch knob in comparison to the plastic cube used in the first study. As shown in Figure 2.6 The surface area of the roof hatch knob (2.52 inches^2) is approximately 63% of the area of the plastic cube (4 inches^2) used in the study conducted by the Department of Trade and Industry (2002). The second reason is the location of the force plate in the studies was at the elbow height of the subjects allowing them to apply greater force because they can use their body weight when to push harder on the force plate. The relative roof hatch knob location for a child is different compared to an adult. As shown in Figure 2.7, a kindergarten age child would have to reach overhead to push the roof hatch knob, whereas the location of the roof hatch knob to an adult would allow them to use their body weight while pushing on the knob.

Another area of interest for operating the roof hatch is the twisting force that must be exerted on the roof hatch knob, which is the first step in releasing the roof hatch. Grasping the roof hatch knob may be challenging to children with small hands due to its unique

Table 2.10: Push Force with Index Finger (Newtons) [Peebles and Norris, 2003]

Age	Gender	No.	Mean	SD	Range
2-5	Male	9	20.3	5.2	16.0 - 35.0
2-5	Female	8	24.9	9.6	15.9 - 38.6
6-10	Male	5	51.5	13.4	30.8 - 61.8
6-10	Female	10	44.0	17.3	23.4 - 70.3

Table 2.11: Push Force with Thumb (Newtons) [Peebles and Norris, 2003]

Age	Gender	No.	Mean	SD	Range
2-5	Male	9	28.1	10.0	17.3 - 41.6
2-5	Female	8	30.9	8.7	16.8 - 42.8
6-10	Male	5	88.8	28.6	53.4 - 126.6
6-10	Female	10	70.2	24.6	36.7 - 107.7

shape. As part of the *Filling 'Gaps' in Strength Data for Design* study, twisting strength on a ridged knob (40 mm length, 15 mm depth) about a half an inch smaller than the length of a roof hatch knob was measured for young children [Peebles and Norris, 2003]. Subjects were allowed to adopt a free posture in front of the measuring device and were instructed to exert a clockwise static twisting force for five seconds [Peebles and Norris, 2003]. The peak torque was measured during the five second exertion period and the data collected for children in the 2-5 year old and 6-10 year old age groups are shown in Table 2.12. However, in a rolled over school bus orientation, the curvature of the school bus roof can act as barrier preventing younger occupants from getting close to the roof hatch which could reduce the amount of force they can apply on the roof hatch knob as shown in Figure 2.7.

Table 2.12: Ridged Knob Horizontal Wrist-Twisting Strength
(Newton Meter) [Peebles and Norris, 2003]

Age	Gender	No.	Mean	SD	Range
2-5	Male	8	0.9	0.4	0.5 - 1.4
2-5	Female	7	0.6	0.3	0.2 - 0.9
6-10	Male	7	2.6	0.7	1.6 - 3.6
6-10	Female	11	2.0	0.9	0.8 - 3.7

Figure 2.6: Surface Area Comparison of Roof Hatch Knob to (50 mm x 50 mm) Plastic Cube

2.8 Anthropometry and Stature of Children

An important factor considered in the design of emergency exits is the relationship between body breadth and size of the emergency exit [Purswell et al., 1970]. Obesity prevalence rates among school age children have been increasing every year [Jackson-Leach and Lobstein, 2006]. There are three main body shapes: ectomorph (small frame and bone structure); mesomorph (heavy muscles and wide shoulders); and endomorph (round physique and large fat layer) [Meredith, 1940]. Based on the morphology of the person, shoulder (bideltoid) breadth and the distance between the widest points of the pelvis (billiac breadth) should be considered when designing the openings of emergency exits. Maximum shoulder breadth measurements are shown in Table 2.13. Another study conducted by the Center of Disease Control (CDC) measured the biiliac breadth of children as summarized in Table 2.14 [McDowell et al., 2009]. As described earlier, roof hatches on school buses need to have an opening that is at least 16 inches (40.64 cm) tall and 16 inches (40.64

cm) wide [NHTSA, 2002]. However, with the rise in obesity levels, this opening may not be large enough for the evacuation of larger passengers.

Table 2.13: Children Shoulder (Bideltoid) Breadth (Centimeters) [Pheasant, 1988]

Age	**Gender**	**Mean**	**SD**	**5th Percentile**	**95th Percentile**
5	Male	27.5	1.7	24.5	30.5
7	Male	30.0	2.2	26.5	33.5
10	Male	33.5	2.7	29.0	38.0
5	Female	27.0	1.6	24.5	29.5
7	Female	29.5	2.4	25.5	33.5
10	Female	33.0	3.1	28.0	38.0

Table 2.14: Biiliac Breadth for Children in the United States (Centimeters) [McDowell et al., 2009]

Age	**Gender**	**No.**	**Mean**	**SD**	**10th Percentile**	**90th Percentile**
5	Male	491	17.7	0.11	16.0	19.2
7	Male	268	19.6	0.19	17.4	21.6
10	Male	292	21.7	0.23	19.4	24.9
5	Female	555	17.7	0.12	16.0	19.5
7	Female	269	19.4	0.27	17.1 (*15th)	22.2 (*85th)
10	Female	255	22.4	0.28	20.2 (*15th)	24.7 (*85th)

Another important anthropometric measurement to be considered is height of children. Height measurements of children were collected by the CDC between 2007 and 2010 and the results are shown in Table 2.15. Figure 2.7 is a scaled illustration of how a rolled over school bus would appear to a 45 inch child (the average height of a child in kindergarten) when trying to operate a roof hatch in comparison to a 70 inch (average height) adult male. The child would have to reach overhead to push the roof hatch knob, whereas the location of the roof hatch knob to an adult would allow them to use their body weight when pushing the knob. Therefore, the high and low force regions would be different for a kindergarten student as compared with an adult. Additionally, the location of the roof hatch in the center of the roof may restrict small children to evacuate through. A small child would have to climb or pull themselves up to be able to evacuate through the roof hatch opening, which could have a significant effect on the evacuation process [Purswell et al., 1970].

Table 2.15: Height of Children in the United States, 2007-2010 (Inches) [Fryar et al., 2012]

Age	Gender	No.	Mean	SD	5th Percentile	95th Percentile
5	**Male**	205	44.8	0.22	41.0	47.9 (*90th)
7	**Male**	215	49.4	0.17	46.1	53.8
10	**Male**	211	59.0	0.24	54.7	64.2
5	**Female**	177	44.3	0.18	41.0	48.1
7	**Female**	207	49.1	0.21	44.7	52.8
10	**Female**	183	56.9	0.21	52.7	61.2

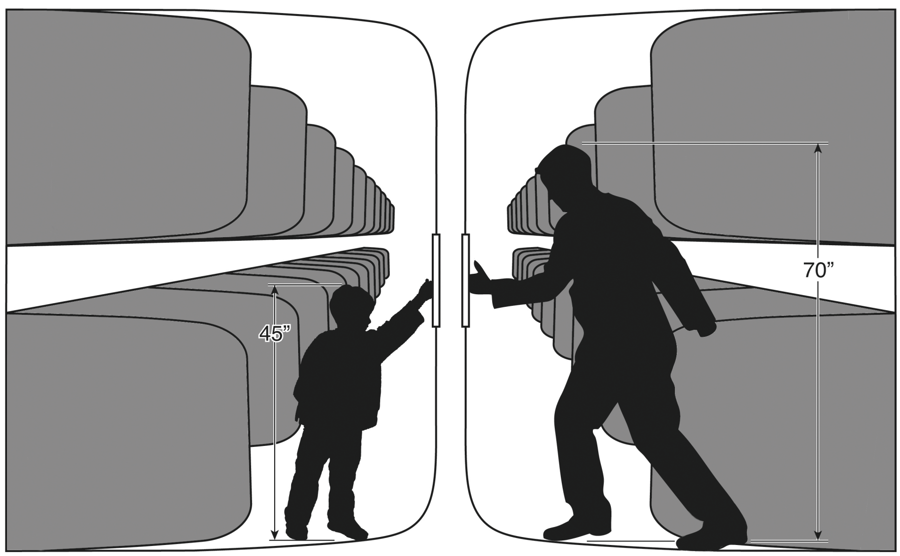

Figure 2.7: Scaled Illustration of Rolled Over School Bus Demonstrating Differences Between an Average Kindergarten Student and Average Adult Male

Hand size is another anthropometric measurement to be considered in the design of emergency escape devices. The use of large handles could prevent some children from getting their entire hand around the handle in order to achieve optimal strength [Link et al., 1995]. Measuring hand length and and width would allow for the design of handles that fit in the hands of children. Hand length is measured from the midpoint of the intersyloid line to the tip of the middle finger, and hand width is measured from the second metacarpal to the fifth metacarpal [Link et al., 1995]. Hand measurements of children is shown in Table 2.16.

Table 2.16: Hand Breadth and Hand Length of Children (Centimeters) [Pheasant, 1988]

Age	Gender	Mean	SD	5th Percentile	95th Percentile
5	Male	6.0/12.5	0.4/0.9	5.5/10.0	6.5/14.0
7	Male	6.5/13.5	0.4/0.9	6.0/12.0	7.0/15.0
10	Male	7.0/15.0	0.4/0.9	6.5/13.5	7.5/16.5
5	Female	5.5/12.0	0.4/0.8	5.0/10.5	6.0/13.5
7	Female	6.0/13.5	0.4/0.8	5.5/12.0	6.5/15.0
10	Female	7.0/15.0	0.5/1.0	6.0/13.5	8.0/16.5

2.9 Limitations of the Existing Research

Three primary limitations have been identified in the existing literature. These limitations are reported in this section, and they are highlighted again in the manuscript chapters whose hypotheses address those limitations.

2.9.1 Measurement of Young Children's Strength and Anthropometry

The lack of child strength and anthropometric data may be due to research programs focusing on workplace design [Peebles and Norris, 2003]. While the literature provides some strength data for children, it is not directly applicable to the design of consumer products, including school bus emergency exits [Peebles and Norris, 2003]. In many studies, subjects are asked to adopt standardized postures which may not be a realistic representation of the environment of a school bus emergency exit.

2.9.2 Incorporating Child Anthropometry and Strength in the Design of Evacuation Systems Standard

As described in the review of the literature, FMVSS No. 217 does not consider the strength and anthropometry of young children in school bus emergency evacuation system standards [NHTSA, 2011]. The force regions defined by FMVSS No. 217 are designed for the physical capabilities of an average male [Pollard and Markos, 2009]. Incorporating the strength and stature of children in the design of emergency evacuation systems would may lead to more accessible emergency exits.

2.9.3 Lack of Evacuation Data for School Buses

There are no standard evacuation times used in the school bus industry when designing the emergency evacuation system and reported evacuation times are sparse. Egress studies have been conducted on motorcoaches to determine flow rates of passengers through exits [Pollard and Markos, 2009, Purswell et al., 1978]. However, there is a lack of reported egress information on school buses carrying children. It is hypothesized that egress times are likely to be higher for children due to their size and inexperience of using emergency exits [Pollard and Markos, 2009].

2.10 Specific Aims

The aims of this research are to: (1) Measure force exertions on the handle of the rear emergency exit door and roof hatch knob at the locations they are presented to the occupants of a school bus in the upright and rolled over orientations; (2) Narrow the gap between the physical requirements of operating the emergency exits on a school bus, and the physical capabilities of youngest group of children (kindergarten through second grade) that typically use school buses for transportation; (3) Collect data on school bus evacuation times with children in different grade levels to determine if there are any improvements that can be recommended for the current setup. The evacuation data can also be used as a basis to determine acceptable evacuation times and evaluate evacuation training performed at school districts throughout the country.

Chapter 3

Physical Requirements to Evacuate a School Bus Through the Rear Emergency Door

3.1 Introduction

While school bus rollover accidents are rare, they tend to be viewed as the most complex type of accidents because the occupants are in an unfamiliar orientation and often injured [Matolcsy, 2010]. The largest usable emergency exit in a rolled over school bus is the rear emergency door which can present itself in three orientations after a rollover accident: (1) Rolled over on its right side (facing forward) causing the emergency door hinges to be located at the bottom; (2) Rolled over on its right side (facing forward) with the door hinges located at the top; or (3) Rolled over on its roof. Each of these orientations presents the door handle release mechanism at different locations with respect to the occupants in the school bus, in comparison to its upright (normal) orientation. It is hypothesized that force exertion capacity on the door handle to unlatch the rear emergency exit is dependent on the location of the handle relative to the school bus occupant.

Kindergarten through second grade (K-2) routes are common in many school districts as a primary means of transportation for children to and from school. For instance, in 2012, Auburn City Schools (Auburn, AL) had 18 routes that exclusively transported students in kindergarten through second grade [Ingram, 2013]. Typically, the only adult on many K-2 routes is the school bus driver. If the driver is incapacitated as a result of injury from an accident, or other factors such as stroke, heart attack, seizure, drugs (prescription or illegal), they may not be able to assist in the evacuation process. Hence, this study seeks to determine if young children are capable of operating the rear emergency door of a school bus in the upright and rolled-over orientations as well as self-extricating without adult assistance or guidance.

3.1.1 Rear Emergency Door Standards

Federal Motor Vehicles Safety Standard (FMVSS) No. 217 specifies the maximum permissible forces required to unlatch the release mechanism on a rear emergency door as shown in Figure 3.1 [NHTSA, 2011]. The maximum permissible force to operate the release mechanism in the high force region is 178 Newtons (40 pounds) and 89 Newtons (20 pounds) for the low force region [NHTSA, 2011]. Paragraph S5.4 of FMVSS No. 217 requires the rear emergency door opening to be large enough for a parallelpiped 45 inches high, 24 inches wide and 12 inches deep to pass through, keeping the 45 inch dimension vertical and the 24 inch dimension parallel to the opening [NHTSA, 2011].

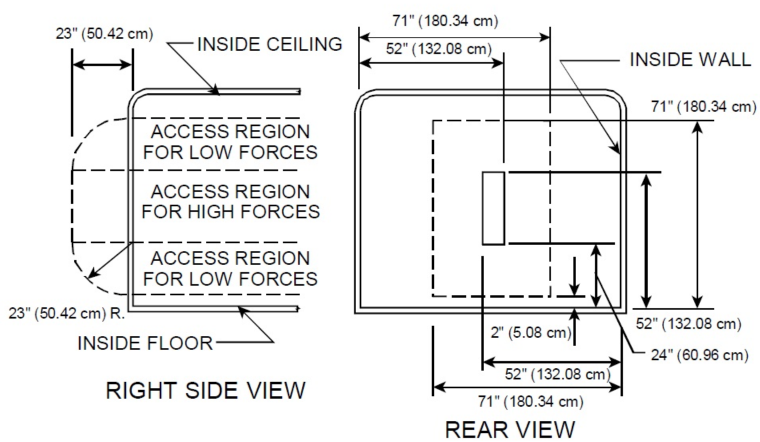

Figure 3.1: Access Regions for Rear Emergency Exit Without Obstructions [NHTSA, 2011]

We have identified three main concerns with regard to children associated with the rear emergency exit access regions defined by FMVSS No. 217. The first concern is that the access regions are designed to accommodate the physical capabilities and stature of an average adult male [Pollard and Markos, 2009]. However, the strength and stature capabilities of children between 5 and 7 years old are significantly less than an average adult male [Department of Trade and Industry, 2002]. The second concern is that the access regions are designed for the school bus in the upright orientation. In a rolled over orientation, the location of the door handle may present itself in the low force region because of its relative location to the occupants of the bus. This could result in the occupants not being able to exert enough force to unlatch the door. Moreover, due to the stature differences between adult and children, the low and high force regions could differ dramatically for children. The seats on 2013 Blue Bird Vision school buses are 36 inches wide and 42.5 inches tall, and the opening of the emergency exit door is 38 inches wide and 54 inches tall. Due to the close proximity of the last row of seats to the rear emergency exit, approximately 44% of the rear emergency exit area is obstructed by the seats, and the usable width of the exit is reduced to 17 inches as shown in Figure 3.2. This may be problematic for young children as it could prevent them from accessing the exit opening, and for larger children as it may obstruct the intended exit area. Furthermore, when the school bus is rolled-over on its left side (facing forward), the door hinges are located on top and gravity causes the door to swing shut. Depending on the size of the passenger, the door must be raised 30-45 degrees from its vertical position to allow for enough space to exit [Purswell et al., 1970]. With the rear emergency door weighing approximately 90 pounds, it creates a significant safety hazard, as the swinging door could lead to injury during evacuations [Purswell et al., 1970].

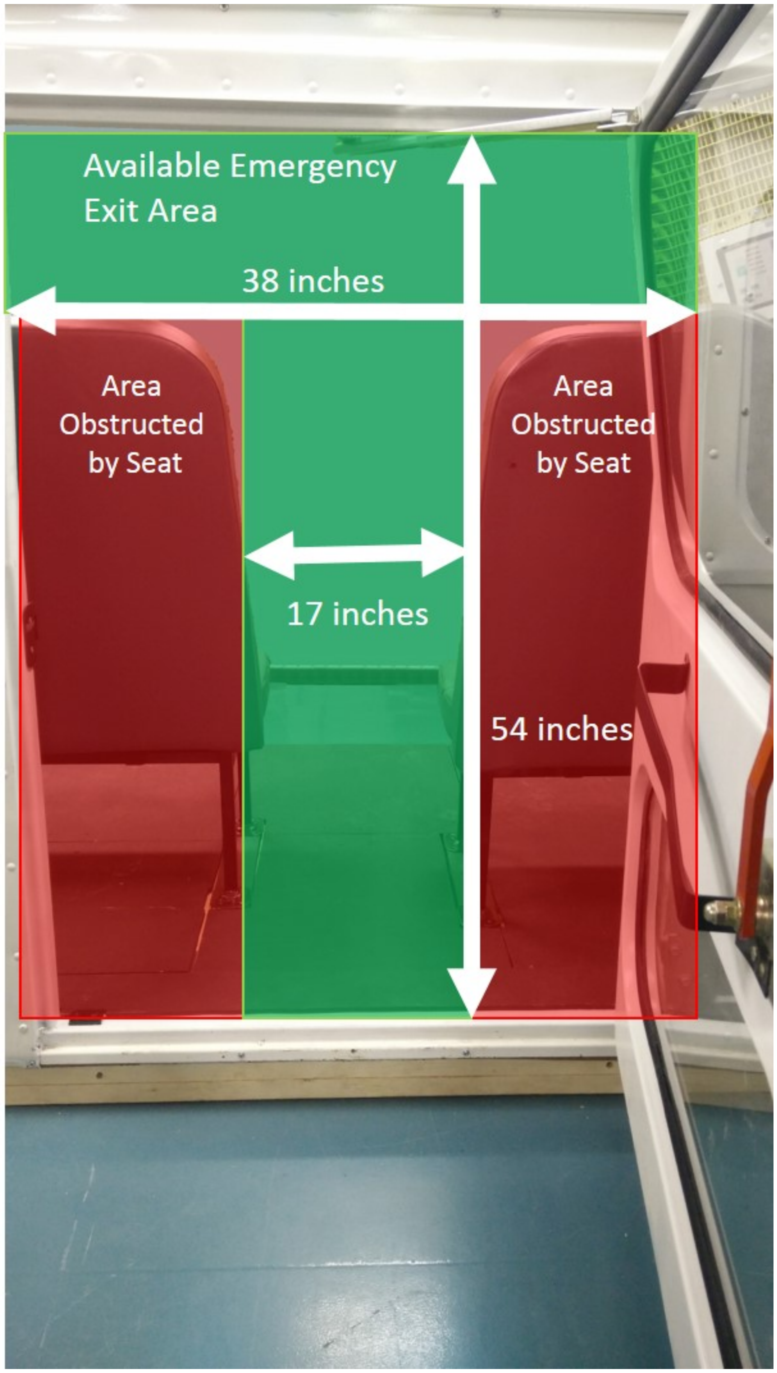

Figure 3.2: Rear Seat Obstruction in the Emergency Exit

3.1.2 Strength Capabilities of Children with Regard to the Emergency Door

In its normal (upright) orientation, the handle on the rear emergency door is pulled upwards to unlatch the door; however, the location and release direction is different if the school bus is in a rolled-over orientation. A study funded by the Consumer and Competition Policy Directorate of the Department of Trade and Industry measured the strength of children and adults to provide designers data applicable for the design of safer products [Department of Trade and Industry, 2000]. Peak pull force on a cylindrical bar (20 mm round and 300 mm long) similar in size to the door handle (25mm wide and 483 mm long) on the rear emergency exit door was measured by instructing the subjects to build up their maximum strength in the first few seconds and to maintain maximum strength for a few additional seconds. The results are shown in Table 3.1 for children between the ages of 2 and 10 years old [Department of Trade and Industry, 2002]. For this data collection, the height of the bar was adjusted to the shoulder height of the subjects to allow them to exert maximum force. The location of the door handle on the rear emergency door is fixed and hence may not be ideal for maximal exertion. Additionally, the seats may act as a barrier preventing the occupants from grasping the door handle comfortably, reducing their maximal exertion.

Table 3.1: Pull Force on Horizontal Cylindrical Bar (Newtons)
[Department of Trade and Industry, 2000]

Age	Gender	No.	Mean	SD	Range
2-5	Male	12	87.99	42.18	51.99 - 171.52
2-5	Female	9	43.22	34.62	35.41 - 114.60
6-10	Male	8	232.97	102.61	111.21 - 381.13
6-10	Female	11	175.09	75.65	88.21 - 365.30

In 1972, a study titled *"Escape Worthiness of Vehicles for Occupancy Survival and Crashes"* was funded by NHTSA to evaluate the maximum pull force children can exert on the emergency exit door handle and the maximum push force on the emergency exit door of a 1971 Superior school bus using both hands [Sliepcevich et al., 1972]. Pull force on the emergency door hand was measured using two methods; pulling with the palm on the top of the handle, and pulling with the palm under the handle [Sliepcevich et al., 1972]. These force exertions are presented in Table 3.2.

Table 3.2: Rear Emergency Door Force Exertions (Newtons) [Sliepcevich et al., 1972]

Male	**Push Force**	**Mean Pull Force Palms Up**	**Mean Pull Force Palms Down**
6 Years	73.4	82.3	104.5
7 Years	87.6	115.6	163.2
8 Years	77.8	174.8	226.8
Female	**Push Force**	**Mean Pull Force Palms Up**	**Mean Pull Force Palms Down**
6 Years	91.2	96.5	137.9
7 Years	53.4	120.1	164.6
8 Years	84.5	183.7	234.4

Given the current limitations of school bus emergency exits with regard to children, the purpose of the current research is to determine if children in kindergarten through second grade are capable of operating the release mechanism of the rear emergency exit in the upright and rolled-over orientations. By determining the physical capabilities of the youngest group of school bus occupants to evacuate through the rear emergency exit, the usability of the rear emergency exit and design of the area surrounding the exit may be evaluated to determine if it accommodates this population. By doing so, the importance of adult presence to assist in the evacuation process can also be ascertained.

3.2 Methods

3.2.1 Objective and Hypotheses

The objective of this experiment was to measure the strength capabilities of children and their ability to evacuate through the rear emergency door in an upright and rolled-over orientation by testing the following:

1. Measure the maximum force that could be exerted on the rear emergency door handle with the school bus in both upright and rolled-over orientations for the population of children in K-2.
2. Determine if K-2 children are able to unlatch the rear emergency exit door in both upright and rolled-over orientations.
3. Determine if K-2 children are able to self-extricate (individually) through the rear emergency exit in a rolled-over orientation.

