Safety Science 121 (2020) 64–70

Contents lists available at ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/safety

School bus rear emergency door design improvements to increase evacuation flow

Leslie Gunter[a], Jerry Davis[a,*], Yousif Abulhassan[b], Richard Sesek[a], Sean Gallagher[a], Mark Schall[a]

[a] Department of Industrial & Systems Engineering, 3301 Shelby Center, Auburn University, AL 36849, United States
[b] Department of Occupational Safety and Health, 157 Industry & Technology Center, Murray State University, Murray, KY 42071, United States

ARTICLE INFO

Keywords:
School bus
Emergency
Evacuation
Egress time
Student safety

ABSTRACT

United States Federal Motor Vehicle Safety Standard (FMVSS) No. 217 specifies the design requirements for school bus emergency exits. One component of a school bus evacuation system requires that the rear emergency door be fitted with a device that is capable of holding the door in an open position at the point at which the door is perpendicular to the rear of the bus body, regardless of the bus orientation. In the case where a school bus is rolled onto the driver's side of the vehicle, the rear emergency door hinge will be located at the top of the door. Due to the substantial weight of the door, pushing the door to the locked open position with the bus in this configuration requires forces that exceed the capabilities, both strength and anthropometry, of many adults and nearly all young children. This would result in the door hanging in the opening of the exit, obstructing the egress of passengers as they attempt evacuation, and increasing the potential for disastrous consequences. The purpose of this study was to design, fabricate, and evaluate an alternative rear emergency door hold-open device that allows the door to be held partially open and provides unobstructed passage. The results revealed that the alternative hold-open device facilitated significantly faster flow rates than the rear emergency door hold-open device currently in use on school buses.

1. Introduction

School bus emergency evacuation research is limited. The earliest studies related to the usability of emergency exits on school buses were conducted at the University of Oklahoma Research Institute in the 1970's (Purswell et al., 1970, 1978; Sliepcevich et al., 1972). These studies were conducted to provide the United States Department of Transportation (USDOT) and the National Highway Traffic Safety Administration (NHTSA) with evaluations of emergency exits on buses and recommendations that could improve their escape worthiness. Typically, the largest exit opening on a school bus is the rear emergency exit door. The effectiveness of the rear emergency exit door in an emergency evacuation can be significantly hindered by the post-accident orientation of a school bus (Abulhassan et al., 2018a). Due to the size of the rear emergency exit on a school bus, the door can weigh as much as 100 pounds (45 kg) and must be raised 30–45 degrees from the vertical (hanging) position to provide sufficient clearance for an occupant to self-extricate through the opening (Purswell et al., 1970).

The physical capabilities of children and their ability to operate and evacuate emergency exits when a school bus is in a rolled-over orientation were recently investigated by Abulhassan et al. (2018a). Results indicated that obstructions to the rear emergency exit can significantly reduce passenger flow rates. In particular, average flow rates measured by the number of passengers per minute (PPM) through the rear emergency exit of a school bus for children in kindergarten through second grade ranged between 11 PPM and 16 PPM when tested with the original seating configuration on a test fixture simulating a school bus rolled over on to the driver's side (Abulhassan et al., 2018a). The test fixture used to measure evacuation through the rear emergency exit included a cut-out of a rear emergency door and the adjacent row of seats from a 2013 Blue Bird Vision school bus. The test fixture had the hinge on the top of the door, but for safety reasons, the door was secured in an open (hanging) position, offering unimpeded access. The authors speculated that had the rear door been left unconstrained, the flow rates measured would have been dramatically reduced from those observed with children from kindergarten through second grade (Abulhassan et al., 2018a).

