Commercial Bus Accident Characteristics and Roadway Treatments

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Traffic accidents involving buses result in about 35,000 injuries in the United States each year. This study describes bus and motor vehicle accident characteristics and recommends roadway-related countermeasures. Analyses were carried out on a primary study file of 8,897 commercial bus crashes in five states—Illinois, Maine, Michigan, Minnesota, and Utah—for 1985 through 1989. A subset file with urban crashes in four states and the entire Illinois motor vehicle accident file with all vehicle types were also analyzed. The overall number of crashes was highest in winter, perhaps partly because of snow and ice. Older buses were overrepresented in injury and fatal crashes in comparison with newer buses. Neither bus driver age nor gender was related to accident involvement. Bus crashes at traffic lights were more likely to cause injuries and fatalities than those at stop signs. In Illinois, the most common bus accident types were rear end with one vehicle stopped, sideswipe same direction, and turning. Rear-end and angle accidents were most likely to cause injuries and fatalities. A number of measures may be used to improve bus safety. Roadway improvements on bus routes include wider travel lanes, paved shoulders or bus pull-off lanes, wider intersection turning radii, separate turn lanes, restriction of on-street parking, proper use and placement of signs and lane markings, and separate left-turn phasing. General roadway improvements in suburban and rural areas that can also reduce bus crashes include flatter roadside slopes and improved design of guardrail and roadway alignment. Future research needs related to bus transit safety are also discussed.

Traffic crashes and injuries related to buses represent a safety problem on U.S. highways. For example, in 1990 an estimated 64,000 of the 627,000 registered buses nationwide were involved in crashes, or 10.2 percent. By comparison, only 5.8 percent of other types of vehicles were involved in crashes in that same year. The crash rate for buses was 11.17/million vehicle miles, compared with 5.51 for passenger cars (*1*). The higher involvement rate of buses results from greater exposure to potential accident situations including stop-and-start operation (and perhaps more encounters with other vehicles associated with congested urban roadways).

Bus crashes take a substantial toll of injuries and deaths. In 1990, an estimated 32,000 bus occupants sustained minor or moderate injuries in highway crashes. Another 3,000 sustained serious injury (*1*), including 32 deaths. The number of occupant injuries or fatalities per 100 crash involvements was 54.7 for buses, compared with only 29.5 for passenger cars (*2*). This higher rate may be attributed to the lack of passenger restraints on buses and to the large number of occupants on buses. In addition, bus crashes are associated with approximately 100 deaths to nonoccupants (largely pedestrians and bicyclists) and 200 deaths to occupants of other vehicles per year, according to the Fatal Accident Reporting System (*2*).

This study quantifies the characteristics and causes of crashes involving commercial buses (i.e., all types of full-sized buses except for school buses) and their resulting injuries. The analysis considers bus crashes with other motor vehicles and bus run-off-road crashes (e.g., rollovers or striking poles, trees, and other fixed objects).

In conclusion, recommendations are made for highway improvements to reduce the number and severity of bus-related highway crashes. Recommended modifications to bus design features and bus driver training are found elsewhere and are directed primarily to highway designers and engineers (*3*).

LITERATURE REVIEW

It is convenient to distinguish between collision and noncollision bus accidents. Collisions include crashes with other motor vehicles, bicycles, pedestrians, and fixed objects. Examples of noncollisions are passenger falls while boarding, alighting, or riding buses. This section discusses previous literature on collision accidents only.

Dixon et al. (*4*), examine the injury-producing mechanisms for five types of collision accidents: head-on, rear-end, sideswipe, side impact, and rollover. Head-on collisions are those that involve impact at the front of the vehicle, causing the bus to decelerate (and where the direction of deceleration is toward the rear of the bus). Rear-end collisions usually involve another vehicle running into the back of the bus, causing the bus to accelerate. Contact with the bus described as a "glancing blow to the side" is a sideswipe collision. A side impact is characterized by lateral acceleration.

Of the five accident types, rollover accidents are the most likely to result in severe passenger injury or death. A lack of occupant restraints (i.e., seat belts) results in uncontrolled body movement, and during rollover passengers fall against internal bus fittings and other passengers. Partial or complete passenger ejection through windows, doors, or openings in the passenger compartment created by the collision may result in severe injuries. Injuries may also occur because of the collapse of a roof or wall into the passenger compartment (*4*). For all motor vehicle accidents, occupants who are ejected are four times more likely to suffer a serious or fatal injury than occupants who are not ejected (*1*).

Jovanis et al. (*5*) conducted one of the few studies that analyzed data bases related to bus crashes on a large scale. That study analyzed accident report data from PACE, a suburban bus transit agency in metropolitan Chicago, for 1982 through 1984. Eighty-nine percent of the 1,800 bus accidents involved collisions with another vehicle or object; 11 percent involved noncollision passen-

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ger injuries while boarding, alighting, or moving about the bus. The authors suggest that buses pose the greatest risk to automobile occupants when the buses are stationary, such as when stopped behind other vehicles or when processing passengers. Bus accidents did not appear to be more prevalent during times of darkness. The number of accidents dropped during night hours, reflecting lower service frequency and lower levels of automobile traffic. The gender and age of bus drivers did not contribute to accidents. However, the number of years of experience was found to be a contributing factor. Drivers with 3 to 6 years of experience at PACE were significantly overrepresented compared with those with less or more experience. The accident frequency by time of day generally followed congestion patterns. The number of accidents along a route was virtually linear with its mileage and negatively correlated with vehicle headway and speed (*5*).

Other researchers have analyzed bus accident data on a large scale in Great Britain; Delhi, India; and Victoria, Australia (*6–9*). In Great Britain, 43 percent of bus passenger injuries occurred as the result of collisions; 57 percent was the result of falls and other incidents under normal conditions (*6*). Another study in Great Britain found that 20 percent of the casualties were pedestrians (*7*). More than 50 percent of bus injury accidents occurring in Delhi involved pedestrians, cyclists, and motorcyclists (*8*). Nearly 14 percent of the bus injury accidents in Victoria involved pedestrians.