The hypotheses of the experiment were:

Hypothesis 1: The maximum force exertion on the rear emergency door handle for children in K-2 is less than the maximum permissible force in the high force region (40 pounds).

$$H_0 : F_{exerted\ by\ K-2\ children} \geq 40\ pounds$$
$$H_1 : F_{exerted\ by\ K-2\ children} < 40\ pounds$$

Hypothesis 2: Mean self-extrication time through the rear emergency door is improved when the last row of seats are removed due to the obstruction the seats present to the emergency exit area.

$$H_0 : \mu_{evacuation\ time\ without\ seats} = \mu_{evacuation\ time\ with\ seats}$$
$$H_1 : \mu_{evacuation\ time\ without\ seats} > \mu_{evacuation\ time\ with\ seats}$$

3.2.2 Experimental Design

The independent variables for this experiment were: grade level (kindergarten, first grade, second grade); height (inches); weight (pounds); and gender.

The dependent variables for this experiment were: force exertion on door handle simulated in the upright and rolled-over orientations; time required to unlatch the emergency door in the upright and rolled-over orientation; time required to self-extricate through the emergency exit opening in a rolled-over orientation.

A total of 126 subjects were recruited from Oak Mountain Elementary School in Birmingham, AL. A breakdown of the number of participants from each grade level is presented in Table 3.3. The same subjects performed all portions of the study, however, some subjects were absent for portions of the study as it was conducted over three days. Group sizes were based on parental consent and exceeded the sample sizes of studies measuring strength abilities of children performed by Peebles and Norris (2003) and the Department of Trade and Industry (2002). Internal Review Board (IRB) letters of consent were distributed by the school to parents and guardians prior to the study. Parental consent and child assent was required to participate in the study. A sample IRB consent form can be found in Appendix A.

Table 3.3: Breakdown of Participants

Grade	**Males**	**Females**	**Total**
Kindergarten	22	17	39
1st Grade	21	25	46
2nd Grade	23	18	41
Total	66	60	126

In order to test the study hypotheses, a test apparatus shown in Figure 3.3 was built to replicate the rear emergency exit area and the last row of seats in a school bus. The rear emergency door section was removed from a 2013 Blue Bird Vision school bus with the assistance of a local fire department and integrated into an apparatus that replicates both the upright and rolled-over orientations. The study was conducted over a three day period during physical education class. During the first day, three stations were set up and subjects were rotated through each station during a 30 minute gym class. Height, weight, gender, and age were recorded in the first station. In the second station, subjects were asked to unlatch the rear emergency exit door as shown in Figure 3.4. In the third station, the subjects were asked to exert their maximum force on the door handle for three seconds in an upward rotary manner (demonstrated by the experimenter) to simulate unlatching the door as shown in Figure 3.5. The subjects were asked to use their dominant hand during the test. Peak force from three force exertions was recorded for each subject with a 30 second rest interval between each exertion. In many strength measurement studies, a two minute rest interval is given in between force exertion trials [Peebles and Norris, 2003, Parvatikar et al., 2009, Häger-Ross and Rösblad, 2002]. However, due to the time constraints with the school schedule, a 30 second rest interval was implemented between trials.

Figure 3.3: Rear Emergency Door Evacuation Test Apparatus

Figure 3.4: Unlatching Rear Emergency Door in the Upright Orientation

The rear emergency door apparatus was placed on its side to simulate a rolled-over school bus for the second day of experimentation. Subjects were instructed to unlatch the door. The time from first touching the door handle to the unlatching of the door was recorded. After subjects in a class performed the unlatching exercise, the door was secured in the open position as shown in Figure 3.6. All subjects were fitted with a helmet, knee pads, and elbow pads. Subjects were then instructed to stand approximately two feet from the door opening, and to evacuate through the opening as fast as they could. The time to self-extricate through the rear emergency door opening was recorded from the start signal until the subject's entire body was on the other side of the door opening. Research assistants monitored the evacuation and provided assistance if needed. In an effort to minimize variability of the study, subjects

Figure 3.5: Door Handle Force Measurement in the Upright Orientation

were not allowed to see other subjects performing the strength exertions and evacuations. The force measurement apparatus was reconfigured to simulate the location of the door handle when a school bus is rolled-over as shown in Figure 3.7. Subjects were asked to exert their maximum force on the door handle for three seconds in a clockwise rotary manner shown by the experimenter to simulate unlatching the door as illustrated in Figure 3.8. The subjects were asked to use their dominant hand during the test. Peak force from three strength exertions was recorded for each subject with a 30 second rest interval between each exertion.

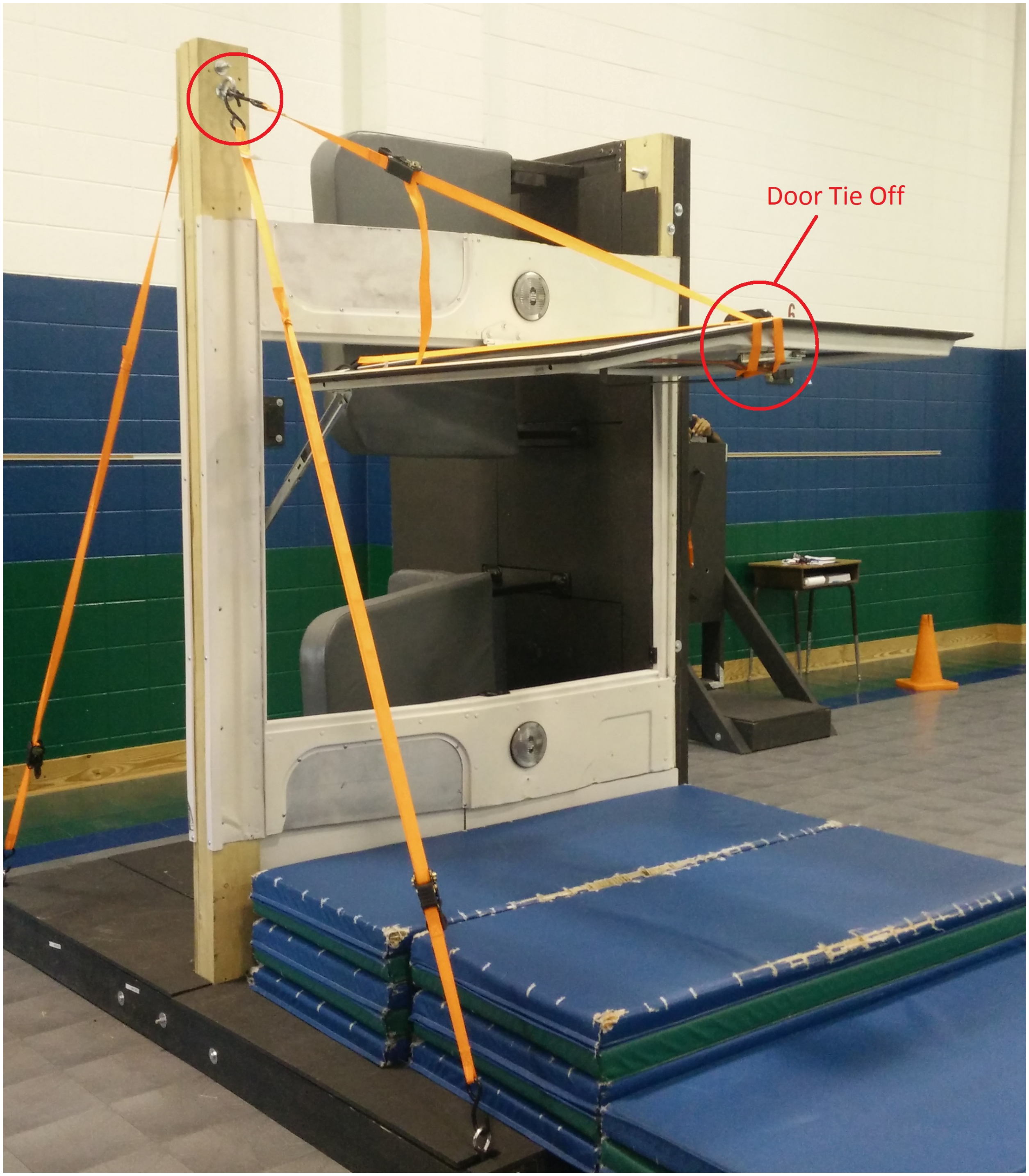

Figure 3.6: Rear Emergency Door Test Apparatus in the
"Rolled-Over" Orientation

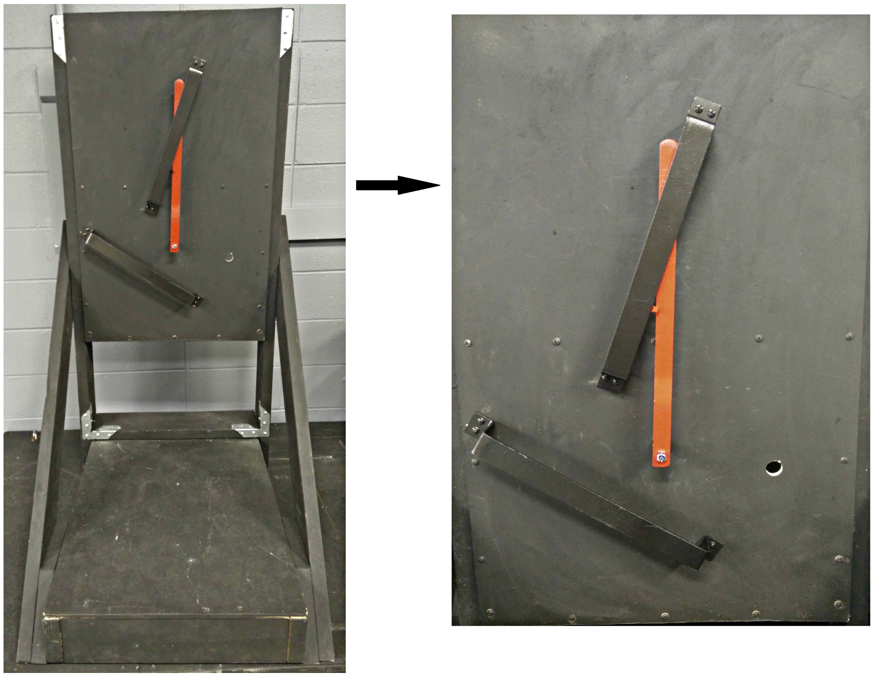

Figure 3.7: Door Handle Force Measurement Apparatus

Figure 3.8: Motion Required to Unlatch Rear Emergency Door on a Rolled-Over School Bus

The lower seat was removed during the third day of testing, and the door was secured in the open position as shown in Figure 3.9. Subjects were fitted with a helmet, knee pads, and elbows pads. They were instructed to stand approximately two feet from the door opening and evacuate through the opening as fast as they could. The time to self-extricate through the rear emergency door opening was recorded from the start signal of the researcher until the subject's entire body was on the other side of the door opening. A detailed protocol of the experiment can be found in Appendix B.

Figure 3.9: Rear Emergency Door Evacuation Test Apparatus
Without Lower Seat

3.2.3 Equipment

The following equipment were used for data collection:

1. Rear emergency door test apparatus
2. Door handle force exertion test platform
3. Mecmesin^{TM} 150 Nm torque transducer and indicator
4. Headsquare retractable measuring tape
5. Weight scale

3.3 Results

3.3.1 Descriptive Statistics

A summary of participant demographic and anthropometric data is presented in Table 3.4. For kindergarten, two males and two females were unable to unlatch the door in the upright orientation, and two females were unable to self-extricate through the door opening with the original rear seat configuration. For first grade, one female and one male were unable to self-extricate through the door opening in the original rear seat configuration. For second grade, one female was unable to self-extricate through the door opening in the original rear seat configuration. Results of the force exertion on the emergency door handle positioned in the same location it would be on a school bus in the upright and rolled-over orientations are illustrated in Table 3.5 and Table 3.6 respectively. Door unlatching and self-extrication times are reported in Table 3.7.

Table 3.4: Participant Anthropometric and Demographic Information

Kindergarten (N=39)	Mean	Standard Deviation	Minimum	Maximum
Age (months)	71.0	4.0	64.0	79.0
Weight (lb)	49.2	7.3	35.5	68.0
Height (in)	46.6	2.3	43.1	51.8
1st Grade (N=46)	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Age (months)	83.3	4.3	76.0	91.0
Weight (lb)	55.4	11.3	41.0	93.5
Height (in)	49.5	3.9	44.6	71.1
2nd Grade (N=41)	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Age (months)	94.2	4.1	88.0	104.0
Weight (lb)	60.8	14.0	38.0	110.5
Height (in)	50.7	2.5	46.9	58.5

Table 3.5: Force Exertion on Door Handle in Upright Orientation

Kindergarten (N=38)	Mean	Standard Deviation	Minimum	Maximum
Trial 1 (lb)	11.6	6.4	1.2	30.7
Trial 2 (lb)	12.6	6.1	1.4	24.9
Trial 3 (lb)	13.2	6.4	2.3	29.4
Maximum Pull Force in Upright Orientation (lb)	14.6	6.7	2.3	30.7
1st Grade (N=46)	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Trial 1 (lb)	15.1	6.1	4.9	35.6
Trial 2 (lb)	16.6	6.2	6.9	32.5
Trial 3 (lb)	17.9	7.7	8.0	42.7
Maximum Pull Force in Upright Orientation (lb)	19.6	7.2	8.7	42.7
2nd Grade (N=41)	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Trial 1 (lb)	19.2	5.8	9.4	27.9
Trial 2 (lb)	20.8	7.5	6.4	41.5
Trial 3 (lb)	21.2	7.2	9.6	42.8
Maximum Pull Force in Upright Orientation (lb)	23.6	7.0	12.2	42.8

Table 3.6: Force Exertion on Door Handle in Rolled-Over Orientation

Kindergarten	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Trial 1 (lb)	10.6	5.7	2.8	31.9
Trial 2 (lb)	10.6	5.3	3.0	21.9
Trial 3 (lb)	11.1	5.6	2.7	25.3
Maximum Pull Force in Rolled-Over Orientation (lb)	13.4	6.7	3.0	31.9
1st Grade	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Trial 1 (lb)	14.8	5.6	6.5	29.5
Trial 2 (lb)	15.6	6.8	6.0	35.4
Trial 3 (lb)	15.7	6.9	7.8	35.5
Maximum Pull Force in Rolled-Over Orientation (lb)	18.6	7.4	9.5	35.5
2nd Grade	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Trial 1 (lb)	15.0	4.4	7.8	26.1
Trial 2 (lb)	17.2	6.6	8.4	33.5
Trial 3 (lb)	17.0	6.5	8.3	35.8
Maximum Pull Force in Rolled-Over Orientation (lb)	18.8	6.9	9.2	35.8

Table 3.7: Door Unlatching and Self-Extrication Times

Kindergarten	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Time to Unlatch Door in Upright Orientation (seconds)	5.8	2.5	3.0	13.0
Time to Unlatch Door in Rolled-Over Orientation (seconds)	4.9	2.9	1.6	16.0
Time to Self-Extricate with Rear Seat (seconds)	6.4	2.8	2.8	15.3
Time to Self-Extricate without Rear Seat (seconds)	3.5	1.6	1.7	8.6
1st Grade	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Time to Unlatch Door in Upright Orientation (seconds)	5.2	2.4	2.0	15.0
Time to Unlatch Door in Rolled-Over Orientation (seconds)	3.5	1.0	1.4	6.2
Time to Self-Extricate with Rear Seat (seconds)	5.6	3.7	2.1	20.9
Time to Self-Extricate without Rear Seat (seconds)	2.3	0.9	1.0	4.9
2nd Grade	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Time to Unlatch Door in Upright Orientation (seconds)	3.2	1.5	1.0	10.0
Time to Unlatch Door in Rolled-Over Orientation (seconds)	2.3	1.2	1.0	6.7
Time to Self-Extricate with Rear Seat (seconds)	4.4	1.9	1.5	8.1
Time to Self-Extricate without Rear Seat (seconds)	1.7	0.7	0.8	4.1

3.3.2 Inferential Statistics

The results of the Ryan-Joiner normality tests displayed in Table 3.8 suggest that the maximum force exertion trials for each grade level exhibit a normal distribution ($\alpha = 0.01$). One-sample t-tests were performed on the force exertion data to determine if the maximum force exertion on the rear emergency door handle is greater than or equal to the specified maximum permissible force in FMVSS No. 217 (40 pounds). As shown in Table 3.9, the null hypothesis: the force exerted on the emergency door handle in the upright and rolled-over orientation is at least 40 pounds is rejected for all three grade levels ($\alpha = 0.05$).

Table 3.8: Ryan-Joiner Normality Test Results for Force Exertions

Grade Level / Measure	**RJ Value**	**P-value**
Kindergarten - Upright Orientation	0.978	p > 0.10
Kindergarten - Rolled-Over Orientation	0.977	p > 0.10
1st Grade - Upright Orientation	0.970	p = 0.034
1st Grade - Rolled-Over Orientation	0.965	p = 0.017
2nd Grade - Upright Orientation	0.962	p = 0.016
2nd Grade - Rolled-Over Orientation	0.968	p = 0.040

Table 3.9: One-Sample t-test Results $H_0 : \mu \geq 40$ *pounds*

Grade / Exertion Type	**N**	**Upper Bound**	**T-Value**	**P-Value**
Kindergarten Upright Orientation Force Exertion	38	16.45	-23.36	0.000
Kindergarten Rolled-Over Orientation Force Exertion	35	15.28	-23.60	0.000
1st Grade Upright Orientation Force Exertion	46	21.41	-19.29	0.000
1st Grade Rolled-Over Orientation Force Exertion	44	20.46	-19.30	0.000
2nd Grade Upright Orientation Force Exertion	41	25.43	-15.07	0.000
2nd Grade Rolled-Over Orientation Force Exertion	39	20.72	-19.06	0.000

An analysis of covariance was performed to determine the effects of grade, gender, height, and weight on the two types of force exertions. Results of the analysis of covariance is displayed in Table 3.10 and Table 3.11. Grade, weight, and gender had a statistically significant effect on force exertion on the door handle in the upright orientation ($p < 0.05$). Only weight and gender were determined to have statistically significant effects on force exertion on the door handle in the rolled-over orientation. A paired t-test was performed to test if the mean maximum force exertion in the upright orientation is higher than the mean maximum force exertion in the rolled-over orientation. The test suggested that the mean force exertions in the upright orientation is higher than the mean force exertions in the rolled-over orientations ($p = 0.002$).

A paired t-test was used to determine if there is an improvement in evacuation time through the rear emergency exit by removing the last row of seats. The null hypothesis: mean self-extrication time through the rear emergency door with the seat obstruction is less than or equal to the self-extrication time through the rear emergency door without the seat obstruction is rejected ($p < 0.001$). Results of an analysis of covariance performed on self-extrication times to determine the effects of gender, weight, and height are shown in Table 3.12 and Table 3.13. Height was the only factor that has a statistically significant effect on self-extrication times for seat configuration ($p < 0.05$).

Table 3.10: Upright Orientation Force Exertion ANCOVA

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	5	3317.36	663.472	18.85	0.000
Weight	1	962.41	962.413	27.35	0.000
Height	1	17.79	17.786	0.51	0.479
Grade	2	592.96	296.482	8.42	0.000
Gender	1	353.23	353.230	10.04	0.002
Error	119	4187.81	35.192		
Lack-of-Fit	118	4187.48	35.487	106.42	0.077
Pure Error	1	0.33	0.333		
Total	124	7505.17			

Table 3.11: Rolled-Over Orientation Force Exertion ANCOVA

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	5	1767.26	353.452	7.13	0.000
Weight	1	605.25	605.248	12.21	0.001
Height	1	0.45	0.454	0.01	0.924
Grade	2	152.70	76.352	1.54	0.219
Gender	1	194.17	194.175	3.92	0.050
Error	112	5553.99	49.589		
Lack-of-Fit	111	5551.84	50.017	23.23	0.164
Pure Error	1	2.15	2.153		
Total	117	7321.25			

Table 3.12: Self-Extrication With Seat Obstruction ANCOVA

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	3	63.512	21.1705	2.43	0.069
Weight	1	12.990	12.9895	1.49	0.225
Height	1	50.932	50.9318	5.84	0.017
Gender	1	2.177	2.1766	0.25	0.618
Error	105	915.032	8.7146		
Lack-of-Fit	104	914.766	8.7958	33.01	0.138
Pure Error	1	0.266	0.2665		
Total	108	978.544			

Table 3.13: Self-Extrication Without Seat Obstruction ANCOVA

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	3	35.549	11.8498	8.46	0.000
Weight	1	2.472	2.4717	1.76	0.187
Height	1	12.456	12.4561	8.89	0.004
Gender	1	0.181	0.1811	0.13	0.720
Error	108	151.347	1.4014		
Lack-of-Fit	107	151.246	1.4135	13.96	0.211
Pure Error	1	0.101	0.1012		
Total	111	186.896			

3.4 Discussion

The majority of subjects were able to unlatch the rear emergency door in the upright and rolled-over orientation. However, **the force exertion data suggests that children in kindergarten through second grade do not have the strength capabilities to exert the maximum permissible force of 40 pounds to unlatch an exit in the high force region.** The force exertion measurements on the door handle in the upright orientation were approximately half the force measurements published in the study conducted by Sliepcevich (1972), where force measurements on the door handle were measured using a two hand force exertion [Sliepcevich et al., 1972]. Additionally, the force exertions on the door handle in the rolled-over orientation were significantly lower than the force exertions on the handle in the upright orientation. This may suggest that the force requirements to open emergency exits should consider the exit handle design and location in both upright and rolled-over orientations. Force exertion on the door handle was calculated by dividing the torque measurement at the end of the door handle by the distance from the center of the subjects hand to the torque transducer. As shown in Figure 3.7 there is a guard protecting the end of the door handle to prevent inadvertent opening of the rear emergency door. A greater torque exertion can be achieved when exerting force at the end of the handle, however, many of the subjects did not grip the handle there because of the guard obstruction.

Nearly all the subjects had the physical and strength capabilities to self-extricate through the rear emergency door opening with and without the rear seat obstruction. However, self-extrication time without the rear emergency seat was significantly lower in the configuration without the seat obstruction. As shown in Figure 3.10 and Figure 3.11, subjects had to pull themselves over the rear seat to reach the door opening whereas in the removed seat configuration, subjects had easier access to the door opening. Emergency exits are often evaluated by their flow rate, or the number of people that can evacuate through the exit per minute. Flow rates for the rear emergency exit in the rolled-over orientation are illustrated in Table 3.14. The Volpe Center measured flow rate of a motorcoach wheelchair access door by conducting egress trials using employees with sufficient knowledge of operating emergency exits to be 25 people per minute [Pollard and Markos, 2009]. The flow rates in the rolled-over orientation are comparable for the removed seat configuration, however, flow rates were much lower for the rolled-over orientation with the rear seat obstruction.

