

Using RFID to Quantify School Bus Evacuation Training Times

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Abstract

Public schools in the United States are mandated by State legislatures to conduct periodic school bus evacuation training for the benefit of students. The approach to this training varies widely among school systems and there is rarely documentation describing the manner of testing. Typically, there is only a record that the training itself was conducted. Radio-frequency identification (RFID) is becoming more prevalent in many applications related to the safe transport of children on school buses. The purpose of this study was to explore the use of RFID to measure evacuation times compared to video and/or stopwatch measurements, for thirty-four passengers on a Type “D” school bus. The results obtained over three evacuation scenarios (front door only; rear door only; both doors simultaneously) revealed no statistically significant difference between those times recorded by RFID and those observed by video analysis for all trials. Based on these findings, RFID has the potential to provide a fast, cheap, non-invasive way to record school bus evacuation times, eliminating lengthy video analysis. Elimination of stopwatch and/or videotape analysis could lead to numerous schools uploading evacuation training times into a central repository, building a reliable source for benchmarking and potential design changes for emergency exit systems.

Keywords

RFID, School Bus, Evacuation, Children, Training

1. Introduction

There is strong evidence that transporting students on school buses is the safest means to move children to and from schools. Approximately six billion (6,000,000,000) miles are driven annually to transport approximately twenty-six million (26,000,000) students daily (American School Bus Council, 2018). Public school systems in the United States are mandated by State legislatures to conduct periodic school bus evacuation training for the benefit of their students (Abulhassan *et. al.*, 2016). The approach to conducting this training varies widely among school systems and there exists only a trace of anecdotal records detailing specifics relating to this requirement, other than that evacuation drills were conducted. The use of RFID associated with school buses has increased significantly over the past decade. Researchers in Qatar published a paper (Shaaban *et. al.*, 2013) detailing several possibilities for RFID to enhance the safety of bus riders. The authors mention monitoring students as they enter and exit the bus, discuss examples of students attempting to get off at the wrong stop, and students who have been left on the bus after the route is completed (Shah and Singh, 2016). The authors also mention that passive RFID tags are preferred over active tags as they last longer, cost much less, and are safe for use around children as they are only powered when near a reader. A 2015 paper (Shyam *et.al.*) discusses the use of Short Message Service (SMS) enabled by RFID to notify parents and school officials of other than expected outcomes.

2. School Bus Evacuation Standards

In 2019, Davis drafted an opinion paper “Should the United States Mandate School Bus Evacuation Times?” This paper details a comparison between aircraft and school buses, and questions why standard evacuation times are required in aviation, but not in the transportation of school children. Davis (2019)

states “the school bus industry, Federal Motor Carrier Safety Administration (FMCSA), and the National Highway Transportation Safety Administration (NHTSA) do not have uniform prescriptive requirements for evacuation times” in stark contrast to the Federal Aviation Administration (FAA), nor “a methodology for collecting, analyzing, and disseminating routinely performed evacuation data and information.”

Sparse research exists on school bus evacuation times. Abulhassan *et al.* published a methodology to establish baseline times in 2016. The authors conducted numerous evacuations via the front door (only), rear door (only), and both doors (simultaneously) for kindergarten and elementary school (1st, 2nd & 3rd grade) aged children. Abulhassan *et al.* (2016) used wireless security cameras to record student evacuation movements which entailed lengthy video analysis time to ascertain individual and group evacuation times. Davis (2019) suggests that the FAA evacuation time of 90 seconds or less should be the goal, or ‘time to reach’, in all school bus evacuations. Such a notion was first broached when Purswell and Dorris (1978) reported that “A standard for maximum evacuation time should be considered”. The use of RFID to quantify individual evacuation times could eliminate the burden of analyzing video recordings, thereby facilitating the collection, and reporting of evacuation times and practices by school systems. Literature suggests that once a bus catches fire, it can be completely engulfed within three (3) to five (5) minutes (Matolcsy, 2010). Therefore, time is a critical factor for evacuation training. It is possible that RFID technology can empower schools to quickly collect and report bus evacuation times, and more easily determine if they are meeting their goals during evacuation training drills. Since there is no federally mandated evacuation time requirement, these data are not typically recorded.

