PROCEEDINGS of the HUMAN FACTORS SOCIETY - 22nd ANNUAL MEETING - 1978

A STUDY OF POST-CRASH BUS EVACUATION PROBLEMS

by

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ABSTRACT

This study was conducted to provide information related to the post-crash evacuation of intercity buses. A review of bus accident data and relevant literature was completed to provide an understanding of the variables related to bus evacuation. A survey was completed to document the passenger characteristics of a typical bus load. A special data base was analyzed for injuries resulting from falls or jumps of eight feet or less. A study was then designed and conducted to investigate bus evacuation under several "worst-case" conditions. The study was then conducted and 16 mm movie films were made of each evacuation. An analysis of the study provided information on time to evacuate for various conditions, hazards in evacuation, subjects reaction to the evacuation tests and recommendations for bus design and operation to minimize evacuation problems.

INTRODUCTION

The U.S. Department of Transportation, Federal Highway Administration entered into a contract with the University of Oklahoma on December 1, 1976 to perform a study entitled "EVACUATION OF INTERCITY BUSES". The stated objectives of this research were as follows:

1) Determine the typical circumstances of intercity bus accidents and important variables affecting evacuability.

2) Determine a profile of a typical intercity bus passenger load.

3) Develop several worst-case intercity bus accident situations for study.

4) Conduct and film a group of empirical tests to determine evacuation time for the worst-case situations as developed in (3) above.

The University of Oklahoma had performed two prior studies of post-crash bus and automobile evacuation (Oklahoma University Research Institute, 1970 and 1972). This study is therefore the third in a series which have been conducted to document the problems of evacuation or escape from buses and automobiles after a crash.

LITERATURE REVIEW

An automobile-bus collision near Baker, California in 1968 which was investigated by the National Transportation Safety Board (NTSB, 1968) provides a spectacular example of post-crash escape problems. According to the accident report, after the collision, fire immediately burst out in the front area of the bus, fueled initially by vaporized power steering oil and shortly thereafter by diesel fuel. Diesel fuel was sprayed, splashed and spilled over a large area of the bus, including the baggage and passenger compartments. The fire spread and grew rapidly in intensity. The bus driver and six passengers escaped through the right windshield area, some with assistance. Five passengers escaped through the rear window of the bus which was opened forcibly by one of the passengers who then rendered assistance to others. Nineteen passengers did not escape and were burned in the fire. The reasons for the nineteen passengers not escaping were stated as one of more of the following reasons: injuries sustained in the crash, shock, disorientation, limited routes of escape, smoke, fire and lack of oxygen.

The files of the bureau of Motor Carrier Safety were reviewed for the period of 1969-1976 and accidents in which evacuation of the bus was a significant consideration were selected for further analysis. Several points emerged as a result of this analysis.

1. Turnovers: For the 14 accidents reviewed, 12 involved bus turnovers, and of these, eight buses turned over on their left side while four buses turned over and came to rest on their right side. It appears that turnovers onto the right side are somewhat more hazardous with respect to evacuation than left-side turnovers in that the forward right hand door is not functional in this case.

2. Illumination: For the 14 accidents reviewed, five occurred during daylight hours, six occurred during nightime and three occurred as dusk or during periods of reduced illumination. One might hypothesize that evacuation of buses during nightime conditions should take significantly longer than during daylight conditions due to the reduced visibility afforded the egressing passengers.

3. Fatalities and injuries: All 14 accidents reviewed resulted in injuries to passengers, while nine of the accidents reviewed resulted in fatalities. There were 17 fatalities, of which the majority were due to various types of neural trauma. The 14 accidents resulted in a total of 372 non-fatal injuries to the passengers which required hospital attention or some type of medical care. Review of the limited data available with respect to the type of injuries sustained in these accidents indicates that the majority of the injuries were to the upper body, while others affected the lower limbs and would have limited the ability of escape from the bus.

4. Post-crash hazards: A bus rolling over and coming to rest on one side usually results in the passengers being piled on top of one another in awkward positions with the complicating problem of disorientation. Under conditions of darkness, attempts to evacuate these buses have resulted in some passengers trampling others in their attempt to evacuate.

5. Bus Passenger Profile: For the 389 persons who were either killed or injured in the accidents reviewed, age and sex information was available for 213 persons. A total of 99 males were injured as opposed to 114 females. Taking into account both injured and non-injured passengers, age and sex information was available for 278 passengers in the 14 accidents. Of this group, 48 percent were male and 52 percent were female.