Figure 3.10: Self-Extrication Without Rear Seat Obstruction

Figure 3.11: Self-Extrication With Rear Seat Obstruction

Table 3.14: Rear Emergency Door Flow Rate in Rolled-Over Orientation

Grade / Configuration	**Flow Rate (PPM)**	**Standard Deviation**	**Maximum**	**Minimum**
Kindergarten With Seat	11	4	22	4
Kindergarten Without Seat	20	7	36	7
1st Grade With Seat	14	6	28	3
1st Grade Without Seat	30	11	60	12
2nd Grade With Seat	16	7	39	7
2nd Grade Without Seat	41	14	80	14

3.5 Limitations

Several limitations were associated with the study. Gym mats were stacked on the outside portion of the rear emergency door opening to provide a softer landing surface during the self-extrication portion of the study. This may have affected the posture of the subjects as they self-extricated through the door opening. Some of the subjects were comfortable to jump out the door and land on either their back or belly as they self-extricate. For safety purposes, the rear emergency door was secured open during the self-extrication portion of the study. Had the emergency door been allowed to swing shut, successful self-extrication rates may have been considerably lower. Due to time restrictions, the ability of children to unlatch the rear emergency door without instruction was not studied. The design of rear emergency exits and door handles vary between manufacturers however, only one type of rear emergency door exit was considered in this study. Additionally, flow rate through the rear emergency exit may be different in a post-accident scenario due to injuries, fear, and other environmental stressors.

3.6 Conclusion

Nearly all subjects in the kindergarten through second grade were able to unlatch the rear emergency door in the upright and rolled-over orientation. However, **subjects in all three grade levels were unable to exert a 40 pound pull force as stated by FMVSS No. 217 to be the maximum permissible force to operate the rear emergency exit.** Additionally, nearly all the subjects were able to self-extricate through the rear emergency exit in the rolled-over orientation. However, the flow rate through the rear emergency exit is significantly increased with the removal of the seat adjacent to the exit opening. The current design of the rear emergency exit may be improved by reducing the force required to unlatch the door and eliminating seat obstructions.

3.7 Acknowledgments

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Chapter 4

Physical Capabilities of Children during Operation and Evacuation of a School Bus Emergency Roof Hatch

4.1 Introduction

School buses in the United States transport approximately 23.5 million children annually. Despite being the safest mode of student transportation, approximately 26,000 school bus accidents still occur every year [NASDPTS, 2000, McCray and Brewer, 2005]. School bus rollover accidents are often viewed as the most complex and dangerous type of accidents especially since occupants are unfamiliar with the rolled-over school bus orientation or the fact that they just rolled over. Roof hatches are one of the primary means of egress for rollover bus accidents [Matolcsy, 2010]. Strength and stature are some of the factors affecting both usability and egress rates from roof hatches [Pollard and Markos, 2009]. Testing the ability of younger school bus riders to self-extricate through a roof hatch is critical for assessing the effectiveness of the current emergency evacuation system.

4.1.1 Roof Hatch Standards

Federal Motor Vehicle Safety Standard (FMVSS) No. 217 specifies the maximum permissible force required to operate the release mechanism on a roof hatch. This force is based on the location of the roof hatch release mechanism within the defined access regions as shown in Figure 4.1 [NHTSA, 2011]. Roof hatch operating mechanisms located within the high force region are required to have a motion that is straight and perpendicular to the undisturbed surface with a maximum operating force not to exceed 178 Newtons (40 pounds) [NHTSA, 2011]. Roof hatches must have one release mechanism with two force applications to release the exit, or two release mechanisms, each requiring one application to release the exit [NHTSA, 2011]. A rotary or straight motion can be used to operate a roof hatch located in the low force region with a maximum force 89 Newtons (20 pounds)[NHTSA, 2011]. Dimensions of school bus emergency exits are regulated by paragraph S5.4 of FMVSS No. 217 [NHTSA, 2011]. An inside opening of at least 41 centimeters (16 inches) high and 41 centimeters (16 inches) wide is required for roof hatches [NHTSA, 2011]. The laboratory test procedures for FMVSS No. 217 specify that an ellipsoid with a minor axis of 33 centimeters (13 in) and a major axis of 50 centimeters (19.7 inches) must be able to pass through the roof hatch while keeping the major axis horizontal at all times as illustrated in Figure 4.2 [NHTSA, 2002].

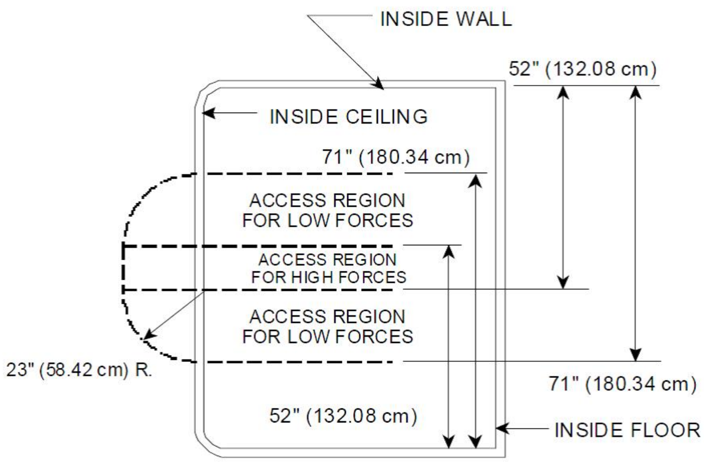

Figure 4.1: Access Regions for Roof Hatch [NHTSA, 2011]

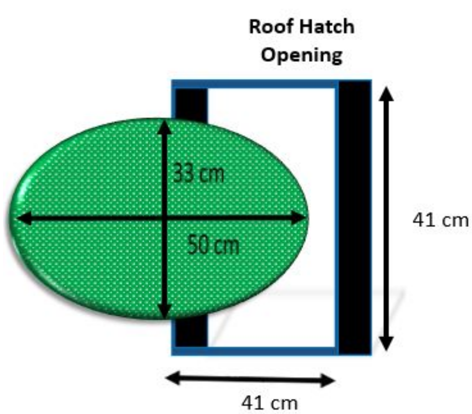

Figure 4.2: Roof Hatch Opening Size Test

The force requirements defined by FMVSS No. 217 are designed for the physical capabilities (including stature) of an average adult male [Pollard and Markos, 2009]. The primary occupants of school buses are young children that may not have the physical capabilities and stature characteristics to meet the force requirements defined by FMVSS No. 217. Many school districts such as Auburn City Schools in Auburn, AL have bus routes exclusive to kindergarten through second grade over which more than 500 children are transported [Ingram, 2013]. In most instances, the bus driver is the only adult on the school bus. Should the driver be incapacitated due to illness, stroke, heart attack, alcohol, or drugs (prescription and illegal), or injury it may be solely up to the children to evacuate the bus until further adult assistance arrives. A known risk factor influencing post-crash outcome of injuries is the difficulty in evacuating passengers from bus accidents [Peden et al., 2004]. Therefore, it is important to determine if children in kindergarten through second grade (K-2) have the physical capabilities to operate a roof hatch and evacuate a rolled-over school bus through the roof hatch without adult intervention. By doing so, the importance of adult presence to assist in an evacuation process can be ascertained.

There are approximately ten types of roof hatches used in school buses, some with different features such as ventilation and powered vents Figure 4.3 [SBP, 2015]. Though roof hatches have different features and designs, most use similar operating mechanisms and have similar size openings (typically, 22 inches x 22 inches). To release the roof hatch, a passenger must turn the red knob from the "latched" position to the "to exit" position, push "sharply upward" on the red knob to partially open the hatch, and then push on the roof hatch to open it all the way [Blue Bird Bus Corporation, 2008]. A common type of roof hatch used on Blue Bird school buses operated by Auburn City Schools transportation department in Auburn, AL is the Transpec 1970 Series Standard Safety Vent shown in Figure 4.4, which was also used in this study.

Figure 4.3: Roof Hatch Types [SBP, 2015]

Figure 4.4: School Bus Roof Hatch

4.1.2 Strength Capabilities of Children

Operation of the roof hatch requires the passenger to rotate the knob and push on it, exerting 89 Newtons of force to release the locking mechanism. A study funded by the Consumer and Competition Policy Directorate of the Department of Trade and Industry measured strength data of children and adults to provide designers with ergonomics data for use in the design of safer products [Department of Trade and Industry, 2002]. Maximum push exertions using two or more fingers of the subject's dominant hand on a (50 mm x 50 mm) plastic cube were measured in the same study which measured maximum pull force on a cylindrical rod [Department of Trade and Industry, 2002]. Strength exertions were recorded for the subjects pushing forward on the plastic cube positioned at elbow height [Department of Trade and Industry, 2002]. Subjects were instructed to build up their maximum strength in the first few seconds and to maintain maximum strength for a few more seconds [Department of Trade and Industry, 2002]. The average push force using two or more fingers for children in the 2-5 year old and 6-10 year old age groups is shown in Table 4.1. Push force can vary significantly due to the ability to use ones body weight. While the use of body weight is usually discouraged when measuring push force. However, in "real world" scenarios, body weight is often used for tasks that require pushing.

Table 4.1: Push Force with Two or More Fingers (Newtons)
[Department of Trade and Industry, 2002]

Age	**Gender**	**No.**	**Mean**	**SD**	**Range**
2-5	Male	9	27.49	13.3	6.70 - 42.00
2-5	Female	8	20.80	9.93	6.10 - 34.70
6-10	Male	5	65.86	24.06	36.10 - 91.30
6-10	Female	8	78.04	29.89	47.20 - 124.70

A similar push force study was conducted by Peebles and Norris (2003), whereby subjects exerted push force with a thumb and index finger on a circular force plate with a 20 millimeter diameter and 2 millimeter depth [Peebles and Norris, 2003]. The peak force was measured while the subjects were instructed to exert their maximum force for five seconds using their dominant hand [Peebles and Norris, 2003]. Results of this study are shown in Table 4.2 and Table 4.3 [Peebles and Norris, 2003]. Based on these two studies, pushing with a thumb resulted in higher average push force compared to pushing with the index finger or pushing with two or more fingers. However, the average push force in the two studies was lower than the 89 Newton threshold set by FMVSS No. 217 for roof hatch operation [NHTSA, 2011]. Furthermore, the push forces measured in these studies are likely to be higher than that which can be exerted on a roof hatch knob. There is less surface area to exert a force on with a roof hatch knob in comparison to the plastic cube used in study conducted by the Department of Trade and Industry (2002). As shown in Figure 4.5 the surface area of the roof hatch knob (2.52 inches^2) is approximately 63% of the area of the plastic cube (4 inches^2) used in the study conducted by the Department of Trade and Industry (2002). Additionally, the location of the force plate in the studies was at the elbow height of the subjects allowing them to apply greater force because they could use their body weight to push harder. The relative location of the roof hatch knob for children is much higher (above elbow height) than for adults. As shown in Figure 4.6, an average kindergarten age child would have to reach overhead to push the roof hatch knob, whereas the location of the roof hatch knob for an average adult would allow them to use their body weight while pushing on the knob.

Table 4.2: Push Force with Index Finger (Newtons) [Peebles and Norris, 2003]

Age	**Gender**	**No.**	**Mean**	**SD**	**Range**
2-5	Male	9	20.3	5.2	16.0 - 35.0
2-5	Female	8	24.9	9.6	15.9 - 38.6
6-10	Male	5	51.5	13.4	30.8 - 61.8
6-10	Female	10	44.0	17.3	23.4 - 70.3

Table 4.3: Push Force with Thumb (Newtons) [Peebles and Norris, 2003]

Age	Gender	No.	Mean	SD	Range
2-5	Male	9	28.1	10.0	17.3 - 41.6
2-5	Female	8	30.9	8.7	16.8 - 42.8
6-10	Male	5	88.8	28.6	53.4 - 126.6
6-10	Female	10	70.2	24.6	36.7 - 107.7

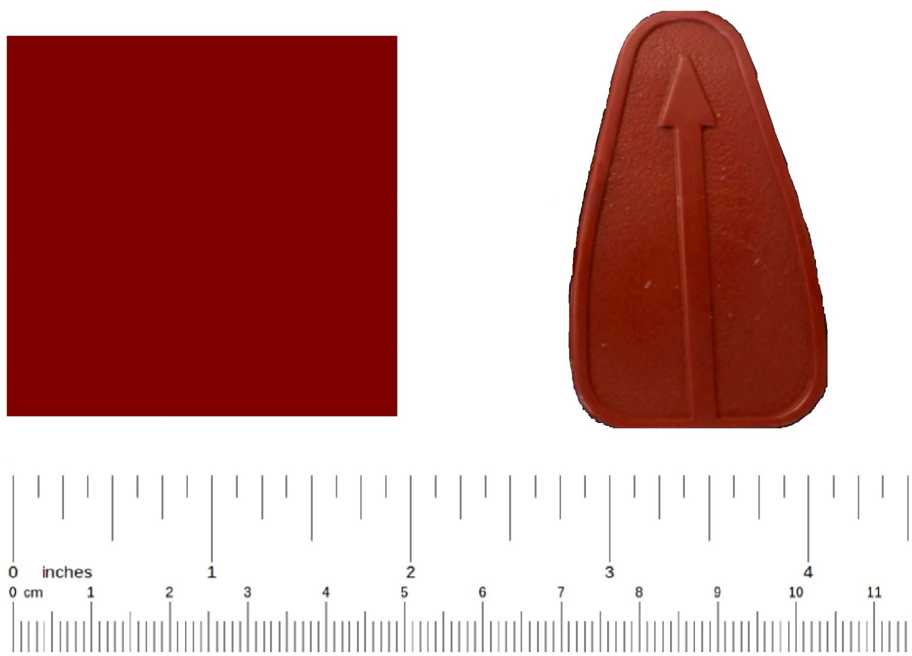

Figure 4.5: Surface Area Comparison of Roof Hatch Knob to Plastic Cube (50 mm x 50 mm)

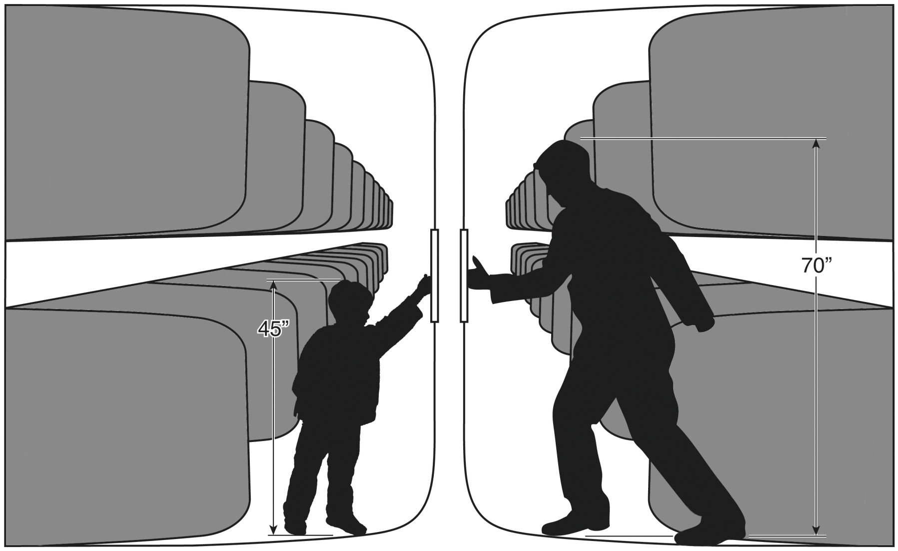

Figure 4.6: Scaled Illustration of Rolled-Over School Bus Demonstrating Differences Between an Average Kindergarten Student and Average Adult Male

Another area of interest for operating the roof hatch is the twisting force that must be exerted on the roof hatch knob, the first step in releasing the roof hatch. Grasping the roof hatch knob may be challenging for children with small hands due to its unique shape. As part of study conducted by Peebles and Norris (2003), twisting strength on a ridged knob (40 millimeter length, 15 millimeter depth) about a half an inch smaller than the length of a roof hatch knob was measured for young children. Subjects were allowed to adopt a free posture in front of the measuring device and were instructed to exert a clockwise static twisting force for five seconds [Peebles and Norris, 2003]. The peak torque was measured during the five second exertion period and data was collected for children in the 2-5 year old and 6-10 year old age groups, Table 4.4. However, in a rolled-over school bus orientation, the curvature of the school bus roof can act as barrier preventing younger occupants from getting close to the roof hatch which could reduce their force generating capability on the roof hatch knob as shown in Figure 4.6.

Table 4.4: Ridged Knob Horizontal Wrist-Twisting Strength (Newton-Meters) [Peebles and Norris, 2003]

Age	Gender	No.	Mean	SD	Range
2-5	Male	8	0.9	0.4	0.5 - 1.4
2-5	Female	7	0.6	0.3	0.2 - 0.9
6-10	Male	7	2.6	0.7	1.6 - 3.6
6-10	Female	11	2.0	0.9	0.8 - 3.7

While several studies have measured different strength capabilities of children, it is difficult to determine if they have the physical capabilities to operate and exit through the emergency escape roof hatch on a school bus. Additionally, the studies conducted by the Department of Trade and Industry (2002) and Peebles and Norris (2003) tested very small sample sizes and no accompanying anthropometric data were provided to determine if the samples are representative of the respective populations. In addition, data was provided over a wide range of ages. The purpose of this study was to determine the strength capabilities of young children by using an apparatus that is identical (in position and orientation) to a school bus emergency escape roof hatch.

4.2 Methods

4.2.1 Objective and Hypotheses

The objectives of this research were to measure the strength capabilities of children to operate a typical roof escape hatch, and their ability to evacuate through a roof hatch of a school bus in a rolled-over orientation by testing the following:

1. Measure the maximum push force and torque that can be exerted on a roof hatch knob positioned at the same location it would present itself in a rolled-over school bus orientation.
2. Determine if children in the kindergarten through second grade are able to disengage the release mechanism and open a school bus emergency escape roof hatch.

3. Determine if children in the kindergarten through second grade have the physical capabilities to self-extricate through a roof hatch representative of a school bus in a rolled-over orientation.

The hypotheses of the experiment were:

Hypothesis 1: The maximum push force exerted on the roof hatch knob for kindergarten, first, and second grade children is less than the force required to open a roof hatch (89 Newtons).

$$H_0 : \mu_{force\ exerted\ by\ children\ K-2} \geq 89\ Newtons$$
$$H_1 : \mu_{force\ exerted\ by\ children\ K-2} < 89\ Newtons$$

Hypothesis 2: Percentage of successful evacuations through a roof hatch of a school bus in a rolled-over orientation increases based on the grade level of the child. A successful evacuation is defined as the ability to self-extricate one's entire body through the roof hatch opening.

$$H_0 : N_{Kindergarten\ evacuations} = N_{First\ grade\ evacuations} = N_{Second\ grade\ evacuations}$$
$$H_1 : N_{Kindergarten\ evacuations} < N_{First\ grade\ evacuations} < N_{Second\ grade\ evacuations}$$

4.2.2 Experimental Design

The independent variables for this experiment were: grade level (kindergarten, first grade, second grade); height (centimeters); weight (kilograms); gender (male/female); hand length (centimeters); and hand width (centimeters). The dependent variables for this experiment were: push force exerted on the roof hatch knob; ability to operate the release mechanism on the roof hatch and unlatch the roof hatch; and the ability to self-extricate through the emergency roof hatch.

Subjects were recruited from Jim Pearson Elementary School in Alexander City, AL, and participated in the study during their physical education class. As shown in Table

4.5 thirty (30) subjects were recruited from kindergarten, thirty four (34) subjects from the first grade, and twenty seven (27) from the second grade (N=91). A summary of the participants demographic data is provided in Table 4.6. Group sizes exceed sample sizes of similar child strength measurement studies performed by Peebles and Norris (2003) and the Department of Trade and Industry (2002). Internal Review Board (IRB) letters of consent were distributed by the school to parents and guardians prior to the study. Parental consent and child assent was required to participate in the study. A sample IRB consent form can be found in Appendix C.

Table 4.5: Breakdown of Participants

Grade	**Males**	**Females**	**Total**
Kindergarten	18	12	30
1st Grade	19	15	34
2nd Grade	14	13	27
Total	51	40	91

Table 4.6: Participants Demographic and Anthropometric Data

Kindergarten (N=30)	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Age (months)	69.1	5.3	63	82
Weight (kg)	22.0	5.5	14.5	42.0
Height (cm)	114.8	5.6	105.4	126.3
Hand Width (cm)	6.1	0.6	4.9	8.3
Hand Length (cm)	12.0	0.9	9.6	14.0
1st Grade (N=34)	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Age (months)	83.2	4.8	76	96
Weight (kg)	25.5	6.6	17.7	54.0
Height (cm)	121.9	6.3	114.1	137.8
Hand Width (cm)	6.2	0.4	5.5	7.3
Hand Length (cm)	13.1	0.8	11.2	14.7
2nd Grade (N=27)	**Mean**	**Standard Deviation**	**Minimum**	**Maximum**
Age (months)	100.4	6.6	93	117
Weight (kg)	32.6	11.9	17.5	67.6
Height (cm)	130.4	8.3	111.4	149.2
Hand Width (cm)	6.7	0.6	5.4	8.2
Hand Length (cm)	14.2	0.9	11.7	15.8

Three stations were set up for data collection. Subjects were rotated between these stations shown in Figure 4.7. Height, weight, hand measurements, gender, grade level and age were recorded in the first station. The Blue Bird Bus Company in Fort Valley, GA donated a rear end section of a 2013 Blue Bird Vision school bus. The school bus section was cut-up by the Auburn, AL Fire Department into a smaller section that contained the roof section from the emergency escape roof hatch to the side window of the school bus. The section was used to build a test apparatus that was safe for testing emergency evacuations through the roof hatch, shown in Figure 4.8.

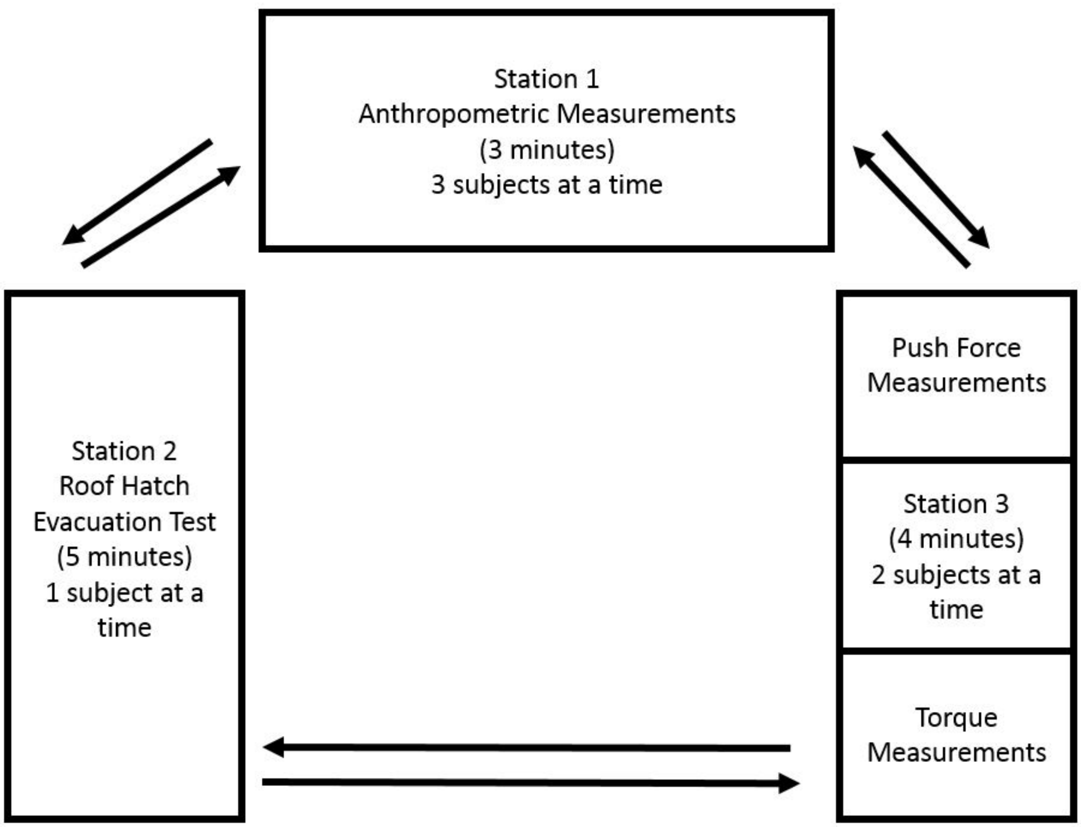

Figure 4.7: Data Collection Stations

Figure 4.8: Roof Hatch Evacuation Test Apparatus

In the second station, each subject's ability to open and self-extricate through the roof hatch was tested. For the first part of the experiment, the subject was asked to stand in front of the roof hatch apparatus and was shown how to unlatch the roof hatch by a researcher. The time from touching the roof hatch knob until the roof hatch was disengaged was recorded. If the subject was unable to operate the roof hatch release mechanism within 30 seconds, the roof hatch was opened for them. The subject was then asked to self-extricate through the roof hatch opening. Time to evacuate through the roof hatch was recorded from the time they touched the roof hatch opening until their entire body was through the roof hatch opening. If the subjects did not want to evacuate they were asked a second time if they were sure that they didn't want to evacuate. If they decided not to, the experiment was stopped. Research assistants monitored the evacuation process and provided assistance as required.