The purpose of this study was to evaluate the use of RFID to measure evacuation training times and compare them to video and/or stopwatch measurements, for thirty-four passengers on a Type “D” school bus in three evacuation scenarios (front door only; rear door only; and both doors simultaneously).

3. Method

The objectives of this experiment were to compare two methods used to measure and track school bus evacuation exercises by performing the following tests:

1. Measure the evacuation time(s) and determine the flowrate(s) (passengers per minute), of adult subjects through the front door only, the rear door only, and both the front and rear doors simultaneously.
2. Compare the evacuation time measurements of each passenger as recorded by RFID with measurements recorded by screening the video of each passenger. Hypothesis: There are no significant differences in the evacuation times for those measured with RFID compared with the same subjects measured with video analysis.

$$H_0: \mu_{\text{RFID}} = \mu_{\text{Video}}$$

$$H_1: \mu_{\text{RFID}} \neq \mu_{\text{Video}}$$

A nearby school system provided a Type (D) school bus (Figure 1) for the experiment. Passive RFID tags [Smartrac Dogbone RFID (MONZA R6-P) Wet Inlay] were adhered to name badges on lanyards (Figure 2) and worn around participants’ necks, who were seated randomly in one of the thirteen (13) rows on the bus. Once assigned, the participants’ returned to the same seating position for each of the three (3) trials. Participants consisted of Auburn University students enrolled in engineering courses. A pre-event brief covered the purpose of the study, why evacuation is important for school-aged children, and instructions on how to exit the bus and where to stand after exiting.



Figure 1. Type “D” school bus and test setup.



Figure 2. RFID tags attached to lanyards.

All subjects provided informed consent approved by the Auburn University institutional review board prior to participating in the trials. The three trials consisted of evacuating via the front door only, the rear door only (using a ‘sit and scoot’ posture versus jumping) and from both the front and rear doors simultaneously. Video cameras were positioned at each door to record passengers’ as their last foot touched the ground, and later analyzed for individual evacuation times. RFID readers (Zebra FX7500-42325A50-WR) and antennas (Alien ALR 8697) were placed in close proximity outside each door (Figure 1) and the power adjusted to recognize the RFID tag as close as possible to the subject completely (physically) off the bus. A Paired t-Test was used to analyze the data at $\alpha = 0.05$ level of significance.

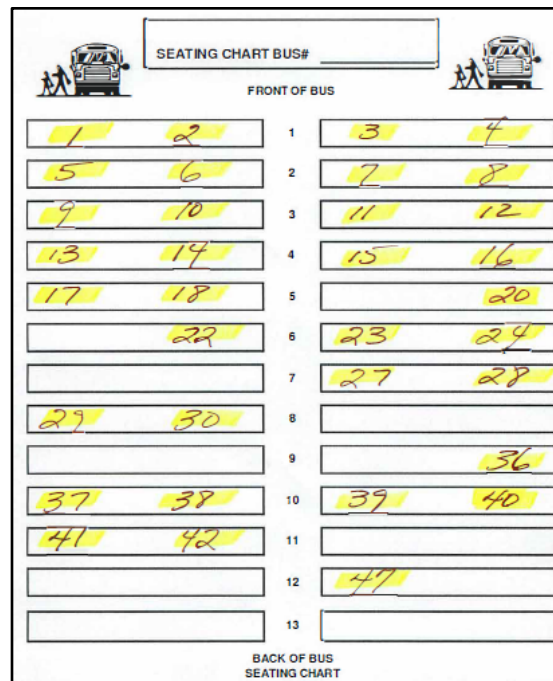


Figure 3. Passenger seating arrangement.

4. Results

Thirty-four adult participants, seated as shown (Figure 3), evacuated from the bus when given a start signal. The times (seconds) associated with RFID and those from video analysis are presented in the following format (RFID: VIDEO).