Additional research is needed to fill the gaps that exist in the literature. For example, the characteristics of bus accidents have not been adequately compared with the characteristics of accidents involving other vehicle types. Little information is available on the role of roadway, driver, or environmental features in bus accidents. Furthermore, additional information is needed on the types of roadway treatments that could potentially reduce the number of bus crashes on streets and highways. This study addresses some of the gaps.

DATA SOURCES

The data base chosen for analysis in this study was the Highway Safety Information System (HSIS). This data base consists of computerized information related to motor vehicle crashes, traffic volume data, and roadway characteristics from Michigan, Minnesota, Maine, Illinois, and Utah. The HSIS data were obtained from the respective states by the University of North Carolina's Highway Safety Research Center through funding from FHWA. The HSIS states were chosen on the basis of the availability of good quality data, the capabilities for merging various data files, and other factors. Although these states may not be representative of the entire United States, they have data on accidents in urban and rural areas, on different types of roads, under a variety of climatic and geographic conditions, and on roadways with various design features. Thus, the information obtained from these states was useful in achieving the primary study objective.

The HSIS files contained information on 8,897 bus crashes that occurred from January 1, 1985, through December 31, 1989. For each accident, the available information included when the crash occurred (i.e., time, day of week, month), environmental conditions (light and weather conditions), vehicle information (e.g., age of bus), driver information (age, gender, injury), accident type (i.e., single vehicle, sideswipe, turning accident, etc.), and crash severity. These variables were analyzed to gain a better understanding of factors related to bus crashes.

ANALYSIS METHODS

Several methods were used to analyze the HSIS bus accident data. The most common analysis technique was a simple comparison among the levels of a particular variable. For example, the numbers of bus-involved accidents reported by day of the week were computed and compared. These simple comparisons were useful when the variable was not related to exposure. The study team also made many comparisons between the levels of a variable on the basis of the percentage of severe accidents (i.e., accidents involving one or more fatalities or injuries). These comparisons show the levels of the variable that deserve particular attention.

For some types of analyses, there was a need to compare crash factors for buses with those of other vehicle types. For example, to determine the types of crashes in which buses were overrepresented (e.g., sideswipe crashes), it was necessary to compare the distribution of crash types for buses with that for cars and pickups, trucks, and school buses. For these analyses, all 620,000 vehicle crash involvements (including 1,500 bus-involved crashes) from the Illinois accident file for 1988 and 1989 were used. Bus crashes were then compared with crashes of other vehicle types for accident types and crash severity.

Some analyses were performed for all bus-involved accidents in the five-state sample. However, these analyses include accidents involving intercity buses on rural highways, which have different characteristics from accidents involving intracity transit buses. Therefore, most detailed analyses were performed for bus-involved accidents on urban surface streets, using the best available definition for those factors in each state.

Although the computer accident files contained a large sample of bus crashes and dozens of variables of interest for each accident, a limitation of the study was that no bus "exposure" data were available. In particular, statewide bus mileage data were not available for computing overall bus accident rates (e.g., in terms of bus accidents per million vehicle miles of travel) or for computing accident rates by driver characteristic, age of bus, and so forth. The lack of suitable exposure data has also been a problem in safety analysis of trucks (e.g., by truck size and configuration) and other vehicle types for research purposes.

A substitute or surrogate measure of exposure can be used, the "innocent victim technique." For this study and for driver categories, driver age, driver sex, and bus model year variables were analyzed with the innocent victim technique. This technique adjusts for the exposure of driver or vehicle-related groups using only accident data. The technique relies on the assumption that a group's (e.g., bus group's) exposure is related to the number of times the group's members are involved in crashes in which they are not the "at-fault" or striking vehicle, and thus are "innocent victims."

The best way to understand the innocent victim technique is to think through an example application. Suppose an analyst wants to know whether younger drivers are overrepresented in intersection-related crashes. The analyst computes that 20 percent of drivers involved in intersection-related crashes were less than 25 years old. The analyst then computes that 15 percent of the innocent victims of crashes at intersections were less than 25 years old. The ratio of the 2 percentages provides an indication of overrepresentation. Because the percentage of younger drivers involved in all intersection-related accidents is higher than the percentage of younger innocent victims, the analyst concludes that younger drivers are overrepresented. The innocent victim technique has been used by researchers in accident studies for more than 20 years. Readers interested in a review of the theory and applications of the technique are referred to Bowman and Hummer (*10*).

