Safety Implications of Seat Belts on Transit Buses

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The findings of a literature search on seat belt installation for passengers on buses are summarized. The emphasis was on transit buses, but school buses were included. The literature search focused on three major areas: legislation, the effectiveness of seat belts, and any related aspects. The legislation portion dealt with the appropriate Federal Motor Vehicle Safety Standards as well as any state or federal laws that pertain to seat belts or passenger restraints on buses. The portion on the effectiveness of seat belts dealt with crash-testing studies and examined the epidemiological implications, accident analysis, likely seat belt usage, and the seating system as an integrated whole. The related aspects covered seat belt design options, seat design, seat design loads, other current seating options, seat anchorage design, bus floor structure, and bus-to-chassis connections. In addition, a survey was made of transit agencies in the United States and Canada to determine the current state of seat belt use. None of the agencies responding to the survey currently require seat belt installation. Overall, the findings tend to be inconclusive; many research papers express conclusions both for and against seat belt installation on buses. However, researchers generally agree that it is not just a matter of installing seat belts on an existing bus design. The entire seating system must be tested as an integrated whole before a conclusive statement on the effectiveness of seat belts on transit buses can be made.

The question of safety implications of seat belts for the passengers of transit buses has not received much research attention. Though there is overwhelming evidence in the literature on the effectiveness of seat belts in reducing the severity of passenger injuries in accidents involving automobiles, little, if anything, is known about the safety implications of seat belts on transit buses.

A study is currently under way at the Department of Civil Engineering, Wayne State University, to assess the safety and structural implications of seat belts on transit buses. The study, jointly funded by the U.S. Department of Transportation and the Michigan Department of Transportation, has two primary objectives: (*a*) to assess the possible safety implications of seat belt usage in transit buses for reducing the severity of injury resulting from traffic accidents and (*b*) to determine whether major changes in the structural elements of the bus frame may be warranted to enable the frames to withstand the instantaneous stress buildup resulting from sudden activation of seat belts.

The study is being conducted in two phases. A review of the literature on seat belt legislation, usage, and accidents was conducted in Phase I along with a survey of representative transit agencies. In addition, a computer-based structural model was developed to analyze the forces likely to be generated within the bus frame components when seat belts are actuated on a fully loaded transit bus. The primary objective of the computer model is to identify "weak links" in the structural components of the bus frame that may be vulnerable to the stress buildup when seat belts are actuated. The broad purpose of Phase II, likely to be initiated during the latter part of 1990, is to conduct a set of experimental tests to validate the computer model and to recommend means to improve the structural integrity of the bus frame.

As part of the study, a search of the relevant literature on transit seat belts was conducted to determine the level of knowledge on this topic. The emphasis was on seat belt installation, but the literature search included papers that contained related information. A summary of the literature review is presented in this paper, focusing on three primary topics: seat belt legislation, the effectiveness of seat belts, and additional aspects related to seat belt installation. Much of the literature found and presented herein involves school buses. School buses must adhere to different and more stringent federal safety standards than transit buses and, therefore, have structural differences. However, it is believed that the dynamics during an accident are similar and that the safety concepts are equally applicable to the two types of buses.

BACKGROUND

The literature review revealed a set of historical developments concerning seat belt installation on transit buses in North America dating back to 1964 and continuing to 1989. In addition, the federal government, through the National Highway Traffic Safety Administration (NHTSA), an arm of the Department of Transportation, has developed standards for various vehicles and vehicular components, known as Federal Motor Vehicle Safety Standards (FMVSSs). The literature review indicated a number of such standards that pertain directly or indirectly to the question of seat belts on transit buses. A capsule summary of the historical developments and the safety standards follows.

Major Developments Concerning Seat Belts and Buses

The first uninstrumented school bus crash tests were performed in Arkansas in 1964 (no literature was found on these tests).

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The first instrumented crash tests were performed on a large intercity bus by the General Motors Corporation (GM) in 1965 (*1*).

The University of California at Los Angeles (UCLA) performed crash tests on full-size school buses in 1966 (*2*).

UCLA followed up the 1966 crash tests in 1972 (*3*).

The Southwest Research Institute performed a major literature search concerning seat belts on buses for the California Highway Patrol in 1976 (*4*).

