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EVACUATION OF INTERCITY BUSES

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FINAL REPORT

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16. 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.

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PREFACE

The co-principal investigators wish to acknowledge the helpful assistance and direction provided by Mr. Alfred Klipple, the Contract Manager, Federal Highway Administration (FHWA). Our research assistants, Mr. Yoshio Ikeda and Ms. Susan Chatfield deserve a special thanks for their work in conducting the study and preparing the final report. Finally, Ms. Robin Burnett, Ms. Barbara Brannon and Ms. Becky Williams contributed significantly in preparation of the report copy.

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EXECUTIVE SUMMARY

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EVACUATION OF INTERCITY BUSES

EXECUTIVE SUMMARY

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 University of Oklahoma had previously performed research related to the evacuation of intercity buses as well as school buses. This research was performed under DOT Contract No. FH-11-7303 and the results were published in December, 1970 with the title, "ESCAPE WORTHINESS OF VEHICLES AND OCCUPANT SURVIVAL". The University of Oklahoma performed an additional study under DOT Contract No. FH-11-1512, and the results were published in July, 1972 with the title, "ESCAPE WORTHINESS OF VEHICLES FOR OCCUPANCY SURVIVALS AND CRASHES". The current study is therefore the third in a series of studies which have been conducted to document the problems of evacuation or escape from automobiles and buses following a crash.

Objectives

The objectives of the studies performed under this contract are:

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 including such variables as height, weight, age and sex.

3. Develop several accident scenarios representative of worst-case conditions.

4. Conduct and film empirical tests of evacuation performance for the conditions selected.

By attaining the objectives above, the research team was able to evaluate the typical intercity bus with respect to escape worthiness, to determine potential sources of difficulty and to provide recommendations for further improvements.

Procedure

The existing literature on escape from intercity buses following a crash was reviewed. Of particular importance were accident investigations on 14 crashes during the period of 1969 - 1976 gleaned from the files of the Bureau of Motor Carrier Safety. On the basis of this review of the literature, the personal and situational factors which were found to be most important were determined. A set of conditions representing post-crash bus orientations was determined and an experimental plan developed and approved by the Federal Highway Administration.

Three basic experimental conditions were utilized with two trials being conducted at each condition. The three experimental conditions used were:

1. The bus was in an upright position on its wheels with the full complement of passengers and the front door blocked and 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, causing the front door to be blocked. A full load of passengers was employed and the escape was conducted under simulated darkness conditions.

3. The bus was overturned on its right side as in condition (2) above. The procedures were identical to those in condition (2) except that an emergency on-board illumination system was utilized.

Personal characteristics of a typical intercity bus passenger load were determined from information supplied by the major commercial intercity bus companies, from observations of passengers at a bus terminal and from the accident investigation files. On the basis of this information, subjects for the experiment were recruited to match the passenger profile in terms of age, sex and body size. The studies were conducted and filmed at the research campus of the University of Oklahoma at Norman.

Conclusions and Recommendations

On the basis of the review of accident investigations, the statistical analysis of escape time data from the experiments, post-experimental interviews with those who participated as subjects and additional data made available to the research team by other investigators, the following conclusions and recommendations were reached:

Conclusions:

1. Rapid and safe evacuation of passengers after a bus accident should be an important performance parameter for bus design. The maximum time to permit for a bus evacuation cannot be fully determined with the data currently available. However, the standard used by the FAA for aircraft evacuation should be carefully considered, i.e., 90 seconds time with one-half the available exits being used. The evacuation should be accomplished without any more than minor injuries to passengers.

2. The typical bus passenger load can be adequately described by the survey conducted for this study.

3. The time to evacuate a bus for a given combination of exits can be predicted satisfactorily for a typical bus passenger load.

4. A significant potential for serious injury exits when jumping or falling from the top side of an overturned bus, especially if the passenger lands on concrete or asphalt.

5. The use of a roof hatch for escape when the bus is on its side is limited by the absence of some type of ladder or "toe hold" support when maneuvering through the opening.

6. The windshield of an overturned bus provides a good escape route if it can be kicked out by a passenger. Passengers in this study showed no reluctance to kick out the windshield.

7. Bus evacuation time could be reduced if the passengers better utilized all of the available exits. However, the use of some exits would produce more injuries, thus presenting a tradeoff of one criterion versus the other.

8. Emergency illumination reduced the escape time through the bus windshield opening as compared to darkness conditions.

Recommendations:

1. A standard should be considered for maximum bus evacuation time. The current FAA standard for aircraft evacuation is an example of a potential standard. The standard should also require that evacuation be conducted with no more than minor injuries sustained by the passengers.

2. A ladder or "toe hold" type arrangement on the inside and outside of roof hatches should be required to improve their utilization as an escape route. At least three roof hatches of approximately 20 x 24 inches should be required on buses so that passengers are not required to use the overhead windows as escape routes from an overturned bus.

3. Clear instructions should be provided on all bus exits for their use. Standards such as those found in Van Cott and Kinkade (1972) should be used for these instructions. A type of escape instruction circular such as used on aircraft should also be provided to passengers.

4. An emergency illumination system should be considered for buses. This system should be able to function after a crash to provide illumination and reduce the evacuation time as well as aid in the first-aid treatment of passengers.

5. Consideration should be given to providing instructions and labels which indicate that the front windshield can be broken out and used as an escape exit. These instructions should note that some object such as a piece of luggage, a tire tool or a reflector stand could be used to reduce the possibility of injury when breaking out the windshield.

6. Window hinges used on buses should have a performance requirement that would prevent the window from breaking off under the loads expected from pushing the windows open rapidly for escape and when passengers attempt to hold onto the window to lower themselves to the ground from the top side of an overturned bus.

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I. 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.

In order to achieve the objectives of the research, a Research Plan was developed and approved by the Federal Highway Administration prior to actually conducting the empirical tests. This research plan encompassed the following tasks:

1) A review of the literature related to bus evacuation as an important post-crash factor.

2) A determination of the most important personal characteristics of bus passengers.

3) The development of an experimental plan which would provide empirical data that could be used in predicting the evacuation time of intercity bus passengers under a variety of post-crash conditions.

4) Conducting the empirical tests to obtain the data.

5) Analyzing the data to provide the evacuation information.

The University of Oklahoma has performed research previously related to the evacuation of intercity buses as well as school buses. This research was performed under DOT contract No. FH-11-7303 and the results were published in December, 1970 with the title, "ESCAPEWORTHINESS OF VEHICLES AND OCCUPANT SURVIVAL". The University of Oklahoma performed an additional study under DOT contract No. FH-11-7512, and the results were published in July, 1972 with the title, "ESCAPEWORTHINESS OF VEHICLES FOR OCCUPANCY SURVIVALS AND CRASHES". The current study is therefore the third in a series of studies which have been conducted to document the problems of evacuation or escape from automobiles and buses after a crash.

The chapter which follows is concerned with a review of the literature which would contribute to an understanding of the post-crash evacuation of buses. This literature is in the form of accident reports, published materials and research reports. Subsequent chapters are devoted to an explanation of the experimental methodology followed in conducting the bus evacuation trials, an analysis of the data obtained from the empirical trials, and finally a chapter which presents the results and conclusions reached as a result of performing the study.

II. 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 or more of the following reasons: injuries sustained in the crash, shock, disorientation, limited routes of escape, smoke, fire and lack of oxygen.

The NTSB recommended in its accident report "that the Federal Highway Administration, as soon as possible, change the basis of its regulatory requirements intended to insure escape from buses so that they are based upon tests of performance of occupants in escaping from buses standing or lying in all basic attitudes". In the development of test criteria, the Board suggested that consideration be given to test procedures presently employed by the Federal Aviation Administration (FAA) for the regulation of the adequacy of escape techniques and systems. Further, the Board stated that "consideration should be given to adopting for buses, the airline practice of placing emergency escape instruction at each passenger location". The Board's last recommendation was "that necessary regulations be expedited to insure that no new types of buses go into service which have not been tested to insure that all occupants can escape rapidly when the bus is in any of its basic attitudes after a crash".

A bus-automobile accident near Wiley, Texas which was investigated by the Medico Engineering Research group of Baylor University provides additional information on the bus escape problem. Team recommendations regarding bus exits were as follows (Baylor University, 1968):

1. Clear, pretrip instructions should be given passengers regarding use of any and all exits available on the particular bus type involved.

2. Exits found on the bus (Scenic-cruiser type with roof hatches) were considered adequate and efficient in the rollover situation and should be placed on all buses in order to insure sufficient points of exit in most collision situations despite final bus positioning.

3. Large, clearly written instructions for escape be posted near exits.

4. Emergency exit time standards should be developed under different collision configurations and that the procedures for establishing the standards could well be patterned after existing FAA aircraft exit standards.

5. Exits should be large enough to permit egress of obese passengers; one occupant weighing 285 pounds had to exit via a large windshield opening. Some of the more seriously injuried passengers and the obese and aged would have been incinerated had there been a major fire.

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. A summary of the information which was developed from an analysis of these 14 bus accidents is included in Table 1. Several points can be made 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. Thus, even though the majority of turnovers reviewed were to the left side, the right side turnover provides a worst case evacuation condition in that only windows, windshields, and possibly a roof hatch are available for egress.

2. Illumination: For the 14 accidents reviewed, five occurred during daylight hours, six occurred during nightime and three occurred at dusk or dawn, suggesting that the majority of accidents occurred 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. However, the information contained in the accident reports was not detailed enough to provide adequate information with respect to actual impairment in egress related to a dark environment.

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. With respect to worst case conditions, the data indicates that a passenger in the state of unconsciousness or with inoperable lower limbs requiring the assistance of his fellow passenger to evacuate the bus was most significant.

4. Crash and post-crash hazards:

(a) Seat detachment--numerous injuries and some fatalities can be attributed to seat deformation and/or actual detachment. The passenger's grasp of the seat for climbing from the bus is very likely to be required in a rollover situation. If the seat detaches or is deformed, the passengers are more likely to be injured and the seats may block escape routes of the passengers.

TABLE 1. SUMMARY OF DATA FOR
FOURTEEN SELECTED BUS ACCIDENTS

DATE	LOCATION	BUS TYPE	NO. OF FATALITIES	NO. OF INJURIES	TOTAL NO. PASSENGERS	ROLL OVER	DAY/NIGHT
4-27-76	MacDoel, CA	'71 MCI MC-7	1	23	31	Right Side	Night
6-10-76*	New Haven, CT	'59 GMC 4104	0	20	40	Right Side	Night
6-19-76*	Salem, NJ	'56 GMC Sceni.	0	32	47	No	Day
5-30-75*	Milwaukee, WI	'66 GMC 450Z	2	11	-	Left Side	Dusk
1-4-75	Fernley, NV	'73 MCI MC-8	0	33	44	Left Side	Day
11-10-74	Indianapolis, IN	'63 GMC 4106	1	36	37	Left Side	Night
12-16-74	Little Falls, NY	'69 MCI MC-6	1	14	**	Left Side	Day
8-17-74	Occoquan, VA	'62 GMC 4106	0	16	39	Right Side	Dawn
7-23-76	Herkimer, NY	'69 MCI MC-6	1	44	45	Left Side	Day
1-4-75	Fernley, NV	'73 MCI MC-8	0	26	37	Left Side	Day
5-11-74	Charleston, MO	'72 MCI Challenger	7	43	51	No	Night
1-6-70*	Sasser, GA	'63 Silver Eagle	2	21	23	Left Side	Night
11-1-69	Ulmers, SC	'64 GMC 4106	1	23	**	Left Side	Night
7-9-67	Spanish Ft., AL	'66 GMC 4107	1	30	**	Left Side	Dusk
			17	372	394		

* Chartered Trips
** Data not available

Sources: Department of Transportation, Bureau of Motor Carrier Safety, Accident Investigation Report; Region and Case No. in order for above: 9-036, 1-047, 1-056, 5-020, 9-008, 5-124, 1-119, 3-092, 1-067, 9-009; Motor Carrier Accident Investigations, Report Nos. 74-1, 69-15, 69-9.

(b) Forward ejection--three of the 17 fatalities occurred when the bus driver or passengers in the first or second row of seats were ejected through the windshield. Six additional ejections occurred through the front windshield which produced non-fatal injuries, also involving the bus driver or passengers seated near the front of the bus.

(c) Impact--the majority of all injuries sustained during the accidents reviewed were of an impact nature. Passengers were either impaled upon fixed structures existing in the bus during collision or rollover; impacted into one another; or were the recipients of injuries sustained from flying objects. It appears that numerous personal articles are carried onto the buses by passengers. During rollover situations, these articles produce a significant hazard, since most appear not to be secured in any manner to the bus itself. Complete rollover also exposes the passengers to the possibility of impact with the ceiling structure which rapidly deforms and may develop numerous fractures which can lacerate like a knife edge. Impact upon these sharp edges has resulted in numerous lacerations to passengers.

(d) Egress--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. Figure 1 shows the distribution of the number of people injured and/or killed as a function of their age and sex. 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. Data with respect to such considerations as height and weight is insufficient to allow analysis of these variables for the 14 bus accidents reviewed.

6. Trip Status: This refers to whether or not the bus involved in a particular accident was a regular intercity bus operated by a commercial carrier or was chartered for a specific trip. For the 14 accidents reviewed, only four were chartered.

7. 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.

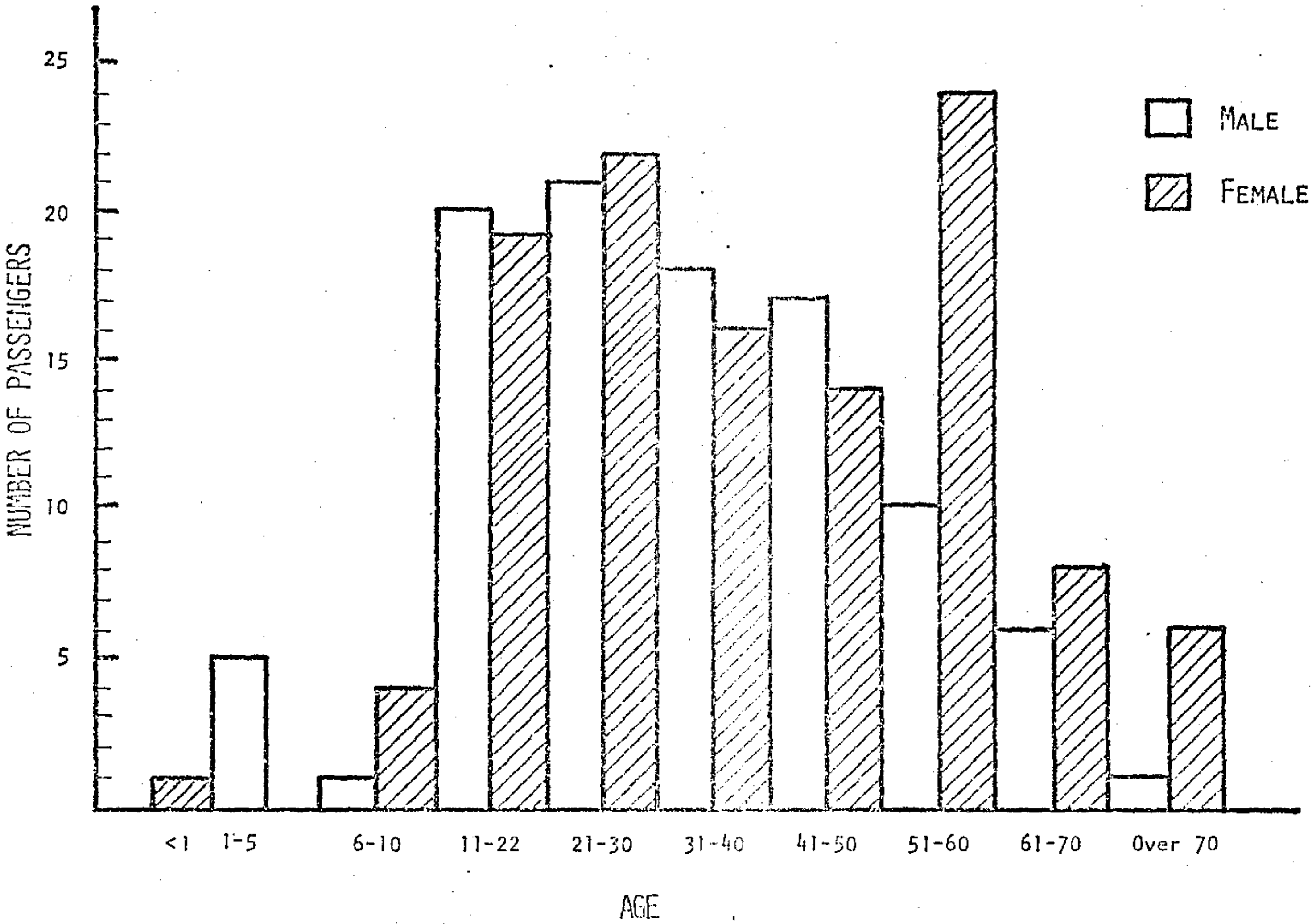

FIGURE 1. DISTRIBUTION OF MALES & FEMALES INJURED IN 14 SELECTED INTERCITY BUS ACCIDENTS

The 1973/1974 Accidents of Motor Carriers of Passengers published by the Bureau of Motor Carrier Safety (BMCS, 1976) states for 1973 that there were 753 bus accidents resulting in 103 fatalities and 2,370 injuries. For 1974 there were 699 bus accidents resulting in 75 fatalities and 2,134 injuries. Statistics from the 1975 Accidents of Motor Carriers of Passengers (BMCS, 1977) show that of 750 bus accidents there were a total of 57 killed and 2,128 injured.

The actual number of fatalities which can be attributed to an inability to escape from the bus is not known, nor is the percentage of injuries sustained during bus escape as opposed to those incurred during the collision phase. This deficiency in the data obtained as a result of investigation of these accidents should be considered in establishing the accident investigation procedures to be followed. It is suggested that it is both feasible and desirable to acquire the additional information needed to better document problems of evacuation in bus accidents.

The data available for bus accidents can therefore be summarized by stating that some bus accidents which have been the subject of in-depth investigations do demonstrate that problems of post-crash evacuation can occur. However, the typical bus accident investigation does not produce complete enough information to permit an analysis of post-crash evacuation problems for all accidents.

Any analysis of post-crash bus evacuation problems must be considered within the overall context of bus safety. An examination of bus safety during the crash and post-crash phases of an accident produces what appears to be contradictory requirements, i.e. bus passengers should be prevented from being ejected during the crash and yet be able to evacuate rapidly during the post-crash phase of the accident.

Federal Motor Vehicle Safety Standard 217 (NHTSA, 1973) addresses the related problems of bus window retention and release. The purpose of this Standard is "to minimize the likelihood of occupants being thrown from the bus and to provide a means of readily accessible emergency egress". A study performed by the All American Engineering Company (1968) for the NHSB showed that the friction-type latches commonly used on buses, at that time to secure push-out windows were inadequate. It was also concluded that friction-type latches which prevented push-out windows from opening during a crash would be too difficult to open when the window was used for emergency egress. The provisions of FMVSS 217 establish a force limit of 1200 pounds for window retention, using a standard test procedure in an attempt to prevent ejection during a crash. The Standard also establishes limits of 20 and 60 pounds, respectively for the force required to open a push-out type window used for emergency egress. While not specifying the type of latch to be used, these two specifications in the Standard are intended to resolve the conflict between retention and release of bus push-out windows. The Standard further establishes a minimum number of square inches of unobstructed opening per passenger; the distribution of exit area on each side of the bus; the requirement of a rear exit or roof hatch; standards for identification and operation of exits.

The Oklahoma University Research Institute (OURI, 1972) reviewed FMVSS217 when it was proceeding through the rule making phases prior to becoming effective in 1973. The comments about the Standard were based on bus evacuation studies completed during 1971 and 1972. It was concluded that FMVSS217 represented a definite step forward in assuring escape worthiness, and also that additional provisions should be included in a revised Standard. The suggestions for changes were as follows:

1. The maximum allowable force of 60 pounds for opening an emergency exit should be reviewed. Data was presented to show that a sample of healthy adult females could not produce a force greater than 35 pounds.

2. Push-out windows serving as emergency exits should be required to include a method for keeping them open after they have been initially opened. The reason for this suggestion was that windows falling back on passengers egressing impede egress and can also produce injuries.

Another problem noted in the report by OURI (1972) was the potential for injury to bus passengers when the escape exit used is 7-8 feet above ground level. A passenger escaping through a push-out window with the bus upright, must get into the window while pushing out against a window hinged at the top which can weigh up to 47 pounds. He or she must then drop or jump to the ground below which can be up to seven feet, two inches below. If the bus is on the side and a passenger must use the side window which is overhead as an escape route, he or she must climb up on the back of the seats or the luggage rack, push the heavy window open and then climb out of the bus. Once on the side of the bus, the passenger must jump or climb approximately eight feet to the ground below. Because this problem was recognized as an important aspect of emergency evacuation, special emphasis was given in the literature search to this area.

