

Appropriate protection for wheelchair riders on public transit buses

Greg Shaw, PhD; Timothy Gillispie, BA

Department of Mechanical and Aerospace Engineering, Center for Applied Biomechanics, University of Virginia, Charlottesville, VA

Abstract—Securement of wheelchairs and occupant restraint for wheelchair riders on buses is one of the most difficult problems facing transit providers. The primary findings of this literature review show that (1) very little information has been published regarding transit bus safety and crash environment; (2) the focus of most reported wheelchair incidents involved noncollision events, in which inappropriate wheelchair securement or rider restraint resulted in minor injuries; and (3) studies spanning 30 years indicate that the large transit bus is an exceedingly safe form of transportation, so that wheelchair riders do not face undue risk of injury in this transportation environment. Further study is required to characterize the rare-occurring severe transit bus crashes. The resulting information is needed to establish an appropriate level of crash protection so that the next generation of U.S. wheelchair securement and occupant restraint systems not only are reasonably safe but also are easy to use and acceptable to wheelchair riders and transit bus operators.

Key words: transit bus, transport safety, wheelchair rider, wheelchair tie-downs.

INTRODUCTION

Offering a safe mode of travel for wheelchair riders is one of the most challenging tasks facing providers who operate large transit “city” buses [1]. Existing strap-type wheelchair tie-down (securement) and occupant restraint systems (WTORS) that comply with U.S. Americans with Disabilities Act (ADA) present problems for both wheelchair riders and transit properties [2]. These requirements include—

- Wheelchair Securement.

- Minimum securement system restraint force capability in a frontal crash.
- 17,800 N (buses over 13,600 kg)—This classification includes large transit buses, which are the focus of this study.
- 22,200 N (buses up to 13,600 kg).
- Occupant Restraint: Seat belt and shoulder harness complying with applicable Federal Motor Vehicle Safety Standard (FMVSS) (49 Code of Federal Regulations part 571).

Abbreviations: ADA = Americans with Disabilities Act, CUTA = Canadian Urban Transit Administration, FMVSS = Federal Motor Vehicle Safety Standard, MAIS = Maximum Abbreviated Injury Scale, NEISS = National Electronic Surveillance System, NTSB = National Transportation Safety Board, RESNA = Rehabilitation Engineering and Assistive Technology Society of North America, SAMIS = Safety Management Information Statistics, TCRP = Transit Cooperative Research Program, UK = United Kingdom, UMTA = Urban Mass Transit Administration, WTORS = wheelchair tie-down and occupant restraint systems.

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Address all correspondence and requests for reprints to Greg Shaw, PhD; Department of Mechanical and Aerospace Engineering, Center for Applied Biomechanics, Automobile Safety Laboratory, 1011 Linden Avenue, Charlottesville, VA 22902; 434-296-7288; fax: 434-296-3453; email: cgs5w@virginia.edu.

Many wheelchair riders object to bus drivers invading their personal space when attaching the straps to the four corners of the wheelchair. Drivers complain of difficulty in attaching the straps to the myriad of wheelchair types and have sustained injuries as a result of their struggles to properly use the systems. Some transit providers report that strap-type systems cause substantial delays [1,3]. A study conducted by the Canadian Urban Transit Association concluded that the ADA compliant four-point strap securement systems is "not always used in practice" and that the "requirement for multiple belts also presents an ongoing problem for accessible buses" [3].

Alternatives to strap WTORS have not provided a satisfactory solution. The American National Standards Institute (ANSI)—Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) sponsored work on a universal WTORS concept that is ongoing. However, a pole of transit system representatives suggests that a significant amount of time will be needed to reach the level of cooperation required between vehicle and WTORS manufacturers for this approach to be viable [1]. Despite over a decade of WTORS development since the ADA regulations, still no system exists that can satisfy the challenging ADA demands of the crash protection standard without hindering the transit process.