Federal Motor Vehicle Safety Standard (FMVSS) No. 217 uses the stature and physical capabilities of the average adult male to identify the access regions of emergency exits on school buses (Pollard and

* Corresponding author.
E-mail addresses: lag0010@auburn.edu (L. Gunter), davisga@auburn.edu (J. Davis), yabulhassan@murraystate.edu (Y. Abulhassan), sesek@auburn.edu (R. Sesek), seangallagher@auburn.edu (S. Gallagher), mark-schall@auburn.edu (M. Schall).

https://doi.org/10.1016/j.ssci.2019.09.007
Received 23 July 2019; Received in revised form 4 September 2019; Accepted 6 September 2019
Available online 11 September 2019
0925-7535/

Markos, 2009). However, previous school bus evacuation studies conducted with young children suggest that the physical capabilities of young children in kindergarten through second grade are much lower than those of an average adult male (Abulhassan et al., 2018a, 2018b). Literature related to the ability of children to successfully evacuate through emergency exits of a school bus is sparse, especially when the school bus is in a rolled-over orientation. Due to limited availability of school bus accident information, the annual frequency of school bus rollovers is difficult to ascertain. However, it is believed that there are between 10 and 100 rollovers that occur annually (Matolcsy, 2003; NTSB, 1999). Increasing the likelihood of children being able to escape, particularly in a timely manner, is critically important for preventing potential fatalities. The specific rollover scenario under investigation in this study involves the rear emergency door with the school bus resting on the driver's side of the vehicle.

1.1. Rear emergency door hold-open device

FMVSS No. 217 mandates that school buses be equipped with a rear emergency exit door that opens outward and is hinged on the right (passenger) side facing forward (NHTSA, 2011). In addition, the regulation mandates that each school bus emergency door be equipped with a "positive opening device" that: (1) Bears the weight of the door; (2) Keeps the door from closing past the point at which the door is perpendicular to the side of the bus body, regardless of the orientation of the bus body; and (3) Provides a means for release, or override (NHTSA, 2011). In the unique orientation of the bus resting on the driver's side (or left side facing forward), the school bus rear emergency door hinge will be aligned with the top edge of the door, and the door will open out and up, away from the inside of the bus as shown in Fig. 1. Typically, school bus rear emergency doors are fabricated from mild steel and fitted with two large windows glazed with safety glass. Rear emergency doors weigh approximately 36 to 45 Kg. Escaping through the rear emergency door of a rolled-over school bus in this orientation would require opening the door and pushing it up and away from the school bus. The forces required to open the door can be estimated as shown in Fig. 1.

Assuming the mass of the emergency exit door is distributed symmetrically, the force required to support it at a given angle (θ) may be estimated by assuming that the center of gravity is located between the hinge and edge of the door with the latching device (NHTSA, 2009). The force applied by the passenger would be applied in line from the latch edge of the door opening to the latch edge of the door, the estimated force to push a 445 N (45 kg) rear emergency door currently fitted on many school buses open is illustrated in Fig. 2. This estimation assumes that the passenger would maintain a pushing position at the far edge of the door as it opens. This would require reaching out 114 cm and applying 314 N of push force. The required force increases as the

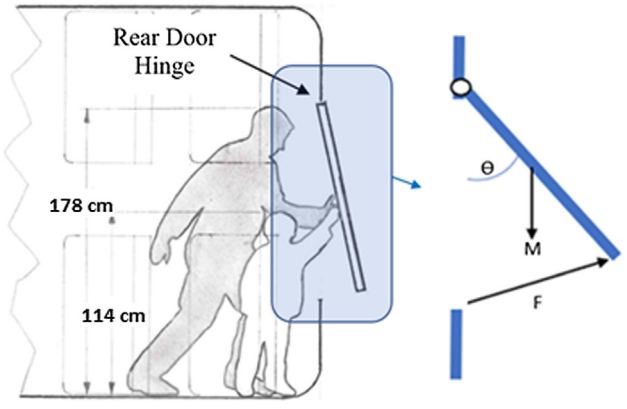

Fig. 1. Size comparison of adult vs. child and free-body diagram of forces to push open rear door.