Recognizing that there are some similarities between aircraft evacuation and bus evacuation, FAA personnel in Oklahoma City were contacted to determine if useful data existed on aircraft evacuation. It was determined that the Civil Aeronautical Medical Institute Biomedical Data Bank includes material gathered from the National Transportation Safety Board and FAA files for the years 1970 - 1974, on 23 planned evacuations and 62 unplanned evacuations of aircraft. In the 23 planned evacuation tests were a total of 74 minor injuries and 14 serious injuries. For the 62 unplanned evacuations there were 158 minor injuries and 63 serious injuries.

An unplanned evacuation occurred on April 1, 1971 of a Transworld Airlines Boeing 727. Several of the passengers evacuated via the window exits and jumped from the left wing the distance of nine to ten feet to the ground. One passenger fractured both legs, two sustained left ankle fractures, a man fractured his left heel and the only woman jumping sustained an ankle fracture.

Shortly before noon on July 11, 1961, a Douglas DC-8 crash-landed at Denver. Initially evacuation through an aft door proceeded at a rapid rate. After a few moments however, ground fire destroyed the evacuation slide and forced the remaining passengers to jump about six and one-half feet to the ground. Survivors stated later that the evacuation then slowed due to the hesitation of many passengers to jump with fire below. A review of the statements reveals that of the 18 passengers who jumped to the ground, six sustained fractures as a result of the jumping.

A united Airlines Boeing 727 crash landed at Salt Lake City on November 11, 1965. Egress from this accident required nine passengers to jump six and one-half feet to the ground. Five of these passengers sustained fractures to the lower extremeties as a result of jumping to the concrete taxi way.

From this limited sample of persons jumping from heights which could be encountered in escaping from a bus after a crash, it can be seen that approximately 40 percent sustained fractures.

After further searching for data which could be used to predict the problems encountered in jumping from a bus during emergency evacuation, it was determined that a large data bank existed for persons involved in a variety of falls or jumps. Dr. Richard G. Snyder, The Highway Safety Research Institute, The University of Michigan has collected data on approximately 32,000 free-falls and jumps over a period of many years. These data were collected through investigation of jumps and falls which were reported in newspapers. A clipping service was employed to identify the parties and/or location of these accidents which were investigated. The accidents therefore represent those which were considered "newsworthy", either because of the injury involved, the lack of injury in relation to the height of the fall or because of the unusual circumstances of the fall. The data base is therefore likely to be biased, but the degree of bias cannot be readily estimated. However, it would be expected that the data is biased in favor of more injuries for a given height of fall when compared to a random sample. Nevertheless, this data represents the most comprehensive sample available for analysis and will therefore be presented as an aid in assessing the injury potential which exists in making an emergency evacuation of a bus.

The most appropriate type of data for application to the question of injury potential in evacuating an overturned bus where passengers may jump from a height of eight feet or more would be data for jumps only, excluding the data for falls. However, this type of data is quite limited, since most people, especially older adults, will not willingly jump from such heights without significant coercion, such as a fire underneath them in the bus. It is also possible that some passengers may fall from the top side of an overturned bus if the evacuation takes place during darkness because they lose their footing. With this explanation of the data it can be seen that it will be skewed toward more injuries involving the head or back and less involving the lower limbs.

The data could not be analyzed to separate falls versus jumps since this information was available for only a small percentage of the cases investigated.

A preliminary screening of the data for all falls or jumps from a height of eleven feet or less was accomplished by HSRI and the data mailed to the University of Oklahoma. This screening produced a total of 1,563 cases for heights of 11 feet or less. A review of this data by the University of Oklahoma produced a total of 356 cases which had occurred from heights of eight feet or less that were documented well enough to determine the type of surface on which the person had fallen or jumped. A total of 80 persons had fallen or jumped onto the ground, while 276 had fallen or jumped onto cement or asphalt.

An analysis of the 80 falls or jumps onto the ground is presented in Table 2. The persons falling or jumping ranged in age from 3-83 years, with a mean age of 48 years. The data for persons jumping or falling onto concrete or asphalt is shown in Table 3.

A comparison of the data for persons falling or jumping onto the ground, versus concrete or asphalt shows that a higher percentage (9.6%, vs. 23.7%) of fatalities occurred when the surface was concrete or asphalt. The percentage of minor and moderate injuries was also much less when jumping or falling onto ground versus asphalt or concrete (75% vs. 57%).

TABLE 2. INJURIES TO PERSONS FALLING OR JUMPING ONTO GROUND FROM HEIGHTS OF EIGHT FEET OR LESS

	Number of Persons of Each Severity Level							
Part of Body Injured	None*	Minor	Moderate	Severe	Serious	Critical	Fatal	Total
Head		7	2	1	1		6	17
Neck				3				3
Face								
Chest		4	2					6
Abdomen		6	10					16
Pelvis								
Extremities		10	13	5				28
Unknown		1			1		1	3
TOTAL		28	27	9	2		7	73

*Seven (7) falls resulted in no injuries.

TABLE 3. INJURIES TO PERSONS FALLING OR JUMPING ONTO CONCRETE OR ASPHALT FROM HEIGHT OF EIGHT FEET OF LESS

Part of Body Injured	Number of Persons of Each Severity Level						
	Minor	Moderate	Severe	Serious	Critical	Fatal	Total
Head	26	45	11	4	3	45	134
Neck		3	1			1	5
Face							
Chest	3	6	1			2	12
Abdomen	8	6	6	1	2	1	24
Pelvis	1			4			5
Extremities	25	28	11				64
Unknown	1					12	13
Total	64	88	30	9	5	61	257

*Nineteen falls or jumps resulted in no injuries.

If all of the data presented for jumps and falls is considered in relation to the evacuation of an intercity bus after a crash, some insight is provided regarding the potential for injury during an evacuation. It seems clear that there is a significant potential for serious injury when escaping passengers jump or fall from heights similar to what would be encountered in escaping from a bus window or from the side of an overturned bus. This statement is made with the acknowledgement that the data analyzed may be somewhat biased, because of the manner in which it was collected and also that bus passengers may be less susceptible to injury because they are jumping rather than falling from the window of an upright bus or the side of an overturned bus. However, it can be argued that the principal difference between falling and jumping would be the addition of more fractures to the lower extremities and the deletion of a like number of head or back injuries.

This chapter has presented information related to bus evacuation from a number of viewpoints. The following chapter contains a description of the methodology followed for the empirical study of bus evacuation.

III. METHODOLOGY

Subjects

Bus Passenger Profile: Task B of the contract required that direct observation at bus terminals or bus companies be used to develop data for the intercity bus passenger characteristics of age, sex, type of clothing, weight and height. An effort was initiated in January, 1977 to obtain bus passenger data with respect to these variables. Four observers were selected and trained in order to estimate these variables from observation and enter their estimates appropriately on the data collection instrument as shown in Figure 2. Upon completion of two weeks training, the observers were examined for accuracy and were found to be sufficiently reliable. The observers then collected data on 959 intercity bus passengers at the Oklahoma City bus depot during mornings, afternoons and evenings for the month of February, 1977. The tabulation of observations appear in Table 4. Table 5 shows the percentage of males and females observed riding intercity buses versus their age group for 10 age categories. These data are also presented graphically in Figures 3, 4 and 5. For the 959 random observations, 46.9 percent were male and 53.1 percent were female. Table 6 presents the distribution of 17 categories of height versus sex and Table 7 presents the 12 categories of weight versus sex. Figures 6, 7, 8, 9, 10 and 11 present histograms of the data contained in Tables 6 and 7. Table 8 shows the percentage of passengers observed to be wearing or carrying some form of coat.

Using 40 bus passengers to represent a typical load, the passenger characteristics observed were used to determine a representative passenger load of this size. Table 9 shows the percentage make-up of males and females with respect to age category for a 40 passenger load. The values in Table 9 are the exact values which would be needed to perfectly duplicate the distribution obtained from the 959 observations at the bus terminal. Since passenger numbers must be integers, the data in Table 9 was rounded to the values shown in Table 10. These proportions of subjects were utilized during the experimental trials. This selection process produced some categories with only one or two persons in the category. An attempt was then made to choose subjects in these categories such that their height and weight were near the mean values of these characteristics. Where larger numbers of people comprised an age and sex category, an attempt was made to obtain a representative sample of heights and weights.

Human Subject Use: The University of Oklahoma operates under a Health, Education and Welfare General Assurance for the protection of human subjects involved in research conducted by the University. A statement of the experimental protocol, risks and benefits of the research and a statement of Informed Consent were prepared for review by the Human Experimentation Control Committee of the University. The Committee reviewed the proposed research and expressed concern for the safety of the subjects over fifty years of age. The principal investigator stated that he believed the scaffold alongside the overturned bus to help subjects to the ground was adequate, but that as an extra precaution, he would station research assistants so they could assist older subjects

Date:____________________ TIME:____________________ BUS DESTINATION:______________________________

SEX		AGE										HEIGHT																	WEIGHT												CLTHG		
Male	Female	Infants	1-5	6-10	11-22	21-30	31-40	41-50	51-60	61-70	> 70	-20"	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-62	63-64	65-66	67-68	69-70	71-72	73-74	> 74	-20 lb	21-40	41-60	61-80	81-100	101-120	121-140	141-160	161-180	181-200	201-220	> 220	HVY COAT	LT COAT	NONE

Observer: ____________________

FIGURE 2. DATA COLLECTION INSTRUMENT FOR BUS PASSENGER PROFILE

TABLE 4. BUS PASSENGER PROFILE - SUMMARY OF OBSERVATIONS (N = 959)

CATEGORIES		M	F	Total
AGE	Infants	-	4	4
	1- 5	8	18	26
	6-10	15	11	26
	11-20	56	83	139
	21-30	134	137	271
	31-40	61	73	134
	41-50	55	51	106
	51-60	49	60	109
	61-70	52	49	101
	>70	20	23	43
HEIGHT	-20"	1	4	5
	21-25	5	9	16
	26-30	5	7	12
	31-35	4	1	5
	36-40	3	7	10
	41-45	2	2	4
	46-50	6	7	13
	51-55	1	8	9
	56-60	6	76	82
	61-62	17	244	261
	63-64	39	100	139
	65-66	84	29	113
	67-68	134	7	141
	69-70	112	5	117
	71-72	22	2	24
	73-74	6	1	7
	>74	3	-	3
WEIGHT	-20 lb.	1	6	7
	21-40	10	9	19
	41-60	3	6	9
	61-80	8	10	18
	81-100	6	28	34
	101-120	23	171	194
	121-140	100	170	270
	141-160	144	64	208
	161-180	105	21	126
	181-200	39	12	51
	201-220	9	4	13
	>220	2	8	10
CLTHG	HVY COAT	104	112	216
	LT COAT	147	208	355
	NONE	190	189	388

TABLE 5. 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
Percentage Total	46.9	53.1	100.0

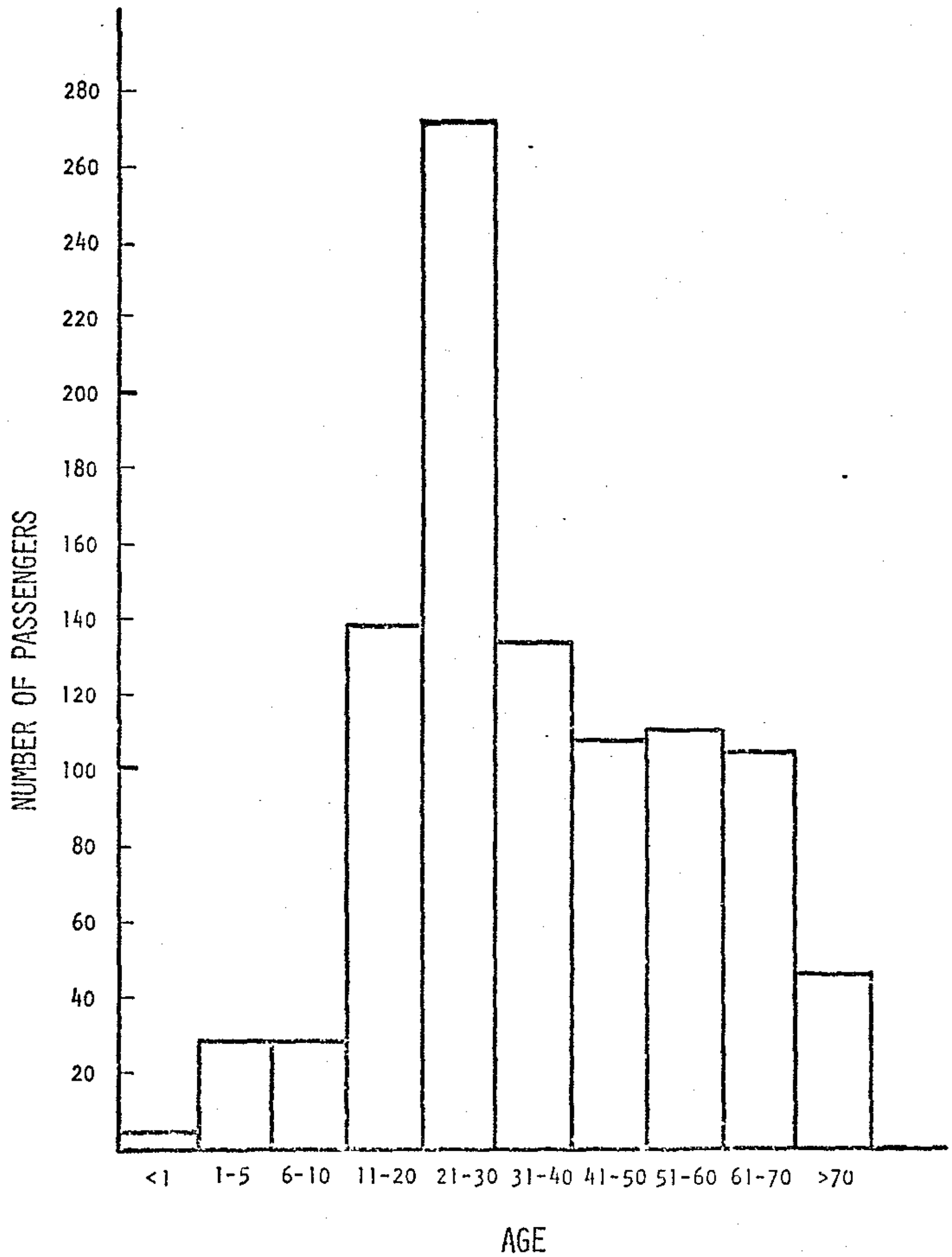

FIGURE 3. AGE DISTRIBUTION OF PASSENGERS OBSERVED RIDING INTERCITY BUSES (N=959)

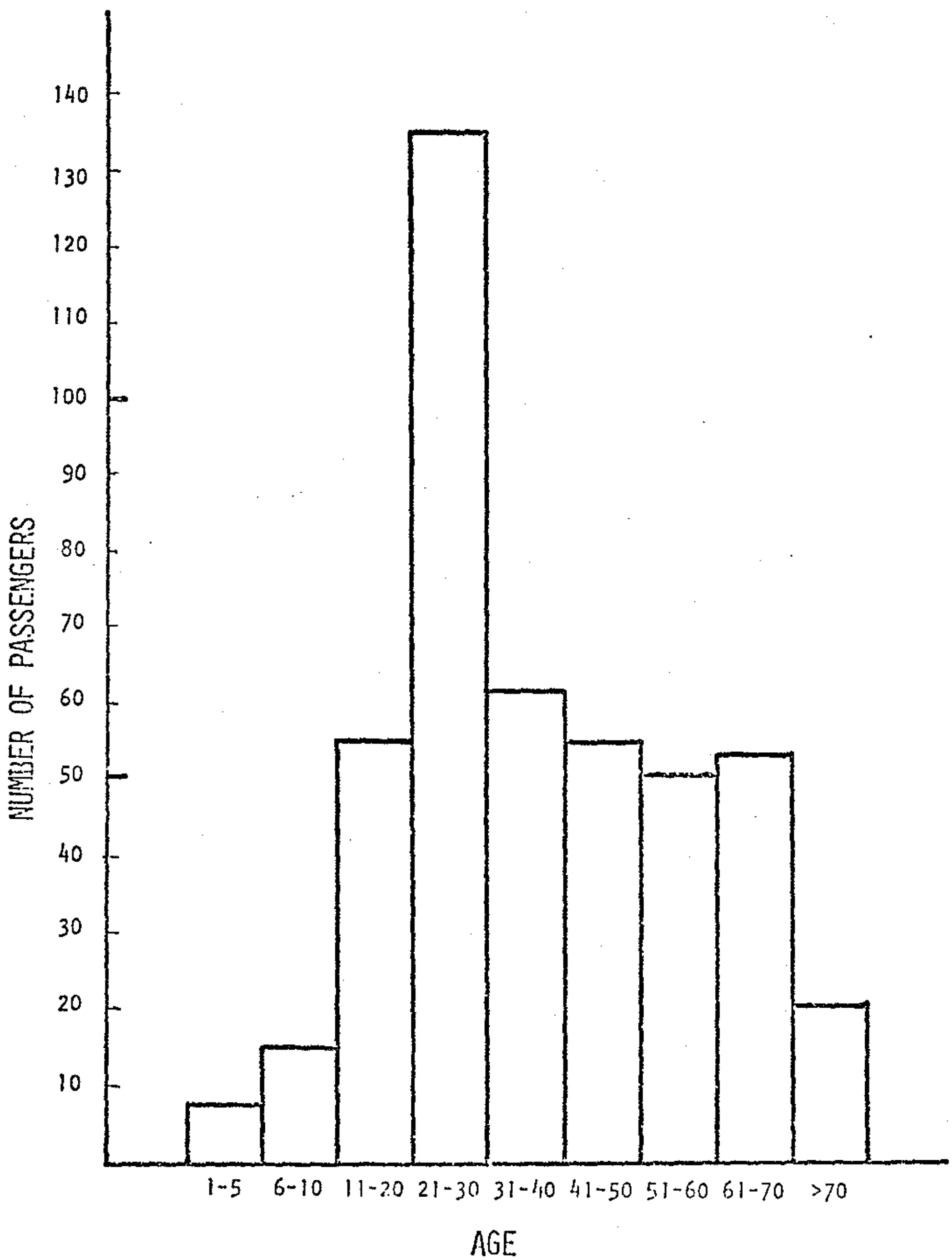

FIGURE 4. AGE DISTRIBUTION OF MALE PASSENGERS OBSERVED RIDING INTERCITY BUSES (N-959)

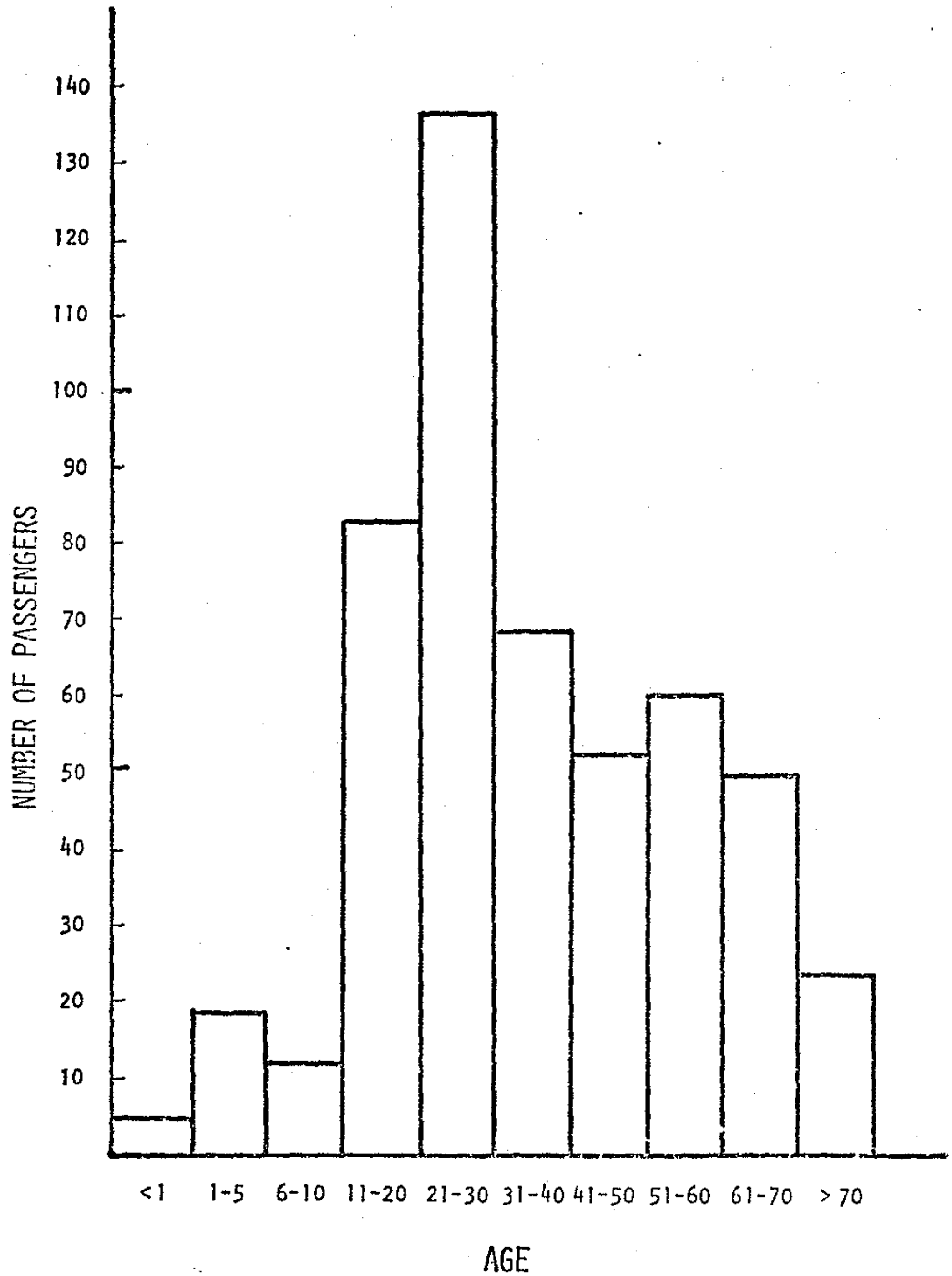

FIGURE 5. AGE DISTRIBUTION OF FEMALE PASSENGERS OBSERVED RIDING INTERCITY BUSES (N=959)