The ADA U.S. national standard for WTORS was developed without adequate information concerning the risk of wheelchair rider injuries or fatalities and virtually without information concerning the transit bus crash environment. The 1990 ADA (public law 101-336) that includes specific requirements for U.S. public transit bus WTORS (see previous list) [2], prescribes strength requirements for the wheelchair tie-downs that were derived from 32 km/h, 8 g to 10 g frontal barrier crash tests performed with large transit buses [4–6]. The barrier crash velocity was chosen to represent the average travel speed of a transit bus [7]. Evaluators of a prototype bus seat considered such a crash to be "very severe" [8]. An English researcher indicated that a 10 g deceleration level was inappropriate for full size buses [9]. The ADA occupant restraint requirements were chosen based on a current FMVSS for passenger cars (48 km/h) and, presumably, because belt systems were available that complied with the standard [6]. The FMVSS standards 209 and 210 specify belt systems capable of providing occupant protection in a 48 km/h frontal barrier crash that usually produces peak decelerations of at least 20 g to 30 g.

In 1996, we reviewed the literature and conducted database searches to determine the crash risk and crash environment for all vehicles that transport wheelchair riders so as to determine if the ADA level of crash protection was appropriate relative to real-world incident data [10]. We found few studies and limited data collection programs exist. This finding is due to both a lack of adequate data collection efforts that identify wheelchair-seated occupants and to a very low number of miles traveled by wheelchair users relative to general bus riders. Our 1996 study found few documented cases of injuries to wheelchair riders aboard buses of any kind. Of the estimated annual average of 53,000 wheelchair related injuries in all settings during 1988 to 1996 [11], about 170 (0.3 percent) involved a wheelchair aboard a moving vehicle. Most of the 1988 to 1996 incidents involved the rider falling out of the wheelchair or the wheelchair tipping over or moving during vehicle maneuvers. Only 6 percent of the incidents were reported to have involved a collision. None of the wheelchair riders sustained injuries severe enough to require hospital admission [10]. We also found that no wheelchair rider injuries in transit bus crashes were documented and that transit buses were, along with school buses, the safest form of transportation for general ridership.

Our current study focuses specifically on wheelchair rider risk aboard large transit buses and sought information to characterize the transit bus crash environment in terms of severity, principle impact direction, and frequency of occurrence. Study objectives include identifying gaps in the knowledge base and collecting the required data. If the findings indicate that a lower level of impact protection is acceptable than that implied by ADA, then the possibilities for alternative WTORS would be greatly expanded.

METHODS

Information Sources

We used several search methods, including a critical review of our existing library of materials that contains reports on wheelchair securement dating from 1978. We also conducted on-line searches of U.S. national organizations charged with enhancing bus safety, such as the Transportation Research Board and the Federal Transit Association, to supplement our existing collection of papers and reports. European sources were also contacted.

In some cases, we contacted the authors to clarify the findings in the paper or report and contacted researchers and transit safety program staff members to identify unpublished or in-process works. The search concluded with a comprehensive key-word search of various reference information databases, including Ovid, Ingenta, Scirus, FirstSearch and Web of Science. These searches included variations of spelling as well as expanded Boolean searches (see the **Appendix** that appears in the on-line version only).

Search Criteria

We searched for all papers and reports describing transit (fixed route) bus accidents, crashes, and injuries sustained by occupants. Wheelchair rider incidents were a priority, but previous experience indicated that few sources would be found. The scope was therefore expanded to include all bus occupants. Crash and injury data for incidents involving all bus riders can be used to estimate the risk for wheelchair riders. Note that the actual risk for wheelchair riders is probably greater than that of the general ridership because wheelchair riders are often more physically fragile. Quantifying this increased risk was beyond the scope of this study.

We expected to find more information for general bus riders' injuries and crashes because passenger miles are ridden vastly more by people on vehicle seats or standing in the aisles than ridden by people seated in wheelchairs. Because little explicit information exists on the severity of the crash environment as described by the level of acceleration and/or deceleration in the passenger compartment (g-level), we expanded our search to include elements such as injury severity, collision partner, and bus damage that would allow us to approximate.