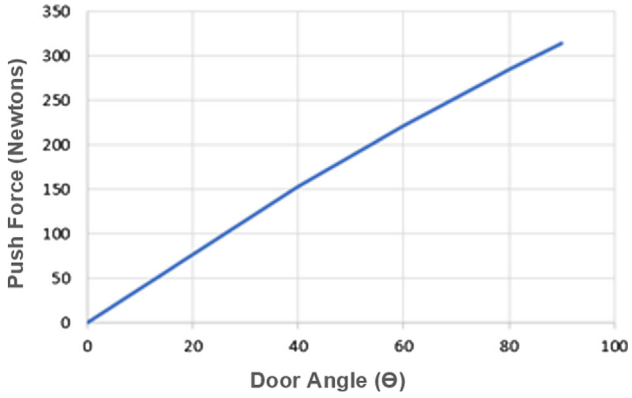

Fig. 2. Estimated force to open rear emergency door to angle (θ).

passenger applies the pushing force closer to the center of the door. Such a feat would be extremely difficult for most adults and improbable for a young child (Abulhassan et al., 2018a). However, this would be required for the rear emergency door to reach the position in which the hold-open device (HOD) currently used by school buses today, latches/locks open, to allow for unobstructed evacuation.

The HOD currently used on school buses consists of two mild steel roll formed channels that telescope together such that the device can extend and contract as the rear emergency door opens and closes. These devices are available in multiple lengths and with various mounting brackets for attaching to the doors and door frames on the various styles and brands of buses as shown in Fig. 3. The HOD mounts on the door frame at one end and to the top of the rear emergency door at the other end as shown in Fig. 3. It is designed so that when the door is fully opened and perpendicular to the bus body, a metal rotating component riveted to one of the slides rotates into position to prevent the slides from contracting, thus holding the door open. Pushing the door in the opening direction towards the extreme open position causes the rotating component to reset, allowing the door to close once again.

1.2. Design of alternative hold-open device

An alternative HOD was fabricated so that it could bolt in the same place as the current HOD. The reason for this approach is simplicity, cost effectiveness, and to make the alternative HOD more likely to be employed on current school buses, by facilitating a direct replacement for the current devices. The alternative HOD utilizes a ratcheting mechanism that *allows the door to remain in an open position at multiple positions from fully closed to fully open*, or perpendicular, to the bus body. This design would allow the first passenger to exit the door by unlatching it, and pushing it open to a position that provides enough opening for their body to egress. The remaining evacuees may follow through the opening left by the first evacuee. If a larger evacuee exits subsequent to the first evacuee, the door could be opened further and held open at a larger aperture, allowing for easier egress for the remaining passengers using this exit. The alternative design meets each of the requirements outlined in FMVSS No. 217.

A typical school bus door that weighs 45 Kg, is 81.3 cm wide, and the center of mass is assumed to be located halfway across the door at 40.6 cm from the hinge. Assuming a static model where all forces are at equilibrium, the force experienced by the HOD would be approximately 1067 N. If a 113 Kg weight is added to the door edge opposite to the hinge such as the weight of a person hanging on the edge of the door, the load on the HOD would increase to 6405 N. Taking into consideration the loading configurations and design of current HODs, buckling of the HOD due to longitudinal loading, shear loading to the locking cog, or shear tear out of the locking cog rivet hole are the most likely contributors to the failure of a HOD.

Buckling failure due to longitudinal loading experienced by the

Fig. 3. Rear emergency door hold-open device.

HOD was estimated using Euler's equation (Young et al., 2012). The length of the support section of the HOD was measured to be approximately 58.4 cm, and the moment of inertia for the roll formed section of the HOD to be 1.143 mm^4. The modulus of elasticity of steel was assumed to be 200 GPa (Oberg et al., 2012). Thus, the theoretical maximum load prior to buckling was determined to be 11,045 N. This value is approximately 10 times the load induced onto the HOD by the door.