TABLE 6. PERCENTAGE OF MALES/FEMALES VERSUS HEIGHT CATEGORIES FOR PASSENGERS OBSERVED RIDING INTERCITY BUSES (N=959)

HEIGHT RANGE	MALE	FEMALE	MALES & FEMALES
Under 21"	.1	.4	.5
21" - 25"	.5	.9	1.4
26" - 30"	.5	.7	1.2
31" - 35"	.4	.1	.5
36" - 40"	.3	.7	1.0
41" - 45"	.2	.2	.4
46" - 50"	.6	.7	1.3
51" - 55"	.1	.8	.9
56" - 60"	.6	7.9	8.5
61" - 62"	1.8	25.4	27.2
63" - 64"	4.1	10.4	14.5
65" - 66"	8.6	3.0	11.6
67" - 68"	14.0	.7	14.7
69" - 70"	11.7	.5	12.2
71" - 72"	2.3	.2	2.5
73" - 74"	.6	.1	.7
Over 74"	.3	0	.3

TABLE 7. PERCENTAGE OF MALES/FEMALES VERSUS WEIGHT CATEGORIES FOR PASSENGERS OBSERVED RIDING INTERCITY BUSES (N =959)

WEIGHT RANGE	MALE	FEMALE	MALE & FEMALE
Under 20 Lbs.	.1	.6	.7
21-40 Lbs.	1.0	.9	1.9
41-60 Lbs.	.3	.6	.9
61-80 Lbs.	.8	1.0	1.8
81-100 Lbs.	.6	2.9	3.5
101-120 Lbs.	2.4	17.8	20.2
121-140 Lbs.	10.4	17.8	27.8
141-160 Lbs.	15.0	6.7	21.7
161-180 Lbs.	10.9	2.2	13.1
181-200 Lbs.	4.1	1.3	5.4
201-220 Lbs.	.9	.4	1.3
Over 220 Lbs.	.2	.8	1.0

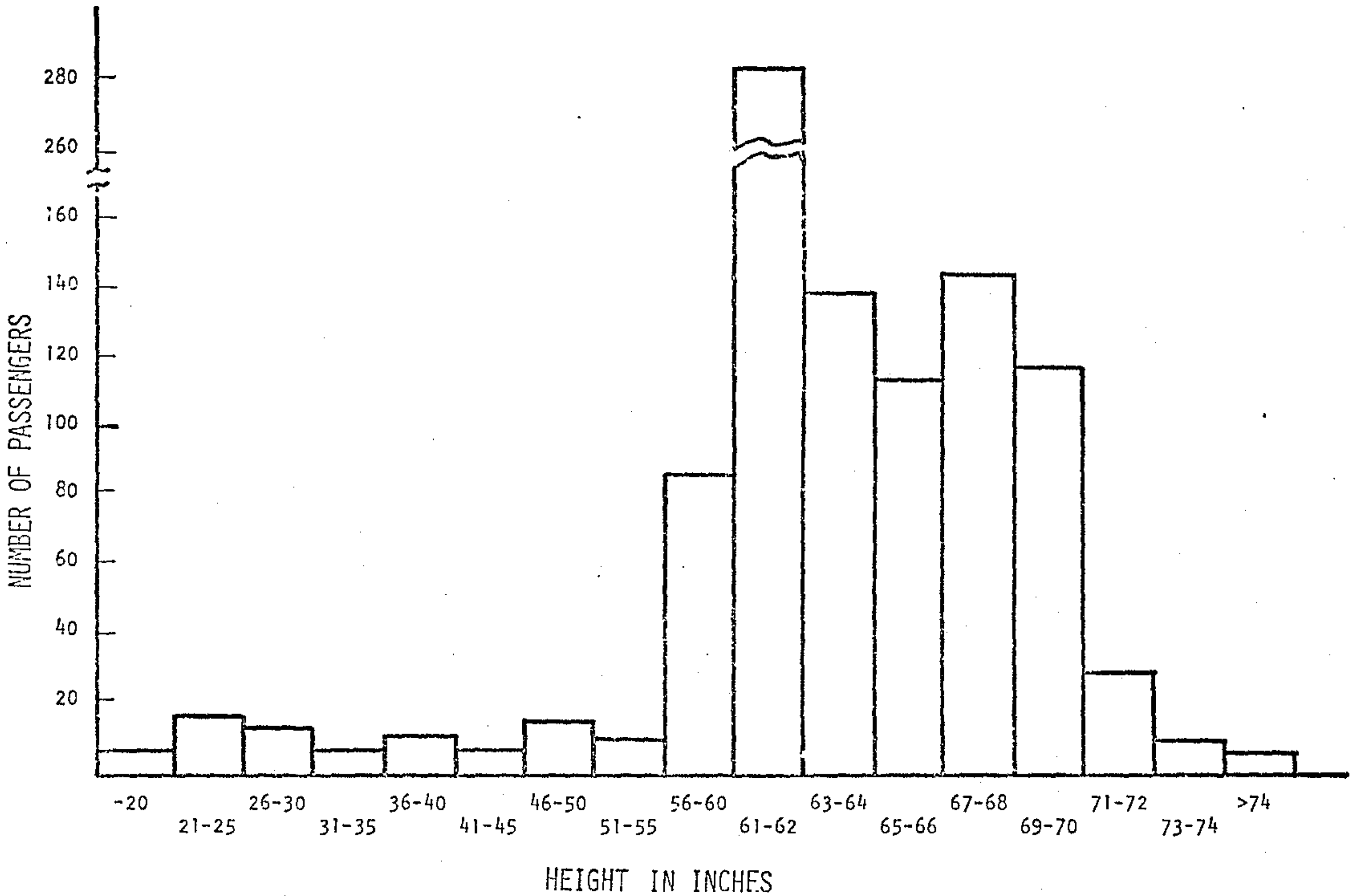

FIGURE 6. HEIGHT DISTRIBUTION OF PASSENGERS OBSERVED RIDING INTERCITY BUSES (N=959)

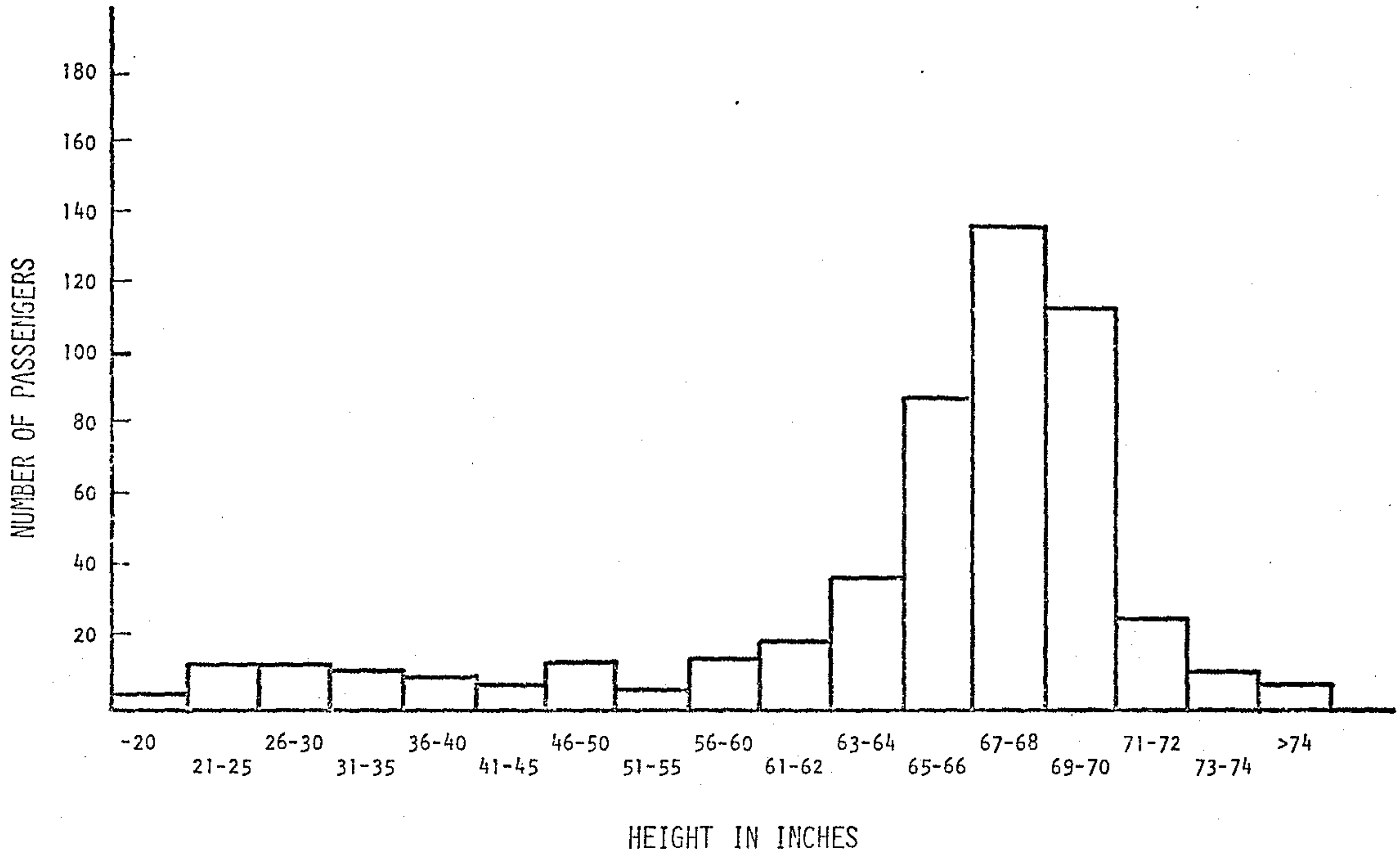

FIGURE 7. HEIGHT DISTRIBUTION OF MALE PASSENGERS
OBSERVED RIDING INTERCITY BUSES (N=959)

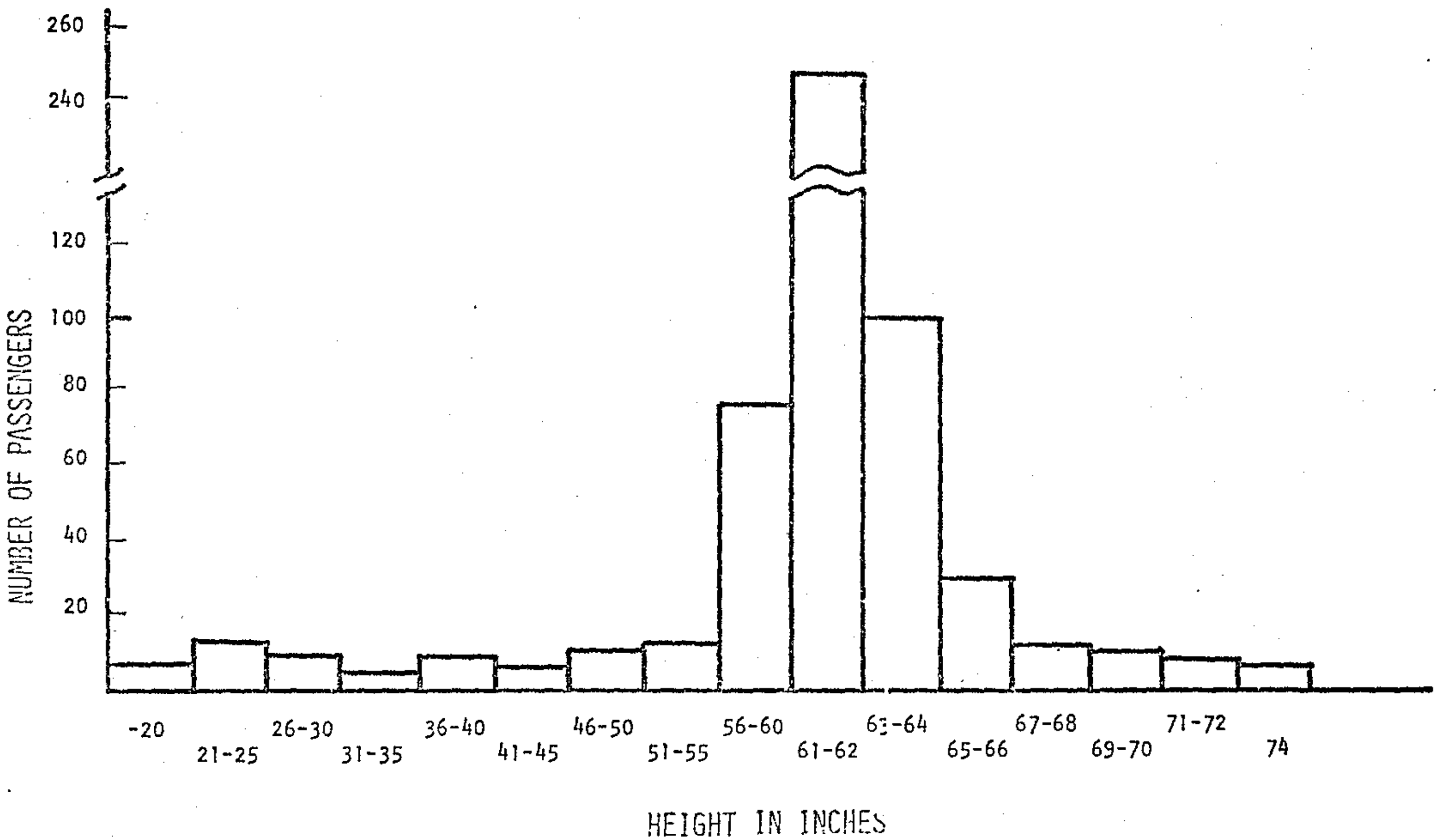

FIGURE 8. HEIGHT DISTRIBUTION OF FEMALE PASSENGERS OBSERVED RIDING INTERCITY BUSES (N=959)

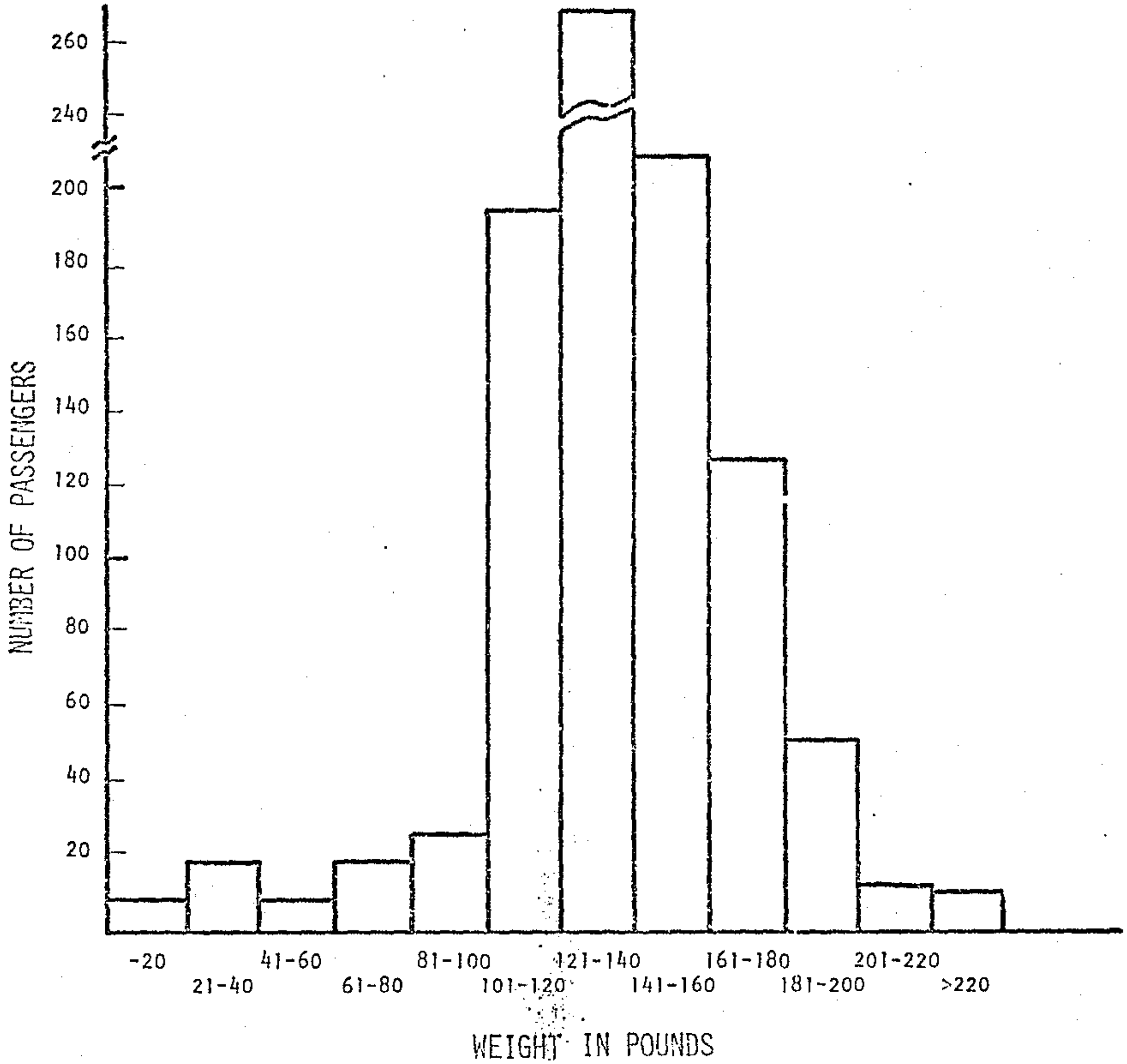

FIGURE 9. WEIGHT DISTRIBUTION OF PASSENGERS OBSERVED RIDING INTERCITY BUSES (N=959)

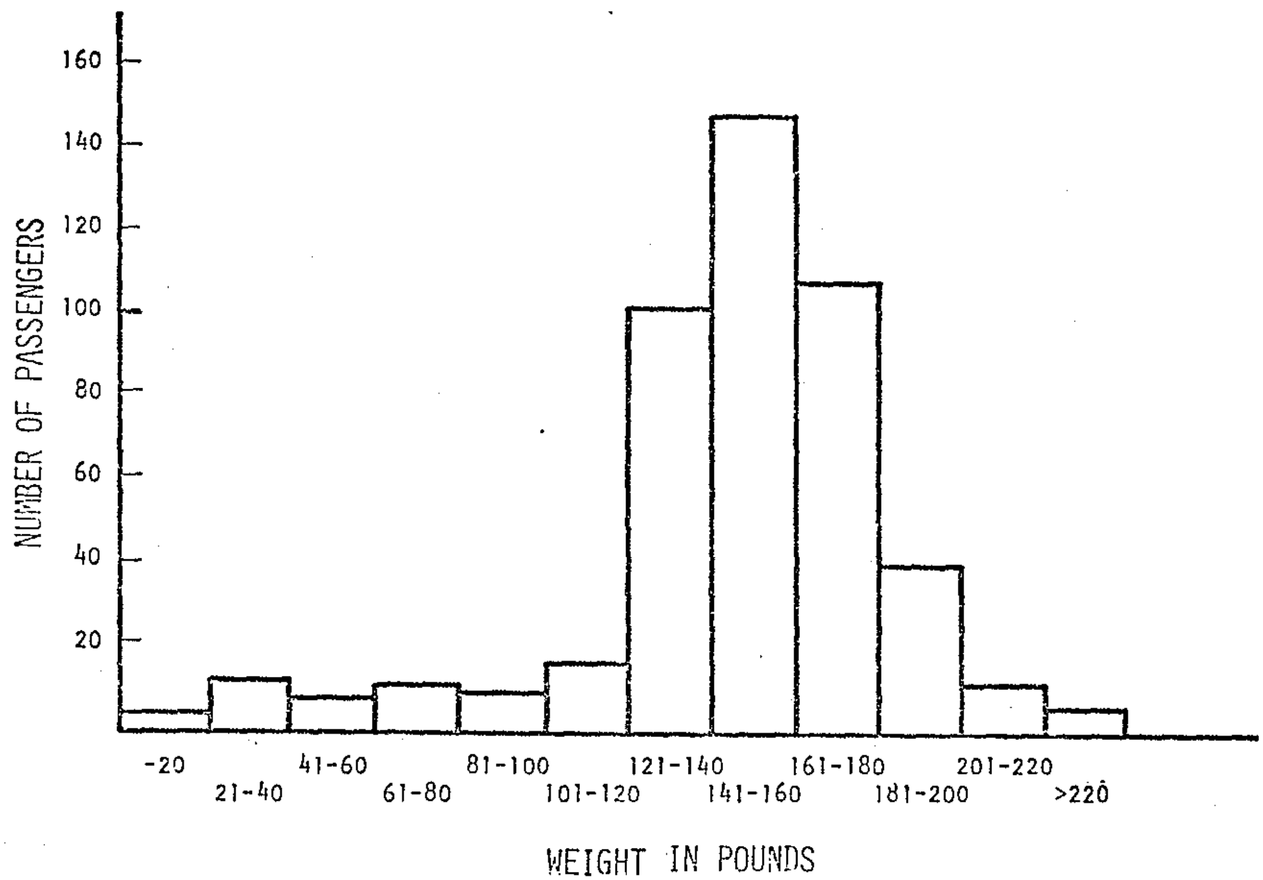

FIGURE 10. WEIGHT DISTRIBUTION OF MALE PASSENGERS OBSERVED RIDING INTERCITY BUSES (N=959)