Force and torque measurements were recorded in the third station. Force and torque stands were built to replicate the location of the roof hatch knob in a rolled-over school bus as shown in Figure 4.9. Subjects were asked to perform three maximal push force and torque exertions on the roof hatch knob. In many strength measurement studies, a two minute rest interval is given in between force exertion trials [Peebles and Norris, 2003, Parvatikar et al., 2009, Häger-Ross and Rösblad, 2002]. However, due to the time constraints with the school schedule, a 30 second rest interval was implemented between trials. A detailed protocol of the experiment can be found in Appendix D.

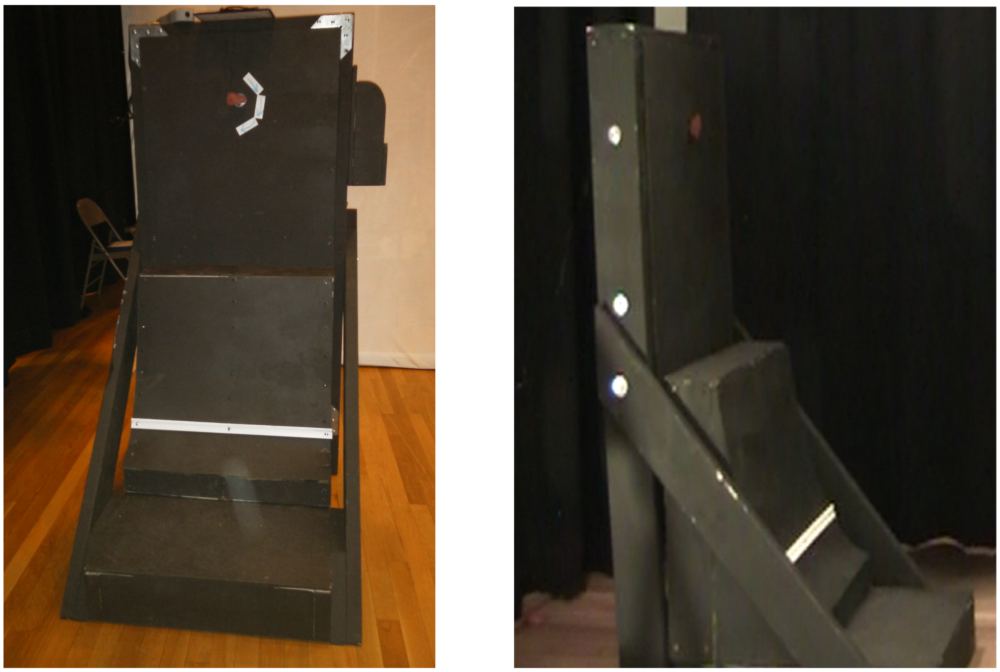

Figure 4.9: Torque and Push Force Measurement Stand

4.2.3 Equipment

The following equipment was used for data collection:

1. Roof hatch test apparatus
2. Push force and torque test platforms
3. Mecmesin™ 15 Nm torque transducer and indicator
4. Chatillon csd200 push pull dynamometer
5. Hand measurement caliper
6. Headsquare retractable measuring tape
7. Weight scale

Figure 4.10: Torque and Push Force Measurement Devices

The torque transducer and push-pull dynamomemter were calibrated and mounted at the same location they would present themselves on a rolled-over school bus. Roof hatch knobs were attached to the torque transducer via a machined wrench socket attachment, and to the push pull dynamometer via a machined threaded rod attachment as shown in Figure 4.10.

4.2.4 Statistical Analyses

A one-sample t-test was performed to determine if the age mean for each grade level sample group was representative of mean age of students in the United States. Mean age and standard deviation of students in the kindergarten through second grade was extracted from data sheets published by the Census Bureau in 2014 and shown in Table 4.7 [U.S Census Bureau, 2014]. Additionally, Ryan-Joiner tests of normality were performed to determine if the maximum force and torque data were normally distributed ($\alpha = 0.05$).

Table 4.7: School Enrollment Age [U.S Census Bureau, 2014]

Grade	**Mean Age (months)**	**Standard Deviation**
Kindergarten	61.3	7.2
1st Grade	74.8	7
2nd Grade	86.8	7.3

One-way ANOVA was performed to determine if there was significant differences in age, height, and weight between the three grade levels ($\alpha = 0.05$). A one-sample t-test was used to determine if mean of the maximum push force trials of each grade were greater than the required force to open a roof hatch (89 Newtons). Effects of weight, height, and hand size on the force exertions were analyzed using Analysis of Covariance. Analysis of Variance (ANOVA) was performed to analyze the differences between males and females and the three grade levels ($\alpha = 0.05$). Best subsets regression was used to develop a model with the best predictor variables that affect push force. The effects of the independent variables on opening the roof hatch and self-extricating through the roof hatch were analyzed using stepwise logistic regression to determine the best fitting model and minimize multicollinearity of the independent variables.

4.3 Results

4.3.1 Descriptive Statistics

Descriptive statistics of torque and push force measurements, time to unlatch the roof hatch, and self-extrication time are provided in Table 4.8. Roof hatch unlatching time was measured from touching the roof hatch until the roof hatch was unlocked, and self-extrication time was measured from when the door was unlatched until the subject's entire body was on the other side of the roof hatch. While only 20% (6/30) of the kindergarten participants were able to open the roof hatch, 87% (26/30) were able and willing to self-extricate. For first grade, 71% (24/34) were able and willing to open the roof hatch and 91% (31/34) were able and willing to self-extricate. Eighty-nine percent (24/27) of the second grade participants were able and willing to open the roof hatch and 96% (26/27) were able and willing to self-extricate. Two data points were excluded from the analyses of the data. One of the participants in the first grade chose not to participate in the study after anthropometric data were collected. Push force data for one of the second grade subjects was excluded due to an inaccurate reading from the push pull dynamometer.

Table 4.8: Descriptive Statistics of Collected Data

Kindergarten (N=30)	**Mean**	**Standard Deviation**	**Maximum**	**Minimum**
Trial 1 - Torque (Nm)	1.782	0.494	2.590	0.900
Trial 2 - Torque (Nm)	1.710	0.467	2.515	0.830
Trial 3 - Torque (Nm)	1.555	0.521	2.595	0.765
Maximum Torque Trial (Nm)	1.855	0.485	2.595	0.935
Trial 1 - Push Force (N)	67.3	24.50	118	24
Trial 2 - Push Force (N)	70.1	25.81	142	20
Trial 3 - Push Force (N)	71.5	24.08	132	28
Maximum Push Force Trial (N)	79.1	26.29	142	32
Time from touching roof hatch to hatch unlatched (seconds)	9.1	4.8	17.9	3.7
Time from hatch unlatched to entire body on other side of hatch (seconds)	6.9	3.6	15.9	2.5
1st Grade (N=34)	**Mean**	**Standard Deviation**	**Maximum**	**Minimum**
Trial 1 - Torque (Nm)	2.092	0.621	4.110	0.935
Trial 2 - Torque (Nm)	2.017	0.620	3.320	1.000
Trial 3 - Torque (Nm)	2.062	0.680	3.610	1.025
Maximum Torque Trial (Nm)	2.427	0.604	4.110	1.220
Trial 1 - Push Force (N)	91.8	25.50	148	24
Trial 2 - Push Force (N)	91.3	26.55	148	20
Trial 3 - Push Force (N)	96.0	27.42	168	30
Maximum Push Force Trial (N)	101.3	26.58	168	30
Time from touching roof hatch to hatch unlatched (seconds)	7.20	3.42	14.89	2.22
Time from hatch unlatched to entire body on other side of hatch (seconds)	5.21	2.94	17.88	1.06
2nd Grade (N=27)	**Mean**	**Standard Deviation**	**Maximum**	**Minimum**
Trial 1 - Torque (Nm)	2.668	0.885	4.750	0.930
Trial 2 - Torque (Nm)	2.464	0.845	4.670	0.880
Trial 3 - Torque (Nm)	2.427	0.790	4.140	0.810
Maximum Torque Trial (Nm)	2.911	0.954	4.750	0.930
Trial 1 - Push Force (N)	114.4	29.72	206	64
Trial 2 - Push Force (N)	116.2	30.56	191	66
Trial 3 - Push Force (N)	118.9	39.71	240	60
Maximum Push Force Trial (N)	125.2	37.20	240	66
Time from touching roof hatch to hatch unlatched (seconds)	5.22	2.89	12.18	1.37
Time from hatch unlatched to entire body on other side of hatch (seconds)	5.69	5.06	28.75	2.31

4.3.2 Inferential Statistics Results

The null hypothesis that no difference exists between the mean age of subjects at each grade level compared to the mean age of students at each grade level in the United States was rejected ($p < 0.001$). The results of Ryan-Joiner normality tests illustrated in Table 4.9 suggest that the maximum push force and torque data for each grade level exhibited a normal distribution with the exception of maximum push force trials of subjects in the second grade. One-way ANOVA testing suggested that statistically significant difference exists in age, height, and weight between the three grade levels ($p < 0.05$). Furthermore, Tukey's Honestly Significant Difference post-hoc tests displayed statistically significant differences in age, height, and weight between all three grade levels.

Table 4.9: Ryan-Joiner Normality Test Results

Grade Level / Measure	**RJ Value**	**P-value**
Kindergarten - Torque	0.985	$p > 0.10$
Kindergarten - Push Force	0.984	$p > 0.10$
1st Grade - Torque	0.979	$p > 0.10$
1st Grade - Push Force	0.983	$p > 0.10$
2nd Grade - Torque	0.996	$p > 0.10$
2nd Grade - Push Force	0.952	$p = 0.033$

Results of the one-sample t-tests indicated rejection the null hypothesis that students in kindergarten are able to exert at least 89 Newtons of force on the roof hatch knob. However, results of the one-sample t-tests also failed to reject the null hypothesis that students in the first and second grade are able to exert at least 89 Newtons of force on the roof hatch knob. Results of the one-sample t-tests are summarized in Table 4.10. Gender was determined not to be a statistically significant factor for maximum push force ($F_{1,85} = 0.06, p > 0.5$). However, grade level was a statistically significant factor ($F_{2,85} = 16.28, p < 0.001$).

Results of the best subsets regression illustrated in Table 4.11 identified grade, gender, weight, hand width, and hand length to be the best fitting predictors of maximum push force. As shown in Table 4.12 weight and hand length had a statistically significant effect on

Table 4.10: One-Sample t-test Results $H_0 : \mu \geq 89$

Grade	**Upper Bound**	**T-value**	**P-value**
Kindergarten	87.26	-2.06	0.024
1st Grade	109.01	2.70	0.995
2nd Grade	137.41	5.06	1.000

Table 4.11: Maximum Push Force Best Subsets Regression

Vars	**R-Sq**	**Adj. R-Sq**	**Pred. R-Sq**	**Cp**	**S**	**Grade**	**Gender**	**Height**	**Weight**	**Hand Length**	**Hand Width**
1	48.2	47.6	44.4	17.7	25.224			x			
1	45.8	45.1	41.9	22.5	25.806				x		
2	55.9	54.8	50.6	4.5	23.416				x		x
2	53.5	52.4	47.3	9.1	24.026			x	x		
3	57.0	55.4	50.8	4.3	23.255		x		x		x
3	57.0	55.4	50.8	4.3	23.256				x	x	x
4	57.9	55.8	51.0	4.5	23.150		x		x	x	x
4	57.6	55.6	50.6	5.0	23.214	x			x	x	x
5	58.5	56.0	50.7	5.3	23.110	x	x		x	x	x
5	58.2	55.7	49.6	5.9	23.197		x	x	x	x	x
6	58.6	55.6	49.2	7.0	23.215	x	x	x	x	x	x

maximum push force ($p < 0.05$), and the adjusted R^2 of the model was 58.61%. As illustrated in Table 4.13 the independent variables that best fit the logistic regression model for opening the roof hatch were height and grade level. The adjusted R^2 of the model was 35.90% and the variance inflation factor of the independent variables was less than three, suggesting low correlation between the independent variables. Height had a statistically significant effect on the ability to open the roof hatch ($p < 0.001$), whereas grade level was on the cusp of being statistically significant ($p = 0.055$). The Hosmer-Lemeshow Goodness of fit test ($p = 0.909$) displayed insufficient evidence to claim that the model does not fit the data adequately. A similar logistic regression was performed on the self-extrication data, but no independent variables were determined to be statistically significant. A Pearson correlation test was performed to determine if there was a correlation between maximum push strength and torque exertion. There was a moderate positive association between the two variables, which was statistically significant, $r(90) = 0.551$, $p < 0.001$.

Table 4.12: Maximum Push Force Regression

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	6	62601	10433.5	19.35	0.000
Weight	1	9678	9678.4	17.95	0.000
Hand Width	1	1254	1254.2	2.33	0.131
Hand Length	1	2203	2203.2	4.09	0.046
Grade	2	813	406.3	0.75	0.474
Gender	1	917	916.7	1.70	0.196
Error	82	44204	539.1		
Total	88	106805			

Table 4.13: Opening Roof Hatch Stepwise Logistic Regression

Source	DF	Adj SS	Adj Mean	Chi-Square	P-Value
Regression	3	47.139	15.7131	47.14	0.000
Height	1	14.236	14.2364	14.24	0.000
Grade	2	5.784	2.8921	5.78	0.055
Error	87	75.819	0.8715		
Total	90	122.958			

4.4 Discussion

While most of the first and second grade students were capable of exerting enough push force to open the roof hatch, the maximum push force data collected in this study suggested that push force exerted by kindergarten students is less than the maximum permissible force specified by standard FMVSS No. 217. As described in the results, weight had a significant effect on the amount of push force children can exert. This could be because subjects may have been able to use their body weight to apply force on the roof hatch knob. Additionally, hand length may be representative of greater hand strength which would allow for greater force exertions. It is important to note that the children were in an ideal environment when performing the push force exertion. Factors such as injuries and obstructions inside and outside the school bus may hinder their ability to open the roof hatch in an actual emergency.

All subjects were able to exert enough torque on the roof hatch knob to rotate it to the “to exit” position. Subjects unable to open the roof hatch were unable to exert enough push force to disengage the locking mechanism. The main reason subjects were unable to self-extricate through the roof hatch opening was due to insufficient upper body strength and/or low friction between the smooth ceiling surface surrounding the roof hatch and their feet. While most school districts have K-2 routes where the older students can open the roof hatch in the event of a rollover accident, most districts use school buses to transport only kindergarten aged students for special events such as field trips.

Even though many students were able to open the roof hatch and self-extricate, it is important to consider the flow rate through the roof hatch to evaluate its performance in an emergency egress scenario. The mean flow rate for the roof hatch was calculated for each grade level by dividing 60 seconds by the egress time as illustrated in Table 4.14. The flow rates of children through the emergency roof hatch is comparable to the 12 people per minute flow rate measured by the Volpe Center from a motorcoach roof hatch [Pollard and Markos, 2009]. The Volpe Center measured the flow rate of a motorcoach roof hatch exit by conducting egress trials on a rolled-over motorcoach and using employees with sufficient knowledge on operating roof hatches [Pollard and Markos, 2009]. Similarly, the Volpe Center measured the mean time required to open a motorcoach roof hatch to be six seconds and as illustrated in Table 4.8 the mean opening time ranged between 5.22 seconds to 9.1 seconds for subjects in kindergarten through the second grade. However, it is important to note that subjects were given verbal instructions on how to open the roof hatch and they have had no prior experience operating and evacuating through a roof hatch, whereas subjects in the study conducted by Pollard and Markos (2009) had sufficient knowledge of opening emergency exits. Subjects unable to open the roof hatch was due to their inability to apply an adequate amount of push force to disengage the locking mechanism.

4.5 Limitations

Several limitations were associated with the study. To insure participant safety, gym mats were stacked on the outside portion of the roof hatch opening to provide a softer landing

Table 4.14: Roof Hatch Flow Rate (Children Per Minute)

Grade	Flow Rate (PPM)	Standard Deviation	Minimum	Maximum
Kindergarten	11	6	4	24
First Grade	15	10	3	57
Second Grade	14	6	2	26

surface during the self-extrication portion of the study. This may have affected the posture of the students as they self-extricated through the roof hatch since the drop in elevation was lessened on the outside of the roof hatch. Due to the time restrictions, the ability of children to operate the roof hatch opening without instruction was not studied. Only one type of roof hatch was tested during this study, there are different types of roof hatches used on school buses that require different operation methods to open. Studying the abilities of children to operate different types of roof hatches would provide a more holistic understanding of the operability of roof hatches. Furthermore, the flow rate through the exit may be different in a post-accident scenario due to injuries, fear, and other environmental stressors. Additionally, flow rates and evacuation times can be better estimated to actual flow rates by simulation models. Further research can also be conducted on different types of roof hatches and identifying countermeasures that could help improve self-extrication through roof hatches.

4.6 Conclusions

The majority of students in the kindergarten level were unable to exert the maximum permissible force specified to open a roof hatch by FMVSS No. 217 (89 Newtons) [NHTSA, 2011]. Additionally, only 20 % of the participants in the kindergarten were able to open the roof hatch. In a controlled environment the majority of students in the kindergarten through the second grade were able to self-extricate through the opening. However in a post accident scenario, other factors may further impede the ability of young occupants to open and exit via the emergency escape roof hatch.

4.7 Acknowledgments

Gratitude is expressed to Dr. Richard Sesek and Mr. Richard Garnett for their help and expertise in building the roof hatch apparatus and strength measurement equipment. We would like to thank Mr. Jamie Forbus, the principal of Jim Pearson Elementary School (Alexander City, AL), for coordinating access to students to participate in the research and allowing us to conduct the study at the school.

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Chapter 5

Establishing Baseline Emergency Evacuation Times for School Buses

5.1 Introduction

Emergency evacuation training and measurement of evacuation times is critical to ascertaining the effectiveness of an emergency evacuation system in any scenario (plane, train, bus, etc.). The Federal Aviation Administration (FAA) **mandates** that all aircraft with a seating capacity of more than 44 passengers to demonstrate that the aircraft can be evacuated using half the exits with full occupancy in 90 seconds or less [FAA, 1990]. This is completed via a full-scale emergency evacuation demonstration, using subjects 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 the 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 pound window exit; and (iii) Must be able to quickly activate the evacuation slide and assist others to exit [Delta Airlines, 2016]. Although a school bus and an aircraft are fundamentally very similar (long, narrow metallic containers used to transport closely-packed occupants), no similar standards exist for school buses in the United States.

The objectives of this experiment were to: (i) Measure egress times of passengers for configurations of exit availability when the bus is in the baseline (upright) orientation; (ii) Evaluate the effectiveness (as measured by egress time) of having a driver (i.e. adult) assist and guide students during egress compared to a no driver assistance/guidance trial; and (iii)

Determine the effectiveness of the emergency exit door(s) by measuring flow rate (people per minute) of the front (stand alone) and rear (stand alone) emergency exit doors, and both doors simultaneously.

5.1.1 Literature Review of Bus Evacuation Studies

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 minutes [Poland et al., 2015]. 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 seconds (∼3-5 minutes) [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, J.L., Dorris, A., and Stephens, R. in 1970 [Purswell et al., 1970]. Two groups of 60 students each from kindergarten through twelfth grade 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 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 [Purswell et al., 1970]. 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 Table 5.1 and Table 5.2. 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.

Table 5.1: 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] Trial conducted with 59 subjects, number in parenthesis is calculated time for 60 subjects.

[B] Trial conducted with 58 subjects, number in parenthesis is calculated time for 60 subjects.

Table 5.2: 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

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 5.3.

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 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. Studies have identified that students with no prior experience operating emergency exits are unable to open emergency exits requiring coordinated action to open, and the uses of these exits were unsatisfactory in panic emergency situations [Sliepcevich et al., 1972, Purswell et al., 1970].

Table 5.3: School Bus Egress Times [Sliepcevich et al., 1972]

Trial Description	**No. of Participants**	**Egress Time (Seconds)**
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

In the State of Alabama, some school transportation departments record evacuation times of school buses when they perform their semiannual evacuation training for comparison.

However, this data is often not obtained in a scientific manner (nor published), with no information on the number of occupants or emergency exits utilized are recorded. School buses and motorcoaches share similar emergency evacuation systems, and they are both regulated by FMVSS No. 217. 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, has 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 were used to keep the emergency exit windows open after they had been unlatched. Results for egress times and flow rates for each egress path are presented in Table 5.4.

Table 5.4: Volpe Center 56 Passenger Motorcoach Egress Times [Pollard and Markos, 2009]

Egress Path Used	**Number of Exits Used**	**Opening Time (min)**	**Flow Rate (exit/ppm)**	**Egress (min)**	**Total (min)**
Front Door	1	0.05	36	1.56	1.61
Windows	6	0.2	9	1	1.20
Wheelchair Access Door	1	0.2	25	2.24	2.44
Roof Hatches	2	0.1	12	2.33	2.43

Egress trials through the roof hatches were performed on a motorcoach that was rolled-over by NHTSA for testing [Pollard and Markos, 2009]. Participants in the study were staff of the Volpe Center and had knowledge on the evacuation system on the motorcoach [Pollard and Markos, 2009]. Therefore, egress times are likely to be **considerably longer** for children on a school bus. In general, factors that could lead to increased emergency evacuation times include no "hold open" mechanisms, an incapacitated driver that cannot assist passengers, injured passengers, passengers with little to no experience using the emergency exits, passengers lacking the agility and strength to use the emergency exits, and keeping emergency exit doors open [Pollard and Markos, 2009]. Based on opening size, the largest exit on school buses is the rear emergency exit door with a typical weight of approximately 90 pounds. The "hold open" mechanism on the rear emergency door is not activated unless the door is moved to the "fully open" position. This could be a significant impediment if the school bus is rolled-over on its left side (facing forward) with the door hinges on top. If the door was unlatched and could be partially swung open, gravity would pull the door shut, slowing down or even preventing egress [Purswell et al., 1970]. In comparison with the front door, the flow rate of adults for roof hatches is approximately one third of the front door due to the size of exit opening and agility required to evacuate through a roof hatch.