Each source was reviewed to determine the information elements that include—

- Information needed to estimate the risk of injury faced by a bus occupant.
 - The number of passenger miles during the reporting period per vehicle type (or other exposure information such as number of trips, average trip length, average number of riders, etc.).
 - Estimated injury severity.
- Information needed to estimate the type and severity of the crash.
 - Collision direction(s).
 - Estimated bus deceleration and/or acceleration caused by the impact.

- Bus type.
- Struck/striking other vehicle type.
- Description of struck roadside obstruction, i.e., telephone pole, bridge abutment, etc.
- Estimated bus impact speed and/or other vehicle impact speed.
- If impact speed not available, bus and/or vehicle estimated travel speed or type of roadway (i.e., urban street, highway, etc.)
- Operating environment(s) typically encountered that may affect crash frequency or severity, such as number of days of snow and ice.
- Description of damage to bus, other vehicle, roadside obstruction. Vehicle repair costs if available.
- Description of bus driver and each passenger movement in crash including precrash position.
- If applicable, description of wheelchair, tie-down, and occupant restraint.
- Estimated injury severity.
- Percent of the injured that was physically fragile, i.e., “frail elderly female.”

Based on previously identified materials, we did not expect to find papers or reports that included all the elements. The search and subsequent analysis excluded information regarding crash injuries to pedestrians and occupants of collision partner vehicles.

RESULTS

We found little information that addressed transit bus safety regarding passengers who ride in wheelchairs. Although there was more information on transit bus safety for the general ridership, we found virtually no information concerning the crash environment of a real-world transit bus that could be used to estimate the forces acting on the wheelchair and its occupant. We found no published case studies of crash-related fatal injuries to bus passengers either seated in a wheelchair or on a vehicle seat.

The search of databases returned few resources not previously identified. The majority of the reviewed publications contained few of the elements listed in the introduction of this paper. Several authors cited deficiencies in data collection efforts [7,12]. In many cases, the bus type was not explicitly stated and the information often included motor coaches, such as over the road (Greyhound) buses or smaller paratransit buses. In other cases,

separating injuries to bus passengers from injuries to pedestrians and collision partner vehicles was difficult [7]. Unfortunately, this finding also applied to the Federal Transit Administration Safety Management Information Statistics (SAMIS) database, the only national data collection effort that tracks U.S. transit bus incidents.

Wheelchair Rider Injury Frequency and Severity

We found no reports of deaths of wheelchair riders aboard transit buses, although this is not surprising given the low fatality rate for all passengers and the relatively low number of passenger miles traveled while seated in a wheelchair. Dejeammes and Bonicel found little published data regarding the risk of crashes and wheelchair occupant injuries [13]. The data that they did find indicated that injuries and fatalities aboard public transport vehicles are “extremely rare” and are usually the result of frontal impacts or abrupt crash—avoidance maneuvers such as sudden braking. However, a 1986 Urban Mass Transit Administration (UMTA) (now the Federal Transit Administration) workshop proceedings reported that the Southern California Rapid Transit District “has documented that wheelchair patrons have an accident rate of over 350 times greater than ambulatory passengers” [6]. Because details were not given regarding resulting injuries or the context in which these accidents occurred, we assume that they included boarding and both noncollision and collision events. A more recent study reported that wheelchair riders account for 3 to 10 percent of passenger incidents [14]. Given the small ratio of wheelchair riders to the general ridership (estimated to be 0.24 percent or less), this finding suggests that the UMTA report

may not be unreasonable.* Again, no detail was provided regarding the nature of the incidents.

A National Electronic Surveillance System (NEISS) database review for the period of 1988 to 1996 identified only three wheelchair rider injuries that occurred while a bus was in motion [10]. Richardson conducted an earlier NEISS study and found similar results [15]. He also identified three deaths associated with wheelchair riders from 1973 to 1991. However, none of the cases involved a transit bus. Only one case, in which a van wheelchair rider was ejected during a sudden stop, included a moving vehicle.