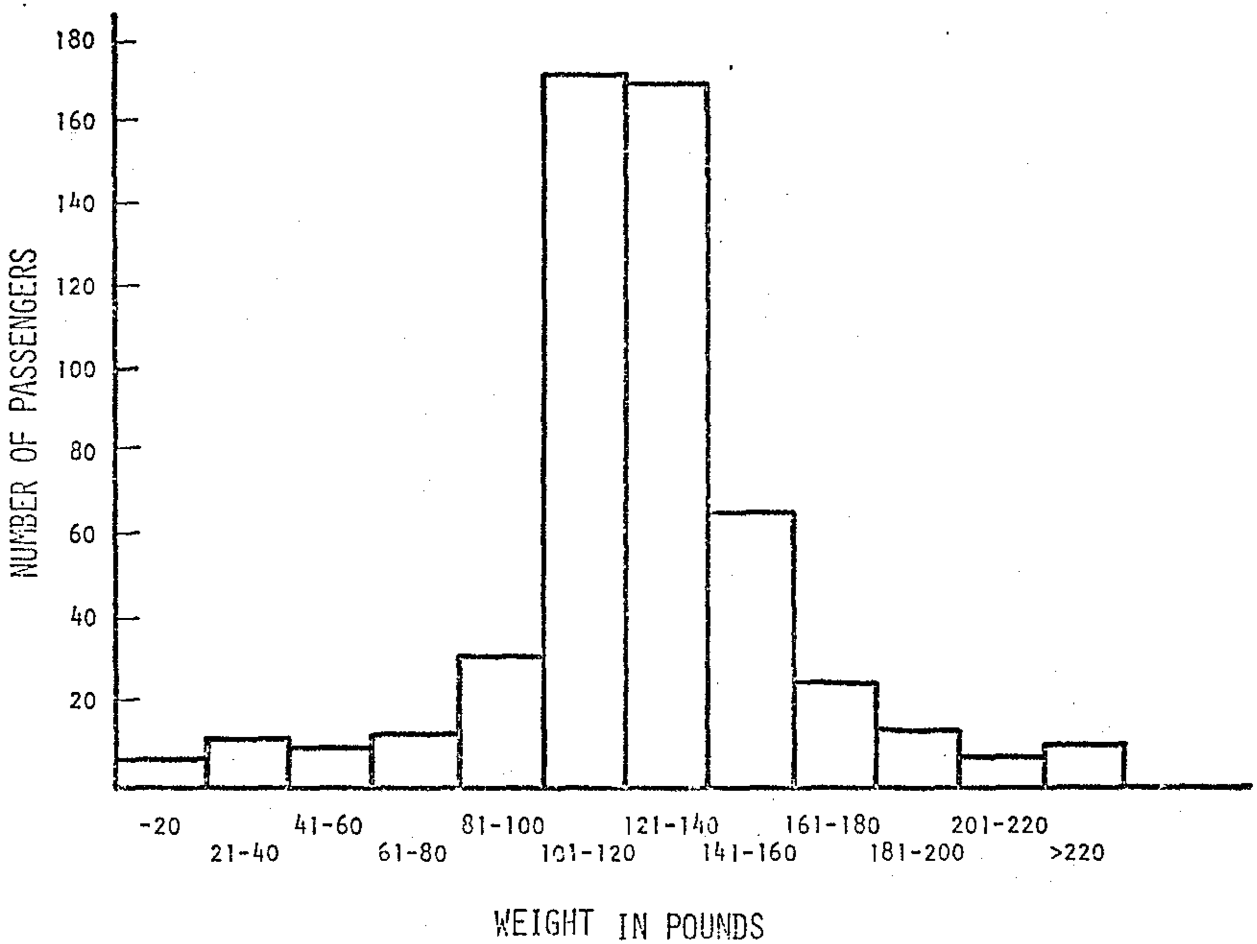

FIGURE 11. WEIGHT DISTIRUBTION OF FEMALE PASSENGERS OBSERVED RIDING INTERCITY BUSES (N=959)

TABLE 8. PERCENTAGE OF MALES/FEMALES VERSUS COAT CATEGORIES FOR PASSENGERS OBSERVED RIDING INTERCITY BUSES (N=959)

COAT CATEGORY	MALE	FEMALE	MALE & FEMALE
Heavy Coat	10.8	11.7	22.5
Light Coat	15.3	21.7	37.0
No Coat	20.8	19.7	40.5

(For Feb. - Mar. 1977 At Oklahoma City)

TABLE 9. PREDICTED PERCENTAGE OF MALES/FEMALES VERSUS AGE FOR A BUS LOAD OF FORTY PASSENGERS

AGE RANGE	MALE	FEMALE
Infants	0	.18
1-5	.36	.86
6-10	.73	.50
11-20	2.64	3.95
21-30	6.36	6.50
31-40	2.91	1.32
41-50	2.59	2.41
51-60	2.32	2.86
61-70	2.45	2.32
Over 70	.95	1.09

TABLE 10. SUGGESTED NUMBER OF PASSENGERS FOR ESCAPE TESTS BY AGE CATEGORY AND SEX TO DUPLICATE THE DISTRIBUTION FOUND FROM 959 OBSERVATIONS

AGE GROUP	# of MALES	# of FEMALES
Infants	0	0
1-10	1	1
11-20	3	4
21-30	6	6
31-40	3	1
41-50	2	2
51-60	2	3
61-70	2	2
Over 70	1	1
	20	20

quickly should any fall and injure themselves. The principal investigator reiterated that a fully equipped ambulance would be on standby at the evacuation site and a registered nurse available to treat any injuries. The Committee then approved the research protocol and the statement of informed consent to be signed by each subject.

A copy of this statement of informed consent as well as a copy of the film rights waiver completed for all subjects appear in the Appendix. The Appendix also includes a subject information sheet which was utilized for recording anthropometric measurements as well as administrative controls.

Anthropometry and Subject Match: On the morning of the escape trials, each subject who was to participate in the evacuations was examined to determine his hip breadth, shoulder breadth, height, weight, age and sex. These data were recorded on the subject information sheet by research assistants. The 135 subjects provided a very good match with the bus passenger profile distribution for the parameters of age and sex. This match was the primary consideration during the subject recruitment phase of the study. There was variability among the three subject groups of 45 people each, and this variability may be discerned from Tables 11, 12 and 13. These tables exhibit the number of subjects within each group for the parameters of age, weight, and height for males and females.

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 overturned on its right side so that the front door was blocked. It should be noted that this was not the worst case in the literal sense in that extreme structural damage was not included nor was the condition such that the bus might rest against another large vehicle, enbankment or wall which could block the front windshield or overhead escape avenues. 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.

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.

TABLE 11. 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 MALES/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
over 70	0	0	1	0	1	0

TABLE 12. NUMBER OF MALE AND FEMALE SUBJECTS BY WEIGHT INTERVALS FOR THE THREE TEST GROUPS

WEIGHT IN POUNDS	GROUP I MALES/FEMALES		GROUP II MALES/FEMALES		GROUP III MALES/FEMALES	
41- 60	1	0	2	1	2	0
61- 80	0	2	0	1	1	2
81-100	1	0	0	0	1	2
101-120	3	6	0	3	0	3
121-140	1	8	2	10	2	7
141-160	3	5	7	5	2	7
161-180	3	4	4	1	7	1
181-200	4	0	7	1	4	1
201-220	3	0	0	0	2	1
over 220	1	0	0	0	1	0

TABLE 13. NUMBER OF MALE AND FEMALE SUBJECTS BY HEIGHT INTERVALS FOR THE THREE TEST GROUPS

HEIGHT IN INCHES	GROUP I MALES/FEMALES		GROUP II MALES/FEMALES		GROUP III MALES/FEMALES	
41-45	0	0	2	0	0	0
46-50	1	0	0	1	2	0
51-55	0	1	0	0	0	1
56-50	1	1	0	1	1	1
61-62	1	2	0	2	0	1
63-64	1	7	0	7	1	6
65-66	0	6	1	3	1	8
67-68	1	6	2	6	1	3
69-70	5	1	10	3	4	3
71-72	6	1	3	0	7	0
73-74	3	0	1	0	1	0
over 74	1	0	3	0	4	0

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 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 various 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 primary independent variables can be related to the design features of the bus, the personal characteristics of the subjects acting as passengers and the physical environment in which the tests were conducted.

1. Vehicle--The principle variable related to escape is the quality of the exits; such as their number, size, location, markings or identifications for their employment and the forces required for their utilization. Other variables such as seat location and design, height of exit above ground level, provisions for emergency lighting and the attitude of the bus are all a function of the vehicle design.

2. Passengers--Two sets of variables which can be distinguished when the effects of passenger escape time are analyzed; one set of variables include such things which are deterministic such as age, sex, anthropometric dimensions, weight and total number of passengers. The other set of variables included those which are probabalistic in their effect on escape time such as panic, injury sustained, and previous escape drills. Other factors such as the arrangement of passengers in the bus could also have an effect on total escape times.

3. Environment--Variables within the environment which could have influenced the post-crash escape activity considered were darkness, obstructions to the escape routes, and the availability of aid to those escaping passengers who required help.

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

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

Manufacturer: General Motors Coach Division

Type: Model PD-4107 (Figure 12)

Condition: Used, in normal service, purchased for conducting the experimental study

Capacity: 45 passengers (no lavatory)

Emergency Exits: Eight pushout windows, 28 inches high and 71 inches wide, with four windows on each side of the bus. These windows were fitted with positive mechanical latches by The University of Oklahoma Engineering Shop in order to bring the windows in compliance with FMVSS-217 retention requirements (Figures 13 and 14). The windows were then operable by lifting a push bar and pushing against secondary friction latches. The height of the window sills was six feet above ground level for the upright bus. One emergency exit roof hatch equipped with a popout plexiglass insert measuring 21½ inches by 19½ inches was located in the rear roof of the bus (Figure 15). The bus door, when available for egress, afforded a 28 inches by 7 feet opening. Two windshield sections, each of which was retained by rubber molding which allowed for their being kicked out by the occupants provided a 42½ inches wide by 32 inches 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 (Figure 16) 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. The timers (Figure 17) had a 10 inch face; where one revolution occurred every one tenth of a minute. The timers were synchronized with the siren and signal lamp.

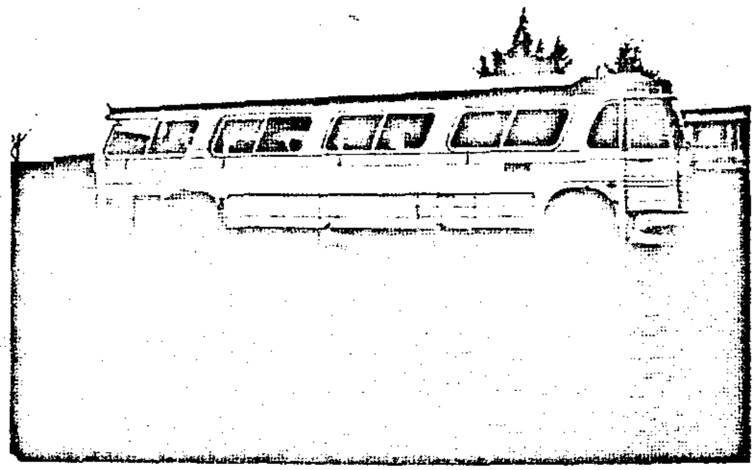

FIGURE 12. VIEW OF GMC INTERCITY BUS
EMPLOYED FOR TESTS

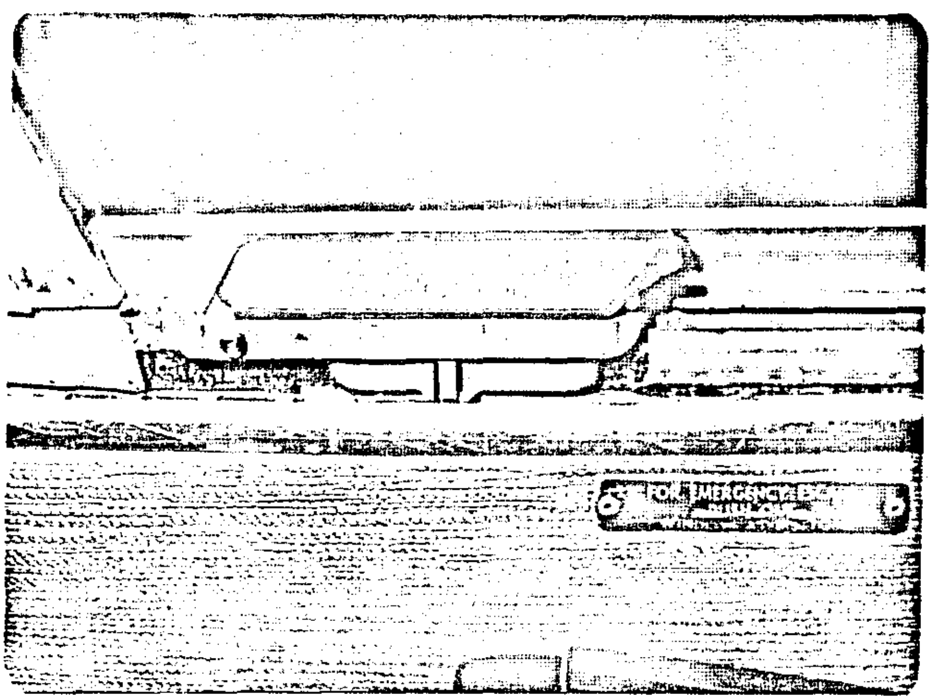

FIGURE 13. VIEW OF BUS
WINDOW LATCH CLOSED

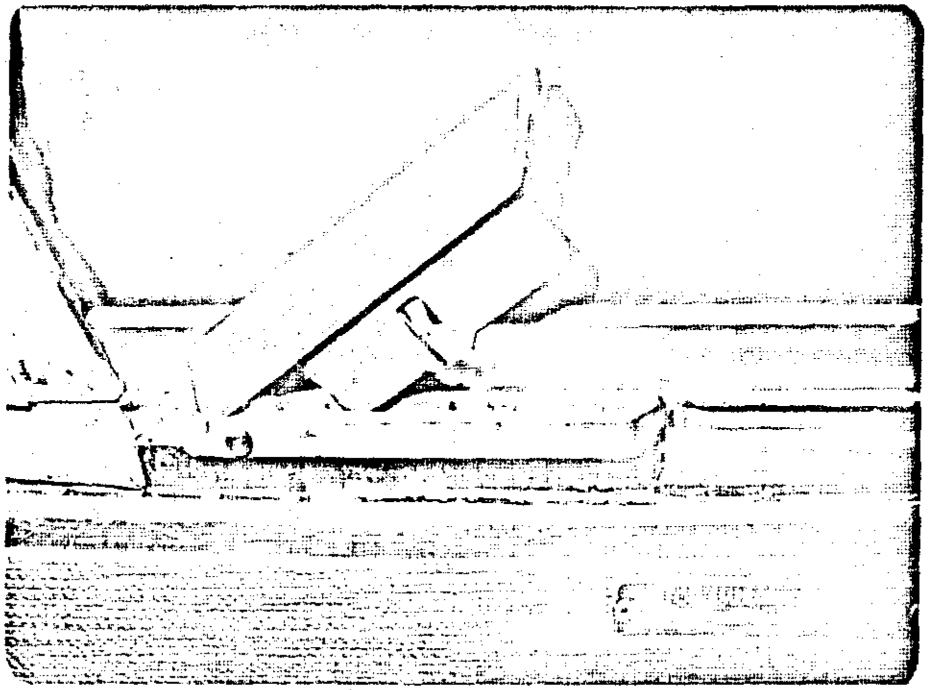

FIGURE 14. VIEW OF BUS
WINDOW LATCH OPENED

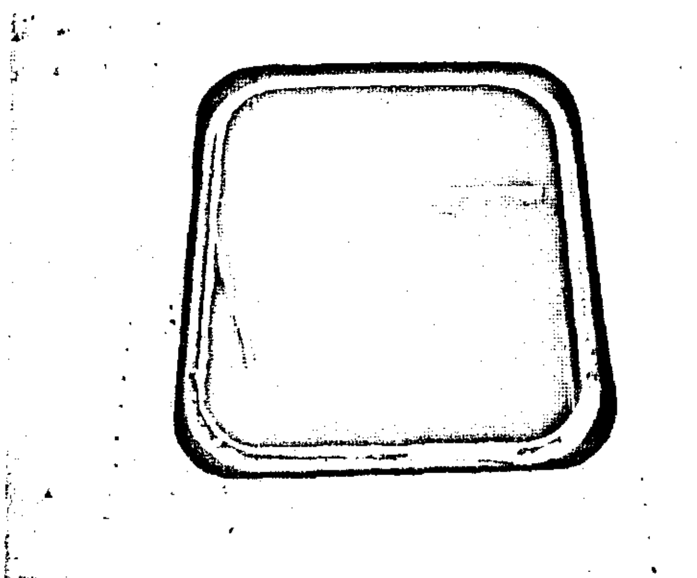

FIGURE 15. VIEW OF EMERGENCY
EXIT ROOF HATCH

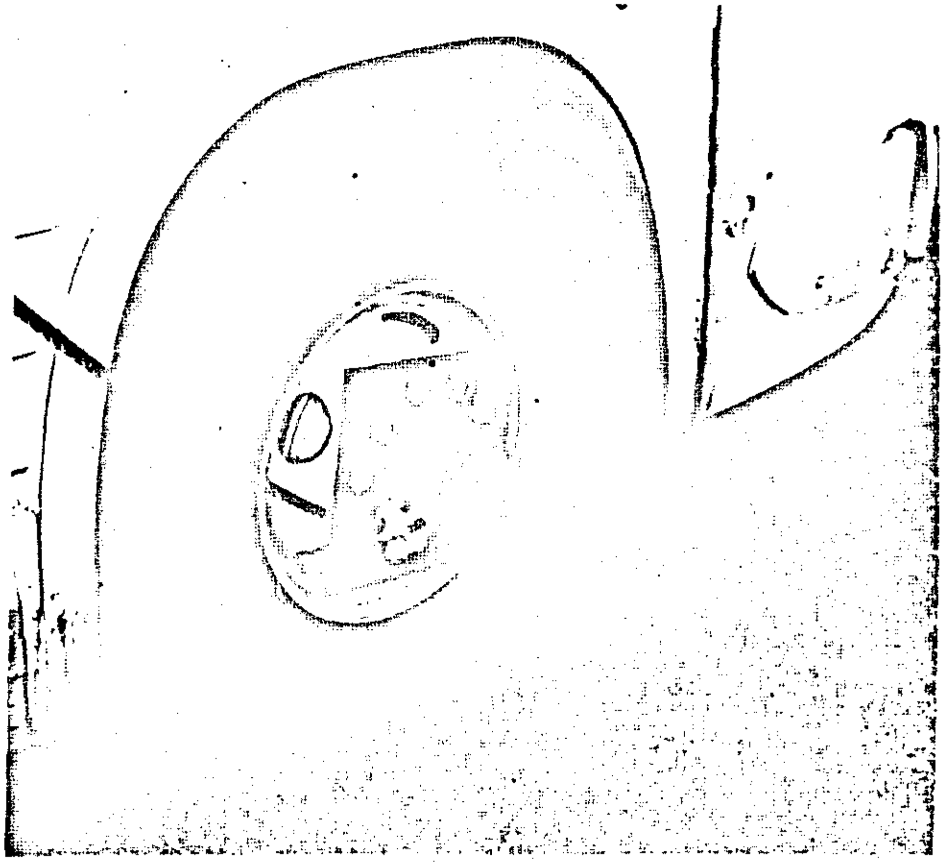

FIGURE 16. VIEW OF SPECIAL FIXTURE EMPLOYED TO TURN BUS OVER

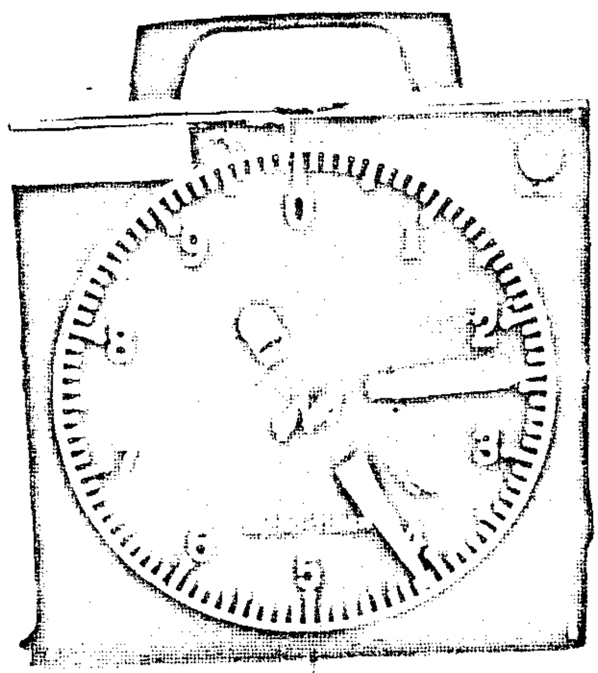

FIGURE 17. VIEW OF TIMER USED TO PROVIDE MOTION PICTURE TIME BASE

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. These light levels were determined through the utilization of a Spectra Brightness Spot Meter, Model SB, by measuring the amount of light reflected from the instructions on the window retention latches to various passenger eye positions. The average darkness value of light available to the eye was found to be .005 FL and the average amount of light reflected under conditions of darkness with the addition of emergency illumination was found to be 0.2 FL. A fixture was prepared on which each pair of goggles was mounted serially, daylight levels of illumination were passed through the goggles and paint was applied until the spot meter registered 0.2 FL on 50 pairs and .005 FL for another 50 pair. 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 (Figures 18 and 19). 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. Fortunately, because efforts were made to reduce hazards in escaping, no major injuries occurred requiring ambulance services. However, a significant back injury did occur during the escape tests and the nurses services were utilized. It is unlikely that passengers in an actual escape would be so fortunate as those subjects employed for these tests.