In a similar study conducted at the University of Technology, Loughborough, egress times were measured using the emergency door and emergency window (with and without podiums) of a motorcoach with three age groups consisting of 48 subjects [Matolcsy, 2010]. Subjects in the first age group were 7-15 years old, subjects in the second age group were 20-45 years old, and subjects in the third age group were 60-75 years old [Matolcsy, 2010]. As shown in Table 5.5, there was no significant difference between the egress times of the first two age groups for the emergency door egress trials, but the third age group experienced significantly longer egress time [Matolcsy, 2010]. However, it is hypothesized that evacuation times of children on kindergarten through second (K-2) grade and third through fifth grade routes may be significantly longer due to their smaller stature and still developing cognitive abilities.

Table 5.5: Egress Times From Motorcoach by Age Group (seconds) [Matolcsy, 2010]

Evacuation Route	**7-15 years old**	**20-45 years old**	**60-75 years old**
Emergency Door with podium	120	150	240
Emergency Door without podium	210	210	N/A [A]
Emergency Window with podium	270	330	600
Emergency Window without podium	N/A [B]	540	N/A [B]

[A] Not all participants could perform the evacuation trial.

[B] Participant group could not perform the evacuation trials.

Upon reflection, the question arises, how long should it take to evacuate a school bus?

5.2 Methods

5.2.1 Objective and Hypothesis

The objectives of this experiment were to establish baseline evacuation times for school buses in the upright orientation by testing the following:

1. Measure the evacuation time of subjects in kindergarten through the third grade (K-3) (by grade) through the front door (stand alone), rear emergency door (stand alone), and both the front and rear exits simultaneously.
2. Compare flow rates of evacuations with driver's assistance/guidance to unguided evacuations.
3. Determine the effectiveness of the emergency exit doors by measuring flow rate (people per minute) of the front (stand alone) and rear (stand alone) emergency exit doors, and both simultaneously.

The hypothesis of the experiment are:

Hypothesis 1: There are significant differences among the mean flow rates of the different grade levels (k-3).

$$H_0 : \mu_k = \mu_1 = \mu_2 = \mu_3$$
$$H_1 : \mu_k \neq \mu_1 \neq \mu_2 \neq \mu_3$$

Hypothesis 2: There are significant difference in the flow rates of evacuations performed with driver's assistance/guidance compared to evacuations performed without driver's assistance/guidance.

$$H_0 : \mu_{with\ assistance} = \mu_{without\ assistance}$$
$$H_1 : \mu_{with\ assistance} < \mu_{without\ assistance}$$

Independent variables for this experiment included grade level, evacuation scenario (front door, rear door, both doors), and adult assistance/guidance. The dependent variable was flow rate. Two classes of each grade level (K-3) were recruited from Oak Mountain Elementary School in Birmingham, AL (N = 475, 251 males/224 females). Each class performed three evacuation trial scenarios (front door, rear door, both doors) either with driver's assistance/guidance or without adult assistance/guidance. Participants were not told which exit to use when performing the front door and rear door (simultaneous) evacuation without driver's assistance. Due to a time constraint the kindergarten class that performed the evacuation trials with driver assistance were unable to perform a rear door only evacuation. Evacuation trials were performed in a randomized order as shown in Table 5.6.

Table 5.6: Evacuation Trials

Grade Level / No. of Participants	**Driver Assistance**	**Evacuation 1**	**Evacuation 2**	**Evacuation 3**
Kindergarten, N = 60 (30 M, 30 F)	Yes	Front Door	Front & Rear Doors	N/A
Kindergarten, N = 56 (28 M, 28 F)	No	Rear Door	Front & Rear Doors	Front Door
First Grade, N = 57 (30 M, 27 F)	Yes	Rear Door	Front & Rear Doors	Front Door
First Grade, N = 52 (25 M, 27 F)	No	Front & Rear Doors	Rear Door	Front Door
Second Grade N = 63 (30 M, 33 F)	Yes	Front & Rear Doors	Front Door	Rear Door
Second Grade, N = 63 (34 M, 29 F)	No	Rear Door	Front & Rear Doors	Front Door
Third Grade N = 61 (36 M, 25 F)	Yes	Front Door	Rear Door	Front & Rear Doors
Third Grade, N = 63 (38 M, 25 F)	No	Rear Door	Front & Rear Doors	Front Door

The Auburn University Internal Review Board (IRB) approved the study. Since the study was performed as part of the required semiannual evacuation training, consent documents were not required. Protocol approval can be found in Appendix E. Subjects were given numbered sport pinnies and were randomly assigned to a seat on the bus. A school bus driver briefed the subjects on the exit(s) to use and took responsibility for the evacuation drill. The script used by the driver can be found in Appendix F. For the front door evacuations with driver's assistance/guidance, subjects remained seated and the driver started at the front row and instructed the subjects to exit through the front door. Similarly for the rear emergency exit evacuation trials with driver's assistance/guidance trial, the school bus driver went to the back of the school bus and instructed subjects seated in the last row to evacuate as he worked his way to the front of the school bus. For front and rear door simultaneous evacuations with driver's assistance, the school bus driver went to the center of the bus and directed subjects seated toward the front of the bus to evacuate through the front door and subjects seated toward the back to evacuate through the rear emergency door. The doors were opened before the start of the evacuation trials and remained open during the trials. To minimize the likelihood of falls, participants were asked to 'sit and scoot' out as they exited the bus from the rear emergency door. Two graduate assistants stood outside each bus door to make sure the participants did not trip or fall as they evacuated the bus. Surveillance cameras were used to determine the location of the subjects throughout the evacuation process.

5.2.2 Equipment

A 2009 Thomas C2 SAF-T-LINER shown in Figure 5.1 was used for all the evacuation trials. The school bus had 12 rows of seats and a maximum capacity of 72 passengers. The school bus was equipped with a four-camera (HD) surveillance system to record the evacuation trials. Subjects were given sport pinnies to wear over their clothing to help identify them in the video footage.

Figure 5.1: 2009 Thomas C2 SAF-T-LINER

5.2.3 Statistical Analyses

An analysis of variance (ANOVA) was performed to determine the effects of driver assistance, grade level, and evacuation scenario on flow rate using an $\alpha = 0.05$. Follow-up Tukey Honestly Significant Difference (HSD) pairwise comparisons were used to evaluate statistically significant differences.

5.3 Results

5.3.1 Descriptive Statistics

Evacuation times for trials performed with and without driver's assistance and guidance are reported in Table 5.7 and Table 5.8, respectively. The number of subjects that participated in the evacuation trials differed because of different class sizes. In order to compare the evacuation trials, the flow rate (people/minute) for each trial was calculated and reported in Table 5.9 and Table 5.10. A graphical comparison of the flow rates for each evacuation scenario are presented in Figure 5.2, Figure 5.3, and Figure 5.4. Detailed flow rate graphs for each evacuation trial can also be found in Appendix H.

Table 5.7: Evacuation Times *with* Driver's Assistance and Guidance (Seconds)

Grade	**Front Door**	**Rear Door**	**Both Doors**
Kindergarten (N = 60)	225	N/A	135
1st Grade (N = 57)	120	169	111
2nd Grade (N = 63)	111	179	98
3rd Grade (N = 61)	103	180	76
Mean (SD)	139.8 (57.3)	176 (6.1)	105 (24.7)

Table 5.8: Evacuation Times *without* Driver's Assistance and Guidance (Seconds)

Grade	**Front Door**	**Rear Door**	**Both Doors**
Kindergarten (N = 56)	133	238	170
1st Grade (N = 52)	139	180	114
2nd Grade (N = 63)	129	204	97
3rd Grade (N = 63)	114	179	68
Mean (SD)	128.8 (10.7)	200.3 (27.7)	112.3 (42.9)

Table 5.9: Flow Rate *with* Driver's Assistance and Guidance (Children/Minute)

Grade	**Front Door**	**Rear Door**	**Both Doors**
Kindergarten (N = 60)	16	N/A	27
1st Grade (N = 57)	29	20	31
2nd Grade (N = 63)	34	21	39
3rd Grade (N = 61)	36	20	48
Mean (SD)	29 (8.9)	21 (0.5)	36 (9.5)

Table 5.10: Flow Rate *without* Driver's Assistance and Guidance (Children/Minute)

Grade	**Front Door**	**Rear Door**	**Both Doors**
Kindergarten (N = 56)	25	14	20
1st Grade (N = 52)	22	17	27
2nd Grade (N = 63)	29	19	39
3rd Grade (N = 63)	33	21	56
Mean (SD)	28 (4.7)	18 (2.9)	35 (15.6)

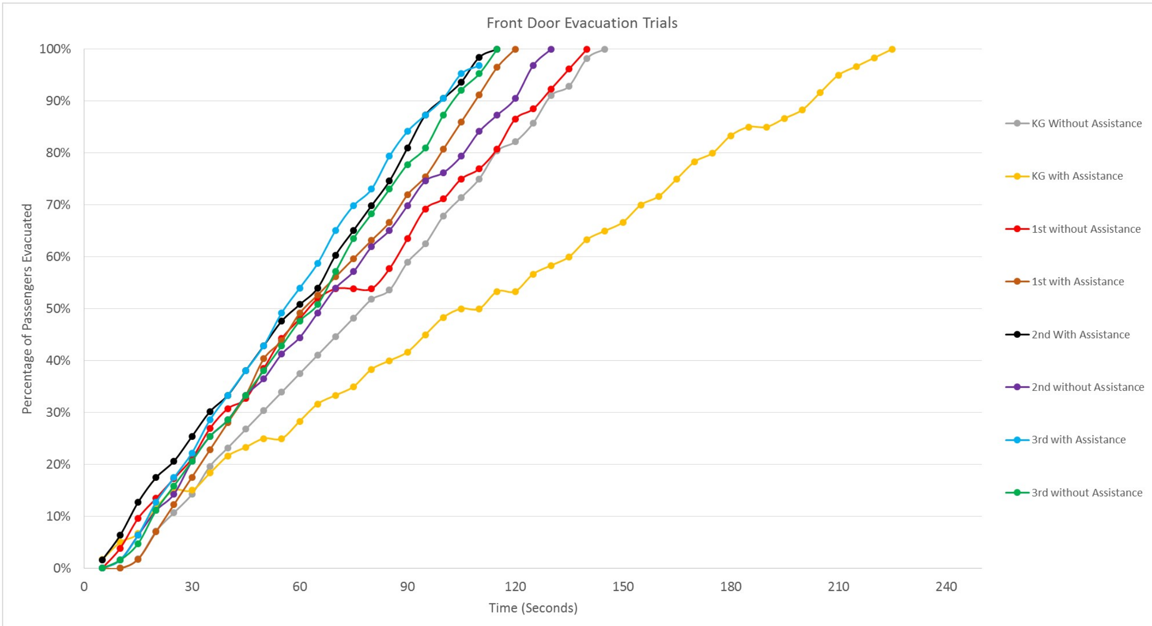

Figure 5.2: Front Door Flow Rate

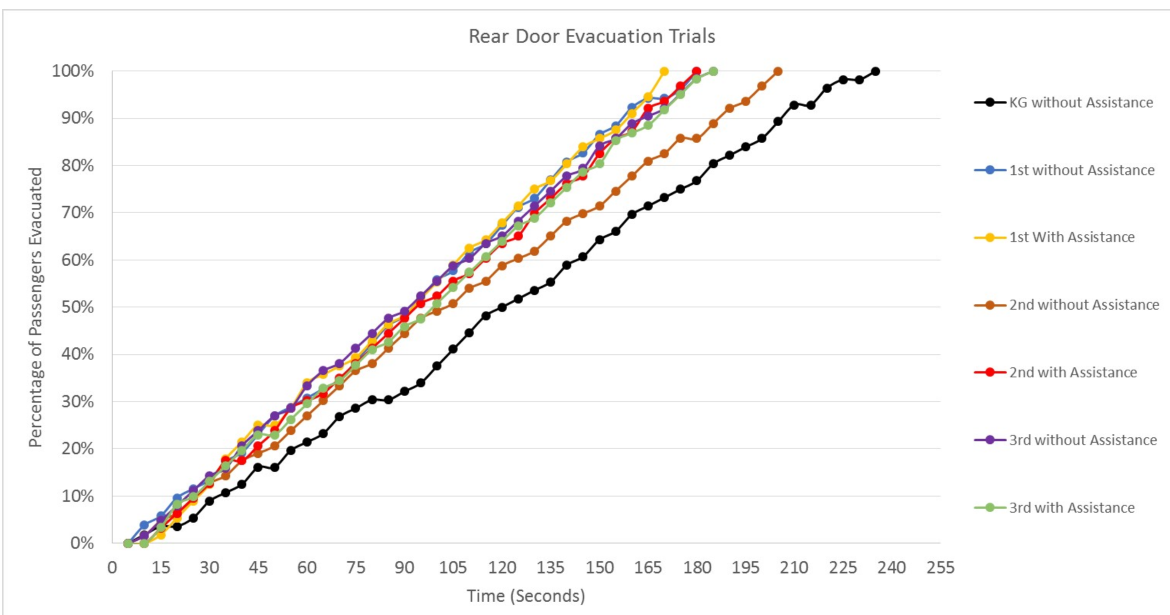

Figure 5.3: Rear Door Flow Rate

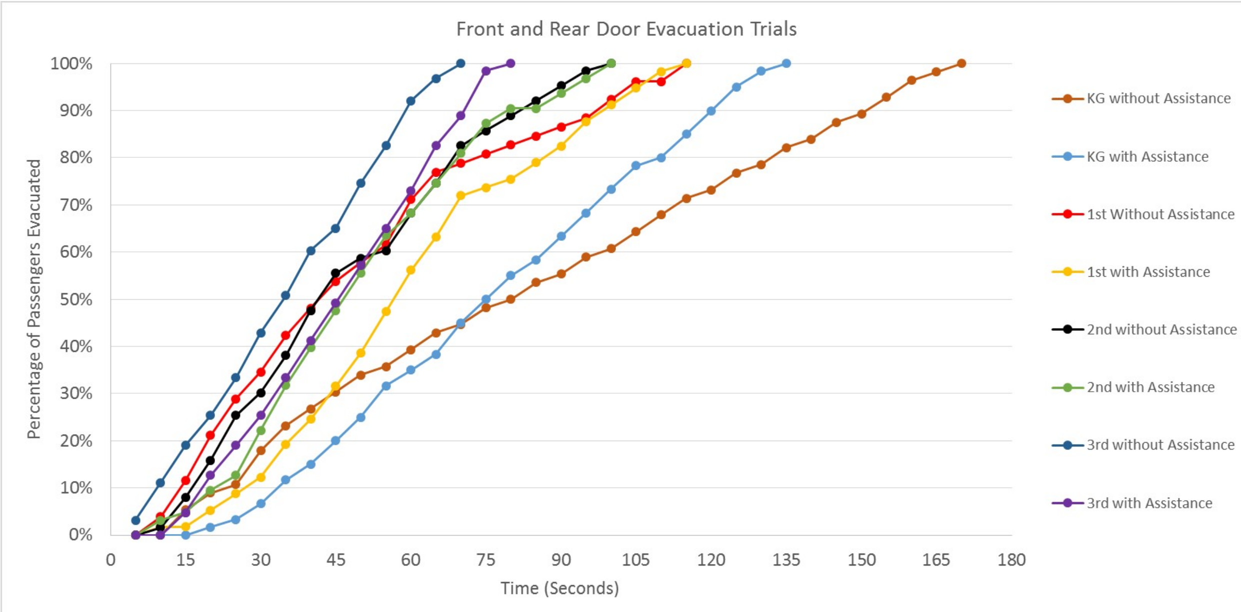

Figure 5.4: Front Door and Rear Door Simultaneous Flow Rate

5.3.2 Inferential Statistics

As shown in Table 5.11, grade level and evacuation scenarios were observed to have a statistically significant effect on flow rate ($p < 0.05$). As shown in Table 5.12 pairwise comparisons indicated that differences in mean flow rates were statistically different ($p < 0.05$) between: (i) third grade and first grade; (ii) third grade and kindergarten; and (iii) second grade and kindergarten. Additionally, the mean flow rate of the front door evacuations, rear door evacuations, and both door (simultaneously) evacuations were found to be significantly different as illustrated in Table 5.13.

Table 5.11: Flow Rate Analysis of Variance

Source	DF	SS	MS	F-Value	P-Value
Driver	1	4.72	4.732	0.23	0.6551
Grade	3	746.61	248.871	11.87	0.0104
Door	2	1018.12	509.062	24.27	0.0027
Driver*Grade	3	40.35	13.451	0.64	0.6206
Driver*Door	2	0.81	0.406	0.02	0.9809
Grade*Door	6	289.92	48.321	2.3	0.1889
Error	5	104.85	20.971		
Total	22				

Table 5.12: Tukey's HSD for Grade Levels

Grade	Mean	Homogeneous Groups†
Kindergarten	35.7	A
First	30.2	AB
Second	24.3	BC
Third	19.1	C

† Means that do not share a letter are significantly different.

Table 5.13: Tukey's HSD for Evacuation Scenarios

Evacuation Scenario	Mean	Homogeneous Groups†
Front and Rear Door Evacuation	35.9	A
Front Door Evacuation	28.0	B
Rear Door Evacuation	18.1	C

† Means that do not share a letter are significantly different.

5.4 Discussion

Measured evacuation times were more than double the evacuation times reported by Sliepcevich in 1972 [Sliepcevich et al., 1972]. This could be because the passengers who participated in that study ranged from kindergarten through twelfth grade, while the passengers in this study were from specific grade levels from kindergarten through third grade. The flow rates of the front door evacuation trials are slightly less, but comparable to the flow rate measured by the Volpe Center for the front door evacuation of a motorcoach using adults as subjects.

By comparing the mean flow rates of the three current evacuation scenarios, it is evident that the mean flow rate of the rear emergency door was approximately 64% of the flow rate of the front door evacuation scenario and 51% of the front and rear emergency door (simultaneous) evacuation scenario. Requiring subjects to sit and scoot out to evacuate through the rear emergency door likely increased evacuation times. While this may be considered a limitation, the rear emergency door is typically 42 inches (3.5 feet) off the ground. An average five year old male is 45 inches tall with a standing eye height of 39 inches, whereas an average adult male is 70 inches tall with an eye height of 64 inches [Fryar et al., 2012, Hayward, 2008]. Comparing the ratio of standing eye height to the 42 inch drop from the emergency door opening to the ground; the perception of a 42 inch drop from the rear emergency door opening to the ground for a child would be similar to the perception of an adult of a 69 inch (5.75 feet) drop. Therefore, it may be reasonable to assume that a small child, such as a kindergarten student, would choose to sit and scoot rather than jump out.

Flow rates for the front and rear door evacuation varied significantly between the four grade levels. After closely examining the video footage of the evacuation trials, the percentage of occupants evacuating through the front door and rear door, reported in Table 5.14, are more equally distributed between the front and rear door for the evacuation trials with driver assistance. For instance, during the kindergarten front and rear door (simultaneous) evacuation trial without driver guidance, the occupants followed the crowd of occupants waiting to evacuate through the rear door even though the front exit was openly accessible. However, with the older grade levels, the occupants waiting in line to evacuate through the rear door realized that the front door was accessible and evacuated the school bus through it.

Regarding the question of how long it takes for kindergarten through second grade students to evacuate a school bus, results indicate that evacuation times are highly dependent on the type of exits available. Measuring flow rates of the current evacuation system is the first step in evaluating the effectiveness of any evacuation system. Baseline flow rates can be used in simulation models to identify improvements that can be implemented in evacuation systems on school buses, and estimate successful evacuation rates in post-accident scenarios.

Table 5.14: Distribution of Evacuees Between The Front Door and Rear Door (Simultaneous)

Driver Assistance	**Grade Level**	**Front Door**	**Rear Door**
Yes	Kindergarten	50%	50%
No	Kindergarten	14%	86%
Yes	First Grade	44%	56%
No	First Grade	46%	54%
Yes	Second Grade	49%	51%
No	Second Grade	51%	49%
Yes	Third Grade	59%	41%
No	Third Grade	62%	38%

5.5 Limitations

Several limitations were associated with the study. The doors were opened prior to the evacuation trials, therefore time opening the exits was unaccounted for in the evacuation times. Research assistants stood outside the exits and helped the subjects evacuate through the rear emergency door. In a post-accident scenario evacuation times may vary based on the amount of help and assistance the occupants receive. For safety purposes, subjects were required to 'sit and scoot' out the rear emergency door. Additionally, in a real emergency more than one passenger may evacuate through an exit at a time, and passengers may help each other during the evacuations. However, as seen in the case study footage, some passengers may wait for explicit instructions to evacuate the school bus.

5.6 Conclusions

Between kindergarten and third grade, grade level and evacuation scenario were statistically significant factors affecting emergency evacuation times and flow rates. Based on these results, school bus emergency exits should consider the physical and cognitive capabilities of children riding school buses. For instance, in the unassisted evacuation trials, children in kindergarten followed their peers who were waiting to evacuate through the rear emergency exit even though the front door was open. It must also be noted that the evacuation trials were performed in optimal conditions. While driver's assistance and guidance did not have a significant effect on the evacuation time, factors such as visibility, smoke, and injuries may prove that driver's guidance/assistance would play a vital role in the evacuation process.

5.7 Acknowledgments

We would like to thank Mrs. Debbie Horton, the Principal of Oak Mountain Elementary School (Birmingham, AL), for coordinating access to students to participate in the research and allowing us to conduct the study at the school. Gratitude is expressed to Mr. Ward Thigpen, Education Specialist at the Alabama State of State Department of Transportation for acting as the school bus driver during the evacuation trials.

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Chapter 6

Conclusions

6.1 Introduction

Successful operation and evacuation through an emergency evacuation system is highly dependent on the physical capabilities of the user population. While school buses are the safest mode of transportation for students, it is believed that evaluating the strength capabilities of children and their ability to open and self-extricate through school bus emergency exits could help improve survivability in a post-accident scenario. The design of the emergency exit system is regulated by Federal Motor Vehicle Safety Standard (FMVSS) No. 217. This standard specifies the location, opening size, and force required to operate emergency exits on school buses. However, FMVSS No. 217 does not consider the physical capabilities of children to open and evacuate through these emergency exits. Additionally, FMVSS No. 217 does not consider the operation requirements of emergency exits if the school bus is rolled-over.

In essence, school buses and aircraft are large metallic tubes that transport people. However, the emergency evacuation system on aircraft must adhere to stricter standards. For instance, emergency exits on aircraft are rated by their flow rate which determines the number and type of exits required on aircraft. Minimal research has been conducted on the flow rates of school bus emergency exits. Furthermore, the Federal Aviation Administration (FAA) mandates specific age and strength requirements for passengers to sit in an exit row to so that they have the capabilities to open the exit in an emergency scenario. Kindergarten through second grade routes are common in many school districts in the United States. Typically, the school bus driver is the only adult on the school bus and if the driver is unable to assist in the evacuation (injury, illness, or drug impairment) it is up to the children to evacuate the school bus until further assistance arrives.

6.2 Summary of Findings

Three experiments were performed in this dissertation. The first experiment measured stature and strength capabilities of children in kindergarten through second grade (K-2) with regard to opening the rear emergency door on school buses. The ability of K-2 children to open and self-extricate through the rear emergency door in the upright and rolled over orientations was studied. The second experiment measured the strength capabilities of K-2 children with regard to the emergency escape roof hatch. Opening and self-extricating through the roof hatch was also studied in the second experiment. Evacuation times and flow rates of three different evacuation scenarios (front door only, rear door only, and both doors simultaneously) were measured in the third experiment for students in the kindergarten through third grade.

The summarized findings of the findings of the first experiment were:

1. Majority of subjects in kindergarten through second grade were unable to exert the maximal permissible force specified by FMVSS No. 217 to open the rear emergency exit.