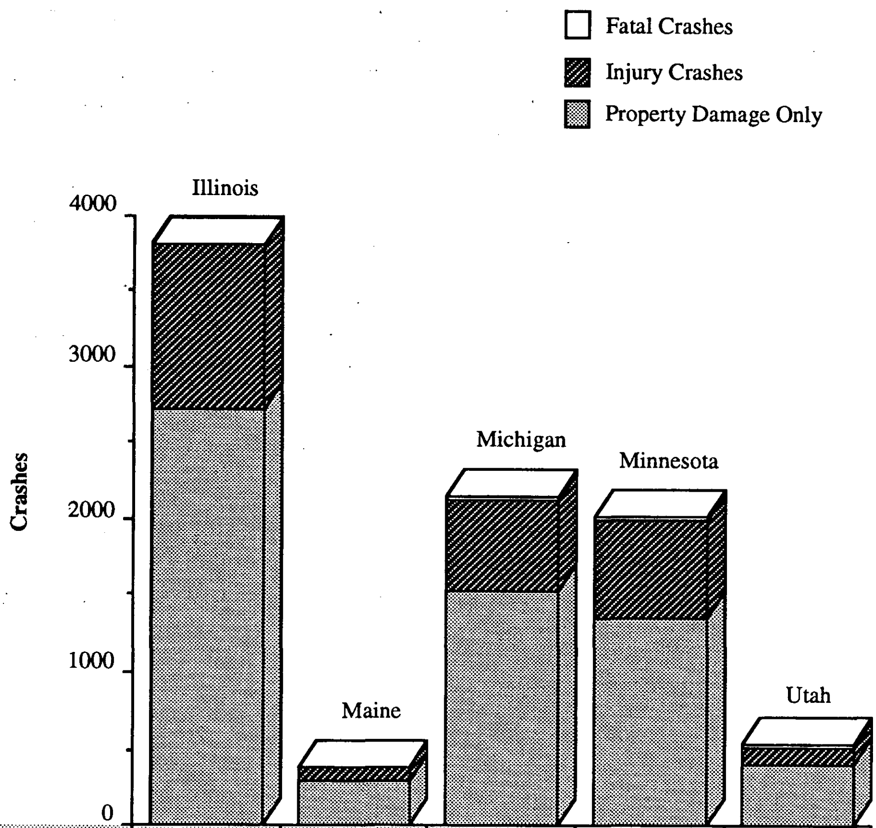
The innocent victim technique was used with data from Michigan and Illinois for bus crashes. To be effective, the technique requires relatively large samples, and the states provided the largest samples of bus-related accidents among the five states. Innocent victims were defined using the best available variables and accident types in the two states. In Michigan, bus innocent victims were identified when the bus driver had "no hazardous action" coded and the other driver had some type of hazardous action coded. This is a very strong definition of an innocent victim. In Illinois, bus innocent victims were identified when a bus was struck in a rear-end collision.

RESULTS OF COLLISION ACCIDENT ANALYSIS

General

A total of 8,897 crashes involving commercial buses was identified from the HSIS files. These bus crashes included 3,825 (43.0 percent) from Illinois (mostly from Chicago), 2,160 from Michigan (24.3 percent), 2,014 from Minnesota (22.6 percent), 526 from Utah (5.9 percent), and 372 from Maine (4.2 percent). A greater number of accidents in a state does not mean that buses are less safe in that state, since no measure of exposure, such as number of buses registered or bus miles driven, is available to normalize these data. Figure 1 shows the distribution of bus crashes by severity of the crash for each of the five states included in the files. Overall, 0.7 percent (65) of the crashes resulted in fatal injury, 28.5 percent (2,537) in nonfatal injury, and 70.8 percent (6,295) in property damage alone. For fatal and injury crashes combined, Minnesota was highest with 32.7 percent and Maine lowest with 22.6 percent. For this study, a serious bus crash was defined as one that resulted in at least one injury or fatality.

Of the total 8,897 crashes, 5,283, or 59.4 percent, were identified as urban crashes. These urban bus crashes had a severity pattern very similar to the overall sample, with 0.5 percent resulting in fatal and 28.3 percent in nonfatal injuries. Most of the urban bus crashes in the HSIS file occurred in Illinois (63.6 percent), with smaller percentages in Minnesota (16.1 percent), Michigan (15.7 percent), and Utah (4.6 percent). The available HSIS data for Maine did not permit the identification of urban crashes.



	Illinois	Maine	Michigan	Minnesota	Utah
Fatal Crashes	23 (0.6%)	1 (0.3%)	18 (0.8%)	17 (0.8%)	6 (1.1%)
Injury Crashes	1,081 (28.3%)	83 (22.3%)	601 (27.8%)	642 (31.9%)	130 (24.7%)
Prop. Damage Only Crashes	2,721 (71.1%)	288 (77.4%)	1,541 (71.3%)	1,355 (67.3%)	390 (74.1%)
Total	3,825	372	2,160	2,014	526

FIGURE 1 Distribution by state of bus crashes in HSIS file.

The analysis of Illinois data comparing bus crashes with other crash types showed that commercial bus crashes represented only slightly more than 0.2 percent of all crashes in Illinois in 1988 to 1989. In comparison, cars and pickup trucks were involved in 87.2 percent of crashes, and large trucks in 6.2 percent. Compared with car and pickup truck crashes, bus accidents are about equally likely to result in a fatality or injury (Figure 2). Truck crashes and events involving other vehicle types were found to have the highest fatality rates.

Temporal

Approximately equal numbers of crashes involving commercial buses were reported for each of the 5 years in the HSIS file. The total number of reported crashes was lowest in 1987 (1,643) and highest in 1985 (1,837) and 1989 (1,838). The number of injury crashes ranged from 499 in 1987 to 568 in 1985. Overall, 29.2 percent of the crashes resulted in injury, with some evidence of a decline in this percentage over the 5-year period.

Injury and overall crashes were lowest in July and August, likely reflecting the reduced number of bus trips and reduced ridership typical during this time. Although the overall number of crashes is greatest in January and February, April and May have the highest percentages of crashes involving injury.

As expected, the percentage of urban crashes on weekends is lower than on weekdays. The distribution of injury crashes is similar to that of total crashes. A higher percentage of crashes occurs on Friday than on other weekdays (significant at the 0.05 level using the chi square test). However, crashes on Friday are less likely to result in injury than on some other days. Traffic volumes may be higher on Fridays, resulting in slower travel speeds, which in turn mitigate accident severity. The greatest percentage of injury crashes occurs on Tuesday.

Frequency of urban bus crashes by time of day generally followed expected bus travel patterns (Figure 3). Crashes were most common during the afternoon rush hours, from 3 p.m. to 6 p.m. (28.3 percent of the total). Another 56 percent of crashes occurred during the morning commute and midday hours, from 6 a.m. to 3 p.m. Although considerably fewer crashes occurred during the evening and night, these tended to be more severe. Nearly 40 percent of bus crashes occurring from 9 p.m. to 3 a.m. resulted in injury.