Used mattresses were placed 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 (Figure 20). Mattresses were placed under the bus for support to minimize damage to the bus during the turnover. Mattresses were placed below the roof hatch emergency exit and the front windshield area to cushion evacuation efforts during the trials when the bus was on its side. The remaining mattresses were stuffed into the window areas on the ground side of the bus where the windows had previously been removed to provide a base safe for the bus occupants.

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 (Figure 21). The bus side below the window openings was carpeted to minimize the risk of slipping as passengers moved from the bus to the scaffolding and two ladders were attached to the scaffolding for subject dismount.

A special piece of plywood was cut to size and placed over the front door window when the bus was on its side. This measure was taken to prevent subjects from injuring themselves by stepping through the door glass as they exited out the front windshield. The front windshields were covered with a five mil transparent Mylar on both sides to provide containment of shattered glass which occurred when the windshields were kicked out (Figure 22). Several spare windshield glasses were acquired and covered in the same manner for utilization throughout the series of tests. The windshields were kicked out

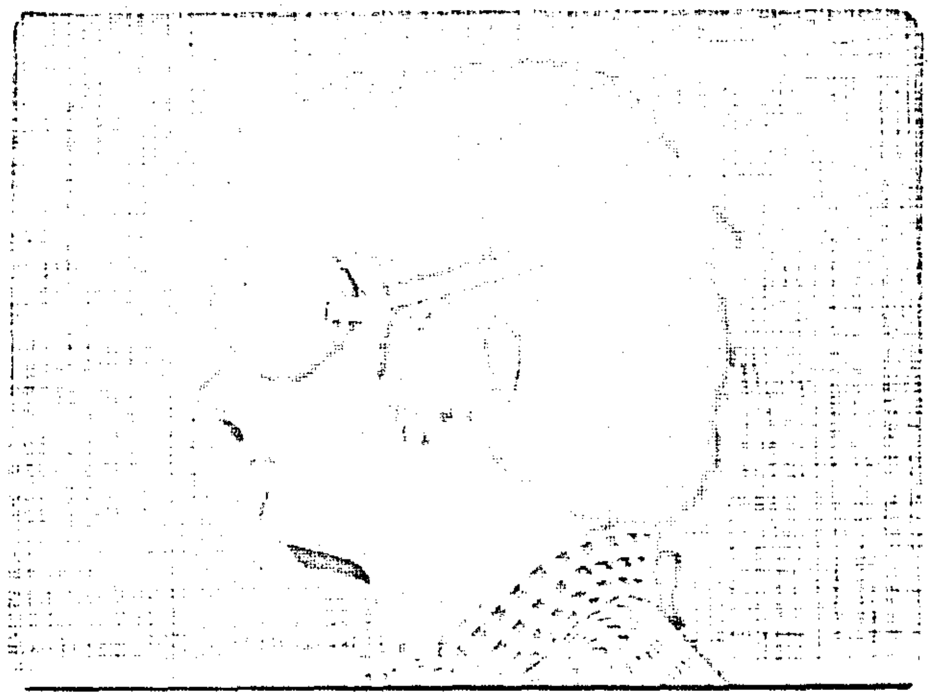

FIGURE 18. SIDEVIEW OF GOGGLES

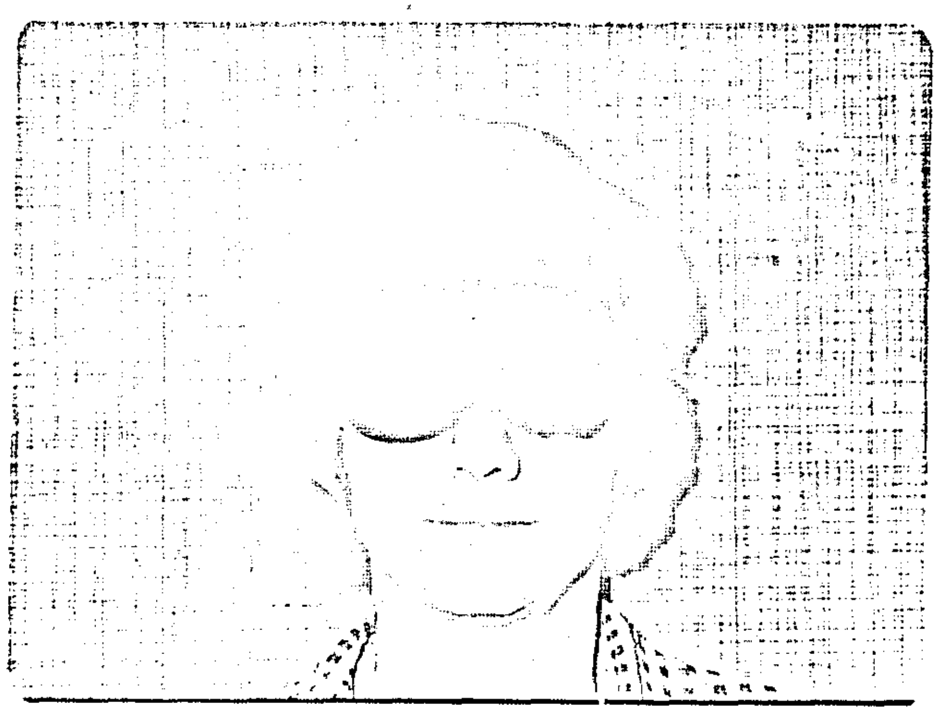

FIGURE 19. FRONTVIEW OF GOGGLES

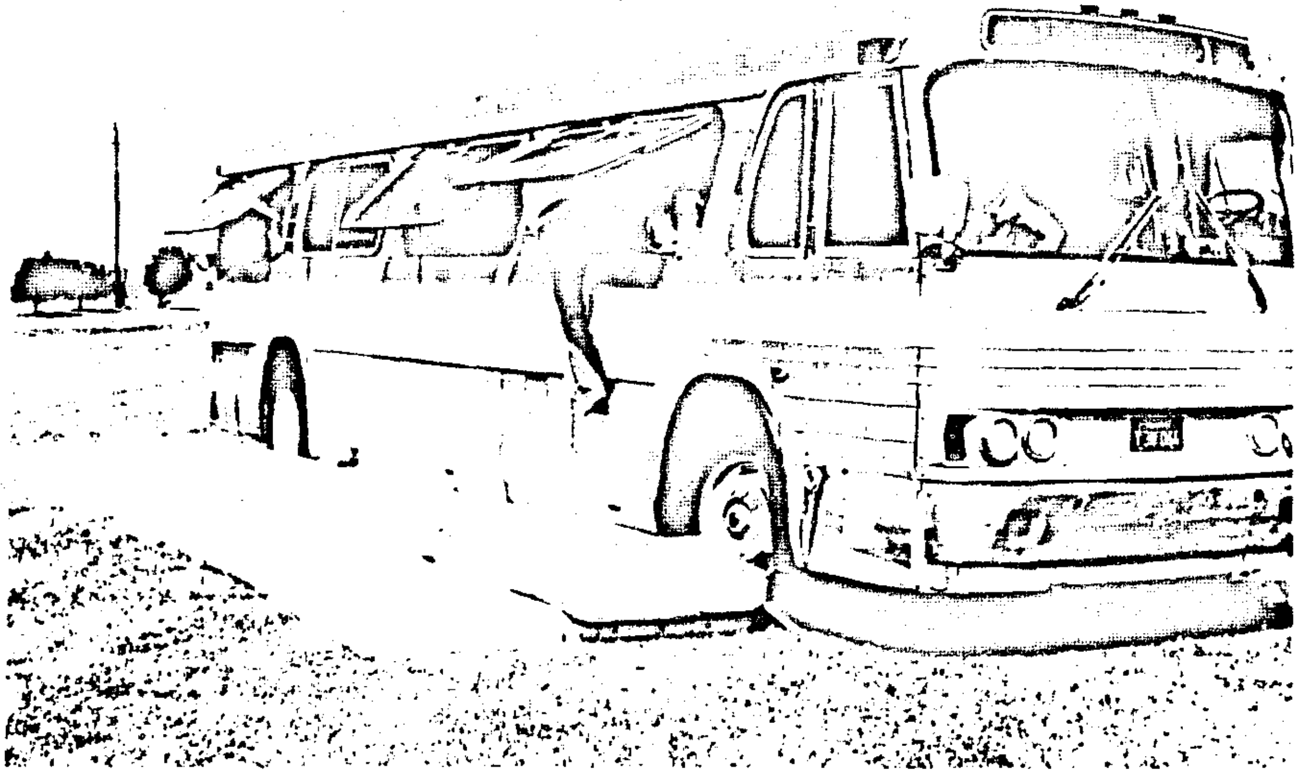

FIGURE 20. VIEW OF MATTRESSES
TO CUSHION SUBJECT FALLS

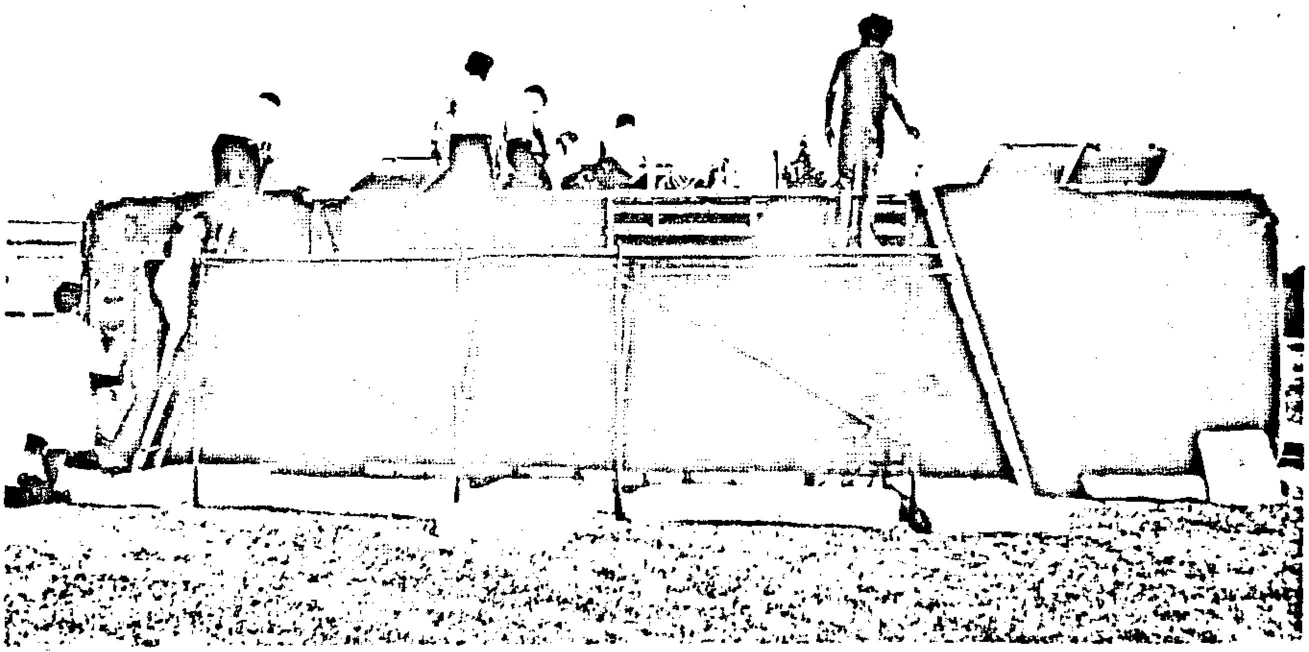

FIGURE 21. VIEW OF SCAFFOLD TO PROVIDE
FOR SUBJECT DISMOUNT FROM BUS

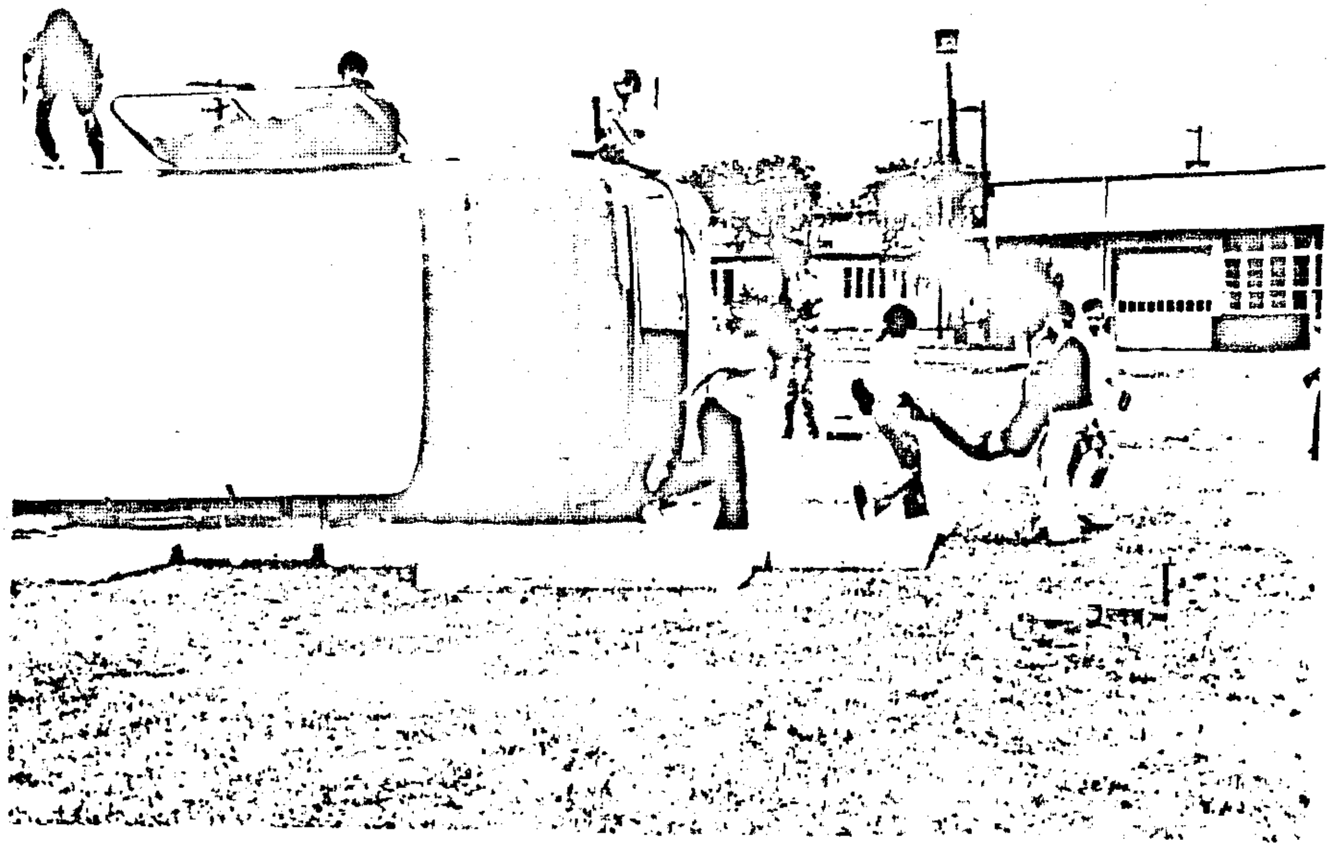

FIGURE 22. VIEW OF SUBJECTS EXITING
VIA FRONT WINDSHIELD

twice while the bus was on its side and not replaced for two trials. They were not replaced at these times because of the excessive time required to install them. Padding and tape were applied to all areas in and around the bus which offered a potential hazard to subjects.

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. Preliminary checks were made with respect to the location of three motion picture cameras used for filming the evacuation. The operations of the signal siren utilized for the start of the test as well as the associated timers were placed in the field of view of the movie cameras and the padding of all potential hazards found on the bus was completed.

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, an example of which is shown in the Appendix. 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, as shown in the

Appendix. Then the principal investigator gave the following instructions to the subjects:

> "In just a few minutes you will be getting on the bus. Just sit wherever you normally would. We will be going from seat to seat testing your goggles. You will be given a little time to adjust your eyes to the darkness. When you hear the siren you are to escape as quickly as possible without risking your safety, but the objective is speed. We don't want you to hurt yourself, but we do want you to get out just as quickly as you possibly can. This first time we want you to use the windows only, not the door, only the windows. There will be mattresses to cushion your landing. Once you are out of the bus move away from it unless you are helping an injured person. There are some people who have been told to feign a specific injury. You may help them if you wish, but you are under no obligation to do so. Once you are out of the bus, we would like for you to gather over in the shade of the building next to the bus. When everyone has gathered, and the bus is completely empty, you will get immediately back on the bus. The same procedure will be followed, except this time you may use the door to escape if you wish. Again, sit where you want. We will probably have to adjust your goggles again. When you hear the siren, get out of the bus as quickly as you can - quickly but safely. If you are out, get out of the way of the others. There will be injuries. This time it will be different people. After this trial, we will want to meet right back here. We have a few questions to ask you, and then you will receive your ten dollars. Remember, don't trip on any cords, try not to get in the way of the cameras. Are there any questions?"

The subjects were then lead 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. Two cameras covered the bus exterior and another camera was hand held inside the bus at the drivers seat by a research assistant, in order to cover the interal activities. 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 asked the following questions in the debriefing exercise:

1. What is your name and were your injured?
2. If you were injured, did anyone help you? How did they help you?
3. Did you actually open an exit? Which time? Which one? Did you have any trouble opening the exit?
4. Did you have any difficulty getting out? Which time? Which exit?
5. If you were not injured, did you help any injured? Which time? How?

6. Was it easier to get out the second time than the first?
7. If this had actually been a bus accident, would you have escaped the same way, knowing that there would not have been mattresses on the ground?

Tape recorders were employed by research assistants who asked the aforementioned qeustions allowing them to actually record the comments made by the subjects. After each subject was debriefed, he was paid ten dollars and sent on his way with the request not to tell anyone else that he believed may participate in a future bus study any of the details of the bus escape.

The next trials required that the bus be positioned on its right side. Special fixtures which had been designed and constructed were attached to the wheel hubs of the bus allowing for large cables to be attached directly to the bus axles. The bus was prepared for turning on its side by removing its batteries, siphoning diesel fuel from its 140 gallon tank, removal of transmission, crankcase and hydraulic fluids. Next, the four right side bus windows were removed and stored, and mattresses were placed on the ground to support the bus cabin.