FMVSS 222, School Bus Passenger Seating and Crash Protection, was enacted in 1977 (*5*).

NHTSA performed sled tests on seat and seat belt designs in 1978 (*6*).

Transport Canada had crash tests performed on school buses in 1984 (*7*).

A company, Thomas Built Buses, had crash testing done on its buses in 1985 (*8–10*).

Transport Canada performed sled tests on various types of seats and seat belt configurations in 1986 (*11*).

Massachusetts and New York State enacted legislation requiring the installation and use of seat belts on school buses in 1986.

A provision of the Surface Transportation and Uniform Relocation Act authorized a study on school bus safety in 1987.

The National Transportation Safety Board (NTSB) released the study *Crashworthiness of Large Poststandard Schoolbuses* in 1987 (*12*).

The National School Bus Safety Act (H.R. 1815) was rejected in 1987 (*13*).

A study entitled *Improving School Bus Safety* was released by TRB in 1989 (*14*).

Summary of FMVSSs

A summary of the relevant FMVSSs for seat belt–related components that manufacturers must comply with is given in Table 1. Of the five standards cited in Table 1, FMVSSs 201, 208, and 222 address the question of occupant protection (*5,15,16*). However, none of these deal specifically with passengers on transit buses. FMVSS 210 is a continuation of FMVSS 208 dealing with the question of seat belt anchorage (*17*). FMVSS 207 concerns seating systems and experimental load tests (*18*).

LITERATURE REVIEW

The literature review of three major aspects of seat belts on transit buses—legislation, effectiveness, and additional aspects—is summarized as follows.

TABLE 1 SUMMARY OF FMVSSs PERTAINING TO SEATS OR SEAT BELTS

FMVSS #	Title	Description
201	Occupant Protection	Applies to buses with a GVWR of 10,000 pounds or less and provides for the testing of interior items (instrument panel, seat backs, interior compartment doors, and armrests) to simulate the impact of a passenger's head with a 6.5 inch diameter head form weighing 15 pounds.
207	Seating Systems	Defines the forces a seat (other than a side-facing bus passenger seat) must be able to withstand as well as the methods of applying test loads. A seat for which the standard does apply must be able to withstand a force 20 times its own weight in either forward or rearward longitudinal directions.
208	Occupant Protection	Requires the bus driver to have either a "complete passenger protection system" (i.e. a passive restraint) or a seat belt. Buses manufactured after September 1, 1990 must have an automatic locking retractor for the driver's belt. This standard sets forth requirements for types of seats, seat belts, belt latches, and arm rests as well as crash dummy specifications and test procedures. This standard does not set any requirements for bus passengers.
210	Seat Belt Anchorage Assemblies	Sets forth requirements for the seat belt assembly anchorages specified in FMVSS 208. The anchorage for a Type 1 (lap only) seat belt and the pelvic portion of a Type 2 (lap-shoulder) seat belt must withstand a 5000 pound force. The anchorage for a Type 2 seat belt must withstand a 3000 pound force.
222	School Bus Seating and Crash Protection	Sets forth requirements for school bus seating systems and restraining barriers. Vehicles with a GVWR of more than 10,000 pounds must meet only FMVSS 222. Vehicles with a GVWR of 10,000 pounds or less must meet FMVSS's 208, 209, 210, and 222. The seat back height is required to be 20 inches minimum as measured from the Seat Reference Point (SRP) to the top of the seat back. The SRP is defined by SAE Standard J826 as the point about which the human torso and thigh pivot. The seat back must not deflect forward more than 14 inches with a maximum applied load of 700 pounds nor should it deflect rearward more than 10 inches with a maximum applied load of 2200 pounds. The seat cushion should not separate from the seat when subject to a force five times its own weight. Maximum spacing between seats is 24 inches without a restraining barrier.

Legislation

Currently, the U.S. federal government requires transit and school buses to have seat belts in the driver's position only, as specified by FMVSS 208, Occupant Crash Protection in Passenger Cars, Multipurpose Passenger Vehicles, Trucks and Buses and FMVSS 222, School Bus Seating and Crash Protection (*5,16*). The rationale is that the driver must be properly restrained to be able to maintain control of the vehicle in the event of an accident. The requirement for passenger seat belts is left up to the individual states. The literature review indicates that no state requires the installation and use of seat belts by transit bus passengers at this time (*19*). Some states may require the use of seat belts if they are installed, but enforcement is given only secondary importance.