Environmental Factors

Light Condition

An analysis of bus crashes by light condition on urban streets was based on data from Illinois, Minnesota, and Utah. Accidents were more common during daylight hours (80.3 percent). Lower percentages of crashes occurred after dark on lighted streets (12.3 percent), during dawn or dusk (4.9 percent), or in darkness with no street lights (2.5 percent). These percentages for urban crashes agreed closely with the total sample (rural and urban areas) of bus crashes. The 2-year sample of Illinois data revealed that 78.7 percent of commercial bus accidents occurred in daylight, compared with 68.8 percent of car and pickup accidents and 92.9 percent of school bus accidents.

Urban bus accidents occurring at night on lighted streets had a higher percentage of injury plus fatal accidents (33.8 percent) than did those during daylight (28.3 percent), dawn or dusk (26.1 percent), or dark without lights (25.2 percent). These differences were significant at the 0.05 level. The higher severity of crashes at night on lighted roadways could be the result of the greater use of lighting on high-speed arterial routes, compared with lower-speed collector or local streets.

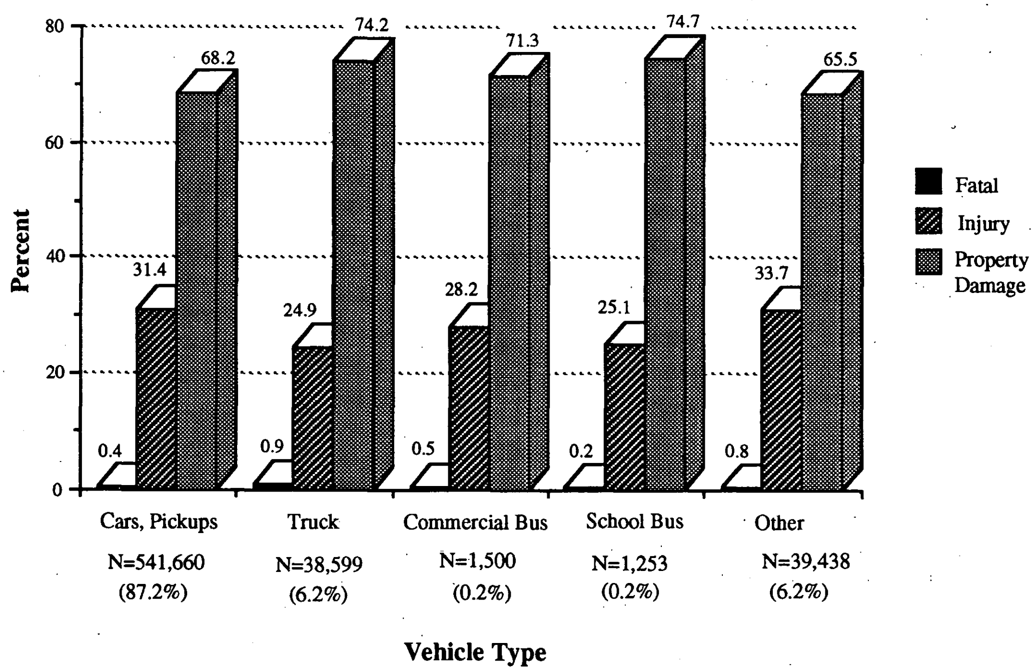


FIGURE 2 Distribution by vehicle type and crash severity of 1988–1989 Illinois crashes. (Note: "Other" includes vans, farm equipment, motorcycles, and vehicles coded as "Other").

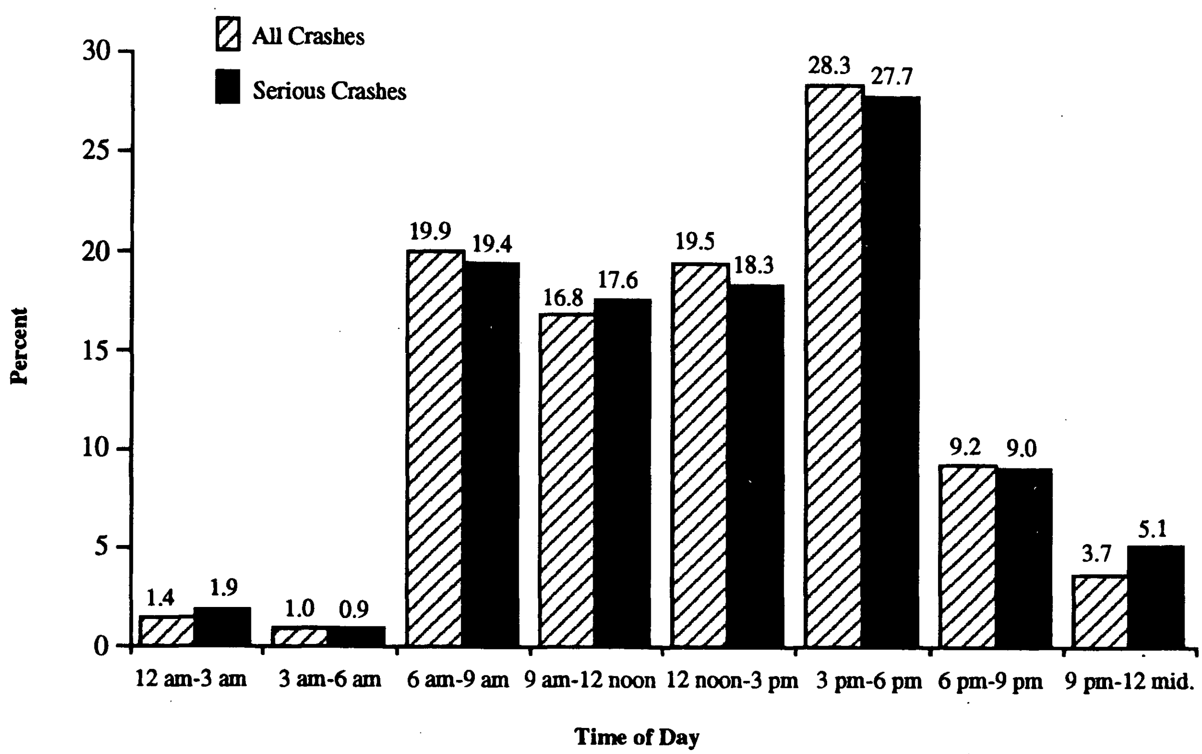


FIGURE 3 Distribution by time of day of urban bus crashes.