A special cable assembly was attached to the axles supported vertically by a large crane. Timbers and cushions were placed between the cable and the bus in order to minimize cabin deformation. Lifting was begun on the left side by two large vehicles equipped with A-Frame supports and was continued until the center of gravity changed and shifted the load to the cable assembly on the right side (Figure 23). The two A-frame vehicles then raised the bus, slowly tipped it to the right until it was supported by the crane. Lowering the bus on its side then began with the supporting timbers being repositioned as necessary until the bus was lowered onto the mattresses (Figure 24). No difficulty was encountered in turning the bus on its side or in righting it later. Minimal damage occurred throughout the procedure.

The eight foot scaffold was then placed next to the bus between the wheel wells. Plywood of sufficient strength was cut to fit the right door window and taped in place. Mattresses were placed around the bus to cover all avenues of escape. The two outside cameras were repositioned in order to provide maximum coverage of the avenues of escape.

The possible hazards in performing these escape trials with the bus on its side required slight modification to the instructions given to the first group utilized in the previous trial with the bus upright. All subjects were warned to be careful of tripping hazards and falling when climbing out the pushout windows overhead. They were advised to remove their goggles before climbing down from the top side of the bus via the scaffolding and ladders to avoid possible injuries. They were instructed not to jump from the top of the bus nor to attempt to climb down the undercarriage of the bus because of hazards.

For the two tests with the bus on its side, the subjects followed the basic format with respect to arrival, anthropometric measurements, procure-

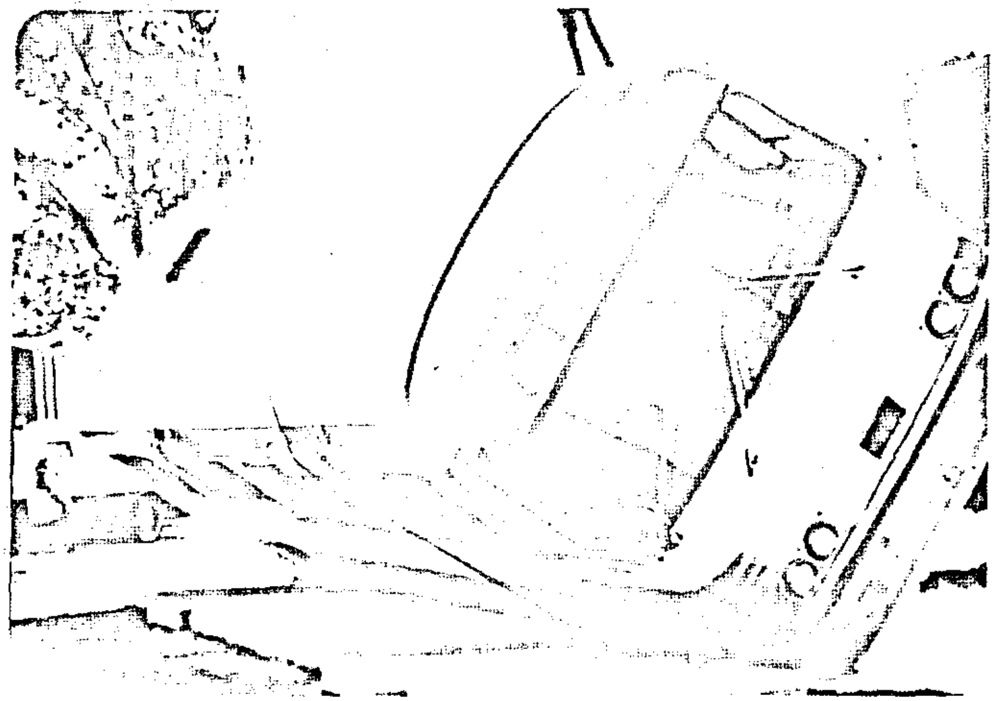

FIGURE 23. VIEW OF BUS TILTED ON SIDE DURING TURNOVER

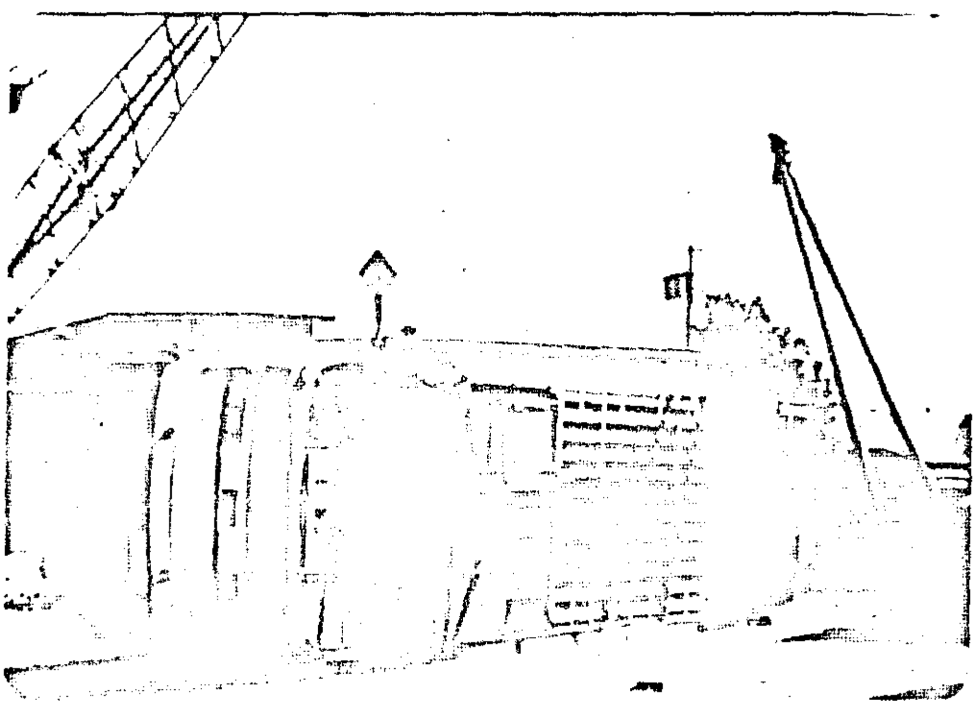

FIGURE 24. VIEW OF BUS LAID ON MATTRESSES COMPLETING TURNOVER

ment of release forms and the dissemination of instructions as had the previous group. The format of the test remained essentially the same with the only new consideration being replacement of the escape hatch and utilization of the windshield as well as the closing of windows and their associated positive latching mechanisms before each trial. Two tests with the bus on its side were held on two separate days for a total of four tests. The first test on each day was performed with the windshield in place; the second tests each day were performed without the windshield in place. This was due to the fact that an excessive amount of time is necessary for the installation of a new windshield. Subjects were allowed to enter the bus via the escape hatch for all tests and via the front windshield for the second trial for each day's test. In no cases were the subjects allowed to enter the bus via the overhead windows. During all four trials, subjects were able to choose among the escape hatch, the overhead windows or the front windshield for avenues of escape.

IV. Results

This chapter presents the results obtained from this study of bus evacuation. The first section is concerned with the analyses performed of the motion pictures made of each evacuation test. The second section presents a statistical analysis of the data obtained from the motion picture films. The remainder of the chapter is devoted to an analysis of the de-briefing comments of subjects in the tests and a discussion of the adequacy of the various escape exits utilized for the tests.

Motion Picture Analysis

A detailed, frame-by-frame analysis of the motion pictures made of the different experimental trials was performed. As a first step, the speed of each movie camera used for filming was checked against the time base provided by the clock visible in the field of each camera. The clock was accurate to plus or minus 0.05 seconds over a two minute interval.

It was determined that the film speed of each camera was within plus or minus 0.02 seconds of the clock over a one minute segment of film. After completing this check for accuracy, the frame-by-frame analysis was then completed for each camera and each experimental trial. The following sections contain a table summarizing the data for each evacuation test and a discussion of the data.

Evacuation Test No. 1: These test data are shown in summary form on Table No. 14. 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.

Table 15 presents a more detailed analysis of the first escape trial, where each passenger is accounted for in terms of the escape time required for a given exit. Note that the arrival time of the exit is considered to begin when the exit has been opened initially. It is evident in this analysis

TABLE 14. 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	11.25	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] 38.88	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 15. BUS EVACUATION
TEST NUMBER 1
DETAILED DATA

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

EXIT USED[1]	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	ASSISTANCE[2]	COMMENTS
LW1M12	10.58	18.96	8.38	WH	Jointly opened window
LW1F41	10.58	23.58	13.00	WH	Jointly opened window - leg caught in window
LW1M11	23.88	29.00	5.13	WH	
LW1F69	31.92	46.71	14.79	WH	Sprained back
LW1M28	73.71	83.33	9.63	WH	Feigned injury - assistance in escaping
LW1M38	75.46	93.54	18.08	WH	Feigned injury - assistance in escaping
LW1M39	85.88	92.46	6.58	WH	
LW1F28	93.88	98.13	4.25	WH	
LW2F20-1	9.46	25.38	15.92	NH	Opened window
LW2F11	9.46	26.79	17.33	NH	
LW2M8	26.83	31.13	4.29	WH	
LW2F20-2	28.33	38.83	10.50	1/2	
LW2M20	37.92	41.58	3.67	WH	
LW2F27	66.96	71.17	4.21	NH	
LW3M24	8.75	18.25	9.50	NO	Head bruised when window opened correctly
LW3F29	38.96	50.96	12.00	NH	Feigned injury - assistance in escaping
LW3F13	38.96	52.63	13.67	NH	
LW3F68	44.42	61.58	17.17	NH	
LW3M20	52.88	64.25	11.38	NH	Opened window
LW3M37	66.67	72.17	5.50	WH	
LW3M68	68.38	75.25	6.87	WH	Opened window

Table 15 (continued)

EXIT USED[1]	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	ASSISTANCE[2]	COMMENTS
LW4F69	13.58	23.04	9.46	1/2	
LW4M46	13.58	29.04	15.46	WH	Sat in window & opened window for LW4F69
LW4F50	29.04	32.46	3.42	WH	
LW4M56	61.38	73.46	12.08	NH	
LW4F57	73.46	80.50	7.04	WH	
LW4F24	81.38	86.25	4.88	WH	Feigned injury - lifted out
LW4M30	88.75	90.88	2.13	WH	Opened window
LW4M24	86.25	91.21	4.96	WH	
LW4M30	99.29	108.54	9.25	NH	
RW1F49	11.25	18.75	7.50	NH	Opened window
RW1M26	11.25	22.58	11.33	NH	Opened window
RW1M52	19.21	22.75	3.54	NH	
RW1M60	21.58	28.04	6.46	WH	
RW2F38	9.46	17.79	8.33	NH	Opened window
RW2F40	9.46	21.92	12.46	NH	
RW2F7	14.17	17.67	3.50	NH	
RW2F20	20.63	31.13	10.50	1/2	
RW2F23	24.71	29.46	4.75	1/2	
RW2F34	31.88	36.88	5.00	WH	
RW3F52	12.54	23.33	10.79	NO	Did not open window correctly - bruised arm
RW4F22	33.25	42.96	9.71	WH	Jointly opened window
RW4F53	33.25	46.58	13.33	WH	Jointly opened window
RW4M53	46.67	52.17	5.50	WH	
RW4F68	44.46	58.29	13.83	WH	

[1]R=right; L=left;W#=window number (assigned from front to rear of bus); FD=front door; WS=windshield; RH=roof hatch; M=male; F=female; number following M or F indicates age.

[2]WH=window held open by someone; NH=window was not held open by someone; NO=window not opened correctly; 1/2=was struggling & someone came to hold window open

that the persons feigning injury were assisted in escaping and they required more time in reaching the exit because most of the bus passengers had to clear the aisle before those assisting could maneuver them into a window and lower them to the ground with the assistance of others who had already escaped. The terminal time of 108.54 seconds was established by a 30 year old male, who had assisted an "injured" person to escape and then made his own escape.

The holding open of a window by a passenger for another passenger to escape was an important variable in influencing the time to escape for each person. The mean time per person for those passengers having the window held open was 7.6 seconds versus 10.6 seconds for those passengers receiving no help. This illustrates the problem of pushing, into the opening against the 47 pound window hinged at the top and then avoiding being impacted by the window as the passenger jumped to the ground.

<u>Evacuation Test No. 2:</u> Table 16 presents a summary of the escape times for the second evacuation trial. This trial was conducted with the same subject group and other conditions except for the addition of the front door as an escape route. The passengers were not told specifically that the door would be available for escape, so this accounts for the time of almost 10 seconds required to open the front door. It is apparent that some passengers waited to use the front door as an exit, even though the window exits were available.

Table 17 presents a more detailed analysis of the escape times for the second trial. The "injured" passengers were all carried out the front door because this was much faster than trying to pass them out through the window. It is apparent from a comparison of Tables 14 and 16 that the experience gained during the initial trial in opening windows resulted in a faster time to open the windows on the second trial. The overall escape times are not comparable as noted earlier because the use of the front door as an exit caused a significant reduction in escape time, particularly for removal of the "injured" passengers.

<u>Evacuation Test No. 3:</u> Table 18 presents a summary of the escape times for the third evacuation trial. This trial illustrates the type of problems which occur in escaping from a bus on the right hand side under conditions of darkness. This trial was conducted to represent a "worst case" condition of bus evacuation.

The first important finding of this trial was that passengers were able to kick out the front windshield of the bus and use this opening as an escape route. In this case two females, age 45 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.

TABLE 16. BUS EVACUATION
TEST NUMBER 2
SUMMARY DATA

Experimental Condition: darkness, bus upright, 45 passengers
Exits available: windows and front doors
Total evacuation time: 77.63 seconds

EXIT[1]	TIME TO OPEN EXIT	TIME OF LAST EXIT (TERMINAL)	NO. PERSONS ESCAPING	TIME LAST ESCAPE/ NO. OF ESCAPES	COMMENTS
RW1	3.08	44.58	4	11.15	
RW2	3.04	47.17	1	47.17	
RW3	Did not open		0		
RW4	5.75	31.46	4	7.86	
LW1	Did not open		0		
LW2	3.50	18.79	6	3.13	
LW3	14.13	59.46	7	8.49	
LW4	3.17	21.46	4	5.36	
FD	9.79	77.63	19	4.09	

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

TABLE 17. BUS EVACUATION
TEST NUMBER 2
DETAILED DATA

Experimental Condition: darkness, bus upright, 45 passengers
Exits available: windows and front doors
Total evacuation time: 77.63 seconds

EXIT USED[1]	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	ASSISTANCE[2]	COMMENTS
LW2M8	3.50	7.79	4.29	WH	
LW2M24	3.50	12.17	8.67	NH	Opened window
LW2F20-1	3.50	14.17	10.67	1/2	
LW2F11	10.63	14.08	3.46	WH	
LW2F20-2	14.67	18.79	4.13	WH	
LW2F7	15.54	16.46	0.92	WH	
LW3F13	14.13	28.96	14.83	NH	Jointly opened window
LW3F38	14.13	38.33	24.21	1/2	Jointly opened window
LW3F29	30.50	36.92	6.42	WH	
LW3F50	37.04	41.25	4.21	WH	
LW3M20	41.92	55.54	13.63	WH	
LW3F34	42.17	51.75	9.58	WH	
LW3M30	57.17	59.46	2.29	WH	
LW4M30	3.17	14.33	11.17	NH	Opened window
LW4F69	3.17	14.04	10.88	NH	
LW4M39	16.25	20.96	4.71	WH	
LW4F24	16.58	21.46	4.88	WH	
RW1M26	3.08	14.71	11.63	NH	Opened window
RW1F19	9.54	15.33	5.79	NH	
RW1M52	16.96	19.38	2.42	WH	
RW1M28	38.17	44.58	6.42	NH	
RW2F68	3.04	47.17	44.13	NH	Opened window

Table 17 (continued)

EXIT USED[1]	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	ASSISTANCE[2]	COMMENTS
RW4F53	5.75	17.13	11.38	NH	Opened window
RW4F20	5.75	18.17	12.42	NH	
RW4M53	18.29	24.63	6.33	NH	
RW4F28	27.92	31.46	3.54	WH	
FDF69	9.79	14.96	5.17		Opened door
FDF40	15.00	16.46	1.46		
FDM68	17.88	20.13	2.25		
FDF68	20.21	23.38	3.17		
FDF23	23.38	25.21	1.83		
FDM11	26.25	27.67	1.42		
FDM60	30.08	33.54	3.46		
FDF41	33.58	35.83	2.25		
FDF52	36.04	38.79	2.75		
FDM12	38.04	43.83	5.79		Feigned injury - carried out by FDM38
FDM38	38.04	43.83	5.79		
FDM56	57.21	60.25	3.04		
FDM24	59.63	63.67	4.04		Feigned injury - carried out by FDM56 & FDF22
FDF22	62.29	64.21	1.92		
FDF27	69.17	71.83	2.67		Feigned injury - carried out by FDM20 & FDM46
FDM20	69.17	70.46	1.29		
FDM46	71.83	72.50	0.67		
FDF57	75.67	77.21	1.54		Feigned injury - helped out by FDM37
FDM37	77.21	77.63	0.42		

[1] R=right; L=left; W#=window number (assigned from front to rear of bus); FD=front door; WS=windshield; RH=roof hatch; M=male; F=female; number following M or F indicates age.

[2] WH=window held open by someone; NH=window was not held open by someone; 1/2=was struggling & someone came to hold window open; NO=window not opened correctly

TABLE 18. BUS EVACUATION
TEST NUMBER 3
SUMMARY DATA

Experimental Condition: darkness, bus on side, 45 passengers
Exits available: side windows, windshield, roof hatch
Total evacuation time: 142.88 seconds

EXIT[1]	TIME TO OPEN EXIT	TIME OF LAST EXIT (TERMINAL)	NO. PERSONS ESCAPING	TIME LAST ESCAPE/ NO. OF ESCAPES	COMMENTS
W1	40.29	59.63	2	29.81	
W2	5.21	142.88	11	12.99	
W3	Did not open		0		
W4	9.42	135.75	7	19.39	
WS	13.58 15.58	74.75	13	5.75	
RH	2.96	111.46	12	9.29	

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

Placing 45 passengers into a bus turned on its side produced a very closely packed load. This resulted in a significant amount of confusion under conditions of darkness (obtained by passengers wearing special goggles) and this shows in the use of the various exits. Some passengers were still trying to use the overhead windows or the roof hatch when the windshield opening provided a much easier means of escape.

The roof hatch proved to be easy to kick open and was used by 12 passengers as an escape exit. Analysis of the films showed that exiting from an opening of this size (19" x 21) presents a problem because of the lack of some type of ladder or other support adjacent to the hatch. The attachment of U-type rings in either direction from the roof hatch to the side of the bus would significantly reduce the potential for injury when using a roof hatch and also decrease the time per passenger required for using the roof hatch. Standards for designing such ladders can be found in VanCott and Kinkade (1972) or other similar references. Problems also exist in getting into the roof hatch from the interior of the bus and therefore a similar arrangement should be considered for the bus interior. The design of the ladder for the bus interior is made more difficult because of the need to provide a covering of energy obsorbing materials. However, this type of design is technically feasible and energy absorbing materials have been in use for many years in automobiles.

Table 19 presents more detailed data for the third escape trial. It can be seen in this table that the first bus window required 40.29 seconds to open by a 62 year old male and a 51 year old female. Windows two and four were opened much more quickly by a 26 year old and a 15 year old male, respectively. The third window was not opened by any passenger.

The confusion mentioned earlier is apparent when it is noted that three of the "injured" passengers were lifted out through the windows overhead when it would have been much easier to carry them out through the front windshield opening.

Evacuation Test No. 4: This trial was conducted with the same passenger group as for No. 3, but the windshield and roof hatch could not be replaced, so these exits were immediately available after the start of the trial. Table 20 presents the summary data for this trial and Table 21 presents the detailed analysis of the film data. The principal difference in Trial Nos. 3 and 4 is that more passengers were aware of the windshield opening and used it as an exit. The time to open the overhead windows was also reduced for the three windows opened. Passengers did not open window number three for this trial as had been the case for Trial No. 3.

Two of the "injured" were still removed by pulling them through the window overhead, while two were removed through the windshield opening.

Problems were again observed in using the roof hatch as noted for Trial No. 3.