The locking cog inside the HOD rotates to prevent the door from closing once it is fully opened and is secured to one of the roll formed rails using a rivet that is 6 mm in diameter at the narrowest point where it protrudes through the rail. The locking cog is subject to shear loading from the weight of the door. Shear stress is calculated by dividing the shear load by the narrowest cross sectional area of the locking cog (Young et al., 2012). Assuming that the maximum shear stress of mild steel is 240,000 kPa (Oberg, et al., 2012), yields a theoretical failure load of approximately 7562 N. This value is seven times the load induced by the door onto the HOD. The locking cog could theoretically fail by shear tear out of the hole the rivet goes through. In this situation, instead of the rivet shearing off, the rivet is pulled through the cog. Solving for the theoretical failure load yields a value of 9675 N. This value is nine times the load induced by the door onto the HOD when the door is fully open.

Calculations for the strength of the current HOD establish a basis for maintaining the materials and thicknesses of the components of the device modified to ratchet and hold the door at different positions as it opens. The modifications to the current HOD involved removing and replacing the rotating component mentioned earlier with a different rotating component called a pawl. The pawl is spring-loaded using an off-the-shelf purchased component called a spring plunger. The spring plunger is adjustable so that the tension on the pawl can be set. A third component called a castle bar was welded into place in the inner telescoping rail. Fig. 4 illustrates the pawl, spring plunger, and castle bar used in the prototype.

The pawl and the castle bar interact to provide the ratcheting feature of the device. The spring plunger interacts with the pawl to locate it in one of two positions. One position sets the pawl so that it interacts with the castle bar to make the device ratchet while it is extending. The second position sets the pawl such that the device no longer ratchets, allowing it to freely contract. A protrusion feature on one of the rails interacts with the pawl to reset it to the second position at the point where the door is fully opened. All components used to build the prototype were machined from mild steel. The pawl and rivet were fabricated to be the same thickness and size of mild steel as the current device in order to support the loads presented by the door. It is believed that the pawl and castle bar components could be fabricated as stampings to reduce manufacturing costs. It may also be possible to incorporate the features of the castle bar into the roll formed inner channel.

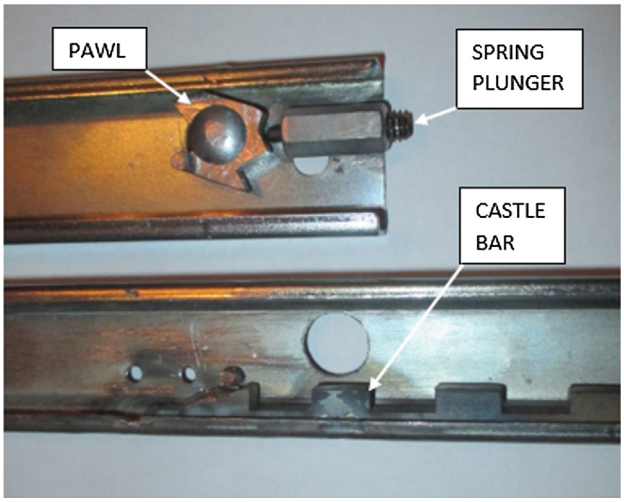

Fig. 4. Components of alternative door hold-open device.

2. Methods

2.1. Strength and durability testing of the hold-open devices

Three samples of both current and alternative HOD's were tested to determine the ultimate axial strength when loaded in compression. The machine used to test the samples was an MTS 810 Material Test System which is capable of tensile and compression testing. Testing was conducted in accordance with ASTM E9-09 (ASTM, 2018). The maximum deflection for each of the samples was 10 mm. The devices were loaded axially using a pin connection through the mounting holes designed into the device for mounting onto the actual rear emergency door of a school bus. This was done so that the loads applied by the test machine would accurately replicate loads applied by a school bus door.