A study similar to the Richardson study reviewed NEISS data from the 5-year period 1991 to 1995 (Table 1) [16]. The bus type was not specified and may include paratransit vehicles, school buses, and transit buses. The data suggest that an average of three wheelchair riders were hospitalized annually because of improper, unused, or nonexistent wheelchair securement in incidents involving vehicle motion.

A review conducted of the National Highway Traffic Safety Administration (NHTSA) and state and municipal crash data found “few fatalities . . . with a passenger seated in a mobility aid (wheelchair)” [7]. Wheelchair lifts were reported to be a more common cause of wheelchair rider injuries aboard paratransit vehicles [10,15] and aboard transit buses than were incidents caused by vehicle motion [14].

*This estimate was calculated with data from Seattle, a city with a large percentage of wheelchair riders [15].

Table 1.

Estimated U.S. WC-related injuries from 1991 to 1995 [16].

WC-Related Injuries and Deaths Classified by Condition	Count	% of Total
Number of WC-Related Injuries and Deaths	299,734	100.0
Motor Vehicle-Related WC Injuries and Deaths*	7,121	2.0
Involving Buses†	856	0.29
Involving Buses Because of Improper or No Securement‡	422	0.14
Seriously Injured	29	0.009
Seriously Injured and Hospitalized§	17	0.006

*Includes incidents in which the wheelchair rider was struck by a motor vehicle.

†Indicates those cases in which “Motor Vehicle-Related WC Injuries and Deaths” involved a bus. In a similar manner, each subsequent case classification is a subset of the preceding one.

‡Assumes percentage of “improper or no securement” for buses was the same for all motor vehicles (vans and buses).

§Assumes ratio of “treated and released” to “hospitalized” for buses was the same for all motor vehicles.

WC = wheelchair

A Project Action study also reviewed the records of an urban center's transit provider and found that 35 of 1.1 million one-way trips included incidents that included wheelchair riders [7], although none of the incidents was because of a vehicle crash (**Table 2**). Other transit providers confirmed that most wheelchair rider injuries are not due to impacts and that 40 to 58 percent of injury-causing accidents were due to improper wheelchair securement or securement failure. The Project Action study also includes a review of a transit provider insurer database that provides incident information from 250 transit agencies over a 20-year period. Most of the insurance claims were for "low level personal disability injuries" caused by falls from lifts, riders unattaching their WTORS, and improper securement.

A 1995 German review of 6 years of wheelchair riders aboard low-floor buses found there were no problems during normal bus operation and "not one accident" had occurred [17]. A German transit system reported no wheelchair accidents in 10 years of operation with low-floor buses [18]. Wheelchair securement aboard low-floor buses in Europe, the United Kingdom (UK), and more recently Canada consists of backing a rear-facing wheelchair against a padded bulkhead and setting the brakes. In some applications, an aisle-side barrier, such as a stanchion or flip-down armrest, is provided. This securement approach is reported to be preferred by German transit operators and wheelchair riders [18]. A former Canadian Urban Transit Administration (CUTA) researcher who has extensive contacts with transit agencies in Europe, the UK, and Canada, has not found any reports of accidents associated with this securement option.*

General Rider Injury Frequency and Severity

As expected, we found much more information regarding general ridership crashes, injuries, and general safety concerns. Several sources began with unambiguous statements that buses are exceedingly safe [8,19–21]; e.g., "The urban transit bus is an extremely safe transportation mode choice. . . ." [8]. Fatality rates for bus passengers, especially school and transit bus passengers, are many times lower than for passenger cars and are even lower than that for trains and planes (see **Figure**). This finding also applies to injury, if one were to assume that moderate and severe injury rates are proportional to fatality rates [10].

*Personal communication with Brendon Hemily, formerly of CUTA, February 2002.

Table 2.

Wheelchair incidents aboard transit buses [7].