TABLE 19. BUS EVACUATION
TEST NUMBER 3
DETAILED DATA

Experimental Condition: darkness, bus on side, 45 passengers
Exits available: side windows, windshield, roof hatch
Total evacuation time: 142.88 seconds

EXIT USED[1]	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	COMMENTS
W1F51	40.29	57.58	17.29	
W1M62	40.29	59.63	19.33	
W2M26	5.21 138.33	10.67 142.88	5.46 4.54	Person climbed out then back in to help injured
W2F27	12.08	21.71	9.63	
W2F18	15.04	21.25	6.21	
W2M21	22.46	26.96	4.50	
W2F29	23.38	28.25	4.88	
W2M23-1	26.96	33.71	6.75	
W2F43	34.17	39.58	5.42	Feigned injury - helped out by others
W2M44	46.13	61.92	15.79	
W2M53	47.33	56.29	8.96	
W2M23-2	59.04	66.79	7.75	
W2F17	127.83	137.04	9.21	Feigned injury - helped out by others
W4M15	9.42	20.92	11.50	
W4M22	9.42	22.08	12.67	
W4F22	9.42	26.00	16.58	
W4F30	62.25	71.58	9.33	
W4F23	69.33	93.38	24.04	
W4M19	96.54	112.50	15.96	Feigned injury - lifted out by others
W4F26	121.54	135.75	14.21	
W5F65	13.58	20.58	7.00	

Table 19 (continued)

EXIT USED[1]	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	COMMENTS
WSF45	20.67	23.58	2.92	
WSM44	24.83	28.13	3.29	
WSF53	28.13	31.54	3.42	
WSF56	31.63	33.83	2.21	
WSF66	34.92	37.63	2.71	
WSF36	37.71	40.38	2.67	
WSF37	42.63	47.58	4.96	
WSF9	47.58	50.96	3.38	
WSM38	59.71	63.92	4.21	
WSM39	63.92	70.17	6.25	Feigned injury - carried out by others
WSM52	70.17	72.46	2.29	
WSF55	72.92	74.75	1.83	
RHM14	2.96	6.00	3.04	
RHM15	7.04	9.33	2.29	
RHM33	10.88	19.17	8.29	
RHM6	19.46	22.21	2.75	Lifted out by another person
RHM5	27.17	28.96	1.79	Lifted out by another person
RHF8	33.83	35.79	1.96	Lifted out by another person
RHF30	40.58	52.17	11.58	
RHF17	53.17	57.08	3.92	
RHF63	57.79	65.42	7.63	
RHM65-1	66.25	79.38	13.13	
RHM65-2	81.29	91.67	10.38	
RHM72	100.88	111.46	10.58	

[1] R=right; L=left; W#=window number (assigned from front to rear of bus); FD=front door; WS=windshield; RH=roof hatch; M=male; F=female; number following M or F indicates age.

TABLE 20. BUS EVACUATION
TEST NUMBER 4
SUMMARY DATA

Experimental Condition: darkness, bus on side, 45 passengers
Exits available: side windows, windshield, roof hatch
Total evacuation time: 98.54

EXIT[1]	TIME TO OPEN EXIT	TIME OF LAST EXIT (TERMINAL)	NO. PERSONS ESCAPING	TIME LAST ESCAPE/ NO. OF ESCAPES	COMMENTS
W1	17.79	37.00	4	9.25	
W2	6.08	94.67	7	13.52	
W3	Did not open		0		
W4	1.96	55.83	6	9.31	
WS	Already open	60.04	17	3.53	
RH	Already open	98.54	11	8.96	

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

TABLE 21. BUS EVACUATION
TEST NUMBER 4
DETAILED DATA

Experimental Condition: darkness, bus on side, 45 passengers
Exits available: side windows, windshield, roof hatch
Total evacuation time: 98.54

EXIT USED[1]	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	COMMENTS
W1M53	17.79	37.75	19.96	
W1F51	17.79	33.58	15.79	
W1F55	44.92	54.04	9.13	
W1M52	30.29	35.29	5.00	
W2M21	6.08	12.33	6.25	
W2F27	16.83	30.96	14.13	
W2M23-1	32.88	36.38	3.50	
W2M26	44.71	50.83	6.13	Feigned injury - lifted out by others
W2M38	53.38	65.50	12.13	
W2F30	77.33	85.13	7.79	Feigned injury - lifted out by others
W2M23-2	90.33	94.67	4.33	
W4F18	1.96	13.29	11.33	
W4M14	1.96	13.75	11.79	
W4M22	11.75	18.67	6.92	
W4M15-1	14.92	23.79	8.88	
W4M15-2	14.92	25.08	10.17	
W4M44	43.96	55.83	11.88	
WSM33	3.04	6.38	3.33	
WSF66	7.21	10.46	3.25	
WSM5	11.58	12.46	0.88	
WSM6	13.46	14.67	1.21	
WSM39	14.83	18.38	3.54	

Table 21 (continued)

Exit USED[1]	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	COMMENTS
WSM44	16.17	18.46	2.29	Feigned injury - carried out by others
WSF45	19.04	20.38	1.33	
WSF8	21.29	22.50	1.21	
WSF30	22.50	24.42	1.92	
WSF36	24.71	26.00	1.29	
WSF69	28.00	30.25	2.25	
WSF43	30.83	33.00	2.17	
WSM65	34.00	37.08	3.08	
WSF23	41.17	46.92	5.75	Feigned injury - carried out by others
WSM65	48.54	52.33	3.79	
WSF9	53.17	55.46	2.29	
WSF37	55.71	60.04	4.33	
RHM62	4.83	12.25	7.42	
RHM19	12.71	16.67	3.96	
RHF56	17.17	21.13	3.96	
RHF22	22.71	29.54	6.83	
RHF63	32.00	37.83	5.83	
RHF53	40.71	49.71	9.00	
RHF26	53.29	60.29	7.00	
RHM72	63.88	70.67	6.79	
RHF29	75.67	85.25	9.58	
RHF17-1	86.13	89.46	3.33	
RHF17-2	92.71	98.54	5.83	

[1] R=right; L=left; W#=window number (assigned from front to rear of bus); FD=front door; WS=windshield; RH=roof hatch; M=male; F=female; number following M or F indicates age.

Evacuation Test No. 5: This trial was conducted under the same conditions as Trial No. 3 except for the use of goggles to simulate emergency illumination and a different passenger load. The summary data is shown in Table 22 and the detailed data from the film analysis is shown in Table 23. The total time to escape was reduced from 142.88 seconds in Trial No. 3 to 112.67 seconds for this trial. The reduction in time apparently was due to better vision which permitted persons helping the "injured" to carry them through the windshield opening rather than lifting them through the windows overhead. Another factor was the very rapid time taken to kick out the front windshield. A 25 year old male wearing leather boots was adjacent to the windshield at the start of the trial and had no difficulty kicking it out of its mounting.

The roof hatch required more time to open and also proved to be a slower means of escape than through some of the overhead windows. Window number three which had not been opened during two previous trials was opened by a 19 year old male after some difficulty, requiring 36 seconds to open.

Evacuation Test No. 6: This trial was conducted with the same passenger load as in Trial No. 5 and the same conditions except that the windshield opening was already open at the start of the trial. The summary data is shown in Table 24 and the detailed data is shown in Table 25. The evacuation time proved to be surprisingly rapid, requiring only 56.04 seconds. This decrease in time occurred because of a more even distribution of passengers in relation to the available exits, i.e., more passengers used the front windshield because they knew from the previous trial that it would be available.

An unexpected failure of the hinges on window number three, when it was pushed open allowed it to fall to the ground along the top of the bus. This failure almost produced a serious injury when it narrowly missed a passenger passing underneath after escaping from the roof hatch.

Statistical Analysis of Data

The data which was presented in tabular form in the preceeding section was subjected to statistical analysis in order to develop a predictive model for escape time as a function of the experimental variables studied. A description of each procedure is presented in the following sections.

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. This data is presented in Table 26 for the time taken to open the windows of the bus.

TABLE 22. BUS EVACUATION
TEST NUMBER 5
SUMMARY DATA

Experimental Condition: emergency illumination, bus on side, 45 passengers
Exits available: side windows, windshield, roof hatch
Total evacuation time: 112.67 seconds

EXIT[1]	TIME TO OPEN EXIT	TIME OF LAST EXIT (TERMINAL)	NO. PERSONS ESCAPING	TIME LAST ESCAPE/ NO. OF ESCAPES	COMMENTS
W1	7.17	32.79	6	5.47	
W2	13.00	49.46	5	9.89	
W3	36.04	50.00	2	25.00	
W4	9.92	86.21	10	8.62	
WS	2.38 2.67	112.67	15	7.51	
RH	6.33	96.83	7	13.83	

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

TABLE 23. BUS EVACUATION
TEST NUMBER 5
DETAILED DATA

Experimental Condition: emergency illumination, bus on side, 45 passengers
Exits available: side windows, windshield, roof hatch
Total evacuation time: 112.67 seconds

EXIT USED[1]	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	COMMENTS
W1M21	7.17	14.71	7.54	
W1M29	7.17	17.29	10.13	
W1F26	10.38	19.54	9.17	
W1M67	19.63	26.25	6.63	
W1M46	21.63	27.92	6.29	
W2F10	22.38	27.17	4.79	
W2F51	31.21	39.25	8.04	
W2F61	34.67	39.33	4.67	
W2F20	43.50	47.83	4.33	
W2F11	45.46	49.46	4.00	
W3M19	36.04	44.42	8.38	
W3F38	43.21	50.00	6.79	
W4M30	9.92	36.38	26.46	Sat in window and lifted out children
W4M6	18.83	20.63	1.79	
W4F8	24.75	27.79	3.04	
W4F69	26.04	41.63	15.58	
W4F26	34.79	51.38	16.58	
W4F54	43.50	51.88	8.38	
W4F13	53.33	59.33	6.00	
W4F27	60.42	66.96	6.54	
W4F25	67.25	73.58	6.33	

Table 23 (continued)

EXIT USED	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	COMMENTS
W4M63	75.63	86.21	10.58	
WSM25	2.38	3.83	1.46	
WSF30	4.46	6.17	1.71	
WSM34	8.33	9.58	1.25	
WSF24-1	9.79	10.79	1.00	
WSM14	10.83	12.38	1.54	
WSF50	12.96	14.42	1.46	
WSM53	17.92	21.04	3.13	
WSM19	17.38	21.42	4.04	Feigned injury - carried out by others
WSF24-2	21.00	22.25	1.25	
WSF25	59.42	61.58	2.17	Feigned injury - carried out by others
WSM30	60.92	62.79	1.88	
WSM54	102.79	107.00	4.21	
WSM32	104.29	107.50	3.21	Feigned injury - carried out by others
WSM40	106.79	109.46	2.67	
WSF32	109.75	112.67	2.92	
RHM72	15.00	20.29	5.29	
RHM8	25.58	28.29	2.71	
RHF57	35.67	40.96	5.29	
RHF20	47.67	55.04	7.38	
RHM27	58.58	64.50	5.92	
RHF41	69.08	77.33	8.25	Feigned injury - carried out by others
RHM(40-50)	92.13	96.83	4.71	

[1]R=right; L=left; W#=window number (assigned from front to rear of bus); FD=front door; WS=windshield; RH=roof hatch; M=male; F=female; number following M or F indicates age.

TABLE 24. BUS EVACUATION
TEST NUMBER 6
SUMMARY DATA

Experimental Condition: emergency illumination, bus on side, 45 passengers
Exits available: side windows, windshield, roof hatch
Total evacuation time: 56.04 seconds

EXIT[1]	TIME TO OPEN EXIT	TIME OF LAST EXIT (TERMINAL)	NO. PERSONS ESCAPING	TIME LAST ESCAPE/ NO. OF ESCAPES
W1	22.08	35.50	2	17.75
W2	3.54	48.88	7	6.98
W3	12.92	56.04	5	11.21
W4	2.67	44.17	5	8.83
WS	Already open	47.33	19	2.49
RH	1.13	40.50	7	5.79

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

TABLE 25. BUS EVACUATION
TEST NUMBER 6
DETAILED DATA

Experimental Condition: emergency illumination, bus on side, 45 passengers
Exits available: side windows, windshield, roof hatch
Total evacuation time: 56.04 seconds

EXIT USED[1]	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	COMMENTS
W1F30	22.08	33.58	11.50	
W1F20	28.71	35.50	6.79	
W2M25	9.63	15.50	5.88	
W2F10	12.96	17.00	4.04	
W2M30	23.08	28.33	5.25	Feigned injury - lifted out by others
W2M46	30.83	48.88	18.04	
W2F41	33.04	36.92	3.88	
W2F25	38.42	43.92	5.50	
W2F32	44.58	48.71	4.13	
W3M19	12.92	22.17	9.25	
W3F50	24.00	39.79	15.79	
W3M40	29.58	35.21	5.63	
W3M53	37.58	46.88	9.29	
W3M67	49.83	56.04	6.21	
W4M(40-50)	2.67	16.79	14.13	
W4M19	2.67	15.92	13.25	
W4M13	2.67	18.00	15.33	
W4M63	18.00	44.17	26.17	
W4M8	23.63	26.92	3.29	
WSM34-1	0.00	1.46	1.46	
WSM21	1.46	5.50	4.04	

Table 25 (continued)

EXIT USED[1]	ARRIVAL TIME AT EXIT	DEPARTURE TIME FROM EXIT	TIME EXIT IN USE	COMMENTS
WSF24	3.96	5.96	2.00	Feigned injury - carried out by others
WSF20	6.54	8.13	1.58	
WSF69	8.38	9.75	1.38	
WSF8	8.42	10.13	1.71	
WSM6	10.08	11.21	1.13	
WSM72	11.58	13.46	1.88	
WSM34-2	28.29	30.92	2.63	
WSM30	29.83	33.25	3.42	
WSF26	31.96	33.25	1.29	
WSF38	33.25	34.54	1.29	
WSF13	34.50	35.42	0.92	
WSF51	36.08	39.13	3.04	
WSM27	39.58	41.83	2.25	
WSF26	38.17	42.21	4.04	Feigned injury - carried out by others
WSM54	42.13	43.08	0.96	
WSF27	43.25	44.92	1.67	
WSF57	45.92	47.33	1.42	
RHM14	3.33	7.13	3.79	
RHF11	7.38	9.25	1.88	
RHF24	9.25	14.29	5.04	
RHF54	15.63	21.33	5.71	
RHF25	22.25	26.83	4.58	
RHM32	27.71	33.88	6.17	
RHF61	34.79	40.50	5.71	

[1] R=right; L=left; W#=window number (assigned from front to rear of ubs); FD=front door; WS=windshield; RH=roof hatch; M=male; F=female; number following M or F indicates age.

TABLE 26. TIME IN SECONDS TO OPEN WINDOWS FOR SIX EXPERIMENTAL TRIALS

Trial Number	Time in Seconds: Mean	Standard Deviation	Significant Difference
1	18.81	13.50	Yes
2	5.45	4.38	
3	18.31	19.15	No
4	8.61	8.21	
5	16.53	13.22	No
6	10.30	9.12	

A practice effect is apparent in the mean time to open windows, even though the variability in the data is large enough to preclude a statistically significant difference for trials 3 versus 4 and 5 versus 6.

The next hypothesis tested was the effect of practice in escaping from the various types of exits after they have been opened initially. This data is shown in Table 27.

TABLE 27. TIME IN SECONDS TO ESCAPE THROUGH VARIOUS TYPES OF EXITS FOR SIX EXPERIMENTAL TRIALS

	Windows		Roof Hatch		Windshield	
Trial Number	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
1	8.66	4.18				
2	9.34	8.72				
3	11.46	5.67	6.45	4.25	3.41	1.43
4	10.08	4.53	6.32	2.01	2.39	1.10
5	7.38	3.56	5.22	1.53	2.04	0.97
6	9.89	6.19	4.70	1.48	1.52	0.54

The data in Table 27 does not indicate that a practice effect occurred during the repeated trials, with the possible exception of the windshield exit. Further analysis of the passengers using the respective exits produced the results shown in Table 28.

TABLE 28. REPEATED USES OF VARIOUS ESCAPE EXITS DURING SUCCESSIVE TRIALS WITH SAME PASSENGER GROUP

	Uses of Exit by Same Passengers			
Type of Exit	Trial 3	Trial 4	Trial 5	Trial 6
window	20	12	23	7
roof hatch	12	3	7	0
windshield	13	8	15	3

Table 28 reveals that many passengers did not return to the same type of exit previously used, but rather chose another type of exit; i.e. only three of the subjects who used the roof hatch for Trial No. 3 returned for Trial No. 4. This behavior may be explained by the position of the subject inside the crowded bus on its side, leaving him or her little room to reach the desired exit. However, there is also the possibility that the inherent seeking after new or novel experiences by most people caused them to seek a new type of exit on the second trial for each group. Thus, in summary, any practice effects which might have occurred were obscured by the behavior of most passengers in choosing a different exit each time.

Effects of Emergency Illumination: The hypotheses of interest in this analysis are whether the use of an emergency illumination system results in a reduction of escape time through the various types of exits. In the first case, the distributions of escape times through the windows for Trials 3 and 5 were compared using the Chi-square statistic, with an α-level of 0.05. The null hypothesis of no difference in the two time distributions could not be rejected; i.e. there is not a significant difference in the two distributions. A similar comparison was made for Trials 4 and 6 with the same result. Finally, the entire distributions of window escape times were compared for Trials 3 and 4 versus 5 and 6 with the same result. Therefore, all of the window escape times apparently came from the same underlying distribution, meaning that the emergency illumination did not significantly affect escape time through the windows, even though the mean time did decrease by almost one second per person with emergency illumination. Perhaps this can be explained by noting that passengers must carefully choose their footing in climbing up the back of the seats and therefore the illumination was less important in this case.

A comparison of the time distributions for escape through the windshield for Trials 3 and 4 versus 5 and 6 using the Chi-square statistic with an

α-level of 0.025 shows that the null hypothesis can be rejected, i.e. the emergency illumination reduced the time to escape. The mean time of 1.52 seconds per person with emergency illumination is only approximately one half the mean time of 2.84 to escape under darkness conditions. This result can be explained by noting that the most important aspect of escape through the windshield is seeing, where one is stepping to avoid tripping and falling when climbing over the bus side windows when the bus is on its side. The emergency illumination allowed passengers to move faster by avoiding tripping as they made their way to and through the windshield opening.

A comparison of the time distributions for escape through the roof hatch for Trials 3 and 4 versus 5 and 6 with an α-level of 0.05 and the Chi-square statistic results in acceptance of the null hypothesis, i.e. the emergency illumination did not produce a significantly lower escape time, even though the time per person did decrease by 1.7 seconds per person with emergency illumination. It has been noted earlier that the absence of a ladder or other support adjacent to the roof hatch makes it difficult to use effectively. Thus, even though emergency illumination is provided there is only a limited ability to improve the escape time by seeing more of the area surrounding the roof hatch.

When viewed as a whole, the provision of emergency illumination appears to decrease the escape time through the windshield significantly and there is an indication that it may improve the escape time through windows and the roof hatch, although this improvement is not statistically significant for the sample size used in this study.

<u>Effect of Passenger Variables on Escape Time</u>: An obvious question of interest is the effect of passenger variables, such as age, sex, height, weight, hip breadth and shoulder breadth on escape time. This question was approached through the use of a multiple linear regression program to predict escape time as a function of these variables. The times to escape through the bus side windows, roof hatch and windshield were each predicted as a function of passenger height, weight, age, sex, hip breadth and shoulder breadth using multiple linear regression equations. In each case the residual term was significant for an α-level of 0.05. Stated another way, the multiple linear regression equations for each exit type which were developed using the group of personal variables did not adequately fit the actual escape times observed.

This lack of fit of the multiple linear regression equations does not mean that the personal variables of the passengers are not related to escape time through various exits, but rather means that other variables such as the amount of illumination, passenger placement prior to the evacuation, and aid rendered to other passengers are more important in influencing the escape time.

<u>Prediction of Bus Evacuation Time</u>

An important objective of this study was the development of data to permit prediction of bus evacuation time for a variety of post-crash conditions.

This section presents an approach for accomplishing this objective.

In the previous section it was shown that the personal variables of the bus passengers could not be used effectively to predict the escape time from various exits, even though noting that these variables do have some influence on escape time. Therefore, the prediction equations for escape time presented in this section are only valid for the typical inter-city bus passenger load studied. If significant departures occur in the composition of a bus passenger load from the one studied, then the prediction equations should be used with caution.

Time to Open Window Exits: The most representative prediction of time to open a window exit was chosen as the first trial for each subject group. This choice was based on the fact that most bus passengers in an actual accident would not have had the experience of opening a window exit. The predicted time is given as a mean value and a confidence interval for this mean value. In all cases the confidence interval was chosen such that 95 percent of the time when sampling from a normal population the true mean μ will be within this interval. The confidence interval is a function of the sample size and the inherent variability of the data. In this instance the confidence interval is large with respect to the mean because of the small sample and the large variability in the data. Table 29 presents data for the predicted time to open bus windows for the three conditions studied.

TABLE 29. PREDICTED TIMES TO OPEN BUS WINDOWS FOR EMERGENCY EVACUATION

Predicted Time-Seconds	Conditions of Use
14.59 ± 9.72	Bus upright, darkness, no practice.
18.63 ± 14.07	Bus turned on side, darkness and emergency illumination combined, no practice.

Time to Open Roof Hatch: The sample of times to open the roof hatch was small, consisting of only four values. Therefore, a prediction with a confidence interval was not feasible. The mean time was 6.53 seconds with a range of 2.96-15.00 seconds.