Weather and Road Conditions

Of the total bus accidents (urban and rural areas), 64.8 percent occurred on dry pavement compared with 20.7 percent on wet pavement and 13.9 percent on snow and ice. On urban streets, accident percentages were slightly higher on dry pavement (66.2 percent) and wet pavement (22.9 percent), but were lower on ice and snow (10.6 percent). This lower percentage of urban crashes on ice and snow could be related to better snow removal or lower speeds, or both, in urban areas than in rural areas.

Bus accidents in the total sample tended to be more severe on wet roads than on other pavement conditions, with 32.2 percent of wet-road crashes resulting in injury or fatality. This compared with 28.9 percent injury or fatal crashes on dry roads and 26.4 percent on snowy or icy roads. Wet roads are more associated with longer braking distances than are dry roads, which can result in higher-speed impacts (all else being equal). The lower severity on snowy or icy roads could be the result of added driver caution, including reduced travel speeds.

Vehicle Factors

The primary vehicle factor available for analysis from the HSIS crash file was the model year. Model year was analyzed with simple comparisons and with the innocent victim technique. Buses built in 1975 through 1979 were involved in a higher percentage of reported accidents (31.8 percent) in the four states with available data than any other model years. This finding is most likely because of a larger number of these vehicles in service (greater exposure) than other model years. Older buses were also overrepresented in injury and fatal crashes. The injury or fatality rate was almost 6 percentage points lower for buses built after 1984 than for buses built before 1975, and the chi-square statistic for this was significant at the 0.05 level.

Because direct vehicle exposure data were not available, the innocent victim technique was used to account for the relative exposure of the different model years. The analysis revealed that older buses were significantly overinvolved in reported accidents in Illinois ($p = 0.01$); in Michigan, the relationship was marginally significant ($p = 0.10$). A possible explanation for the better performance of newer buses is that changes in bus design through the years, such as better visibility from the driver's seat, power steering, and improved brakes, have had a positive impact.

Driver Factors

Several driver-related factors were analyzed. Driver age was investigated through simple comparisons. In the full five-state sample, drivers near the age of 40 years were involved in many more reported crashes than were other age groups. More than 30 percent of all reported bus crashes involved a bus driver aged 36 to 45. Of course, this finding may be because of a greater number of bus drivers aged 36 to 45, or the large number of miles driven by this age group, or both.

Drivers near the age of 40 experienced more serious crashes than they did all other crashes. In contrast, the proportion of serious crashes for drivers under 35 and over 65 years old was lower than that for all crashes. This finding, which was statistically significant at the 0.005 level, may be because of the route and schedule tendencies of the different driver groups. Younger and older drivers may drive less demanding routes or schedules with fewer passengers, or both. On the other hand, the innocent victim analysis showed that driver age was not related to accident involvement.

Another driver age-related variable analyzed was driver experience, which was recorded only in Utah. No statistically significant differences were found among groups with different amounts of driving experience in terms of involvement in injury and fatal accidents. Note that this variable was driving experience, and not bus driving experience. None of the five states recorded that.

The gender of the bus driver proved to be unrelated to accident involvement. Male bus drivers were involved in almost 80 percent of the crashes in the four states where data were available (Maine did not report driver gender). However, the innocent victim technique showed that there was no strong relationship between driver gender and accident involvement. In addition, there was no statistically significant relationship between driver gender and accident severity ($p > 0.10$). This finding was corroborated with the innocent victim technique.

The bus driver condition reported on the accident form proved to be minor in explaining accidents. Ninety-seven percent of all bus-involved accidents in Illinois, Maine, and Minnesota (where driver condition was reported) had a "normal" bus driver condition recorded. The driver condition recorded for most of the remaining cases was "other" or "unknown." The bus driver was reported to have been drinking alcoholic beverages in only 14 of 5,861 accidents (less than one-fourth of 1 percent). In the 2-year Illinois sample of accidents, a driver was reported to have been drinking in about 3 percent of car and pickup truck accidents as compared with less than 1 percent for drivers in commercial bus-involved accidents.

Roadway Factors

The full bus crash data base showed that there was no traffic control present in about 46 percent of the cases. In other cases, a traffic signal (34.3 percent) or a stop sign (12.4 percent) was present. Bus crashes at traffic signals were more likely to cause injuries and fatalities than bus crashes at stop signs. This difference was significant at the 0.01 level.

Road alignment data for urban streets were collected in Michigan, Minnesota, and Utah. Most collisions (about 95 percent) took place on straight roads. Injuries and fatalities appear to be more likely in accidents on straight roads than on curved roads (29.9 percent versus 20.2 percent), but this finding is based on a small sample of curved roads and should be interpreted with caution.

The 2-year sample of Illinois accidents (comparing buses with other vehicles) revealed that about 55 percent of commercial bus accidents occurred at nonintersections, and the remaining 45 percent occurred at various types of intersections. Relatively similar percentages of car and pickup crashes and school bus accidents happened at intersections. However, only one-third of truck accidents occurred at intersections. Situations that may result in bus accidents at intersections include the following:

- Buses stopping to pick up passengers from stops located at intersections (while the general traffic stream is moving on a normal green phase) and
- Buses entering or leaving curb loading areas (which may not be anticipated by some drivers).