2. Flow rate through the rear emergency door of a school bus in the rolled-over orientation is significantly increased with the removal of the seats adjacent to the exit opening.

3. Grade, weight, and gender have a statistically significant effect on force exertions to the emergency door handle of a school bus ($p < 0.05$).

4. Children in K-2 are able to exert more force on the emergency door handle when it is oriented in the upright orientation compared to a school bus rolled over on its left side (driver side) ($p < 0.05$).

The summarized findings of the second experiment were:

1. Only 20% (6/30) of the kindergarten participants were able to open the roof hatch, 87% (26/30) were able and willing to self-extricate. For first grade, 71% (24/34) were able and willing to open the roof hatch and 91% (31/34) were able and willing to self-extricate. Eighty nine percent (24/27) of the second grade participants were able and willing to open the roof hatch and 96% (26/27) were able and willing to self-extricate.

2. Majority of students in kindergarten are unable to exert the 20 pounds of push force on the roof hatch knob stated by FMVSS No. 217 to be the maximal permissible force to open an emergency escape roof hatch. Weight and hand length had statistically significant effects on push force exertions ($p < 0.05$)

The summarized finding of the third experiment were:

1. Between kindergarten and third grade, grade level and evacuation scenario (front door only, rear door only, and both doors simultaneously) had a statistically significant effect on flow rate ($p < 0.05$).

2. The mean flow rates were statistically significant ($p < 0.05$) between: (i) third grade and first grade; (ii) third grade and kindergarten; and (iii) second grade and kindergarten.

A holistic view of factors influencing the opening and successful evacuation through school bus emergency exits are summarized in Appendix H. Grade level, which is also indicative of the age and strength capabilities of children, is an important factor to consider when evaluating emergency exits. Considering the strength capabilities of the youngest group of school bus riders in the design of emergency exits is necessary to ensure that the exits are usable in a post-accident scenario. While children in kindergarten through second grade were able to exert enough force to operate current school bus emergency exits, strength data collected in the studies suggest that they do not have the strength capabilities to operate emergency exits designed to be operated with forces as high as the maximum permissible forces specified by FMVSS No. 217.

6.3 Limitations of the Research

Limitations associated with this research included:

1. Gym mats were used on the outside portion of the rear emergency door and emergency escape roof hatch apparatuses to provide both a higher softer landing surface during the self-extrication studies. This may have affected the posture of the subjects as they self-extricated through the exit openings, as some subjects were comfortable to jump/climb through the opening and land on their back or belly.

2. For safety purposes, the rear emergency door was secured open during the self-extrication portion of the study. Had the emergency door been allowed to swing shut, successful self-extrication rates would have been considerably lower.

3. Only one type of emergency escape roof hatch and rear emergency door was tested in the experiments.

4. The ability to open and self-extricate through the emergency door and roof hatch can be hindered with the presence of post-accident factors such as injuries, fear, disorientation, and hazards (fire, smoke, etc.).

6.4 Recommendation for Future Research Studies

Several opportunities have arisen from this study:

- Determine the ability of children to open the rear emergency door on a school bus rolled-over on its left side (driver side), and the door hinges were on top. This would test how far up subjects are able to push the door, and if they are able to lock it in the open position.

- Compare the ability of children to open and evacuate through other types of school bus emergency escape roof hatches, rear emergency doors, and emergency windows.

- Design countermeasures and evaluate their effectiveness by comparing the success rates of opening and self-extricating through emergency exits with and without them.

- Further analyses of self-extrication through the rear emergency door and roof hatch through the use of inertial motion units and motion capture systems to improve the design of emergency exits.

- Measure the effects of environmental factors such as smoke and darkness on evacuation trials.

- Measure evacuation times and flow rates of evacuation scenarios using emergency windows.

- Utilize simulation models to predict evacuation times and flow rates of school buses in the rolled-ever orientations.

- In general, more data needs to be collected on the ability of children to open and self-extricate through emergency exits. Evaluating the ability of children beyond kindergarten through second grade to operate emergency exits will provide a better understanding on the stature and strength capabilities of children with regard to the design of school bus emergency exits.

Appendices

Appendix A

IRB Parental Consent Forms for “Physical Requirements to Evacuate a School Bus Through the Rear Emergency Door”

AUBURN
UNIVERSITY

SAMUEL GINN
COLLEGE OF ENGINEERING

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

PARENTAL PERMISSION/CONSENT
for Research Study entitled
"Physical Requirements to Evacuate a School Bus Using Emergency Evacuation Systems"

Your child is invited to participate in a research study to investigate the physical requirements needed to evacuate a school bus using the emergency evacuation systems. Yousif Abulhassan and Dr. Jerry Davis in the Auburn University Department of Industrial and Systems Engineering are conducting the study. Your child was selected as a possible participant because he or she is a student at Oak Mountain Elementary School. Since your child's age is 18 or younger we must have your permission to include him/her in the study.

What will be involved if your child participates? If you decide to allow your child to participate in this research study, your child will be asked to voluntarily pull on an emergency door handle measurement device, and crawl through the rear emergency door of a controlled school bus mock-up. These activities will be performed during gym class. The following measurements will be recorded: 1. Height and weight 2. Hand dominance and anthropometric hand measurements. 3. Force exertion measurements on school bus emergency exit door handle. Your child will be videotaped during testing to identify their posture during force exertions tests and crawling. Any incurred medical costs are not covered through this research.

Are there any risks or discomforts? The risks associated with participating in this study are minimal and are limited to muscle strains or impact with equipment. We will not allow any horse playing around the equipment. Additionally, we will have all students wear a bicycle helmet, elbow, and knee pads to protect against any impacts or abrasions.

Are there any benefits to your child or others? If your child participates in this study, your child can expect to learn how to interact with the emergency exit device (windows, door, and roof hatch) in a non-emergency scenario. We cannot promise you that your child will receive any or all of the benefits described.

The Auburn University Institutional Review Board has approved this document for use from
3/19/15 to 4/15/16
Protocol # 14-136 MR 1404

Parent/Guardian Initials______

Will you or your child receive compensation for participating? We cannot provide any type of compensation to your child for participating.

Are there any costs? There is no cost for your child to participate in this study.

If you (or your child) change your mind about your child's participation, your child can be withdrawn from the study at any time. Your child's participation is completely voluntary, and you are welcome to observe your child during the study. Your decision about whether or not to allow your child to participate or to stop participating will not jeopardize your or your child's future relations with Auburn University, the Department of Industrial and Systems Engineering, or Shelby County Schools.

Your child's privacy will be protected. Any information obtained in connection with this study will remain anonymous. Information obtained through your child's participation may be used to fulfill an educational requirement, published in a professional journal, used by general industry, and/ or presented at a professional meeting.

If you (or your child) have questions about this study please contact Yousif Abulhassan at 503-880-5045 or Dr. Jerry Davis at davisga@auburn.edu, (334) 332-7745. A copy of this document will be given to you to keep.

If you have questions about your child's rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH FOR YOUR CHILD TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO ALLOW YOUR CHILD TO PARTICIPATE.

Parent/Guardian Signature	Investigator obtaining consent
Printed Name	Printed Name
Date	
Child's name	

The Auburn University Institutional Review Board has approved this document for use from 3/19/15 to 4/15/16 Protocol # 14-136 MR 1404

VIDEO RELEASE - MINOR

During your child's participation in this research study, "Physical Requirements to Evacuate School Bus Using Emergency Evacuation Systems", your child will be videotaped. Your signature on the Informed Consent gives us permission to do so.

Your signature on this document gives us permission to use the videotape(s) for the additional purposes of publication and training beyond the immediate needs of this study. These videotapes will not be destroyed at the end of this research but will be retained indefinitely.

Your permission:

I give my permission for videotapes produced in the study, "Physical Requirements to Evacuate School Bus Using Emergency Evacuation Systems", which contain images of my child, to be used for the purposes listed above, and to also be retained (*indefinitely*).

______________________________ ______________________________

Parent/Guardian's Signature Date Investigator's Signature Date

______________________________ ______________________________

Parent/Guardian's Printed Name Investigator's Printed Name

____

Minor's Printed Name

Appendix B

"Protocol and Data Collection Form for "Physical Requirements to Evacuate a School Bus Through the Rear Emergency Door"

The study will be conducted over a three day period. Subjects will be assigned a random identification number to identify them throughout the duration of the study.

On the first day, three stations will be set up. The following measurements will be collected at the first station:

1. Gender
2. Grade
3. Date of birth (month and year)
4. Height (with shoes on due to time constraints)
5. Weight

At the second station, a researcher will show the subjects how to operate the release mechanism on the rear emergency door test apparatus and the following script will be used to guide the subject:

"Hi, I will show you how to open the back door on a school bus (researcher unlatches door, then latches it) . Now I want you to try to open the door." If the subject is unable to open the door or does not want to attempt to open the door, the researcher will ask the subject, "Let's try to open the door one more time" If the subject can't or refuses to open the door, the experiment will be stopped. The time from touching the door handle until the door is unlatched is recorded.

At the third station, maximum force measurement on a rear emergency door handle is recorded. The door handle is oriented in at the same position it would be on the rear emergency door in the upright orientation. A researcher will welcome the subject with the following script:

"Hi. We will be measuring how much force you can generate on the red door handle. I will show you how to pull on the red handle and I will want you to do the same thing as hard as you can when I tell you to start."

The researcher will use a stopwatch and ask the participant to start pulling and stop after three seconds. The handle is labeled at every half inch for the researcher to measure the distance from the center of the subjects hand to the torque transducer. The peak torque on the handle will be recorded. Subject will be asked to rest for 30 seconds. The following procedure will be repeated until three trials are complete.

On the second day the rear emergency door apparatus will be reconfigured to simulate a school bus rolled to the left (facing forward) with the door hinges located at the top. Subjects will be escorted to the apparatus and after shown how to unlatch the door will be asked to unlatch the door. The time from touching the door handle until the door is unlatched is recorded.

After all subjects in a class have attempted to unlatch the door the door is secured in the fully open position using a ratchet strap. Researchers will fit the subjects with a helmet, knee pads, and elbow pads. Subjects were instructed to stand approximately two feet from the door opening and asked to self-extricate through the door opening as fast as they can. Time was measured from the start signal until the subjects entire body was on the other side of the door opening. The door handle on the force exertion apparatus was reconfigured to the location the handle would be when a school bus is rolled-over. The same procedure was followed to measure force exertions on the door handle in the upright orientation.

On the third day, the lower seat of the rear emergency door apparatus will be removed and the door will be secured in the fully open position. Subjects will be fitted with a helmet, knee pads, and elbow pads and asked to self-extricate through the door opening. The same evacuation procedure will be followed and self-extrication time will be measured from the start signal until the subjects entire body is on the other side of the door opening.

Subjects have the right to not participate in any portion of the experiment. Curtains will be placed around the rear emergency door test apparatus for subject privacy when performing the evacuation portion of the experiment.

Date: ____________

Rear Emergency Door Study

Data Collection Form (Day 1: Upright Orientation)

Subject No: ______________

Grade: ______________

Anthropometric Measurements

Gender: Male / Female

Month/Year of Birth (mm/yyyy): ______/_______

Weight (lbs.): ______________ Height (cm): ______________

Dominant Hand: Left Handed / Right Handed

Hand Width: ______________

Hand Length: ______________

Door Handle Force Exertion (in-lb)	
Trial 1	**Distance from Center of Hand to Torque Sensor (in.)**
Trial 2	**Distance from Center of Hand to Torque Sensor (in.)**
Trial 3	**Distance from Center of Hand to Torque Sensor (in.)**

Upright Orientation

Subject able to unlatch door? Yes / No

Time to unlatch door: ____________

Date: ____________

Data Collection Form (Day 2: Rolled Over Orientation)

Subject No: _____________

<u>Rolled Over Orientation</u>

Door Handle Force Exertion (in-lb)	
Trial 1	**Distance from Center of Hand to Torque Sensor (in.)**
Trial 2	**Distance from Center of Hand to Torque Sensor (in.)**
Trial 3	**Distance from Center of Hand to Torque Sensor (in.)**

Subject able to unlatch door? Yes / No

Time to unlatch door: ____________

Time to self-extricate through the door: ____________

*If subject was unable to self-extricate write "X"

Data Collection Form (Day 3: Rolled Over Orientation No Seat)

Time to self-extricate through the door: ____________

*If subject was unable to self-extricate write "X"

Appendix C

IRB Parental Consent Forms for “Physical Capabilities of Children to Operate and Exit a School Bus Through an Emergency Roof Hatch”

DEPARTMENT
OF PSYCHOLOGY

AUBURN UNIVERSITY
COLLEGE OF LIBERAL ARTS

Research Study on Bus Evacuation

Your child is invited to participate in a research study investigating whether children can exit buses through emergency roof hatches. This study is being conducted by Dr. Aimee Callender and Dr. Jerry Davis of Auburn University.

Why is my child invited to participate? We are inviting children in grades K-2 to participate.

What is the purpose of the study? We want to know two things. 1. If children in grades K-2 can read and understand the emergency exit instructions. 2. If children in grades K-2 can physically exit through the roof hatch on a bus.

What will my child be asked to do? Your child will take 2 sets of assessments:

1. Cognitive: We will test cognitive and reading abilities.
2. Physical: We will take physical measurements, strength assessments, and then ask your child to exit through the roof hatch.

Are there any risks? There are some risks since your child will be climbing on a mock bus structure. There will be adult supervision at all times and we will monitor your child's safety.

How long will the study take? The study will take approximately 1 hour to complete. It will be done during school hours on the school grounds.

What if I have questions? You may contact either Dr. Callender at 334-844-6926 or Dr. Davis at 334-332-7745.

What should I do if I want my child to participate? *Please sign and return the accompanying consent form to your child's teacher.*

226 Thach Hall, Auburn, AL 36849-5214; Telephone: 334-844-4412; Fax: 334-844-4447

www.cla.auburn.edu

AUBURN UNIVERSITY

(NOTE: DO NOT AGREE TO PARTICIPATE UNLESS AN APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

PARENTAL PERMISSION/CONSENT
for Research Study entitled
"Cognitive & Physical Capabilities of Children in Operating and Exiting a Rolled-Over School Bus Escape Hatch"

Your son or daughter is invited to participate in a research study to: (1) Evaluate the cognitive abilities of children to comprehend written instructions on the roof escape hatches; (2) Evaluate the strength and stature requirements to operate the roof hatches; (3) Compare current school bus standard requirements to the strength and physical capabilities of children; (4) Determine if 5 to 8 year old children can evacuate a rolled over school bus through the roof hatches in the event that the driver is disabled or unable to assist. The study is being conducted by Dr. Aimee Callender and Dr. Jerry Davis, professors in the Auburn University departments of Psychology, and Industrial & Systems Engineering respectively. Your son/daughter is invited to participate because he/she is a 5 to8 year old student in the Jim Pearson Elementary School. Since he/she is age 18 or younger we must have your permission to include him/her in the study.

What will be involved if he or she participates? If you decide to allow him or her to participate in this research study, he or she will be asked to complete a short general intelligence test, two different reading assessments, strength measurements, physical measurements of height, weight and hand size, and crawl through a roof hatch. Reading time and accuracy for completing each step will be recorded from the reading assessments. Hand width and length measurements will be recorded using an imaging device, and maximum voluntary push force and torque will be measured using an advanced force gauge. Posture and speed will be measured by videotaping your child crawling through a roof hatch mock-up apparatus. The videotapes will be used only for research purposes. Your son/daughter's total time commitment will be approximately one hour.

Are there any risks or discomforts? The risks associated with participating in this study are minimal and are limited to muscle strains or impact with equipment. We will not allow any horse playing around the equipment, and will have adult/ teacher supervision during the entire study. All equipment will be constructed with safety precautions such as padding.

The Auburn University Institutional Review Board has approved this document for use from 3/11/15 to 3/10/16
Protocol # 15-115 MR 1503

Parent/Guardian Initials______

Are there any benefits to your child or others? Participants in this study will learn how to evacuate a school bus using an emergency escape roof hatch. The learned knowledge is extremely beneficial to the young subjects as they will have practiced how to interact and operate the emergency devices in a scenario that is not life threatening. We cannot promise you that your child will receive any or all of the benefits described.

Will you or your child receive compensation for participating? We cannot provide any type of compensation to your child for participating.

Are there any costs? There is no cost for your child to participate in this study.

If you (or your child) change your mind about your child's participation, your child can be withdrawn from the study at any time. Your child may choose to discontinue participation at any time. Your child's participation is completely voluntary, and you are welcome to observe your child during the study. Your decision about whether or not to allow your child to participate or to stop participating will not jeopardize your or your child's future relations with Auburn University, the Department of Psychology or Department of Industrial and Systems Engineering, or Jim Pearson Elementary.

Your child's privacy will be protected. Any information obtained in connection with this study will remain confidential. Information obtained through your child's participation may be used to fulfill an educational requirement, published in a professional journal, used by general industry, and/ or presented at a professional meeting.

If you (or your child) have questions about this study please contact Dr. Aimee Callender at aac0005@auburn.edu, 334-844-6926, Dr. Jerry Davis at davisga@auburn.edu, (334) 332-7745, or Yousif Abulhassan at yaa0002@aubun.edu, 503-880-5045. A copy of this document will be given to you to keep.

If you have questions about your child's rights as a research participant, you may contact the Auburn University Office of Human Subjects Research or the Institutional Review Board by phone (334)-844-5966 or e-mail at hsubjec@auburn.edu or IRBChair@auburn.edu.

Parent/Guardian Initials______

The Auburn University Institutional Review Board has approved this document for use from 3/11/15 to 3/10/16 Protocol # 15-115 MR 1503

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH FOR YOUR CHILD TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO ALLOW YOUR CHILD TO PARTICIPATE.

____
Parent/Guardian Signature

____
Investigator obtaining consent

____
Printed Name

____
Printed Name

____
Date

____
Minor's Name

The Auburn University Institutional Review Board has approved this document for use from 3/11/15 to 3/10/16
Protocol # 15-115 MR 1503

VIDEO RELEASE - MINOR

During your child's participation in this research study, "Cognitive & Physical Capabilities of Children in Operating and Exiting a Rolled-Over School Bus Escape Hatch", your child will be videotaped. Your signature on the Informed Consent gives us permission to do so.

Your signature on this document gives us permission to use the videotape(s) for the additional purposes of publication and training beyond the immediate needs of this study. These videotapes will not be destroyed at the end of this research but will be retained indefinitely.

Your permission:

I give my permission for videotapes produced in the study, "Cognitive & Physical Capabilities of Children in Operating and Exiting a Rolled-Over School Bus Escape Hatch", which contain images of my child, to be used for the purposes listed above, and to also be retained *indefinitely*.

____
Parent/Guardian's Signature Date

____
Investigator's Signature Date

____
Parent/Guardian's Printed Name

____
Investigator's Printed Name

____
Minor's Printed Name

The Auburn University Institutional Review Board has approved this document for use from 3/11/15 to 3/10/16 Protocol # 15-115 MR 1503

Appendix D

Protocol and Data Collection Form for "Physical Capabilities of Children to Operate and Exit a School Bus Through an Emergency Roof Hatch"

Subjects will be assigned a random identification number. An attendance sheet will be used as a key to identify subjects during the study and will be destroyed after data collection is complete. Three stations will be set up for data collection. Data collection at the first station will collected by male researcher for male subjects and female researchers for female subjects. The following measurements will collected at the first station:

1. Gender
2. Grade
3. Date of birth (month and year)
4. Height
5. Weight
6. Hand width
7. Hand length

Hand width will be measured from the second to fifth metacarpal, and hand length will be measured from the intersyloid line (crease of the wrist) to the tip of the middle finger.

At the second station, a researcher will show the subjects how to unlatch the roof hatch on the roof hatch apparatus and will read the following script:

"I will now show you how to open a roof hatch, I will then want you to open the roof hatch for me when I tell you to start."

The researcher will use a stopwatch to record the time from when the subjects touches the roof hatch knob to when the roof hatch is open. If the subject is unable to open the roof hatch they will be asked to try one more time, and if they still can't or unwilling to, that portion of the experiment will be stopped.

For the second part of the experiment, the researcher will secure the roof hatch door on the open position and will say the following to the subject:

"I want you to crawl through the roof hatch as fast as you can when I tell you to start." The researcher will use a stopwatch measure the time from when the subject touches the roof hatch opening until their entire body is on the other side of the roof hatch apparatus. Video recording will also be used to record the subjects evacuating through the roof hatch. If the subject is unable or unwilling to evacuate through the roof hatch the will be asked if they want to try one more time and if they still can't or unwilling to, that portion of the experiment will be stopped.

At the third station, the push force and torque measurement stands will be set up. A researcher will show the subject to push on the red knob and will say the following to the subject:

"I want you to push as hard as you can on the red knob when I tell you to start until I tell you to stop." The researcher will use a stopwatch and have the subject push on the knob for three seconds. A 30 second rest interval will be given to the subject between three trials.

The same procedure will be followed for the torque measurement. The researcher will show the subject how to turn the roof hatch knob and will say the following to the subject:

"I want you to turn the knob as hard as you can when I tell you to start until I tell you to stop." The researcher will use a stopwatch and have the subject push on the knob for three seconds. A 30 second rest interval will be given to the subject between three trials.

Subjects have the right to not participate in any portion of the experiment. Curtains will be placed around the roof hatch test apparatus for subject privacy when performing the evacuation portion of the experiment. Subjects can rotate between the stations in any order based on availability.

Date: ____________

Roof Hatch Study

Data Collection Form

Subject No: ______________

Grade: ______________

Gender: Male / Female

Month/Year of Birth (mm/yyyy): ______/_______

Weight (lbs.): ______________ Height (inches): ______________

Hand Anthropometric Measurements

Dominant Hand: Left Handed / Right Handed

Hand Width (cm): ______________

Hand Length (cm): ______________

Maximum Voluntary Torque (Nm)		
Trial 1	Trial 2	Trial 3

Maximum Voluntary Push Force (N)		
Trial 1	Trial 2	Trial 3

Time from touching knob to opening roof hatch: ____________

Time from touching roof hatch to entire body evacuated: ______________

***If not able to open door or evacuate out of roof hatch write "X"**

Appendix E

IRB Approval for “Establishing Baseline Emergency Evacuation Times for School Buses”

Yousif Abulhassan

From:	IRB Administration <irbadmin@auburn.edu>
Sent:	Friday, April 17, 2015 2:29 PM
To:	Jerry Davis
Cc:	Yousif Abulhassan; Jorge Valenzuela
Subject:	Approval, Protocol #15-155 EP 1504
Follow Up Flag:	FollowUp
Flag Status:	Flagged

Use IRBsubmit@auburn.edu for protocol-related submissions and IRBadmin@auburn.edu for questions and information. The IRB only accepts forms posted at https://cws.auburn.edu/vpr/compliance/humansubjects/?Forms and submitted electronically.

Dear Jerry,

Your protocol entitled " Establishing Baseline Emergency Evacuation Times for School Buses " has received approval as "Expedited" under federal regulation 45 CFR 46.110(5).

Official notice:
This e-mail serves as official notice that your protocol has been approved. A formal approval letter will not be sent unless you notify us that you need one. By accepting this approval, you also accept your responsibilities associated with this approval. Details of your responsibilities are attached. Please print and retain.

Consent documents:
Since you do not have to wait to for the return of any consent documents, please conduct your study at your convenience.

Expiration:
Your protocol **will expire on April 11, 2016**. Put that date on your calendar now. About three weeks before that time you will need to submit a final report or renewal request.