FMVSS 222 is based on a concept known as compartmentalization, which has an indirect implication for seat belts on school buses (*5*). By limiting minimum seat height, maximum seat spacing, and maximum seat deformation, a "compartment" is created, which restrains the passenger and limits the severity of the injuries sustained in an accident. The seat spacing must be no more than 24 in. as measured from a seat's reference point (SRP) to the back of the next seat. The SRP is defined by SAE Standard J826 as the point about which the human torso and thigh pivot. The seat back must be a minimum of 20 in. high when measured from the SRP to the top of the seat. FMVSS 222 also limits the deflection of the seat back, both forward and rearward. The seat back must deform forward a minimum of 6 in. and a maximum of 14 in. because of a maximum force of 2,400 lb. In the rearward direction, the deformation must not exceed 10 in. with a maximum force of 2,200 lb. This deformation limit, it was believed, allows the seats to deform sufficiently to absorb some of the force of impact while limiting the deflection so that the forces are distributed more evenly over the passenger's head and upper torso. Also, keeping the seat back relatively upright serves to keep the passenger from being forced over the seat and creating a domino effect. There are no similar federal standards for transit bus seats.

Only two states, Massachusetts and New York, require seat belt installation and usage by law for all school bus passengers as well as the driver. Maine requires seat belt usage on school buses only if they are installed by the manufacturer. In addition, New York and Illinois require school bus seats to have 24-in.-high seat backs (as measured from the SRP). At least one foreign country is known to require seat belts in transit buses. Germany requires seat belts to be installed in long-distance buses in only the most forward and rearward seating positions (*20*). Canada does not mandate any seat belts for either transit or school buses, although at least eight provinces require seat belt use if any are installed by the manufacturer (*7*). In addition, the Canadian Motor Vehicle Safety Standards are patterned after the U.S. FMVSSs and are virtually identical in content, format, and specifications. Therefore, any research study done in one country, either the United States or Canada, is equally valid in the other country.

In an effort to compile up-to-date information about seat belts on transit buses, a mail-back survey was conducted among a representative group of transit agencies (a total of 68) in the United States and Canada. The smallest agency owns 26 buses, and the largest has 2,624 buses. Three agencies in Canada and 52 agencies in the United States responded, a response rate of 81 percent. The questionnaire requested information on whether the agency operates buses equipped with seat belts or knows of any agencies that do, whether it has conducted or knows of any research studies involving seat belts, and the bus construction specifications used by the agency. None of the agencies responding currently own transit buses equipped with seat belts or know of any agencies that do.

Seat Belt Effectiveness

There appears to be little doubt that a properly designed automobile passenger restraint system reduces passenger injuries in the event of an accident. One might assume that the same holds true for buses. There is, however, considerable controversy about whether seat belts for transit bus passengers are effective or even desirable. Many questions have arisen concerning possible epidemiological complications, accident analysis, the expected voluntary seat belt compliance, and the seating system as an integrated whole.

Epidemiological Aspects

The possible epidemiological implications are the major source of controversy over seat belt use on buses. Some researchers believe that a seat belt could do more harm than good in three possible types of accidents: front-end, side, and rear-end.

A passenger not wearing a belt in a frontal impact tends to slide forward on the seat and strike the back of the next seat with the knees. Then the upper torso moves forward and strikes the back of the seat. "This results in the forces being spread more evenly over the upper torso" (*7*). On the other hand, a passenger restrained by a lap belt would bend forward and strike the top of the next seat with the head and chest. Thus the lap belt tends to decrease the forces on the lower torso but increase them for the upper body. Transport Canada concludes the following from its 1984 crash test:

> In general the results indicated that the belted dummies experienced higher head and lower chest accelerations than did the unbelted ones. Furthermore, from the film data [of the crash tests] the belted dummies experienced more severe neck extensions due to the angle at which they struck the seat ahead of them than did the unbelted ones. The neck extensions of several restrained dummies was judged to be life threatening. (*7*)

Weber and Melvin, however, question Transport Canada's conclusions about the neck extensions (*21*). Their major criticism concerns the lack of discussion or reference to the biomechanical justification for its judgment. Weber and Melvin state that "we do not believe that the Canadian School Bus Safety Study can be used to draw the conclusion that the use of belts on recent-model large school buses poses a potential danger to the occupants."