Count	Bus Mode When Incident Occurred
25	Bus turning
4	Sudden stop
4	Normal operation
Count	Result/Cause
14	Improper securement
11	Passenger fell from wheelchair
5	Tie-down failed ("claw" type)
2	Tie-down failed ("strap" type)
3	Wheelchair failed

Several authors stated [12,20,21], or implied, that the crash and injury data alone did not justify the reported research, but they indicated that the research was conducted because of a low public tolerance for injury or death aboard buses: "While transit bus industry is vastly safer in comparison to other forms of transportation, for various reasons, there is no doubt that public transit is subject to greater scrutiny in the eyes of the public" [21]. A small number of fatal crashes involving school buses or motor coaches attract media attention which, in turn, has led to research efforts in the United States, Canada, and Europe [20].

While there has been public demand and often begrudging interest in committing research dollars to school and intercity bus safety, public concern has not resulted in substantial safety research programs for transit buses. U.S. and Canadian bus safety programs that were primarily concerned with passenger safety have largely ignored transit buses. We found only one brief case report of an injury-producing transit bus crash: In January 1999, 23 passengers were injured when a New Jersey transit

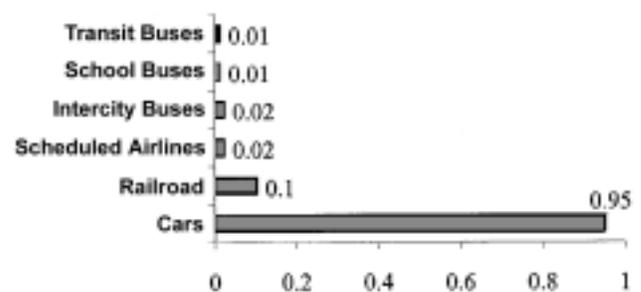


Figure.

Average fatalities per 100 million passenger miles from 1989 to 1994.

bus was rear-ended by a tractor-trailer [22]. No studies were found that critically examined severe transit bus crashes as has been done by the National Transportation Safety Board (NTSB) for school and intercity buses [23]. In fact, the NTSB report, titled "Highway Special Investigation Report Bus Crashworthiness Issues," excluded transit buses. Conversations with NTSB staff in July 2001 indicated that the agency has no firm plans to investigate transit bus crashes. Very few Canadian transit bus accidents have been investigated;* it is difficult to uniquely identify transit buses in provincial crash databases [24]. We did find one UK study that presented an overview of bus passenger injuries and recommended policy decisions to improve bus safety. The study concluded that efforts be directed toward reducing the number of injuries caused by noncollision events [12].

The focus of some transit bus safety efforts has been cost reduction [25,26]. Transit bus safety programs were promoted because of the possible net savings to be realized by the transit agencies. A U.S. UMTA study found that the cost of employee compensation for injuries that occurred on the job was nearly equal to that of the costs related to settling claims related to crashes and other bus incidents [25]. Note that most of the employee compensation claims did not result from drivers involved in bus collisions and that this analysis combined liability of all the injured in collisions, including the occupants of the collision partner vehicle (most commonly a passenger car) and pedestrians.

Had a substantial number of collisions occurred with severe passenger injuries, a transit agency's liability would have been much higher. A 1996 Transit Cooperative Research Program (TCRP) study (TCRP A-18) estimated that each bus incident involving a fatality costs 2.7 million dollars [26]. However, the average cost for an incident reported by five transit agencies in the UMTA study was \$2,500 [25]. The UMTA study authors cautioned that this average cost did not reflect more severe events that were not captured in the 3-year study period. They estimated that "catastrophic" events costing between \$100,000 to \$1,000,000 do occur but "the frequency rate is relatively low." Interesting to note is that the cited examples of these severe events (a severely injured pedestrian run over by a bus [\$1.1 million], a bicyclist that collided with a bus [\$125,000], and a wheelchair rider injured by the wheel-

chair lift [\$350,000]) did not include passenger injuries sustained while the bus was in motion or involved in a crash.