6. Escape Routes: The majority of these accident reports contained little information about the escape routes utilized by passengers to evacuate the bus. For those reports which do delineate specific routes, the majority of passengers evacuated via the front windshield. These windshields had already popped out during the rollover of the bus and provided a quick and easily discernible route for escape. Only one instance of the utilization of the overhead escape hatch was noted. This result might possibly be due to insufficient information in the accident report with respect to egress technique or the buses involved in the accidents may not have had an escape hatch available.

METHODOLOGY

Subjects

It has been noted earlier that the objective of this study was to develop data related to bus evacuation for a set of "worst-case" conditions. One possible choice in conducting the study was to choose a subject population of older adults who presumably would have more difficulty in evacuating a bus after a crash than more agile, younger adults or teenagers. Although some charter buses could be expected to have such passenger loads, it was decided that the subjects should be chosen to represent the age and sex characteristics of the overall intercity bus rider population.

A survey was conducted in the Oklahoma City bus terminal during January, 1977 to develop information about the age and sex of bus passengers. The survey produced the information shown in Table 1. Some intercity buses can carry as many as 45 passengers, so this was the number chosen for the bus load for purposes of the study. Using the information shown in Table 1 as a guide, with 45 passengers as the bus load, the number of subjects selected by age and sex are shown in Table 2. Each subject over 50 years of age was screened by a registered nurse to assure that they were physically able to participate in the evacuation tests. The hip breadth, shoulder breadth, height, weight, age and sex of passengers were recorded prior to each test.

TABLE 1. PERCENTAGE OF MALES/FEMALES OBSERVED RIDING INTERCITY BUSES VERSUS AGE (N=959)

AGE RANGE	MALE	FEMALE	MALE AND FEMALE
Infants	0	.4	.4
1-5	.8	1.9	2.7
6-10	1.6	1.1	2.7
11-20	5.8	8.7	13.5
21-30	14.0	14.3	28.3
31-40	6.4	7.6	14.0
41-50	5.7	5.3	11.0
51-60	5.1	6.3	11.4
61-70	5.4	5.1	10.5
over 70	2.1	2.4	4.5
% Total	46.9	53.1	100.0

Experimental Design

Conditions: On the basis of the review of the literature and the examination of the reports on bus crashes, it was determined for purposes of this study that the worst case post-crash condition involved the bus over-turned on its right side so that the front door was blocked. While the overturned bus presented the expected worst case escape condition within practicality constraints, it could be argued that a majority of bus crashes do not involve turnovers. So it was considered desirable to study the worst case with the bus upright on its wheels. It was concluded that this case would occur under darkness conditions with the front door exit blocked. Thus, this condition was chosen for study in addition to the case with the bus overturned.

TABLE 2. NUMBER OF MALE AND FEMALE SUBJECTS BY AGE INTERVALS FOR THE THREE TEST GROUPS

AGE IN YEARS	GROUP I MALES/FEMALES		GROUP II MALES/FEMALES		GROUP III MALE/FEMALES	
1-5	0	0	1	0	0	0
6-10	1	1	1	2	2	2
11-20	4	6	4	3	4	4
21-30	6	5	5	7	6	8
31-40	3	3	3	2	3	2
41-50	1	3	2	2	2	2
51-60	4	3	2	4	2	3
61-70	1	4	3	3	2	2
above	0	0	1	0	1	0

Three experimental conditions were studied:

1. The bus was in an upright position on its wheels with the full complement of passengers and the front door blocked with darkness conditions simulated. A second trial was performed with conditions identical to those just noted, but with the front door accessible.

2. The bus was overturned on its right side blocking the front door with a full load of passengers escaping under simulated conditions of darkness.

3. The bus was turned on its right side and the experimental conditions of this trial identical to the second set of experimental conditions except that an on-board emergency illumination level was simulated.

Each condition was repeated twice for the three passenger groups to give a total of six escape trials. The purpose of this approach was to obtain a measure of the effects of practice on evacuation performance. The replication of the first experimental condition was conducted with the front door available as an exit. This modification permitted the time per passenger escaping to be developed which was not appreciably affected by practice.

Variables: The variables studied included the escape routes available to escaping passengers which consisted of the windows, front windshield, the roof hatch and in one case, the door. Also considered was the orientation of these escape routes relative to the attitude of the bus. The use of darkened goggles provided the mechanism for investigation of two levels of illumination. Darkness as well as a partial degree of darkness equivalent to an emergency illumination level were simulated. The investigators concluded that the presence of injured passengers during the crash phase could increase the total time required for all passengers to escape. Several passengers were instructed to feign injuries which resembled paralysis of the upper or lower appendages; therefore, they required the assistance of other passengers in order to succeed in their escape.