Front-Door Only –The first passenger exited the bus at (2:3) seconds and the last passenger at (32:33) seconds. The mean passenger departure interval (the successive time between passengers (2-34) leaving the bus) was 0.91 seconds, ranging between 0-2 seconds. RFID counted the passenger before the video analysis three (3) times, counted the passenger the same as the video analysis twenty-seven (27) times, and counted the passenger after the video analysis four (4) times. All seven (7) disagreements in time between RFID and the video analysis were within one (1) second (of last foot striking the ground). A Paired t-Test failed to reject the null hypothesis of no difference between the RFID times and the video analysis times for passengers evacuating via only the front door (see Minitab results in Figure 4). The mean flow rate for the front exit door was **61.9 passengers/minute**.

Rear-Door Only - The first passenger exited the bus at (2:3) seconds and the last passenger at (55:55) seconds. The mean passenger departure interval (the successive time between passengers (2-34) leaving the bus) was 1.6 seconds, ranging between 0-2 seconds. RFID counted the passenger before the video analysis fourteen (14) times, counted the passenger the same as the video analysis twelve (12) times, and counted the passenger after the video analysis eight (8) times. All twenty-two (22) disagreements in time between RFID and the video analysis were within two (2) seconds. A Paired t-Test failed to reject the null hypothesis of no difference between the RFID times and the video analysis times for passengers evacuating via only the rear emergency door (see Minitab results in Figure 5). The mean flow rate for the rear exit door was **37.1 passengers/minute**.

Paired T-Test and CI: RFID-FD, VIDEO-FD

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
RFID-FD	34	17.62	9.09	1.56
VIDEO-FD	34	17.59	9.09	1.56

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for $\mu_{\text{difference}}$
0.0294	0.4596	0.0788	(-0.1309, 0.1898)

$\mu_{\text{difference}}$: mean of (RFID-FD - VIDEO-FD)

Test

Null hypothesis $H_0: \mu_{\text{difference}} = 0$
 Alternative hypothesis $H_a: \mu_{\text{difference}} \neq 0$

T-Value	P-Value
0.37	0.711

Figure 4. Minitab Paired t-Test of front door only evacuation.

Paired T-Test and CI: RFID-RD, VIDEO-RD

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
RFID-RD	34	27.82	15.72	2.70
VIDEO-RD	34	27.74	15.93	2.73

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for $\mu_{\text{difference}}$
0.088	0.965	0.166	(-0.248, 0.425)

$\mu_{\text{difference}}$: mean of (RFID-RD - VIDEO-RD)

Test

Null hypothesis $H_0: \mu_{\text{difference}} = 0$
 Alternative hypothesis $H_a: \mu_{\text{difference}} \neq 0$

T-Value	P-Value
0.53	0.598

Figure 5. Minitab Paired t-Test of rear door only evacuation.

Both Doors - The first passenger exited the front door of the bus at (3:2) seconds and the last passenger at (22:22) seconds. The mean passenger departure interval (the successive time between passengers (2-34) leaving the bus) was 0.61 seconds, ranging between 0-2 seconds. RFID counted the passenger before the video analysis four (4) times, counted the passenger the same as the video analysis twenty-four (24) times and counted the passenger after the video analysis six (6) times. All ten (10) disagreements in time between RFID and the video analysis were within two (2) seconds. A Paired t-Test failed to reject the null hypothesis of no difference between the RFID times and the video analysis times for passengers evacuating via the front door and the rear emergency door simultaneously (see Minitab results in Figure 6). The mean flow rate for both exit doors was **92.7 passengers/minute**.