Injury-Producing Bus Incidents

Noncollision Events

While we found little information regarding injury-producing bus crashes, we found several reports of noncollision events that resulted in passenger injury. This finding suggests that noncollision injury events are of more concern to transit providers than are infrequent injury-producing crashes. Many bus passengers are injured getting on or off the bus or when no collision is involved. A study that used the 1993 SAMIS data reported that 26 percent of all injuries related to transit bus incidents mostly were due to passengers not being seated while the bus was accelerating or braking and that 18 percent were due to falls getting on and off [14]. This study included injuries to bus passengers, collision partner passengers if a crash occurred, and injuries to pedestrians.

In a study cited by Zegeer et al. that specifically examined onboard passenger injuries [27], 57 percent of passenger injuries were due to falls under normal operation conditions. Another study of bus passenger injuries found that 56 percent occurred during braking and one-half of these occurred during sudden braking [8]. The typical scenarios included people standing or walking to the rear of the bus when the bus accelerated or braked causing them to fall to the floor. Most (53 percent) of the injured were over 50 years old and female (82 percent). White and Dennis and Shanley also reported the predominance of injuries occurring to older riders [12,28].

Collision Events

Transit buses are involved more frequently in collisions than other types of vehicles [8]. In comparison to passenger cars, buses have over three times the number of collisions per vehicle mile. However, the collisions, which frequently occurred at slow speed on congested urban streets, are usually minor with respect to the bus. A study of 17 transit agencies during 1985 to 1987 reported that 85 percent of the bus collisions involved another motor vehicle and 13 percent involved a fixed object [25]. The consensus of the material reviewed was that frontal collisions, those causing the bus to decelerate, potentially are more injurious than the more common sideswipes and rear collisions [8,11,19,22,25]. Zegeer et al. reported that

*Personal communication with Bill Gardner, Transport Canada, February 2002.

many crashes were due to the bus hitting the rear of a car or vice versa, in congested traffic [27]. Matolcsy found that frontal collisions were more severe [29], i.e., produced a greater change in the velocity of the bus than in side or rear impacts. However, the authors of the 1995 Project Action study concluded that the crash data [7], because they do not distinguish between injuries to the bus driver and bus passengers, are insufficient to conclude that frontal impacts are the most injury-producing for the passengers. Drivers, especially those unbelted, are particularly vulnerable in a frontal crash and may be injured when bus passengers are not.

Although some studies described the principal direction of the crash and provided qualitative and rank order information regarding the crash severity, none provided deceleration-acceleration g-levels required to fully characterize the crash environment. We found no reports of passenger injuries caused by potentially very severe bus collisions with roadside objects such as bridge abutments.

Injuries to Bus Passengers

A single study conducted by Langwieder, Danner, and Hummel provided more than a cursory description of bus passenger injuries [19]. The study involved German buses that seated over 25 passengers, included “mini-buses,” and reviewed injuries caused by vehicle maneuvers (without collision) and caused by vehicle collisions. The primary injury-causing noncollision event for transit buses was standing passengers who fell and hit their heads after emergency braking. In general, most driving maneuver injuries were minor to moderate. Braking caused 85 percent of events without a collision, and all were coded as Maximum Abbreviated Injury Scale (MAIS) 3 (serious) or less [30].

In accidents resulting from vehicle accelerating or turning, minor chest contusions were most common, although some cases resulted in multiple rib fractures. The more serious injuries, including skull fractures, femur fractures, and multiple rib fractures, were caused by falls because of braking. These injuries were most common for older passengers who had difficulty holding themselves up and who were more physically frail than the general ridership.

Langwieder et al. reported fewer and less severe occupant injuries on transit buses than on motor coaches for events that involved collisions [19]. Of the 40 occupants killed on all types of buses during 1978 to 1985,

38 were killed on motor coaches and none were killed on transit buses.