An endurance test of the alternative HOD was conducted by mounting the device to the test fixture as shown in Fig. 5 which replicates the rear end of a school bus. The rear emergency door was opened and closed repeatedly until the device failed to operate. The normal operation of the rear emergency door occurs when the bus in an upright orientation, such that the weight of the door is completely supported by the hinges. The HOD was tested when the school bus is in

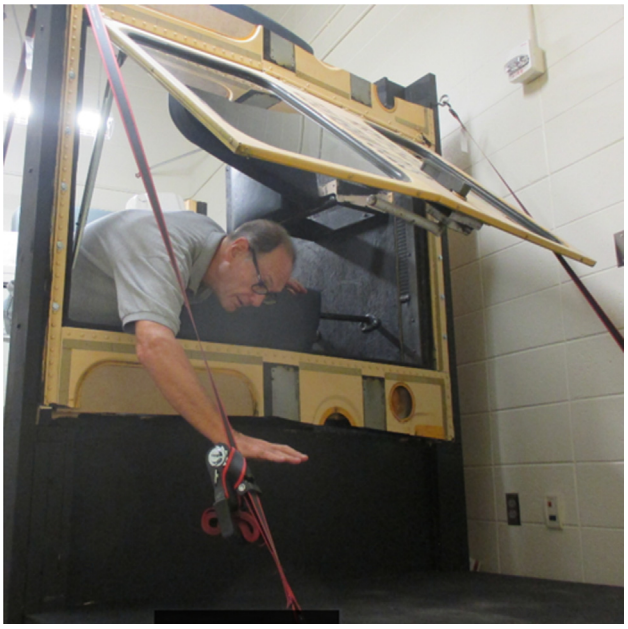

Fig. 5. Rear emergency exit door test fixture.

a rolled-over orientation which is a more demanding scenario because the weight of the door is supported by the HOD during operation. There are a total of 180 school days in a typical school year. In the State of Alabama for instance, many school districts require the school bus driver to check the operability of the rear emergency door twice daily prior to beginning the morning and afternoon bus routes. Based on this assumption, it was determined that an endurance test of 400 cycles would indicate satisfactory operation of the alternative HOD.

2.2. Test fixtures

For this study, the test fixture used by Abulhassan et al. (2018a) and a nearly identical test fixture (Fig. 5) was fabricated and used to measure child evacuation with the currently used HOD and the alternative HOD. The test fixtures replicate the rear emergency exit configurations of late model school buses rolled over onto the driver side.

2.3. Subjects

The research team partnered with two schools in Pike County, Alabama, to recruit subjects for the experiment. Parental consent and child assent were required to participate in the study. Parents were provided Auburn University Institutional Review Board (IRB) approved letters of consent prior to the start of the study. A total of 139 elementary and high school students consisting of 69 males and 70 females participated. Demographic information collected from the students included age, grade, gender, as well as height and weight information that was used to calculate body mass index (BMI). Demographic data of the participants is listed in Table 1.

Table 1
Participant demographics.

Grade Level	No. of Subjects	Male Subjects	Female Subjects	Average BMI (SD)	Min BMI	Max BMI
1	40	20	20	18.3 (5.8)	11.2	38.0
4	53	33	20	19.4 (5.0)	11.7	35.1
7	24	8	16	20.1(3.4)	13.7	27.4
10	22	8	14	25.4 (6.9)	16.6	40.4
Total	139	69	70			

2.4. Experimental setup

Subjects were outfitted with bicycle helmets prior to participation. All subject testing occurred during physical education classes at each school. Subjects were assigned a unique number, which was fixed to the helmet, and each group evacuation was videotaped for subsequent analysis. The study consisted of group evacuation trials consisting of participants from each of the four grade levels: first, fourth, seventh, and tenth grades. An additional trial was conducted that included students in the seventh and tenth grade levels combined. Two stations were set-up corresponding to each device (current and alternative HOD) used in the trials (Fig. 6). Each station was staffed with two researchers, and the entire data collection process was supervised to ensure safety and compliance with the study protocol.

Group trials consisted of organizing all subjects in single file behind one device, informing them what they were going to do, obtaining verbal assent, and then giving the start signal. No assistance was provided unless it was required for safety purposes. Students were deemed to not want to participate if they were asked three times whether they wanted to participate, and no response was given; verbally assented, but failed to start within thirty seconds of the start signal (two attempts at this); or the child verbally stated they did not want to participate. The group trial ended when the last subject exited the device. After completing the evacuation at the first station (randomly assigned), groups were moved to the other test station. The order of each group was randomly assigned.