Paired T-Test and CI: RFID-Comb, VIDEO-Comb

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
RFID-Comb	34	11.24	5.85	1.00
VIDEO-Comb	34	11.29	5.79	0.99

Estimation for Paired Difference

Mean	StDev	SE Mean	95% CI for $\mu_{\text{difference}}$
-0.059	0.694	0.119	(-0.301, 0.183)

$\mu_{\text{difference}}$: mean of (RFID-Comb - VIDEO-Comb)

Test

Null hypothesis $H_0: \mu_{\text{difference}} = 0$
 Alternative hypothesis $H_1: \mu_{\text{difference}} \neq 0$

T-Value	P-Value
-0.49	0.624

Figure 6. Minitab Paired t-Test of combined door evacuations.

5. Discussion

The RFID times matched the video analysis times for 61% of the observations. As RFID recognized the tag (subject) in 21% of the observations before the video analysis time, it is possible that the receiver was located too close to the exit of the bus, and/or the receiver was not adequately shielded. As the receiver is omnidirectional, it is possible to read the tag before the subject exits (or fully exits) the bus. Posture while exiting the bus can also affect the data. When evacuees are exiting through the front door, they are only slightly leaning forward to see the stairs. However, when they are exiting through the rear door using the ‘sit-and-scoot’ method, they lunge forward in the doorway to sit down, then push off before both feet hit the ground. These natural gyrations associated with egress may have influenced RFID sensing accuracy. However, the differences were never more than 2 seconds for any individual evacuee. The present study was conducted using four tags per evacuee, one hanging on a lanyard in the front, one hanging on a lanyard in the back, and one on each shoulder of each participant. However, the data from only the tag that hung in front was used for this study. Shaaban *et. al.*, 2013, reported that the use of two tags per person “led to accurate detection of all people who participated”.

During preliminary trials it was noted that passengers should not be allowed to hold any item during the evacuation due to the potential of the RFID tag being blocked from the receiver. Even a single sheet of paper can potentially hide the tag(s) from the receiver(s). Items like back packs and loose clothing should be avoided as well. Also, the receivers should not be attached to the bus doors because subjects tend to evacuate in a rhythmic (bouncing) pattern which could affect the stability of the receivers.

Statistically, there was no difference between the RFID times and the video analysis times for the front door, rear emergency door, and combined door trials. The video analysis facilitated the measurement of the point that both feet of the subject were on the ground outside the bus to the nearest second. The RFID sensors provided data in fractions of a second, however it was rounded to the nearest second for comparison purposes. It should be noted that because the RFID sensors are omnidirectional the setup of the school bus to accurately read precise departure from the bus is somewhat tedious. However, it may be possible to develop a system designed specifically to attach to school buses to measure evacuation performance. Such

a system would incorporate the appropriate means to fasten it to the bus and be designed to obtain accurate measurements (e.g., with appropriate directional shielding).

In this study, we measured and analyzed the individual bus departure times. However, for evacuation training purposes, the time of greatest practical interest is the time that it takes for the last passenger to exit the bus. For all trials, the RFID times and video analysis times were identical for the last passenger. Lessons learned include: 1) Do not allow passengers to hold any item during evacuation training trials as even a single sheet of paper can potentially hide the tag(s) from the receiver(s); 2) Receivers should not be attached directly to the bus doors as subjects tend to evacuate rhythmically causing the steps to rise and fall; and 3) It may be beneficial to attach two (2), or more, RFID tags [4], versus the use of a single tag, to the upper arms or shoulders to increase the probability of detecting a tag. Combinations of passenger size and exit velocity may contribute to tags being missed. No tags were missed (not read) during the present study.

6. Conclusion

To the best of our knowledge, this is the first study that has attempted to compare RFID with Video analysis to determine school bus passenger evacuation times. The RFID technology demonstrates that it can accurately record evacuation times for bus passengers and present that information to decision makers in a minimal amount of time. Use of this technology could provide more information to transportation coordinators and eliminate some of the subjectivity associated with timing such trials manually. Future research should seek to find better placement of RFID receivers (perhaps a bit further from the doors), improved shielding techniques, and potential locations of passive RFID tags on subjects, to record individual evacuation times more accurately. Limitations of the study include: 1) Small sample size (N=34). The bus was not at full capacity. Assuming older/larger passengers are capable of seating two abreast, such a bus could hold up to 56 passengers; 2) Did not use school aged children for this demonstration; and 3) No attempt was made to simulate the intensity (environment) of an actual emergency evacuation.