The dependent variables relative to the above mentioned independent variables for this study were time to escape, passenger behavior, and injury. Where time to escape was measured absolutely, behavior during the escape was obtained subjectively by the investigators examining multiple motion pictures. Injury was evaluated with respect to the actual number of injuries during the escape trial, as well as those potential injuries which may have occurred if various safety precautions undertaken for the test were not available to the escaping passengers.

Equipment

GMC Intercity Bus: Bus specifications pertinent to the escape tests are as follows:

Manufacturer: General Motors Coach Division

Type: Model PD-4107

Capacity: 45 passengers (no lavatory)

Emergency Exits: Eight pushout windows, 71cm high and 180cm wide, with four windows on each side of the bus. These windows were fitted with positive mechanical latches which complied with FMVSS-217. The windows were then operable by lifting a push bar and pushing against secondary friction latches. The height of the window sills was 1.83m above ground level for the upright bus. One emergency exit roof hatch equipped with a popout plexiglass insert measuring 54.6cm by 48.9cm was located in the rear roof of the bus. The bus door, when available for egress, afforded a 71cm by 2.13m opening. Two windshield sections, each of which was retained by rubber molding which allowed for their being kicked out by the occupants provided a 108cm wide by 81cm high exit space when viewed from the upright bus position.

Seats: Eleven rows of two seats on each side of the aisle with one bench seat across the rear of the bus at the end of the aisle allowed for 45 seated passengers.

Supporting Equipment: Three 16 millimeter motion picture cameras were used to film the series of trials. Two cameras were placed outside the bus to view all exits, and the third camera was utilized inside the bus from the driver seat position to record activity within the bus. Several 35 millimeter cameras were employed around the bus for documentation photographs.

One large crane and two large trucks were employed along with special fixtures attached to the bus wheel hubs to tip the bus over on its right side and avoid body deformation.

A loud siren exterior to the bus as well as an incandescent lamp within were employed to signal the start of each test. They remained on throughout the escape process.

Two large timers were strategically placed to provide a check on the time base on the movie films taken. They were synchronized with the siren and signal lamp.

Procedures

The first escape trials were performed with the bus in its upright configuration. The bus was located in a large open field and mattresses were placed around all available exits.

All subjects had been simply informed previously that they would participate in an intercity bus test and no other information was provided about the details of the escape prior to their arrival at a building approximately 500 yards from the test site. Upon the arrival of the subjects they were gathered together and the appropriate release forms were completed by each subject. Several stations were available to take anthropometric measurements and each subject was examined for his height, weight, shoulder breadth and hip breadth and this information was recorded on the subject information sheet. Then the principal investigator instructed the subjects regarding the procedure for the test.

The subjects were then led as a group to the test site, where they were issued their goggles and allowed to enter the bus and be seated.

Upon a previously arranged signal from the experimental director, cameras were started and five seconds later the sirens, a signal light and timers were activated. Filming as well as the siren wailing continued until the bus was completely evacuated. At that point, the cameras and associated signal equipment were turned off.

Upon returning to the building, the subjects were briefed using a specific set of questions.

Tape recorders were employed by research assistants, allowing them to record the comments made by the subjects for later transcription and analysis.

goggles were used to simulate both night conditions and darkness with an emergency illumination system for the bus escape test. The goggles were specially fabricated by spraying flat black paint over dark plastic material until predetermined light levels were transmitted. Adjustable elastic bands on the goggles provided a secure fit for all head sizes and eliminated any light which might enter around the goggle periphery due to a loose fit. Subjects were allowed to wear their goggles sufficiently long enough before each trial began in order for them to properly adapt their vision.

A registered nurse along with an ambulance and complete first aid facilities were available to treat injuries.

Used mattresses were place along both sides and front of the bus to provide a landing position for the subjects when they jumped from the bus during the test. A scaffold was constructed and placed beside the bus undercarriage when trials were conducted with the bus on its side. The scaffold was approximately eight feet above ground, five feet wide and extended from the front wheel well to the rear wheel well.