If you have any questions, please let us know.

Best wishes for success with your research!
Susan

IRB / Office of Research Compliance
115 Ramsay Hall (basement)
Auburn University, AL 36849
(334) 844-5966
irbadmin@auburn.edu *(for general queries)*
irbsubmit@auburn.edu *(for protocol submissions)*

Appendix F

Protocol and Data Collection Form for "Establishing Baseline Emergency Evacuation Times for School Buses Driver Script"

1. Script for Evacuation with Drivers Assistance

May I have your attention please?

My name is (Driver's Name).

We will be conducting an emergency evacuation drill using the (front door/ rear door/ both front and rear doors) of the school bus.

When I say Start I want you to follow my directions and evacuate the school bus.

When exiting through the rear emergency door, 'sit and scoot' out the door.

Move quickly and orderly. Do not run! Does anybody have any questions?

School bus driver will go down each row and direct the students to the appropriate exit.

2. Script for Evacuation without Drivers Assistance

May I have your attention please?

My name is (Driver's Name).

We will be conducting an emergency evacuation drill using the (front door/ rear door/ both front and rear doors) of the school bus.

When I say Start I want you to evacuate the school bus through the (front door/ rear door/ both front and rear doors) of the school bus.

When exiting through the rear emergency door, 'sit and scoot' out the door.

Move quickly and orderly. Do not run! Does anybody have any questions?

School Bus Egress Times Data Collection Form

Date: _______________

Grade: _______________

Front Door Evacuation:

Evacuation Trial without School Bus Driver Assistance: ______________________

Evacuation Trial with School Bus Driver Assistance: _________________________

Rear Door Evacuation:

Evacuation Trial without School Bus Driver Assistance: ______________________

Evacuation Trial with School Bus Driver Assistance: _________________________

Front and Rear Door Evacuation:

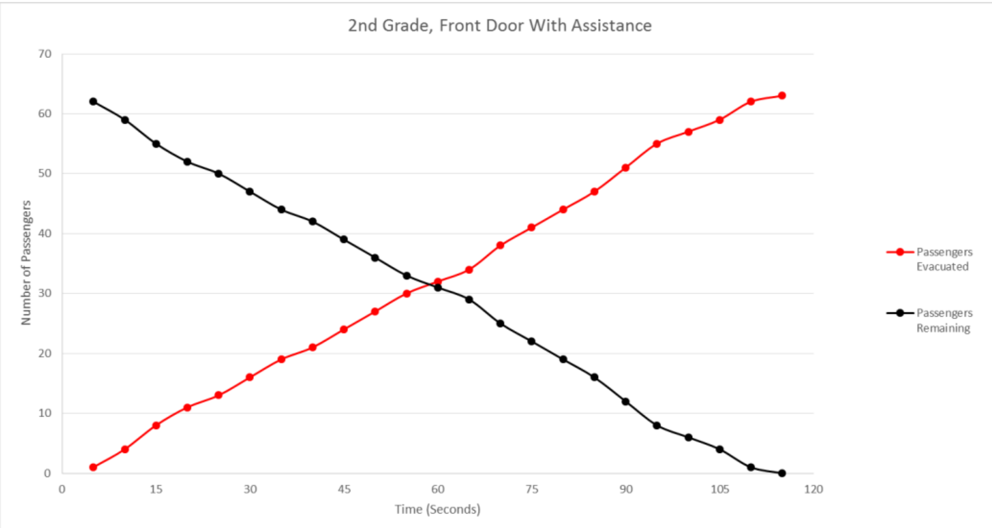
Evacuation Trial without School Bus Driver Assistance: ______________________

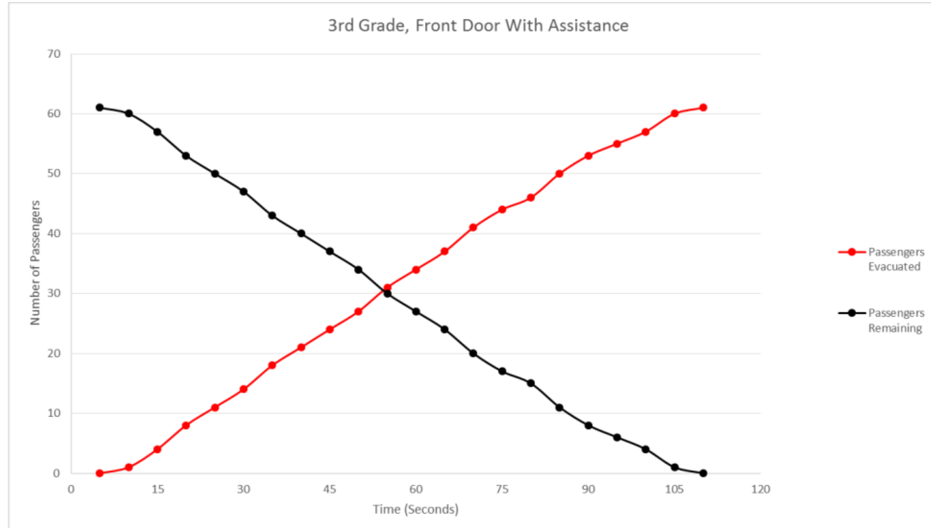
Evacuation Trial with School Bus Driver Assistance: _________________________