Accident Type

Each of the five HSIS states coded accident type differently. Extra attention was paid to analyzing accident type because this variable reveals patterns of accidents and helps suggest possible countermeasures related particularly to roadway design and bus driver operation.

Figure 4 provides a general accident-type breakdown for all bus-involved accidents in Illinois. Rear-end accidents with one vehicle stopped (probably most often the bus), sideswipe same-direction accidents, and turning accidents were the most common in the sample. Pedestrian and pedalcycle (bicycles, tricycles, etc.) accidents were uncommon, but when they occurred they usually resulted in an injury or fatality. Rear-end accidents, angle accidents, and other accidents (mostly single-vehicle, fixed-object accidents) also had high percentages of injuries and fatalities. Other states showed basically similar patterns.

Results from the 2-year Illinois sample comparing commercial buses with other vehicles helped clarify the general pattern. Commercial bus-involved accidents are more often "sideswipe same-direction" accidents and are less often "rear-end, both moving" accidents, compared with accidents involving other vehicles.

Single-vehicle bus accidents on urban streets (including fixed-object, overturn, and animal accidents, but not including pedalcycle and pedestrian accidents) were not common and resulted in injuries or fatalities less often than other accident types. Only 139 such accidents were reported on urban streets in four states (Illinois, Michigan, Minnesota, and Utah) during the sampled years. Only 27 of those accidents involved an injury, and there were no fatalities. Single-vehicle accidents on urban streets tend to occur more often than multivehicle accidents at night, in the snow and ice, and during right turns.

In multivehicle accidents, buses were more likely to be struck than to strike another vehicle. The 2-year Illinois sample comparing commercial buses to other vehicles showed that

- Commercial buses were struck by automobiles 1,474 times but struck automobiles 1,051 times.
- Commercial buses were struck by trucks 180 times but struck trucks 77 times.
- Commercial buses were struck by other vehicles (not trucks or automobiles) 100 times but struck other vehicles 61 times.

The comparison between buses and trucks, both large vehicles, is revealing. Overall, commercial buses did the striking 1,204 times and were struck 1,769 times; trucks did the striking 40,826 times and were struck 28,885 times. Thus, buses were less likely to be the offending vehicle in bus crashes; trucks were more likely to be the offending vehicle in truck crashes. School buses had a similar accident pattern to commercial buses.

A breakdown of multivehicle bus-involved accidents on urban streets in Illinois revealed some interesting trends. Almost 12 percent of all 3,075 multivehicle accidents in this sample were reported as sideswipe same-direction accidents when the bus was going straight. These accidents may have been the result of buses pulling into and out of curb loading areas. In 84 percent of the angle accidents, the bus was reported to be going straight. For rear-end accidents in which one vehicle was stopped, the bus was coded more often as stopped in traffic rather than picking up passengers, going straight, or stopped for traffic control. The bus was coded turning in about half of the turning accidents. Only 6 percent of the 3,075 multivehicle accidents involved a right-turning bus.