Time to Kick Out Windshield: Only two times were observed because the windshield could not be refitted for the second trial with each subject group. The third trial produced a time of 13.58 seconds and the fifth trial a time of only 2.38 seconds. Since the third trial time was produced by two older females, it probably can be viewed as an upper limit for this type of exit.

Time to Escape Through Bus Windows: The prediction of escape time for bus windows was developed so that the time begins when the passenger arrives at the window after it has been opened and ends as the person jumps or climbs from the window. In the case for the bus upright this is effectively the entire escape time. In the case for an overturned bus, it will be necessary for the passengers to move to the side of the bus and either jump, risking serious injury, or try to climb down the bus roof or underbody. The hazards of these methods of getting down from the top side of the bus, will be discussed in a subsequent section as well as the additional time required.

Table 30 presents the predicted time for window escapes for the different conditions of the study.

TABLE 30. PREDICTED TIME PER PASSENGER
TO ESCAPE FROM BUS WINDOWS AFTER INITIAL OPENING

Predicted Time-Seconds	Conditions of Use
8.68 $\pm$ 1.34	Bus upright, darkness, no injury.
9.53 $\pm$ 1.21	Bus on side, darkness or emergency illumination, no injury.
11.148 $\pm$ 7.56	Bus upright, darkness, injured passenger assisted by other passengers.
8.293 $\pm$ 4.05	Bus on side, darkness or emergency illumination, injured passenger assisted by other passengers.

The predicted times in Table 30 for injured passengers are based on small samples and therefore have a much larger confidence interval than those for non-injured passengers. It is somewhat surprising that the removal of an injured passenger through the window of an overturned bus would require less time than for the bus to be upright. This may be a statistical abberation or more likely represents the difference in handling the "injured" as they are passed through the window. In the bus upright case, the injured passenger was more difficult to catch by those outside and lower to the ground than when the "injured" was taken out an overhead window. In this case the "injured" was pulled through the window and laid on the side of the bus without the difficulty of lowering them to the ground. As noted earlier, the predicted time does not cover the removal of the "injured" to the ground from the side of an overturned bus.

Predicted Time for Roof Hatch Escape: Table 31 presents the predicted times for roof hatch escapes.

TABLE 31. PREDICTED TIME PER PASSENGER TO ESCAPE FROM BUS ROOF HATCH AFTER INITIAL OPENING

Predicted Time-Seconds	Conditions of Use
5.86 ± 0.96	Darkness or emergency illumination, bus on side, non-injury.
8.25 (1 case)	Darkness or emergency illumination, bus on side, injured passenger assisted by other passengers.

Predicted Time for Windshield Escape: Table 32 presents the predicted times for escape through the bus windshield.

TABLE 32. PREDICTED TIME PER PASSENGER TO ESCAPE THROUGH BUS WINDSHIELD AFTER BEING KICKED OUT INITIALLY

Predicted Time-Seconds	Conditions of Use
2.84 ± 0.53	Darkness, bus on side, non-injury.
1.77 ± 0.33	Emergency illumination, bus on side, non-injury.
4.76 ± 3.96	Darkness, bus on side, injured passenger assisted by other passengers.
3.15 ± 0.89	Emergency illumination, bus on side, injured passenger assisted by other passengers.

Predicted Time to Escape Through Front Door: Table 33 presents the predicted time to escape through the front door of the bus.

TABLE 33. PREDICTED TIME TO OPEN FRONT DOOR AND TIME PER PASSENGER TO ESCAPE THROUGH FRONT DOOR OF BUS WITH BUS UPRIGHT

Predicted Time-Seconds	Conditions of Use
9.79 (1 case)	Time to open door under darkness conditions, no prior knowledge that door was available as an exit.
2.22 $\pm$ 0.72	Time per passenger to escape, darkness conditions, non-injury.
3.51 $\pm$ 2.91	Time per passenger to carry injured passenger through front door to escape.

The predicted times for the initial opening of each type of bus exit and escape through these exits can be combined to predict bus evacuation time for a typical passenger load under a large variety of conditions. In order to predict the overall bus evacuation time for any set of conditions, one would proceed as follows:

1. Select the bus configuration, i.e. upright or on the side.

2. Select the number of each type of exit to be available for escape and the number of passengers to use each type of exit and also whether the passengers are "injured" so that they are immobile and require assistance.

3. Select either darkness conditions or emergency illumination.

4. Select whether a mean time, an upper limit time (pessimistic) or a lower limit time (optimistic) is to be predicted.

5. Apply the appropriate prediction equations for each type of exit, for the time to open and for the number of passengers to use the exit. The longest time for any of the respective exits will determine the overall evacuation time prediction.

The determination of how many passengers will use each type of exit is related to the type of discipline exercised during an evacuation, given that some set of exits is available for escape after a crash. It was noted earlier that passengers do not distribute themselves optimally at all of the available exits and therefore increase the overall evacuation time. This behavior could possibly be modified by instructions from the bus driver or hostess during an evacuation. The prediction of how much the evacuation time could be reduced can be accomplished by varying the number of passengers using each type of exit until the optimal arrangement is reached.

Finally, it was noted earlier that the predicted escape time from the bus windows for the case with an overturned bus does not include time to descend to the ground. In order to protect the subjects from a potentially serious injury, they were not permitted to jump or climb to the ground after escaping through the bus window since the distance to the ground was at least eight feet. Thus, no times were measured to descend to the ground by jumping or climbing down.

In order to account for the additional time that this activity might add to the bus evacuation time, several possibilities must be considered.

1. If each passenger chooses to jump to the ground as soon as he or she is through the bus window, then the only time which would be added is the time of the last passenger to move to the edge and jump, which should not exceed five seconds. All of the time for the prior passengers would be internal to the overall evacuation time and not be additive, i.e., the person jumping to the ground will be doing this while some other person is climbing through a window. Therefore, the only additional time for evacuation would occur when the last person climbing through a window must move to the side of the bus and jump.

2. If some passengers are afraid to jump and wait on the top side of the bus while others are escaping through the windows, then the overall evacuation time would be increased by whatever time it takes these passengers to decide to jump, which could be a substantial increment of time. It would appear that many passengers, particularly those over 50 years of age, would perceive a significant hazard in jumping and be reluctant to jump unless a fire in the bus was considered to be a greater hazard. The injury data reviewed earlier in this report showed that jumping from the side of an overturned bus is a significant hazard, especially if jumping onto concrete or asphalt. It therefore seems likely that many passengers would perceive that a hazard exits and weigh the hazard in jumping versus remaining on the side of the bus.

3. If some passengers try to climb down, rather than jumping, then this could also increase the evacuation time substantially. The time added would be a function of how rapidly the person could climb down, which would probably be quite slow under darkness conditions. It was also noted that the opened windows when the bus is on its side comprise a significant barrier for jumping or climbing down the top side of the bus. Since the windows were found to be easily broken off their hinges, they would present a significant hazard if a passenger was attempting to hold to them while lowering himself to the ground over the top of the bus. The window could break off and fall onto the passenger.

4. If some of the injured passengers are in need of special care in lowering them to the ground, then this could also significantly increase escape time.

It should also be noted that some bus evacuations will involve a fire and result in the need to remove injured passengers from the area as quickly as possible. Given the potential for injury as a result of an accident and also in jumping to the ground, a significant number of passengers could be injured seriously enough to require help in evacuating the area. If this occurred, then the bus evacuation could be increased by several minutes. However, it must be remembered that the front windshield presents a much better exit if it can be broken out, and therefore the problems in jumping from the bus would be greatly reduced or eliminated. The actual accident data reviewed earlier indicated that the front windshield was often used as an escape route from an overturned bus.

Hazards Observed in Bus Evacuations

The escape from a bus side window when the bus is in an upright condition presents two types of hazards. First, there is the hazard of being struck by the window as a passenger is entering the window after another has just preceded him through the window. The bus windows on the bus as tested weigh approximately 47 pounds and can fall with a significant force to bruise or otherwise injure a passenger if they are opened to an angle of 30 degrees or more by the passenger who preceded him in escaping. It is obvious that the use of mechanisms for latching the window which produce sharp points or edges increase the risk of injury from windows falling on passengers. Consideration should be given to requiring some mechanism for holding windows open once they are initially opened.

The other hazard observed to passengers in escaping through the windows with the bus upright was that of falling from the window to the ground below. As noted earlier, one of the older female passengers incurred a serious back sprain which required several weeks of medical treatment before she was healed. The literature review presented earlier contained information obtained from a survey of the injuries sustained by persons falling from various heights. It was shown in this analysis that the potential exists for serious injury, especially to older adults when falling from heights up to eight feet. The descent from the bus window is only from a height of six feet, but still presents a significant potential for injury to older adults; and also to younger adults if the surface on which the person is landing is concrete or asphalt, which could be the case for a bus evacuation.

If the bus is turned onto its side as a result of an accident, then a different group of hazards are present in escaping from the bus. In escaping through the windows which are eight feet overhead, the passenger encounters a hazard when stepping on the windows which are underneath his feet because of the danger of lacerations from broken glass. An additional hazard exists as the passenger attempts to climb to the window overhead, using the back of the seats and the luggage rack as footholds. In this climbing maneuver, there is a possibility, though not observed in these tests, for losing his or her balance and falling back onto the bus windows or other bus passengers. If the passenger is successful in achieving a satisfactory foothold, then there is the hazard of the bus window falling back onto the person as he or she attempts to fully open the window. As noted earlier, the window has not been designed to resist any significant amount of force when it has been fully opened with the bus on its side and therefore it can be broken off and fall across the top of the bus onto passengers who may be below. An examination of the failed window hinge showed that it first fractured at the center hinge and then the two hinge pins at the outside hinges bent sufficiently to permit the window to fall from the bus. The moment arm produced by the height of the window with the bus overturned and the window opened completely is too great for the strength of the hinge. The hinge is not subjected to this loading when the bus is in the usual upright position. If the passenger then succeeds in climbing through the window overhead when the bus is on its side, he or she is then presented with the need to find some method of descending to the ground. The possibility exists of jumping eight feet or more to the ground below, but this presents a serious potential for injury, especially to passengers jumping onto a surface such as concrete or asphalt. The injury potential is increased if the passenger is an older adult. The data for jumps and falls from various heights presented earlier in the review of the literature demonstrates that a significant proportion of passengers could be expected to incur serious injury if they jump or fall from the side of the bus after having escaped through the overhead windows.

A descent from the top side of the bus, across the roof of the bus might appear to be feasible to some passengers by using the opened side windows as a means of holding on while lowering themselves to the ground. However, in view of the limited amount of force which these open windows could sustain, this would become a hazardous maneuver because of the danger of the window weighing approximately 47 pounds falling onto a passenger as he or she were attempting to lower themselves to the ground by holding onto the open window.

The escape from the roof hatch can be considered significantly less hazardous than jumping from the side of the bus in its overturned position after climbing through the window overhead. However, this type of exit still presents a hazard because of the lack of satisfactory hand holds and footholds in maneuvering through the relatively small roof hatch opening. It was noted in an earlier section that the utility of a roof hatch could be significantly increased by providing a ladder-type of arrangement on both the inner surface and the outer surface of the bus adjacent to each of the roof hatches provided.

Escape through the windshield of the bus may present a hazard to the first passenger who must kick out the windshield in order to utilize the opening for escape. The windshield was taped and covered with a heavy plastic film in the test conducted because of the hazard of laceration from broken glass which exists in kicking out the windshield. In an actual evacuation, the use of a tool such as a tire repair tool or a large reflector could decrease the possibility of laceration while dislodging the windshield from its opening. The hazard to subsequent passengers using the windshield opening as an escape exit is limited to the danger presented by stepping onto the bus side windows as they exit through the windshield opening.

Subject Debriefing Information

Each person participating in the bus evacuation tests was debriefed immediately after the tests using a standard set of questions as presented earlier in this report. This section presents the information obtained as a result of the subject debriefing.

The first two debriefing questions covered the subject's name, whether they were asked to feign an injury and if injured, whether anyone helped them to escape. Having the subject's name permitted a classification of the responses by age and sex of the subject. The response regarding whether they had been asked to feign injury permitted identification of these subjects in viewing the movie film to tabulate the data presented earlier for escape times.

The third question related to whether the subject had opened an exit and if difficulty had been experienced in opening the exit. Table 34 shows the number of persons who said they had difficulty in opening an exit for each type of evacuation test.

TABLE 34. TABULATION OF PERSONS REPORTING DIFFICULTY IN OPENING AN EXIT

Test Number	Exit Type	Number of Persons Having Difficulty Opening Exit
1 and 2	window	12 out of 16 windows
3 and 4	window	5 out of 8 windows
	windshield	female subjects said "it took alot of kicking"
4 and 5	window	5 out of 8 windows

For the bus windows in Tests 1 and 2, the two reasons for difficulty were not understanding how latch operated or not having enough force to open window. In the tests with the bus overturned, the reasons for difficulty were not understanding how the latch operated and not being able to lift the window to open it.

The subjects were asked in Question 4 whether they had any difficulty in getting out an exit. For the first two tests with the bus upright, the most frequent reason given for those who had difficulty was in getting out a window unless it was held open by someone. The persons feigning injury reported difficulty as expected, although they were helped by other passengers.

In Tests three, four, five and six, the most frequent reason given for those who had difficulty was the problem in climbing through the roof hatch. It was noted that the luggage rack presented an obstacle on the inside and that it was a problem to get through the hatch and drop to the ground without risking injury. Some passengers reported difficulty in climbing out the windows overhead, especially with the goggles simulating darkness conditions. For those people who went out the windows one time and the roof hatch the next time, the window was considered easier for escape. However, this view probably would have changed had they been required to find a way to the ground from the top side of the bus instead of using the scaffold and ladders provided.

Question number five related to helping those who feigned injury. Two persons out of 16 said they were not helped to escape.

Subjects were asked in Question six whether it was easier to get out the second time than the first. Table 35 presents this data.

TABLE 35. WAS SECOND ESCAPE EASIER THAN FIRST?

Test Number	Yes	Same	No
1 and 2	47%	29%	24%
3 and 4	61%	9%	30%
5 and 6	64%	23%	23%

If the subjects answered yes, the most frequent reasons stated were:

1. I knew what to expect.

2. I was not helping someone.

If the person answered no, the most frequent reasons stated were:

1. I was injured.

2. I was helping an injured.

3. I used a different type of exit.

The final question was an attempt to determine whether the person would have behaved in the same way had there been an actual bus accident rather than the test. Table 36 presents the responses to this question.

TABLE 36. WOULD YOU BEHAVE THE SAME WAY IN AN ACTUAL BUS ACCIDENT?

Test Number	Yes	No	Don't Know
1 and 2	84%	16%	0%
3 and 4	88%	12%	0%
5 and 6	84%	14%	2%

It is clear that most subjects thought they would behave the same way in an actual accident. For those who said no, the reasons given were:

1. I would have panicked.

2. I would have used a different exit.

The subject debriefing information provides some additional insight into the problems of escaping from a bus after an accident. If the debriefing information is summarized, the most important findings were as follows:

1. Instructions for operating window latches created problems for some passengers.

2. The overhead windows with the bus on its side are too heavy for some passengers to open without help.

3. The roof hatch exit is a problem because its overall size does not permit the maneuverability necessary to avoid falling. As noted earlier, some ladder-type supports around the roof hatch would help alleviate this problem.

4. Most of the passengers thought they would behave the same way in an actual bus accident.

V. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions have been reached as a result of the literature reviewed and the studies conducted:

1. Rapid and safe evacuation of passengers after a bus accident should be an important performance parameter for bus design. The maximum time to permit for a bus evacuation cannot be fully determined with the data currently available. However, the standard used by the FAA for aircraft evacuation should be carefully considered, i.e., 90 seconds time with one-half the available exits being used. The evacuation should be accomplished without any more than minor injuries to passengers.

2. The typical bus passenger load can be adequately described by the survey conducted for this study.

3. The time to evacuate a bus for a given combination of exits can be predicted satisfactorily for a typical bus passenger load.

4. A significant potential for serious injury exists when jumping or falling from the top side of an overturned bus, especially if the passenger lands on concrete or asphalt.

5. The use of a roof hatch for escape when the bus is on its side is limited by the absence of some type of ladder or "toe hold" support when maneuvering through the opening.

6. The windshield of an overturned bus provides a good escape route if it can be kicked out by a passenger. Passengers in this study showed no reluctance to kick out the windshield.

7. Bus evacuation time could be reduced if the passengers better utilized all of the available exits. However, the use of some exits would produce more injuries, thus presenting a tradeoff of one criterion versus the other.

8. Emergency illumination reduced the escape time through the bus windshield opening as compared to darkness conditions.

Recommendations

1. A standard should be considered for maximum bus evacuation time. The current FAA standard for aircraft evacuation is an example of a potential standard. The standard should also require that evacuation be conducted with no more than minor injuries sustained by the passengers.

2. A ladder or "toe hold" type arrangement on the inside and outside of roof hatches should be required to improve their utilization as an escape route. At least three roof hatches of approximately 20 x 24 inches should be required on buses so that passengers are not required to use the overhead windows as escape routes from an overturned bus.

3. Clear instructions should be provided on all bus exits for their use. Standards such as those found in Van Cott and Kinkade (1972) should be used for these instructions. A type of escape instruction circular such as used on aircraft should also be provided to passengers.

4. An emergency illumination system should be considered for buses. This system should be able to function after a crash to provide illumination and reduce the evacuation time as well as aid in the first-aid treatment of passengers.

5. Consideration should be given to providing instructions and labels which indicate that the front windshield can be broken out and used as an escape exit. These instructions should note that some object such as a piece of luggage, a tire tool or a reflector stand could be used to reduce the possibility of injury when breaking out the windshield.

6. Window hinges used on buses should have a performance requirement that would prevent the window from breaking off under the loads expected from pushing the windows open rapidly for escape and when passengers attempt to hold onto the window to lower themselves to the ground from the top side of an overturned bus.

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APPENDIX

1. Statement of Informed Consent Form
2. Waiver of Film Rights Form
3. Subject Information Sheet

STATEMENT OF INFORMED CONSENT

I, ____ understand that I am being asked to participate in a test of the ability of people to evacuate a bus under simulated emergency conditions. I understand that the conditions stated below will exist during my escape from the bus and I also understand that it is possible for me to be excused from participating in any of the tests when I feel that my personal safety is in question.

The escape tests will be conducted for either a bus upright on its wheels where the escape routes are through the front door and the side windows; or a bus which has been turned on its side where the escape routes will be through a roof hatch, the side windows which will be overhead, or the front windshield of the bus. The passengers will escape when the bus is upright by exiting through the windows and dropping to a mattress which will be underneath to cushion the descent. The passengers will escape from the bus when it is on its side by kicking or pushing open the roof hatch or the front windshield and using these as an escape route. They may also choose to escape by climbing out the windows which will be overhead through the side of the bus. Passengers who choose to use the windows overhead, when the bus is on its side, as an escape route will be required to use a specially constructed scaffold in descending to the ground from the side of the bus. Passengers will be required to enter the bus and then to use goggles which will simulate darkness conditions throughout the escape trials.

I understand a registered nurse and an emergency vehicle will be on standby to treat me should I incur any injury, however minor, as a result of these tests.

I understand that through a document which I have signed, that the movie films taken of these escape trials can be shown by the Department of Transportation to audiences through the public media and to other researchers. I understand that I will not be identified by name in any of these movie films.

I understand that by signing this statement of informed consent, I am not waiving any of my legal rights or releasing the institution for liability for negligence in conducting these tests.

I understand that the benefits of this research are primarily for society as a whole, rather than me personally.

If I have any questions after the experiment, I can contact Dr. Jerry Purswell at The University of Oklahoma, School of Industrial Engineering, 325-3721.

I, ______________________________ have provided a copy of this statement of informed consent to the person named above who read it and signed it in my presence. This signed copy was then given to this person.

Subscribed and sworn to before me this _____ day of _________, 1977.

____

Notary Public

My Commission Expires: ____________

WAIVER OF RIGHTS IN FILM OR VIDEO RECORDING

I, ____,

in consideration for my participation in the "Evacuation of Inter-City Buses Experiment", do hereby waive, release, deny and otherwise relinquish any rights, title or claim to any royalties, payment or other consideration resulting from or made in connection with the distribution or showing of the filmed account of this experiment.

____

SUBJECT INFORMATION

NAME: ______________________________

ADDRESS: ____________________________

PHONE NUMBER: _______________________

SOCIAL SECURITY NUMBER: _______________

AGE: ________________________________

IF OVER 50, DATE OF LAST MEDICAL EXAM: ______________________

HEIGHT: __________in. __________cm.

WEIGHT: __________lbs. __________kg.

SHOULDER BREADTH ________in. __________cm.

HIP BREADTH _________in. __________cm.

NO. OF HOURS WORKED: _________________

RATE OF PAY PER HOUR: _________________

I have participated in an experiment entitled Evacuation from Intercity Buses which was conducted by Drs. Jerry L. Purswell and Alan Dorris, who were the principal investigators.

____

Subject's name