Opinions vary concerning the usefulness of a seat belt in a side-impact collision. After its crash tests, Thomas Built Buses concluded that "in the side-impact tests, compartmentalization appears to work just fine, and seat belts would not make any significant difference one way or another, as far as head or chest injuries" (*10*). In the absence of any other lateral support, a passenger with a lap belt could be bent over sideways and possibly suffer abdominal injuries. Ursell notes that

"the human body was not made to flex to a significant degree in the lateral direction and therefore considerable injury usually results from any severe deflections of the upper torso in the lateral directions" (*4*). On the other hand, Transport Canada notes that "in these types of accidents, a seat belt would aid in preventing possible ejection and being thrown around the interior of the vehicle" (*11*).

Few data are available on the implications of a lap belt in a rear-end collision. Severy et al. note that "lap belts should not be used for low seatback units because their use substantially increases the highly adverse forces to the spinal column resulting from whiplash" (*2*). However, they made their comments in 1967 before FMVSS 222 was enacted. There have been no known full-scale rear-end crash tests since 1966, and it is not clear how bus seats conforming to the current standards would perform.

An argument that has frequently been used against the installation of seat belts on both automobiles and buses is that the belt may trap the passenger in the event of an accident that leads to a fire or rollover. Transport Canada claims that "in such an emergency, which is a very rare occurrence, the belted occupant has a much greater chance of remaining conscious and alert" (*7*).

Despite the testing that has been done, opinions on whether seat belts should be used are still divided. Severy et al. state that "lap-type safety belts would provide substantial protection to the school bus passengers, seated in high back seats that have efficient padding on the rear panels of the backrests" (*2*). Wojcik and Sandes state that "for buses provided with safety seats having a performance profile comparable to the UCLA design, seat belts will contribute a significant measure of safety" (*3*). Ursell recommends "that seat belts not be installed in school buses, transit buses or farm labor buses" (*4*). Bayer concludes that "lap belts do not appear to have a significant effect on the response characteristics of a 50th percentile adult male dummy, for the test conditions" (*6*). Transport Canada refrains from making any final recommendation on seat belt installation. NTSB states in a recent report:

> [NTSB] does not recommend that Federal school bus safety standards be amended to require that all new large school buses be equipped with lap belts for passengers. The safety benefits of such actions, both in terms of reduced injuries for school bus passengers and in seat belt use habit formation, have not been proven. (*12*)

Finally, TRB writes in a recent report:

> The committee concludes that seat belts, when properly installed on large, post-1977 buses, are not inherently harmful and that they may reduce the likelihood of death or injury to passengers involved in school bus crashes by up to 20 percent. The committee further concludes that the overall potential benefits of requiring seat belts on large school buses are insufficient to justify a federal requirement for mandatory installation. (*14*)

In all of the crash tests performed, it was assumed that the seat belts were properly installed and adjusted. Transport Canada points out that "the effectiveness of a seat belt in reducing injury and death is, of course, dependent upon its proper use" (*7*).

Accident Analysis

Little information is available on the performance of seat belts in actual accidents. Buses tend to be involved in few accidents compared with automobiles, few of these accidents result in serious injury, and virtually none involve buses equipped with seat belts. TRB reports that "to date there have been no statistical or epidemiological studies of the effectiveness of lap belts on Type I school buses because of the relatively small number of belt-equipped buses involved in accidents" (*14*).

Most attempts at accident analysis involved determination, for bus accidents in which seat belts were not used, of the probable results had the passengers been wearing lap belts. This is the approach taken by NTSB (*12*), Stanisfer and Romberg (*22*), and Hatfield and Womack (*23*). The data for these studies involve comparisons with automobile accidents, bus crash tests, and sled tests rather than with other bus accidents. NTSB states that "arguments for and against lap belts on school buses cannot rely on passenger car data for an answer" (*12*). In addition, there is a lack of uniformity in the reporting of bus accidents. Therefore, there is a large measure of uncertainty in the results of these types of studies.