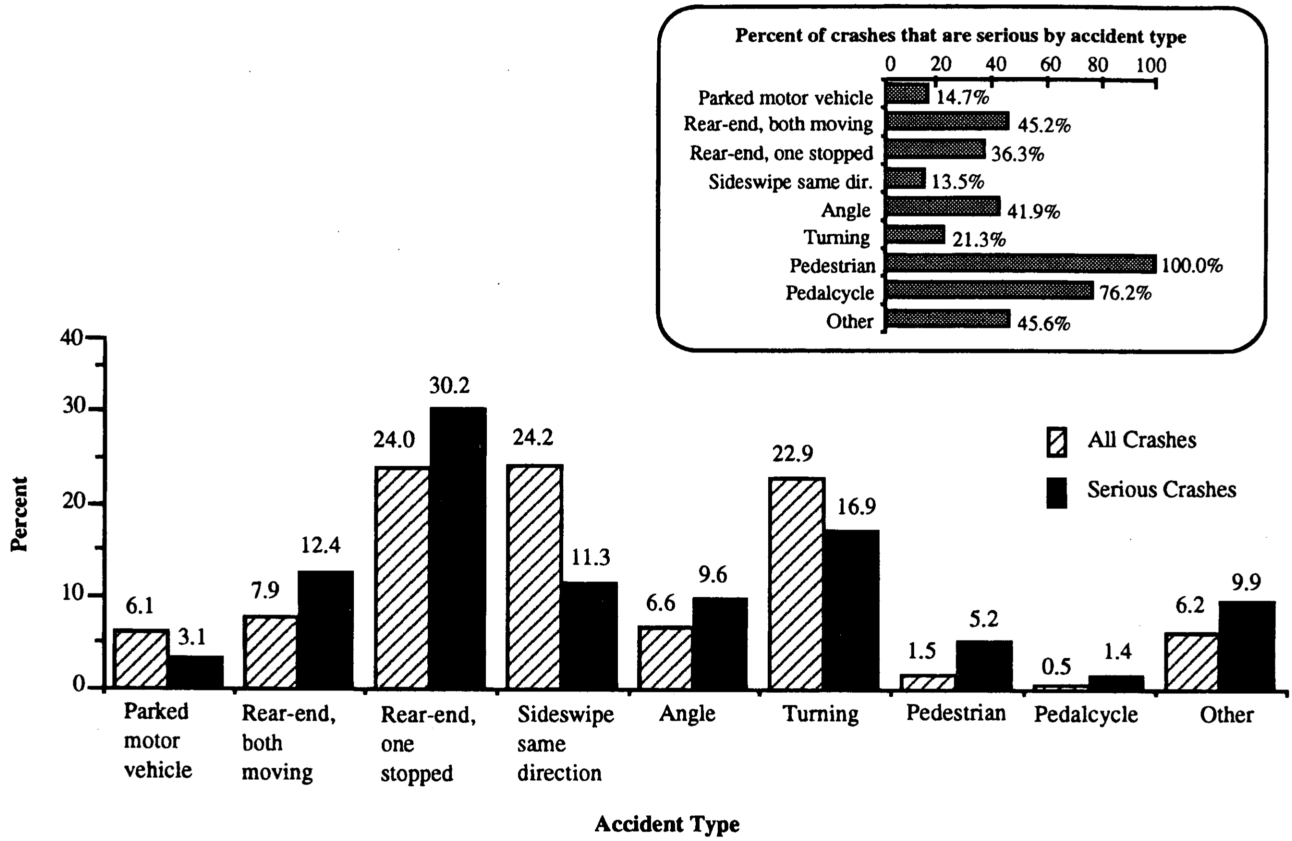


FIGURE 4 Distribution by accident type of bus crashes in Illinois.

Accident type and time of day were significantly related at the 0.005 level. Angle accidents were overrepresented at nighttime, rear-end accidents with one vehicle stopped were overrepresented during morning peak hours, parked vehicle accidents were overrepresented during early afternoon, and sideswipe same-direction accidents were somewhat overrepresented during afternoon peak hours.

Of the 8,897 commercial bus crashes in the HSIS files, pedestrians were involved in 189 (2.1 percent). Nearly all (98.4 percent) of these pedestrian accidents resulted in injuries or fatalities. In fact, 13 accidents (6.9 percent) were fatal. The 2-year Illinois data file showed that 1.2 percent of all commercial bus crashes involved pedestrians, compared with 0.3 to 0.5 percent of other vehicle types. Many of these bus-pedestrian crashes may occur when individuals running to or waiting at a bus stop are struck by an approaching bus or when individuals exiting are struck by a departing bus.

CONCLUSIONS AND RECOMMENDATIONS

This study was carried out to examine the characteristics of crashes involving transit buses (defined in this study as all buses involved in a reported motor vehicle crash except school buses) and to make recommendations for reducing the incidence of bus crashes and related personal injuries. The study included a detailed review of the available literature and an analysis of 8,897 bus accidents in Illinois, Maine, Michigan, Minnesota, and Utah. These crashes became the primary study file. In addition, separate analyses were carried out on a smaller sample of 5,283 crashes (59 percent of the original study sample) identified as occurring on urban streets. The study also examined the characteristics of noncollision bus-related injuries, such as falls while boarding or alighting the bus (*3*).

The analysis was primarily descriptive, involving cross tabulations of selected variables of interest and testing of differences in the resulting distributions. In addition, application of the innocent victim technique allowed some control over exposure differences that might otherwise confound results. Using the Illinois data only, a comparative analysis was conducted comparing bus crashes with other motor vehicle (passenger car, truck, etc.) crashes.

In terms of crash severity, less than 1 percent (0.7 percent) of bus crashes in the overall five-state file resulted in fatal injury; 28.5 percent resulted in nonfatal injury, and the remaining 70.8 percent involved property damage only. The pattern for urban crashes only was similar, with 0.5 percent fatal and 28.3 percent nonfatal injury.

Commercial bus accidents represented less than one-fourth of 1 percent of all motor vehicle crashes occurring in Illinois during 1988 to 1989. Also from the Illinois data, bus accidents and car and pickup accidents were all about equally likely to result in a fatality; however, truck accidents were twice as likely to result in a fatality as accidents involving other vehicle types.

The number of bus crashes is lowest in July and August and highest in January and February. However, winter crashes tend to be less severe, so that the greatest percentage of injury crashes actually occurs in May.

Although the analyses of the 8,897 bus crashes in this study were not in-depth case study investigations, the analyses of many crash factors allow educated judgments of probable causes and develop potential countermeasures corresponding to each probable cause. On the bases of results of the analyses of bus crash factors, the bus safety literature, and decades of highway safety research and experiences on causes and treatments for various crash types, a number of general measures are recommended to reduce the likelihood of bus crashes and resulting passenger injuries. Measures relating to roadway design include the following:

1. Wider intersection turning radii—The analysis showed that rear-end crashes represent one of the most common bus crash types, particularly at intersections. One means of reducing the incidence of rear-end crashes to the bus at intersections is to provide wider intersection turning radii. Because of the length of transit buses, problems may occur when buses turn right at intersections or driveways with a very tight turning radius. This will require the bus to swing wide and often encroach on the oncoming lane of the side street to the right of the bus, which can increase the risk of an accident with an oncoming vehicle from the side street. In addition, with a tight turning radius, the bus must slow down considerably when making such a right turn, and a rear-end crash to the back of the bus can result. By designing or reconstructing the curb radius to be wider, the bus can then make an easier turn without slowing to a near stop and without swinging across the center line as it makes its right turn. This can reduce the risk of rear-end and other crashes involving the bus.

2. Wider lanes on bus routes—Another primary transit bus accident type involves sideswipe collisions between buses and other motor vehicles. Because of the wider vehicle dimensions on buses, it is important that lane widths be adequate to minimize the chance for sideswipe accidents involving vehicles in adjacent lanes. With narrower lanes, the potential for sideswipe accidents is increased, particularly when a bus passes or is being passed by a large truck or other bus. Along major arterials where buses and large trucks are likely to travel, consideration should be given to providing lane widths of 12 ft when possible, or at least 11 ft. This will increase the lateral spacing between buses and other motor vehicles.

3. Turn lanes at intersections along bus routes—The analysis of data from Illinois revealed that 17 percent of bus crashes were turning accidents. Rear-end accidents may occur when adequate separate turning lanes are not available at intersections where buses turn. First, the bus must slow down during right turns and may be rear-ended. When making left turns with no left-turn lane, the bus will often be forced to stop in the left-most through lane and wait for oncoming traffic to clear before turning left into an adequate gap in through traffic. Again, the bus is exposed to the potential for rear-end collisions. For these types of accidents, a potentially effective countermeasure involves adding separate left-turn and right-turn lanes when feasible.