2.5. Statistical analysis

The independent variables in the evacuation evaluation portion of the study were: type of HOD (current HOD and alternative HOD), age, grade level, and BMI. The dependent variable was evacuation time through the rear emergency exit. A regression model was used to identify which independent variables had a statistically significant effect on evacuation time through the rear emergency door when the school bus is in a rolled-over orientation with an alpha value of 0.05.

3. Results

3.1. Hold-open device strength and durability results

The weakest point of both the current HOD and alternative HOD was the rivet that secures and locates the locking pawl that interacts with the sliding rails to lock and hold the door open. The rivet did not shear as discussed in the theoretical analysis, but the rivet material yielded and began to pull out of the slide to which it was attached. The slide, or rail, also eventually yielded under the compression load. On the current design, the pawl itself also yielded and bent out of shape. Fig. 7 illustrates the damage induced by the compression testing. As the HOD's were loaded, the applied force increased at a constant rate until the mild steel materials began to yield. The maximum loads achieved from the compression test by the three alternative HOD samples tested were 3834 N, 4310 N, and 4777 N before the HODs yielded, or bent, 10 mm. The maximum loads achieved by the three current HOD samples were 2215 N, 2277 N, and 1779 N before the device yielded, or bent, 10 mm.

3.2. Rear emergency door evacuation trial results

The alternative HOD operated such that the door remained in an open position after the initial person in each trial pushed the door open to approximately 30–40 degrees from vertical (requiring approximately 667 N to reach). The multiple hold-open locations provided by the alternative HOD resulted in a substantial increase in evacuation flow rate relative to the current design (Table 2 and Fig. 8).

It should be noted that in the combined seventh and tenth grade

Fig. 6. Data collection stations.

trial, the participants proceeded through each test fixture two times. Individual egress times were extracted from the video of each group trial, from the moment when the subject arms moved toward the opening until both feet were on the floor. Results of the regression analysis indicated that age, BMI, and type of HOD used had a statistically significant effect on evacuation time through the rear emergency door (Table 3). Interactions between independent variables did not yield statistical significance.

4. Discussion

The compression load at which the HOD began to yield was approximately twice as high for the alternative design compared to the current design. The higher loads achieved by the alternative design can be attributed to the larger diameter rivet and thicker material used for the pawl. The rivet was predicted to be the weakest point, however, the significant deflection of the slide rail was unexpected. The calculated load from the weight of the door was 1067 N. The average maximum load for the current HOD was 2091 N implying a factor of safety (FS) of

Fig. 7. Compression test failure modes.

Table 2
Evacuation flow rates in passengers per minute (PPM).

Participant Group Grade level	Test Fixture with Current HOD	Test Fixture with Alternative HOD	Percentage Increase
1[a]	5.0	8.9	78%
4[a]	8.1	16.5	103.7%
7	12.5	27.7	121.6%
10	18.5	26.9	45.4%
7 and 10	15.5	26.3	70.8%

[a] Based on the average of the two groups from these respective grade levels.

approximately two (2), and for the alternative HOD the maximum load was 4306 N, implying a FS just over four (4).

Although two students opted to not attempt egress through the doors (one first grader, and one tenth grader), the vast majority were able to self-extricate through the test fixtures. The alternative HOD *prevents evacuees from "fighting" the weight of the door as they exit the bus*, whereas the current design mandates that passengers exert effort to push on the door the entire time they are exiting. The flow rates provided by the alternative HOD design allow the evacuees after the first person to egress with significantly less impediment. The first evacuee through the door with the alternative HOD was always slower than all the subsequent evacuees in each group. This is because the first person has to push the door open, which slows them down. Once the alternative HOD engages in a given hold-open position, the subsequent evacuees egress time is much lower (faster) since they only have to push on the door if they need a larger opening than previous subjects. Therefore, every subsequent subject that is smaller than the preceding subjects does not have to push on the door at all. The first evacuee's evacuation time ranged from 2 to 4.5 times the average evacuation time of subsequent evacuees.