Evacuation Test No. 1: These test data are shown in summary form on Table 3. Two passengers could not open the pushout window adjacent to their seat for escape. They did open the window as it would be opened for ventilation and then climbed out through this opening, which was approximately one half the size of the full bus windows. One of these two passengers, later identified as a 52 year old female, received a very badly bruised arm, as it was caught in the window opening when she dropped to the ground. The injury was treated and she recovered satisfactorily. A 24 year old male was the other passenger escaping through a window opened only to the position for ventilation. He received a bruise to the head when the window was opened by pushing out while he was still in the process of escaping.

Despite the precautions taken to avoid injuries to subjects, a 69 year old female escaping through the first left window, fell and sprained her back. She was attended by a nurse on duty and completed the next evacuation trial by exiting through the front door which was available for this trial. However, she later required the care of a physician for several weeks before recovering from her injury.

It is apparent that there is a great disparity in the total time which each window exit was used for escape and the number of persons escaping.

Each of the evacuation tests were analyzed and data developed in the same format as presented in Table 3. Additional analyses were performed in detail to obtain the escape time for each passenger, with the age and sex identified. Space does not permit a full presentation of this data. Table 4 provides an overall summary of the remaining six evacuation trials.

An important finding of trials 3 and 5 was that passengers were able to kick out the front windshield of the bus and use this opening as an escape route. In one case two females, age 45

TABLE 3. BUS EVACUATION
TEST NUMBER 1
SUMMARY DATA

Experimental Condition: darkness, bus upright, 45 passengers
Exits available: bus side windows
Total evacuation time: 108.54 seconds

EXIT[1]	TIME TO OPEN EXIT	TIME OF LAST EXIT (TERMINAL)	NO. PERSONS ESCAPING	TIME LAST ESCAPE/ NO. OF ESCAPES	COMMENTS
RW1	11.24	28.04	4	7.01	
RW2	9.46	36.88	6	6.15	
RW3	12.54[2]	23.33	1	23.33	Climbed out window without pushing open - injured arm
RW4	33.25	58.29	4	14.57	
LW1	10.58	98.13	8	12.27	Fell hard - sprained back
LW2	9.46	71.17	6	11.86	
LW3	8.75[2] 33.88	75.25	1 6=7	10.75	First person climbed out without pushing window open
LW4	13.58	108.54	9	12.06	

[1] R = Right
L = Left
W# = window number; numbers assigned from front to rear of bus
FD = front door
WS = windshield
RH = roof hatch

[2] Passenger slid window back to open position for ventilation and escaped through this exit.

TABLE 4. OVERALL EVACUATION TIMES
45 BUS PASSENGERS

EXPERIMENTAL TRIAL NO.	EXPERIMENTAL CONDITION	EXITS AVAILABLE	EVACUATION TIME IN SECONDS
1	darkness, bus upright	side windows	108. 4
2	darkness, bus upright	side windows and front door	77.63
3	darkness, bus on side	side windows, windshield, roof hatch	142.88
4	darkness, bus on side	side windows, windshield, roof hatch	98.54*
5	emergency illumination, bus on side	side windows, windshield, roof hatch	112.67
6	emergency illumination, bus on side	side windows, windshield, roof hatch	56.04*

*windshield already open for these trials.

and 65 repeatedly kicked the windshield until it was broken and dislodged from the opening. The windshield had been covered prior to the test with a heavy plastic sheet to prevent lacerations if passengers did decide to kick it out and use it as an escape route. Whether this covering encouraged these passengers to be more daring than they would have been in a real evacuation is unknown. However, it seems likely that they would have proceeded in the same way in an actual emergency evacuation, given that they had not been injured in the crash.

Effects of Practice: One of the hypotheses to be tested in conducting the trials was whether the same passenger group would decrease the time to open a window and escape because of the experience gained during the initial trial. The only practice effect observed was the ability on trial no. 2 to open the windows more rapidly to escape.

Emergency Illumination: The only significant effect of the emergency illumination (simulated by goggles) was in reducing the time to escape through the windshield opening. The evacuation times for other exits were not changed by having emergency illumination available.

Effects of Passenger Variables on Escape Time: An attempt to use a regression model to predict escape time as a function of age, sex, height, weight, hip breadth and shoulder breadth produce a significant lack of fit, i.e. other sources of variation were more important than personal variables.

Prediction of Bus Evacuation Time: A set of prediction equations for total bus evacuation time was developed as a function of the number and type of exits available, bus orientation and level of illumination. These equations were shown to have good reliability for a wide range of possible escape conditions. Space does not permit their full enumeration here.

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