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8. References

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Biographies

Shivaprasad Nageswaran is a PhD student and Graduate Research Assistant in the Department of Industrial and Systems Engineering at Auburn University. Shiva received his bachelor's degree in mechanical engineering in 2013 from Amrita University, India and Master's in industrial & systems Engineering in 2018 from Auburn University, Alabama. After graduating, Shiva worked for Hyundai Rotem as a Design Engineer and as an on-site manager in the erection and commissioning team for the Final Assembly Shop at the Ford India Motors Sanand Plant. Mr. Nageswaran is a certified Associate Ergonomic Professional (AEP). Shiva has also received a Diploma in Product Design (2013) and a Graduate Certificate in OSE (2018). He has been associated with Radio Frequency Identification (RFID) research at the RFID Lab at Auburn University since 2016. His research interests include occupational safety, school bus safety & evacuation systems, RFID technology, and engineering design. He is currently working on a research project involving emergency evacuation considerations for seat belt equipped school buses. Shiva has been part of school bus safety research conducted at Auburn University since 2017.

Leslie A. Gunter holds a bachelor's degree in mechanical engineering (1977) from the University of Alabama, as well as a master's degrees in mechanical engineering (2001) from Purdue University (Indianapolis) and an MBA (2004) from Indiana University (Columbus). He has also earned a Master's (2014) and a PhD (2019) in industrial and systems engineering from Auburn University. His research interests include human performance issues associated with evacuation, restricted spaces, and human-machine interaction. Dr. Gunter is a Senior Staff Manufacturing Engineer for Lockheed Martin and has worked in manufacturing for more than forty years focused on product and process design and implementation. Dr. Gunter is a registered Professional Engineer in the State of Alabama, is board certified in the practice of professional safety (CSP), holds a Lean Six Sigma Black Belt with Lockheed Martin, and is a member of the American Society of Mechanical Engineers (ASME).

Richard F. Sesek holds bachelor's degrees in General Engineering (1988) and Psychology (1988) as well as a Master's in General Engineering (1990) from the University of Illinois (Urbana-Champaign). He has also earned a master's degree (1998) in Public Health and a Ph.D. (1999) in Mechanical Engineering with an emphasis on Ergonomics and Safety from the University of Utah. He has taught graduate and undergraduate level safety and health related courses for over 20 years. Prior to academia, he worked as an OSHA consultation consultant (State of Georgia), as safety and environmental engineer and as an ergonomics consultant. He has been active in the safety profession for over 30 years. He is currently the Tim Cook Associate Professor of Industrial and Systems Engineering at Auburn University in the Department of Industrial & Systems Engineering. He is the Director of the Business and Engineering Technology Program in the Thomas Walter Center for Technology Management. He has been active as a safety and ergonomics consultant for over 25 years and is the President of WD Ergonomics, LLC and a principal partner in Trusted Scholar, LLC. Dr. Sesek is a Certified Professional Ergonomist (CPE).

Gerard A. Davis received the B.S. degree in mechanical engineering from the University of South Carolina in 1988, and the M.S., M.Ed., and Ph.D. degree in industrial and systems engineering from Auburn University in 1996 and 2001, respectively. Jerry has been on the Auburn University faculty since 2001 and is the Daniel & Josephine Professor of industrial and systems engineering, as well as, associate department chair. His research interests include human performance issues associated with evacuation, restricted spaces, and human-machine interactions. Prior to joining academia, Jerry was a US Navy nuclear trained submarine officer, serving on five ballistic missile submarines during his twenty-year career. Dr. Davis is board certified in the practice of professional safety (CSP) and professional ergonomics (CPE), and is a professional member of the American Society of Safety Professionals (ASSP). He has served as an expert witness in numerous matters involving occupational safety, personal protective equipment, and time study, in both state and federal venues.