The average flow rate for all the trials (first through tenth grade) through the test fixture with the current HOD design was 12 PPM. Pollard and Markos (2009) measured the same rate, 12 PPM, for adult evacuations of emergency roof hatches and Abulhassan et al. (2016) measured 18 PPM when studying kindergarten through third graders exiting the rear emergency door of an upright bus without adult assistance. The data revealed that the fourth, seventh and tenth grade students displayed progressively faster flow rates in comparison to the first-grade students through the test fixture utilizing the current HOD. Fig. 8 displays that the flow rate for current HOD design increases for each grade level, which could be indicative of the increasing relative size and strength characteristics for the participants.

5. Limitations

There are several limitations that need to be acknowledged. While the rear emergency exit configuration used in this study is common to many school buses, there are other configurations of rear emergency exits that were not taken into consideration. Additionally, safety mats were used on the outside of the test fixture with the current HOD configuration to provide a softer landing surface. This may have artificially increased flow rates due to the comfort perceived from the availability of safety mats. Furthermore, no attempt was made to simulate the intensity of an actual rollover emergency evacuation. The test fixtures used in this study are mockups fabricated from school bus components and may not fully represent a school bus in a rolled-over configuration. However, the test fixtures did use actual school bus rear emergency exit doors and seating configuration of the last row of seats to replicate the rear emergency exit area of a rolled-over school bus. The sample size is another limitation to this study. Due to the limited time availability and logistical constraints, only four out of thirteen grade levels were sampled. Despite the limitations of the sample size, the grade levels of participants represent a wide range of school aged children. The comparison of the current and ratcheting HODs did not use identical rear doors. Ideally, comparisons would be made using the same test fixture for both HODs. The door fixtures, however, were very similar in weight, size, and clearances.

6. Conclusions

Evacuation trials were conducted to simulate the evacuation of a rolled-over school bus, and compare the current rear emergency door HOD to an alternative design that complies more closely to the Federal Motor Vehicle Safety Standard No. 217 requirements for an unobstructed emergency exit (NHTSA, 2011). When every second counts in a critical emergency evacuation, the proposed alternative HOD design could significantly reduce evacuation time. This research suggests that the alternative HOD design is a possible lifesaver when considering its significant effect on increasing passenger flow rates, enabling the rear emergency exit to be unobstructed, and reducing the risk of injury from the door closing as young passengers evacuate a rolled-over school bus. Future research could include further testing of the alternative HOD under normal use conditions to better understand the durability of the device under fatigue loading. Additional considerations such as exit opening size and seat obstructions to the rear emergency exit should be further studied to improve evacuation flow rates through the rear emergency exit of a rolled-over school bus.

Acknowledgements

This study was partially supported by the Deep South Center for Occupational Health and Safety, a National Institute for Occupational Safety and Health (NIOSH) Education and Research Center (Grant 2 T42 OH008436-13). The contents are solely the viewpoint of the authors and do not necessarily represent the official views of the Deep South Center or NIOSH. Gratitude is expressed to Dr. Mark Bazzell,

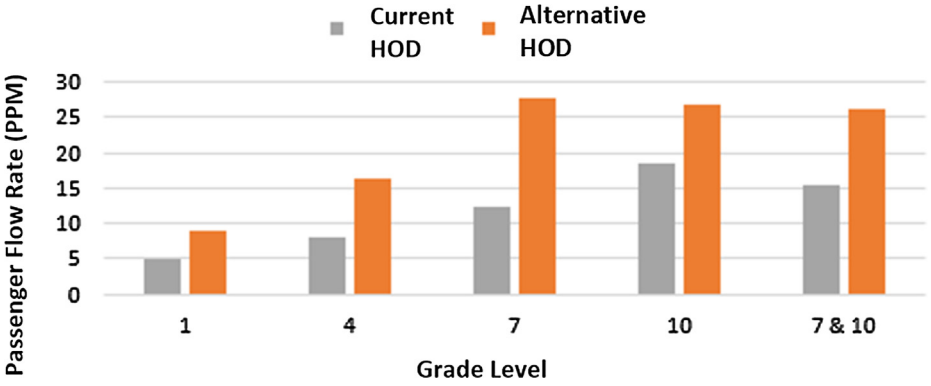

Fig. 8. Flow rate versus grade level.