Estimated Seat Belt Compliance

Some researchers believe that the average voluntary seat belt compliance among bus passengers would be extremely low. Stanisfer and Romberg reported an average expected compliance rate of 10.9 percent and a maximum compliance rate of 17.6 percent (*22*). They based these values on surveys conducted by the National Association of Motor Bus Owners in 1965 and 1973. Because these studies were based more on opinion than experience and automobile seat belt laws have probably increased public acceptance of seat belts, the reliability of these predictions is in doubt. Both Transport Canada and TRB have examined school bus seat belt use in school districts that use them (*7,14*). The reported compliance varied from 20 percent in a district where usage is optional to as high as 95 percent in districts where usage is mandatory. However, seat belt usage tends to decrease as the child's age increases. Of course, experiences with children who are required to wear belts probably have little relation to the reactions of adult passengers on transit buses who were never required to wear belts on buses before.

In addition to mere resistance to the notion of wearing seat belts, transit bus passengers may find the seat belt installations to be inconvenient. Passengers making short trips may not take the time to buckle up, especially if they are carrying packages. A passenger sitting in the aisle seat would find it inconvenient to unbuckle to allow a passenger in and out of the window seat. The seat belt anchorages may protrude and be uncomfortable. The belts themselves, if they are of a nonretractable type, may hang on the floor and accumulate dirt, thereby discouraging their use. The belts and their latching mechanisms are easy targets of vandalism, which would render them inoperative. No matter how effective a seat belt might be, it is of little value if the passenger does not use it. For this reason, some researchers have recommended against the installation of seat belts (*4,20,22*).

Passenger Restraint System

Much of the literature points out that it is not enough to simply install seat belts on a bus. Ursell, in particular, points out that the passenger restraint system is an integrated whole, which includes such items as seat strength, seat height, padding, seat spacing, seat anchorages, seat belts, and bus body-to-chassis connections. He recommends against the installation of seat belts in buses until more thorough and comprehensive research has been done (*4*). Transport Canada reported:

> As a result of the crash tests (in 1985), the need to investigate the entire seating system became apparent. It was not just a simple matter of adding a lap belt to a seat. (*11*)

In summarizing Bayer's test results (*6*), TRB notes:

> This finding emphasizes that any attempt to characterize the safety of school bus seats by a single factor (e.g., seat back height or seat spacing) is overly simplistic. The relative safety of a school bus seat is a function of several variables acting in concert. Among the variables of consequence are seat back height, spacing, padding, deformation characteristics, and the use or nonuse of a lap belt. (*14*)

Related Aspects

The installation of seat belts, as previously noted, involves the entire bus as an integrated passenger restraint system. The type of seat belt to be installed, the design of the seat itself, other seating options, and the magnitude of the load with which the seat is designed must be considered. The manner in which the seats are anchored, the bus floor structure, and the manner in which the bus body is connected to the chassis are also important.

Seat Belt Design Options

The type of seat belt to be used should be considered seriously. Most studies have concentrated on the lap belt only, perhaps because it is the simplest to install. Severy et al., however, state that "the cross-chest lap-belt combination when properly fitted provides significantly more passenger protection than does the use of only a lap belt" (*2*). The Thomas Built Bus crash tests of 1986 appear to verify this conclusion (*9*). However, Severy et al. go on to recommend against the use of such belts in school buses. A shoulder belt, to be of maximum value, must lie across the chest. If a belt designed for an adult were used by a child, it would lie across the neck and could cause more injury than it would prevent. Shoulder belts can also cause "submarining," in which the passenger slides out from underneath the belts. However, submarining would be less of a problem on bus seats than on the relatively softer automobile seats. Adequate anchoring of a shoulder belt is an even more serious problem. The upper part of the belt would have to be attached to the seat back, at least for the aisle seat. Because FMVSS 222 not only allows but also requires a certain amount of seat back deformation under a given load, the shoulder belt would not be capable of serving its function on current seats unless the seat back were considerably strengthened. Transport Canada observed:

> It must be emphasized that if seats with lap and shoulder belts are installed in buses, it is imperative that the belts be worn at all times. Otherwise, any injuries due to unrestrained occupants striking the seat back would be more severe than with an existing seat due to the increased seat rigidity. (*11*)

The type of adjustment and locking mechanisms should also be considered. Severy et al. recommend a "retractable, inertial-lock mechanism" (*2*). Ursell also specifically states that "only retractor type belts should be used on buses" (*4*). Most recently, Transport Canada states that "all belts should be adjustable by means of an emergency locking retractor" (*24*). Transport Canada also concludes that "it is felt that manual belts are too prone to being improperly adjusted to be considered for use" (*11*). However, it warns that "the retractors should be protected to prevent destruction under impact conditions" (*11*). FMVSS 208 requires that bus drivers have a belt with either an emergency locking retractor or an automatic locking retractor for vehicles manufactured on or after September 1, 1990 (*16*).