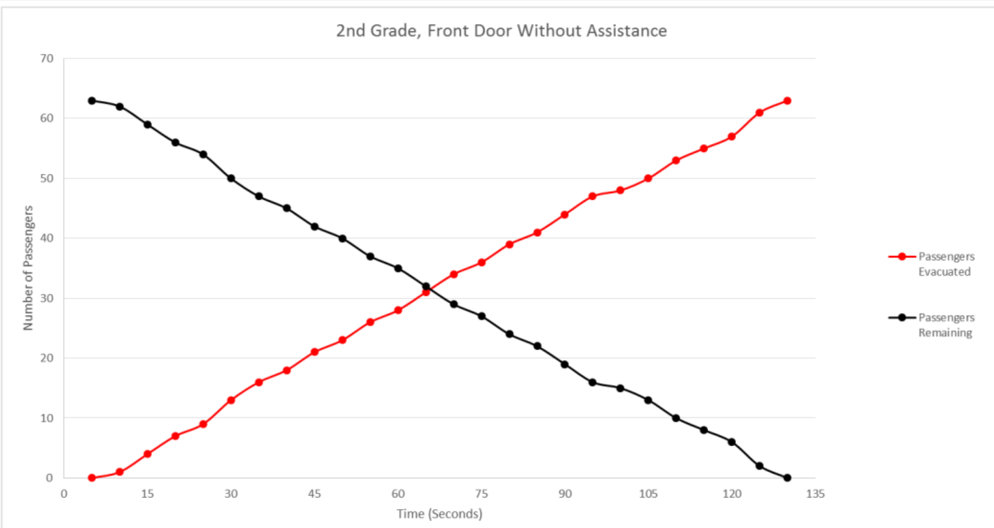
Appendix G

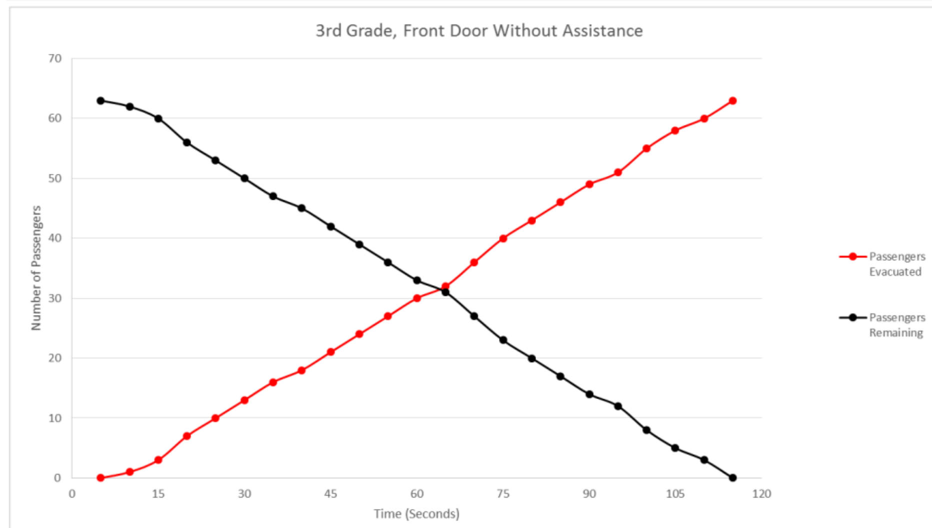
Evacuation Trials Flow Rate Graphs

Front Door Evacuation Flow Rate Graphs

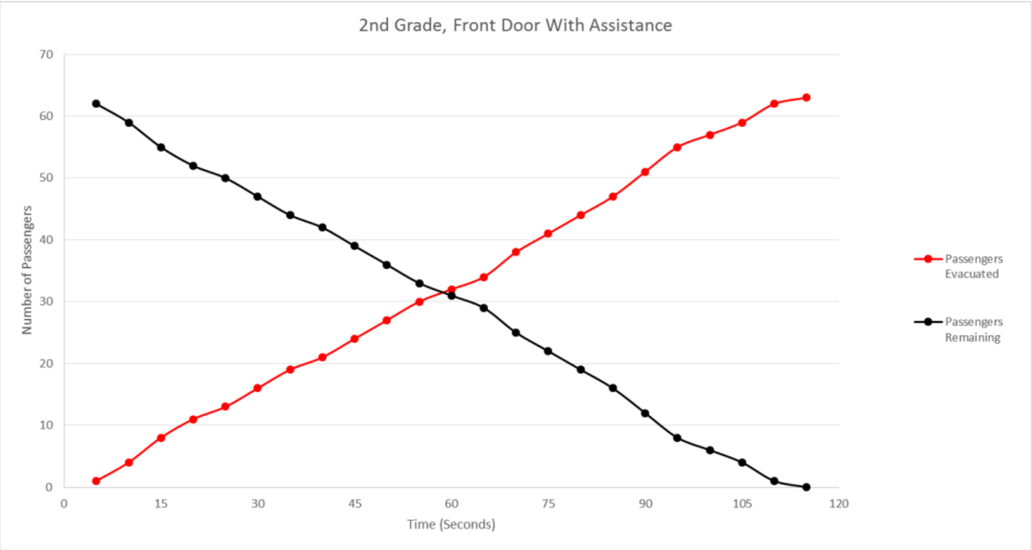


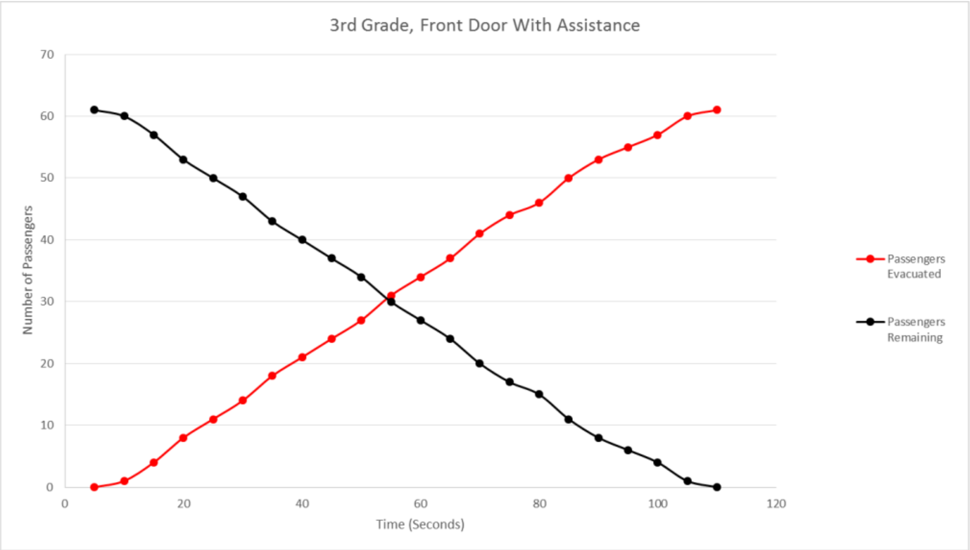


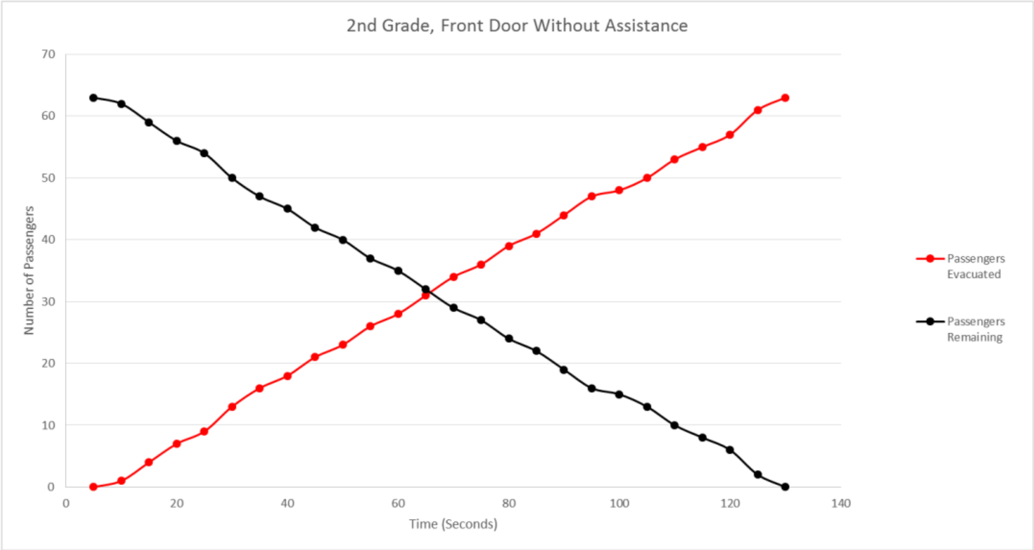


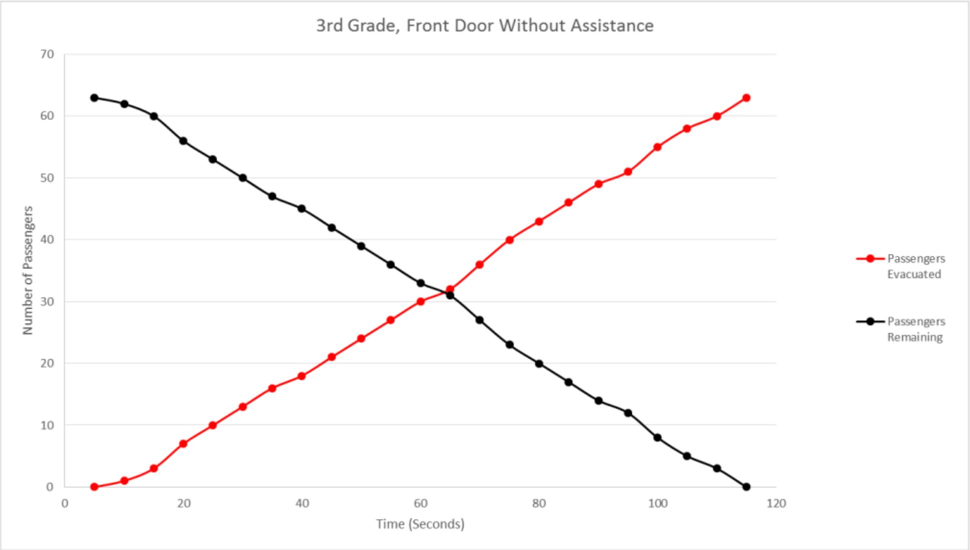


Front Door Evacuation Flow Rate Graphs

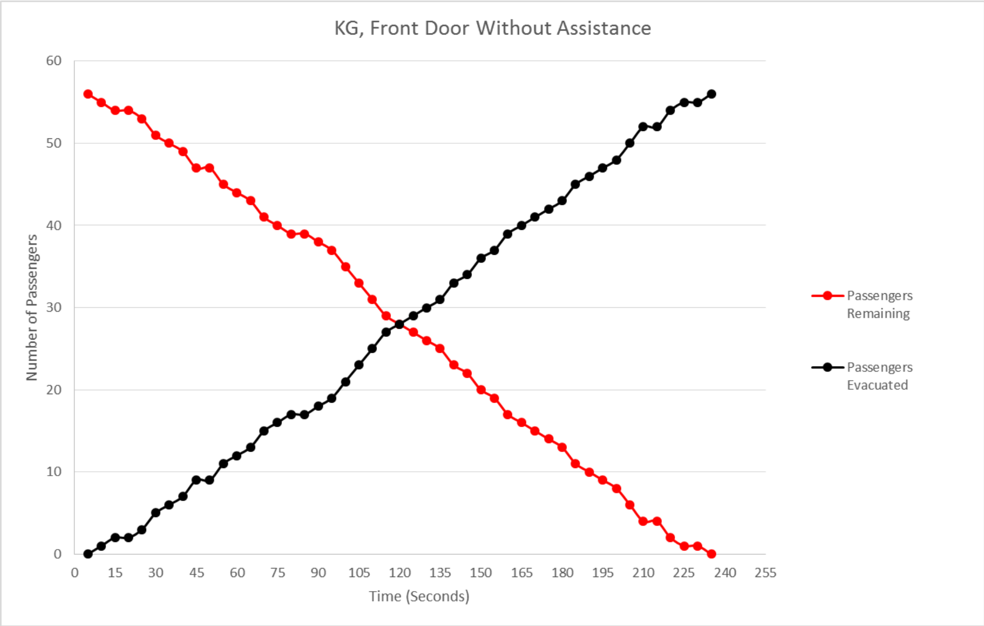


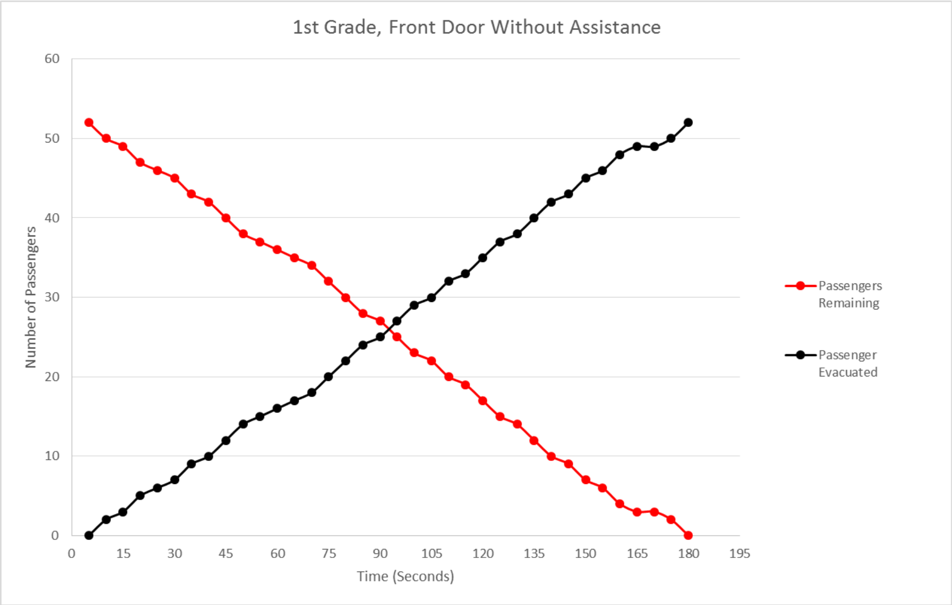


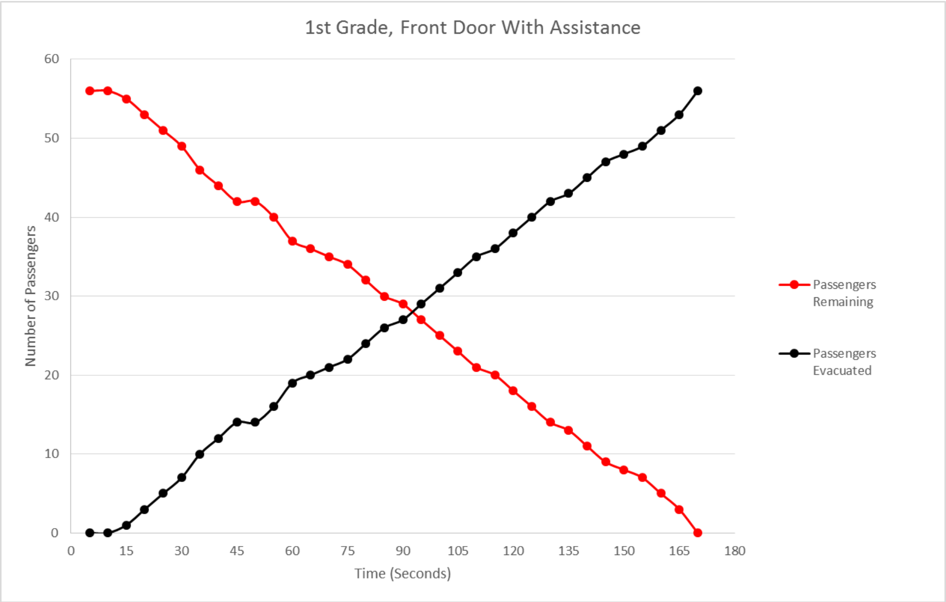




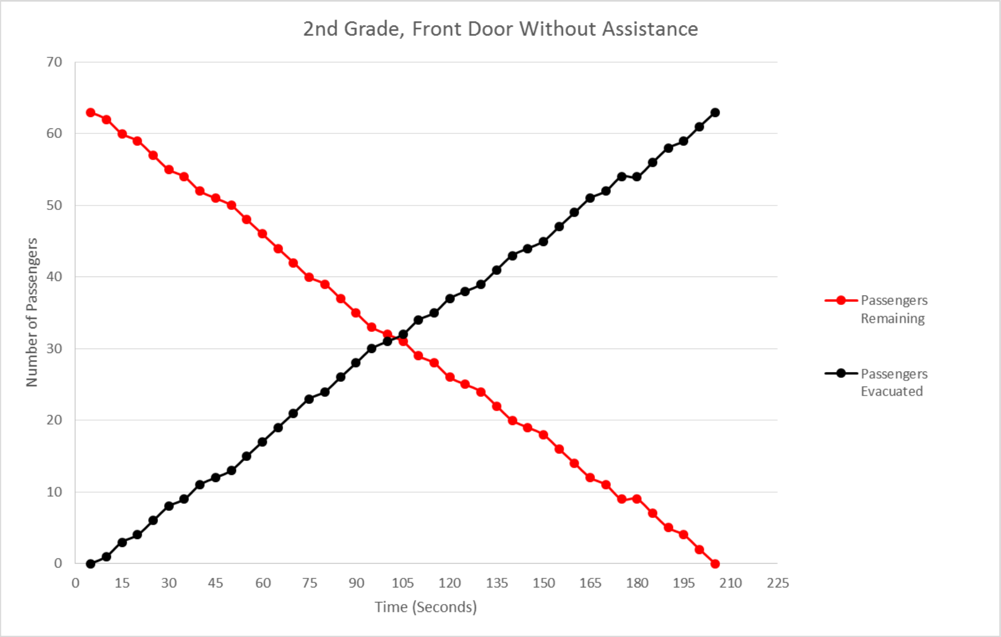
Rear Door Evacuation Flow Rate Graphs

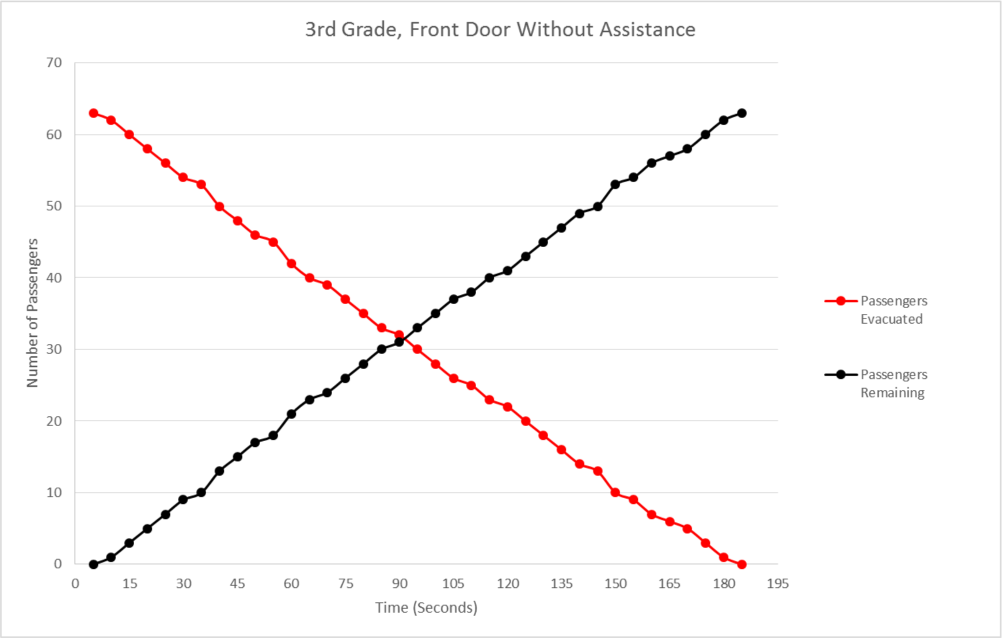


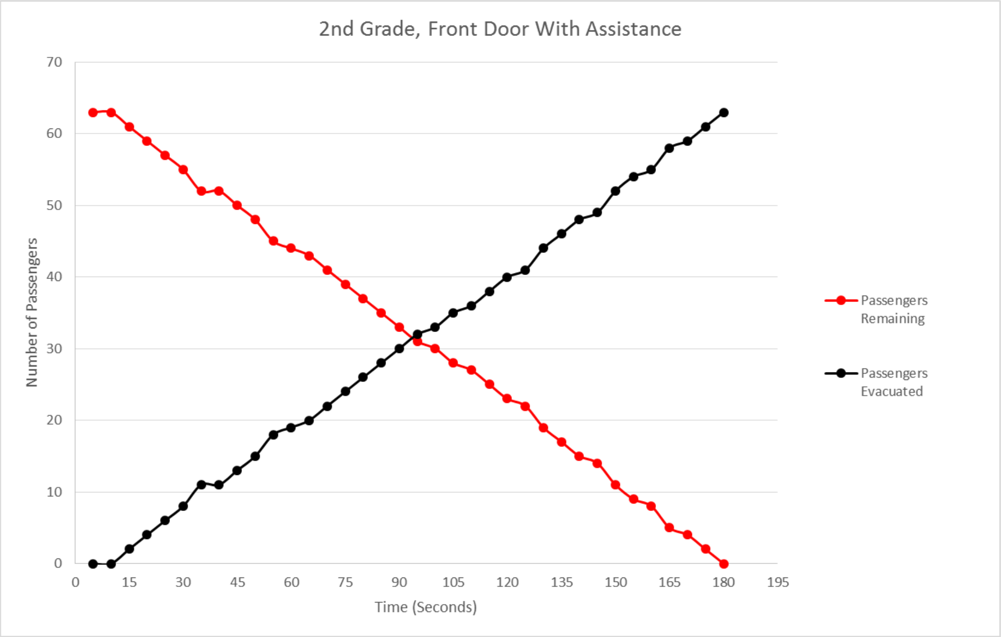


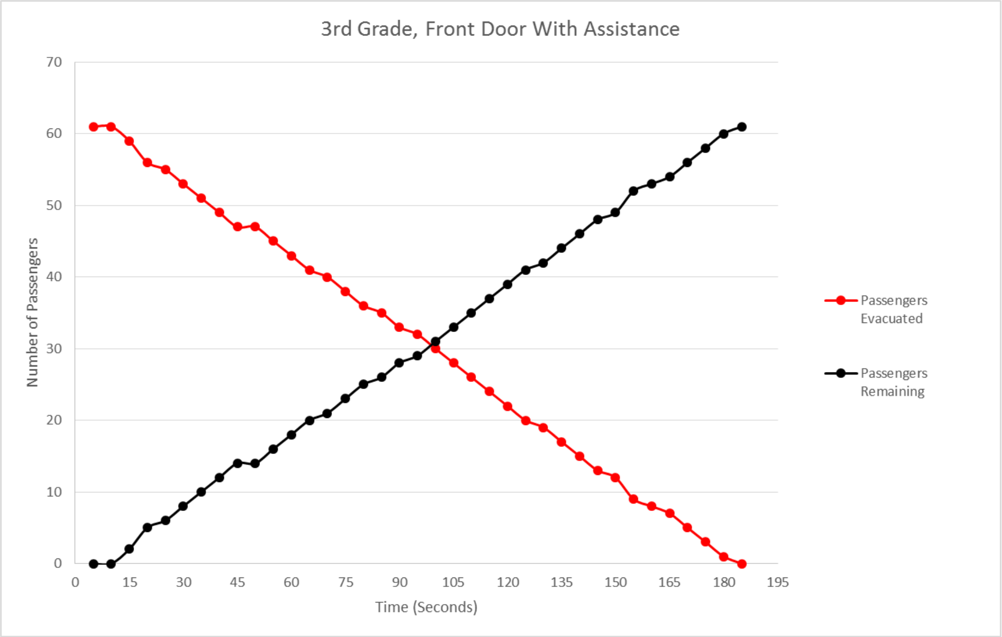


Rear Door Evacuation Flow Rate Graphs

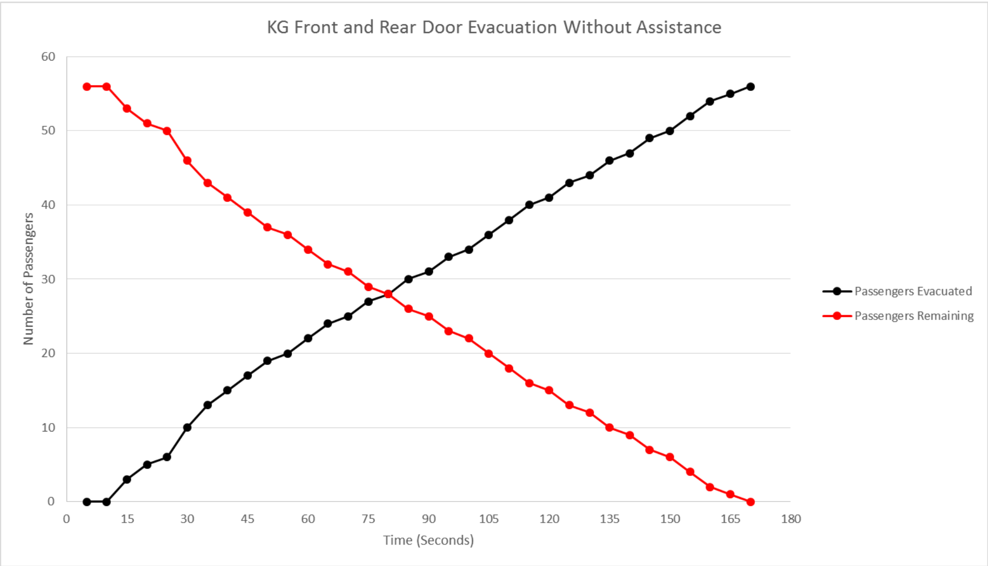


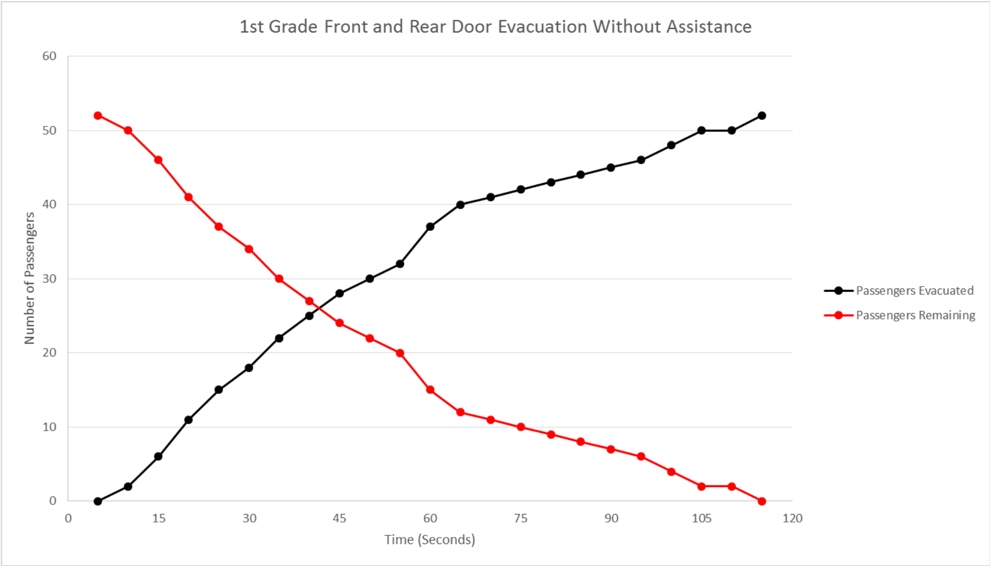


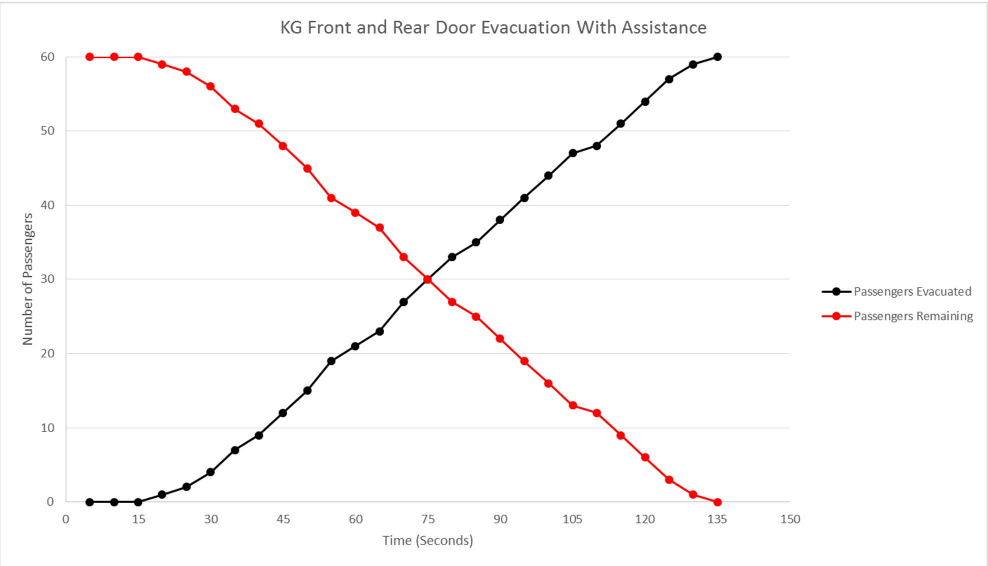


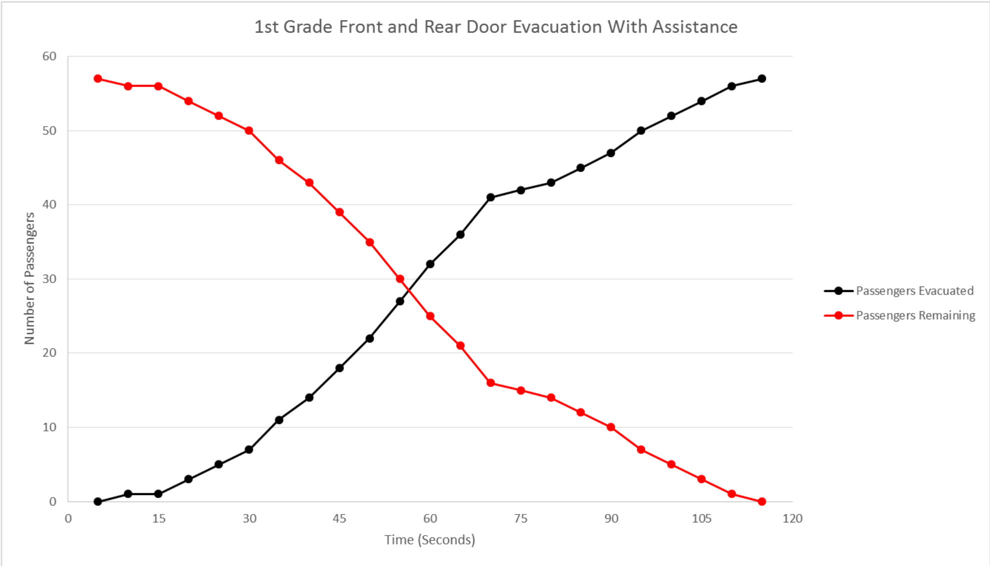


Front and Rear Doors Evacuation Flow Rate Graphs

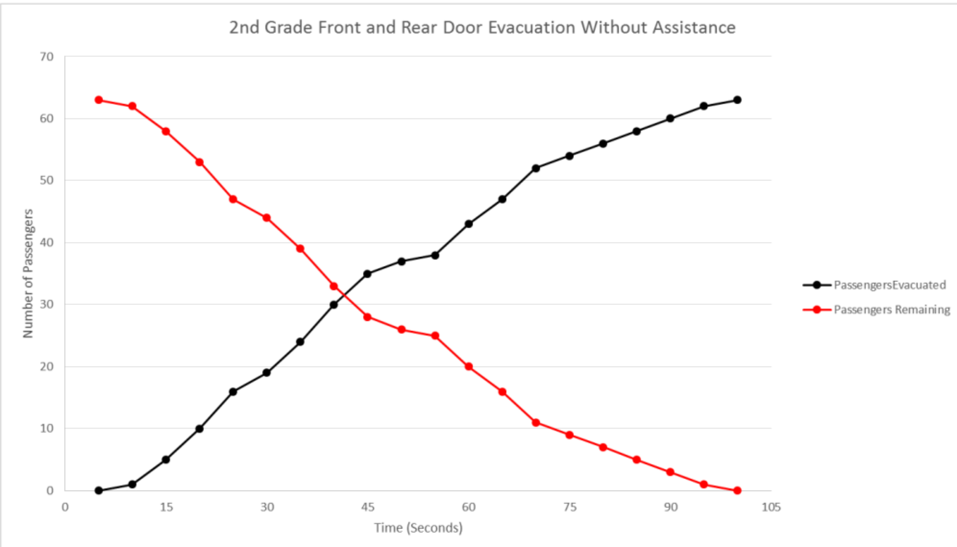


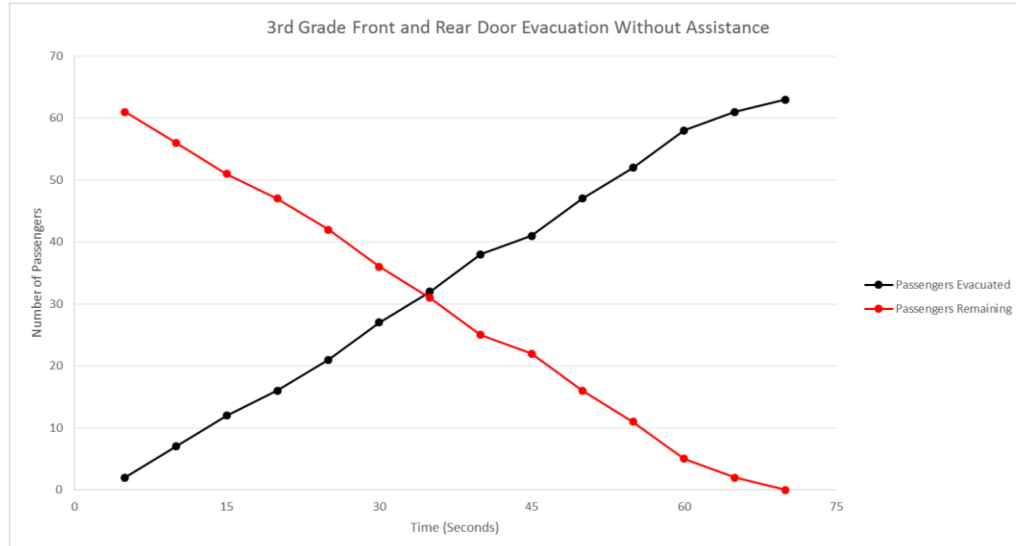


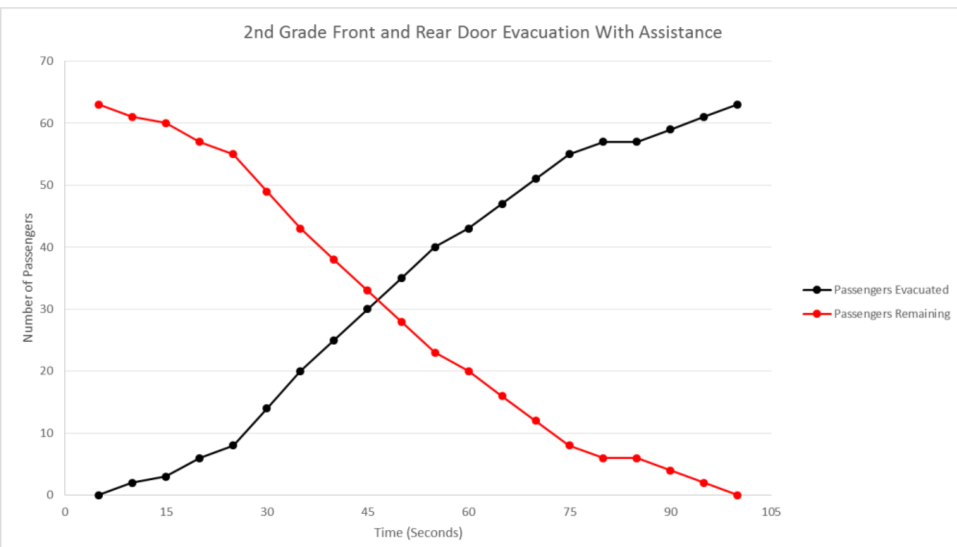


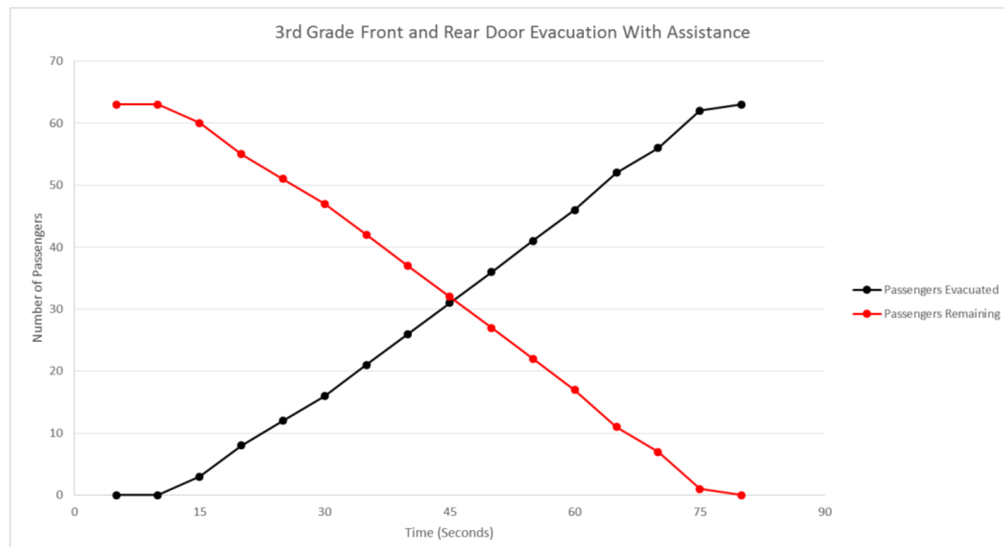


Front and Rear Doors Evacuation Flow Rate Graphs



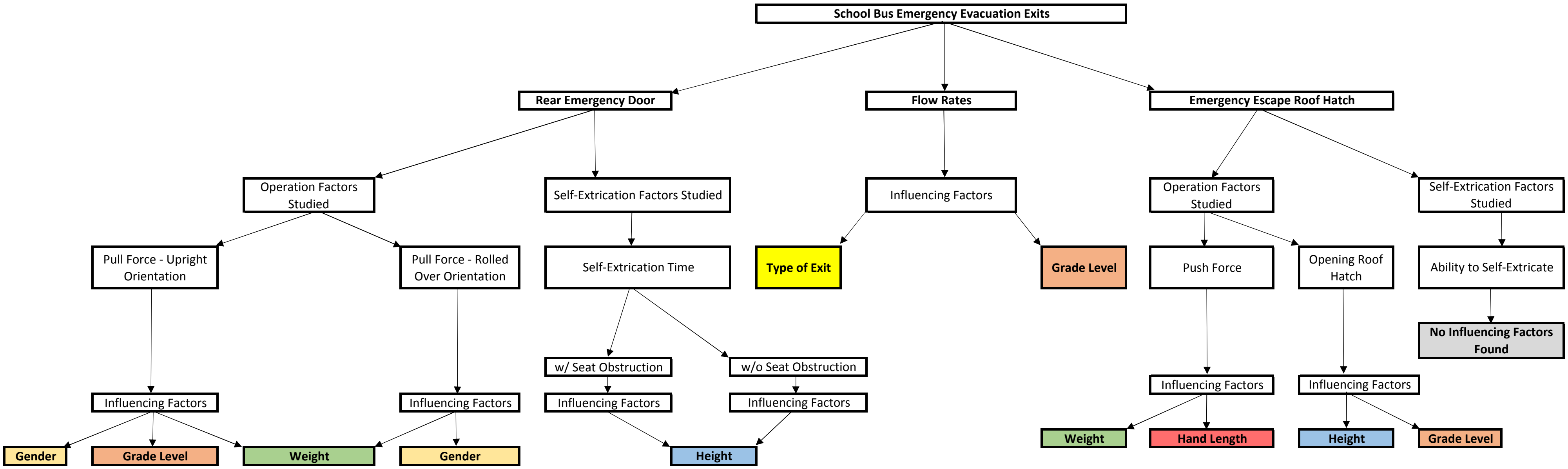






Appendix H

Summary of Factors Influencing Evacuation Through School Bus Emergency Exits



School Bus Emergency Evacuation Exits
Rear Emergency Door
Flow Rates
Emergency Escape Roof Hatch
Operation Factors Studied
Self-Extrication Factors Studied
Influencing Factors
Operation Factors Studied
Self-Extrication Factors Studied
Pull Force - Upright Orientation
Pull Force - Rolled Over Orientation
Self-Extrication Time
Type of Exit
Grade Level
Push Force
Opening Roof Hatch
Ability to Self-Extricate
No Influencing Factors Found
w/ Seat Obstruction
w/o Seat Obstruction
Influencing Factors
Influencing Factors
Influencing Factors
Influencing Factors
Influencing Factors
Influencing Factors
Gender
Grade Level
Weight
Gender
Height
Weight
Hand Length
Height
Grade Level

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