Table 3
Evacuation time analysis of variance.

Source	DF	Adj SS	Adj MS	F	*p*
Regression	4	1.06	0.26	58.42	< 0.001
Subject	1	0.03	0.03	6.85	0.009
Age	1	0.59	0.59	129.59	< 0.001
BMI	1	0.06	0.06	13.80	< 0.001
HOD	1	0.40	0.40	89.33	< 0.001
Error	273	1.23	0.00		
Total	277	2.29			

Superintendent Pike County Schools, Dr. Wanda Corley, Principal Goshen Elementary School, Mr. Kendrick Britford, Principal Goshen High School, Eric Wells, Pike County Schools Maintenance Supervisor, and the participants in the study.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssci.2019.09.007.

References

Abulhassan, Y., Davis, J., Sesek, R., Schall, M., Gallagher, S., 2016. Establishing school bus baseline emergency evacuation times for elementary students. Saf. Sci. 89, 249–255.

Abulhassan, Y., Davis, J., Sesek, R., Schall, M., Gallagher, S., 2018a. Evacuating a rolled-over school bus: considerations for evacuees. Saf. Sci. 108, 203–208.

Abulhassan, Y., Davis, J., Sesek, R., Schall, M., Gallagher, S., Callender, A., 2018b. Relating the strength capabilities of children to the design of school bus emergency roof hatches. Saf. Sci. 110, 265–272.

ASTM E9-09, 2018. Standard Test Methods of Compression Testing of Metallic Materials at Room Temperature, American Society of Testing Materials.

Matolcsy, M., 2003. Unusual statistics about rollover accident of buses. 85th GRSG Working Party on General Safety Provisions.

NHTSA, 2009. Human Factors Issues in Motorcoach Emergency Egress. Interim Report 1 – Final. Prepared for NHTSA/USDOT by the John A. Volpe National Transportation Systems Center, Cambridge, MA.

NHTSA, 2011. 49 CFR, Part 571, (FMVSS). §571.217, Standard No. 217, Bus Emergency Exits and Window Retention and Release. USDOT. National Archives and Records Administration, Washington, DC.

NTSB, 1999. Highway Special Investigation Report–Bus Crashworthiness Issues. vol. PB99-917006, NTS Board, Ed.: NTIS.

Oberg, E., Jones, F., Ryffel, H., McCauley, C., 2012. Machinery's Handbook, 29th revised ed. Industrial Press Inc., US, pp. 432.

Pollard, J.K., Markos, S.H., 2009. Human Factors Issues in Motorcoach Emergency Egress. National Transportation Safety Board Interim Report.

Purswell, J.L., Dorris, A., Stephens, R., 1970. Escapeworthiness of Vehicles and Occupant Survival. Prepared for FHA/NHTSA/USDOT by School of Industrial Engineering. University of Oklahoma Research Institute (OKRI), Norman, OK.

Purswell, J.L., Dorris, A.L., Stephens, R.L., 1978. Evacuation of Intercity Buses. Prepared for FHA/USDOT by School of Industrial Engineering. University of Oklahoma Research Institute (OKRI), Norman, OK.

Sliepcevich, C.M., Steen, W.D., Purswell, J.L., Krenek, R.F., Welker, J.R., 1972. Escapeworthiness of Vehicles and Occupancy Survivals and Crashes. Prepared for NHTSA/USDOT by School of Industrial Engineering. University of Oklahoma Research Institute (OKRI), Norman, OK.

Young, W.C., Budynas, R.G., Sadegh, A.M., 2012. Roark's Formulas for Stress and Strain. McGraw-Hill.