4. Elimination of on-street parking along bus routes—Parked vehicles along bus routes can be associated with several types of bus crashes. These include (a) parked vehicles being struck by the bus, (b) pedestrian accidents as the result of pedestrians stepping or running into the path of the bus from between parked cars, or (c) sideswipe accidents between the bus and other motor vehicles in adjacent lanes (as the result of the bus swerving over the lane line to pass parked vehicles.) To reduce the probability of such accidents, the elimination of on-street parking along selected sections of a bus route is sometimes an effective solution.

5. Adequate paved shoulders or a bus pull-off lane—In suburban and rural areas, some crashes occur when buses stop in the lane to pick up or drop off passengers, thereby resulting in a rear-end collision. Such accidents could be reduced by providing paved shoulders of 8 to 12 ft along such bus routes to allow buses to pull out of the through lane and onto the shoulder to pick up and unload passengers. Where continuous paved shoulders are not feasible, a paved pull-off lane at the bus stop should be considered to allow buses to pull out of the travel lane. Such pull-off lanes are particularly important at bus stop locations where sight distance is severely limited for approaching motorists because of horizontal or vertical alignment. For example, if a bus is stopped in the through lane around a sharp curve, the driver of an oncoming vehicle may not have enough time to see the bus and stop before striking the bus in the rear.

6. Larger traffic signal lenses—The intersection of two roadways is often associated with large numbers of rear-end and turning collisions as a result of conflicting traffic movements. To reduce such intersection collisions involving buses (and other motor vehicles as well), a number of traffic signal–related improvements may be helpful. For example, the use of 12-in. signal lenses instead of the customary 8-in. lenses allows approaching motorists to see the signal more clearly. Vehicles following a transit bus are, therefore, more likely to see a red light and stop behind a bus at the intersection. This is important, because vehicles behind a bus have a limited field of vision of the traffic signal because of the height of the bus and may see the signal of a larger red signal head sooner.

7. Longer clearance intervals—The use of adequate signal clearance intervals can reduce the chance of angle accidents between buses and vehicles at intersections. This is because some intersections are programmed with a minimal amount of yellow time that results in more vehicles running red lights and colliding with vehicles on the cross streets. Angle accidents may be a particular problem for transit buses because of their greater length and greater target area for vehicles coming from cross streets.

8. Separate left-turn phasing—Left-turning buses are involved in accidents more often than right-turning buses. Without left-turn phasing, a left-turning bus must wait in traffic for an adequate gap in oncoming traffic before turning. Under congested conditions, bus drivers may be tempted or forced into making a left turn with an inadequate gap and may be struck by an oncoming through vehicle. This is a particular problem for buses because they are much longer than cars and require a larger gap in traffic to complete a left-turn safely. Separate left-turn phasing stops oncoming traffic, allowing a protected interval for the bus to turn left.

9. Roadway design improvements—Although bus crashes are primarily an urban problem, rural and suburban bus crashes may be reduced by many types of roadway improvements that have shown to be effective for reducing motor vehicle crashes in general. These include providing flatter roadside slopes (to reduce bus rollovers) and clearing roadsides of trees, utility poles, and concrete culverts to the extent possible. Further, guardrail and other roadside hardware should be designed that consider the possibility of bus impacts. On rural roads, adequate widths of lanes (i.e., 11 or 12 ft) and shoulders (paved if possible) and adequate roadway alignment can also be beneficial to bus safety.

10. Improved snow and ice removal—Based on the analysis discussed earlier, bus crashes tend to be more frequent during winter than summer. This may be partly because of the increased snow and ice on the roadways that could contribute to rear-end and other

crashes. Snow removal is a problem in many northern states, but special effort should be made to clear streets of snow and ice promptly along bus routes.

FUTURE RESEARCH NEEDS

The primary future research need is for a study that integrates accident data with high-quality, widespread exposure data. Exposure data could help answer more subtle questions about routes, drivers, and vehicles that could not be answered with the methods of this study. These questions include the following:

- What are the levels of bus exposure (mileage) by bus age, bus type (Interstate versus local transit), type of roadway, and driver factors (age or experience)?
- What types of streets and highways have the highest bus accident rates?
- Are bus accident rates higher at certain times of day and for various types of buses or driver factors?
- What are the effects of specific improvements (routing, bus stop location, geometric and traffic control improvements, etc.) on bus crash rates?

The HSIS data base does not separate local transit and intercity buses. Yet these types of buses are likely to have different levels of exposure and are operated under different conditions. Bus exposure data can be obtained from local transit agency and Interstate bus company records.

The study team also identified several other areas for promising future bus safety research. First, accident data should be obtained from states not included in the HSIS data base. Many states will incorporate a wider range of roadway and weather conditions and increase the sample of bus crashes. This could allow additional conclusions relating accident characteristics to bus crashes and associated injuries.

Another area of needed research involves a more extensive data base, to be obtained from local transit agencies, of noncollision accidents such as falls by passengers. This would allow better comparisons of various bus designs and operating practices on passenger injuries. Research is also needed on accidents in which the bus contributed to an accident but did not collide with persons or other vehicles. For example, pedestrians may step out in front of buses and be struck by passing automobiles. Such accidents would not have appeared in the data base in this study.

ACKNOWLEDGMENTS

This document is disseminated under the sponsorship of the U.S. Department of Transportation, University Transportation Centers Program, through the Southeastern Transportation Center, in the interest of information exchange. The authors appreciate the input and guidance of Roy Field of the Federal Transit Administration throughout this research study.

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Publication of this paper sponsored by Committee on Traffic Records and Accident Analysis.