Seat Design

Seat design is a concern whether seat belts are installed or not. Criteria that must be considered include seat dimensions, seat spacing, padding, armrests, and even the direction the seats face.

As previously noted, FMVSS 222 sets seat back height on school buses at 20 in. above the SRP. Severy et al. repeatedly recommend that the seat back height be a minimum of 28 in. to prevent whiplash (*2*). They go on to recommend against the installation of seat belts on any seat that is less than the specified 28 in. (*2*). However, TRB points out that the UCLA researchers measured their seat backs from the top to the base rather than to the SRP. If measured from the SRP, their seat back would be between 24 and 25 in. high (*14*). TRB currently advocates raising the height of seat backs in school buses to 24 in. and in a recent report states:

> The committee believes that the operational objections to higher seat backs have not been supported by field experience and that they can be installed in a manner consistent with NHTSA standards. (*14*)

Seat spacing can also influence seat belt effectiveness. Bayer studied the results of sled tests done with seat spacings of 20, 22, and 24 in. He concluded that "seat spacing appears to have only a minor effect on the response characteristics of the adult dummy and only a slightly higher effect on the child dummy" (*6*).

Seat padding is an extremely important design factor, because it can help absorb the force of a passenger's impact with the back of the next seat. The padding becomes even more critical if seat belts are installed because, in such a case, a passenger could experience greater forces in the area of the head and upper torso. Several of the papers examined mention the necessity of proper padding to dissipate these forces, but none went into detail on the design criteria that should be considered.

Severy et al. emphasize the benefit of having armrests for lateral support, even if they make entering the seats inconvenient. They recommend that "as a minimum requirement,

each school bus seat should have an armrest on the aisle side" (*2*). UCLA's follow-up crash tests in 1972 included a seat of its own design following the principles Severy et al. advocated after the crash tests of 1966. The seat consisted of a 28-in.-high seat back (by the UCLA method of measurement), an aisle side armrest, and a 3-in.-thick styrofoam head restraint pad. Wojcik and Sandes concluded that "for the side impact exposure, the UCLA armrest side restraint appeared to provide passenger protection as effectively as full use of lap belt restraints" (*3*). Other than these two reports, no mention of armrests has been found.

Some testing has also been done on rearward-facing seats as an alternative to conventional designs. UCLA performed crash tests on a full-size school bus with two rearward-facing seats in 1972. Wojcik and Sandes concluded that this type of seat "appears to offer no apparent safety advantage for either the head-on or the side-impact exposure" (*3*). Transport Canada performed sled tests on various seat designs, including rearward-facing seats with high seat backs and seat belts in 1987. It concluded, in contrast, that "this seat yielded the best results of all configurations" (*11*). Transport Canada subsequently fitted three school buses with high-backed, rearward-facing seats with lap belts and lent them to various school districts for evaluation (*24,25*). Overall, they experienced few real problems with this design except for some cases of nausea and driver complaints about the lack of rearward vision.

Other Current Seating Options

On current transit buses, besides using forward-facing seats, passengers are allowed to use side-facing seats or to stand. There is considerable controversy on how or if such passengers could be restrained. Although these topics are generally outside the scope of this paper, they are briefly examined in relation to a seat belt-equipped bus.

Several researchers have questioned the practice of using side-facing seats. Wojcik and Sandes state that side-facing seats "tend to compromise the safety of the passengers unless strong, well padded armrests are provided to protect passengers from head-on and rear-end collision forces and a high-back seat is provided to support the passengers' heads against the forces of side-impact" (*3*). Ursell states:

> Passengers in a side-facing position are subject to more damage or injury during an impact than those that are facing forward or facing aft. Seat belts on side-facing seats could withstand greater loads than those on the forward-facing seats because the side-facing seat belts could be attached directly to the side wall structural seat rail and easily withstand the seat belt loads. However, the side-facing passengers would be bent over sideways, either in a forward or aft direction and probably receive severe injuries if they were belted in place. (*4*)

Neither Wojcik and Sandes nor Ursell, however, specifically recommended against the use of side-facing seats. In any case, the necessity of providing room for wheelchair restraints in handicapped-accessible buses virtually demands the use of side-facing seats that fold out of the way.

The practice of allowing passengers to stand is also questioned by researchers. Severy et al. state that "the practice of transporting passengers in the aisle is dangerous and should not be permitted, especially for school bus passengers" (*2*). TRB claims:

> Passengers who are out of position during a school bus crash may sustain unnecessary injuries while endangering others as they are thrown about inside the passenger compartment. Several states have enacted laws that prohibit school bus operators from allowing passengers to stand in the aisle. In other states, standees are permitted when school bus seating capacity is exceeded. The committee recommends that all states prohibit standees on school buses operated by or for public or private schools. (*14*)

Transit buses, of course, frequently have standing passengers because of the short distance the passenger may be traveling and the large number of passengers such buses often carry. Ursell points out:

> When seat belts are installed this would be an automatic requirement for elimination of standees and therefore would increase the required number of operating buses and drivers as well as maintenance. (*4*)

One can argue that intercity transit buses travel at slow enough speeds that, given sufficient hand-held support, standing passengers should be able to support themselves adequately. Of course, such an argument would also negate the necessity of having seat belts in the first place. Also, transit buses do occasionally travel at highway speeds. In such a case, there could be legal ramifications should a standing passenger be injured while a seated passenger had the protection of a seat belt.

Interior projections, such as handrails, could be dangerous if a passenger is thrown against them. Severy et al. recommend that "tubular struts, protruding hand grips and similar protruding rigid structures should be eliminated" (*2*). However, because current practice generally allows standing passengers on transit buses, some sort of handrails are necessary. Therefore, Booz-Allen (*26*) conducted a study on the safety of transit bus interior design and reached the following conclusions:

1. On-board observations indicate that these rails (seat back handrails) are generally too low and poorly configured for effective use by standing passengers. Thus, current transit bus seat back grabrails are substantially inferior for passenger support compared with vertical stanchions.
2. All seats should be equipped with passenger assists at the aisle side, which provide the walking passenger with a nearly vertical bar to grab. The bar should be above the shoulder of a typical seated passenger, so that it is always available even in a crowded bus.

Seat Design Loads

The design load applied to a bus seat must be considered in both the design and testing phases. FMVSS 222 is specific about both the loads a school bus seat must withstand and the means of testing (*5*). Researchers, on the other hand, do not appear to agree on what the standards should be. LaBelle recommended that an acceleration of 10 *g* be used (*1*). Rompe and Kruger of Germany made no recommendations but used

accelerations of both 5 and 10 *g* in their studies (*20*). Severy et al., in contrast, recommended that the FMVSS require a design load of 30 *g* (*2*). This recommendation, however, does not appear to have any analytical basis and has never been implemented. Despite the conclusion of Severy et al., the UCLA researchers developed a seat using a 20-*g* design load for their 1972 crash tests (*3*).

Seat Anchorages

Crash tests by UCLA and GM, as well as studies of accident data, have indicated that some of the most serious injuries result from seats becoming detached from the floor. A seat is subject to forces whether from a belted passenger or a passenger striking the seat from behind. Therefore, a seat's anchorages must be able to withstand the force of impact whether seat belts are installed or not. Ursell notes:

> Pull tests of this type seat [wall mounted] indicate that it is much superior to the other types with all legs attached to the floor with respect to the forward direction. On the other hand, all types of structures have their shortcomings and in the event of a side impact on the bus wall, this wall mounted seat would receive a much higher acceleration. (*4*)

The wall-mounted seat supports experience smaller moments than the floor-mounted supports because of the shorter lever arm. No further studies have been found on seat pull-testing. Transport Canada notes that "the use of lag screws to attach seats and barriers to the bus floor appears to be inadequate for some vehicle designs" (*7*).

Bus Floor Structure

Although a large amount of research has been compiled on the testing of bus seats, little information is available on the performance of the floor itself. Contacts with a number of bus manufacturers and transit agencies indicate the dominance of two types of materials for bus floors: sheet metal and plywood. Plywood is by far the more common. Most of the crash and pull tests appear to have been done on buses with sheet metal floors, although few of the researchers specifically make mention of it. The UCLA and the GM reports both point out that the floors buckled in a front-end collision, thereby implying that the floors were made of metal (*1,2*). Plywood, in contrast, would splinter rather than buckle. Ursell, however, points out:

> The sheet metal floor pan is superior to the floor that uses only plywood. The plywood is subject to deterioration much more rapidly than the steel and as a bolt crushes into plywood, even with a large area washer, the bolt can eventually loosen up. (*4*)

He does not elaborate on the subject any further. Plywood does have the advantage of acting as insulation, thus making the interior of the bus quieter.

Bus-to-Chassis Connections

As a consequence of having all of the bus passengers belted in, the bus frame may be subjected to increased forces. One of the buses used in the UCLA crash tests displaced forward by 17 in. (*2*). Transport Canada reported displacements of up to 2 ft in its tests (*7*). Such a displacement would probably have resulted in the death of the bus driver. Severy et al. state that the "collapsing of the passenger compartment applies violent collision forces directly to the driver and passengers, even when they are adequately restrained" (*2*). Therefore, they recommended that "bus design should insure that the passenger compartment is securely attached to the frame of the bus by appropriately sized shear bolts at frequent intervals from front to rear along both frame members" (*2*). On the other hand, Thomas Built Buses crash-tested a bus in 1986 that was specially built with unitized construction, which in crash tests successfully reduced body displacement to ¾ in. (*8–10*). However, it is not clear whether any of these design changes has ever been successfully incorporated into production models or if such changes would adversely affect the safety of the bus passengers because of the increased stiffness of the bus structure.

CONCLUSIONS

This literature search was conducted to determine the current level of information available on seat belt installation on transit buses. Three areas were examined: legislation, effectiveness of seat belts, and additional aspects. In addition, a mail-back survey of a representative group of North American transit agencies was conducted to compile up-to-date information on seat belt installation.

Neither the U.S. government nor any individual state requires the installation and use of seat belts on transit buses except for the driver. In addition, no such legislation is known to be pending. No transit agency responding to the mail-back survey requires seat belt installation in its buses. Only two states, New York and Massachusetts, require seat belt usage in all school buses by law for all of the passengers as well as the driver. The only federal regulations for the testing of bus seats apply to school buses only and not to transit buses.

The findings concerning the effectiveness of seat belts on buses are inconclusive. Some research involving crash testing implies that a bus passenger who is restrained by a lap belt could experience dangerously high acceleration of the head and upper torso in the event of a sudden deceleration of the bus. However, a properly installed shoulder belt may reduce the severity of head injury in such cases. Some researchers believe that seat belt usage would benefit passengers by preventing them from being thrown around the interior of the bus and possibly ejected entirely. Accident analysis has been of little value in resolving the issue because of the relatively small number of serious accidents involving buses and the lack of correlation between automobile and bus accidents. Several early studies conclude that, even if seat belts are installed, voluntary usage would be small. Most researchers agree, however, that the installation of seat belts on buses requires a careful examination of the entire seating system.

The seating system includes, among other factors, the type of belt that is used, the design of the seat itself, the spacing between seats, the method of anchoring the seat, the design of the bus floor, and the method of attaching the bus body to the chassis. The lap-shoulder belt combination is generally accepted as superior to the lap belt only. However, the lap-

shoulder belt is unsuitable for installation on current buses due to the difficulty of adequately anchoring the shoulder belt. For any type of belt, an emergency locking retractor is generally considered to be desirable. Several researchers have advocated the use of seats with a 24-in.-high seat back (as measured from the SRP). One paper contends that a seat anchored to the wall of a bus is generally superior to one anchored to the floor. The same paper states that steel plate is superior to plywood as a flooring material. However, plywood is used more commonly because of its ease of workability and its sound-deadening qualities. Finally, several crash tests have demonstrated the potential problem of the bus body sliding along the chassis during a front-end accident and intruding on the driver's compartment.

Further studies encompassing the preceding factors are recommended to assess the entire seating system. Such an assessment will require comprehensive experimental studies involving crash tests and analytical modeling so that the effects of all the factors and their interactions can be determined.

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