The authors also reported a relationship between the severity of transit bus occupant injuries and the bus collision partner. Only four (0.4 percent) of transit bus passengers involved in bus and/or car collisions sustained serious injuries. In all cases with serious injuries and in many cases with slight injuries, a frontal crash occurred in which the bus was decelerated by the impact. In 43 bus and/or car crashes, no deaths of bus passengers occurred, but there were 22 deaths of car occupants. This finding suggests that bus and/or car crashes severe enough to kill car occupants do not usually pose a significant injury threat for bus passengers. The chance for suffering injury, especially serious injury, is greater if the collision partner is a truck (**Table 3**). Most (61 percent) of the injury-producing bus and/or truck crashes involved impact to the front of the bus. Many of the seriously injured passengers in a bus and/or truck collision were seated in the intrusion area. **Table 3** lists a serious event involving a single bus in which all of the passengers were either slightly or seriously injured. Whether or not this event involved collision with a fixed object or a rollover, the most injury-producing event, was not indicated.

DISCUSSION

This study confirmed our previous finding that very little information exists regarding either wheelchair or general passenger injuries for transit bus crashes. Significant and new data have not been published since 1996, the date of our last review [10].

This lack of available information suggests that relatively few efforts have been undertaken to investigate and to improve transit bus passenger safety. Compelling evidence suggests passenger safety is not a high-priority concern given that the transit bus is one of the safest modes of transportation.

The few reports of severe bus passenger injury coupled with no reports of severe wheelchair rider injury suggest that severe bus crashes are uncommon. Because there are very few wheelchair riders relative to other passengers, it is not surprising that severe bus crashes involving wheelchair rider injuries have not been reported. Despite serious deficiencies in bus crash reporting systems, substantial numbers of wheelchair riders injured in bus crashes most likely have not occurred.

Table 3.

Distribution of injury severity as a function of crash type for transit buses.

Crash Type	Slightly Injured* (%)	Percent Seriously Injured† (%)	No. of Passengers Onboard
Bus and/or Car	9.1	0.4	276
Bus and/or Truck	18.9	3.1	328
Single Bus	52.2	47.8	46

Note: Table was constructed using data from Langwieder et al. [19]. No fatalities were reported. Some collision events involved preimpact braking.
 *(Slightly injured/All passengers) × 100. MAIS level not indicated.
 †(Seriously injured/All passengers) × 100. MAIS level not indicated.

Note that future studies should monitor the number of wheelchair riders aboard large transit buses. Wheelchair ridership may increase because of an aging U.S. population and more transit buses equipped for wheelchairs.

We found no explicit information concerning the crash environment of the real-world transit bus and the forces that would act upon the wheelchair and its occupant. Only one source, the Langwieder et al.'s paper [19], provided potentially useful information that suggested that an overall similarity may exist between collision and noncollision events severity. Analysis of the Langwieder et al. data suggests that the *average* injury risk of the noncollision injury-producing incident was similar to that of the bus and/or truck collision. The ratio of seriously injured to slightly injured occupants for the bus and/or truck collision case was 16 percent versus 14 percent for the noncollision case (Table 4). If the ratio of slight to seriously injured indicates crash severity, i.e., a greater percent of the injuries are serious in a more severe crash, this analysis suggests that the g-levels experienced during evasive maneuvers are, on average, comparable to those experienced in a bus and/or truck collision. Given that bus acceleration levels do not exceed 1 g in any direction under abrupt driving and braking (Table 5), this suggests that bus and/or truck collisions

produce similar acceleration levels that, *on average*, do not exceed 1 g [31]. Moreover, many of the reported collisions most likely were preceded by evasive maneuvers, such as abrupt braking. In these cases, the peak decelerations and most injurious events may not have been due to collisions.

Note that this analysis, based on only a single study, should be considered speculative. The analysis assumes that the only injury-producing mechanism is inertial forces and does not consider bus and/or truck crash intrusion, reportedly a common cause of serious injury [19]. Other assumptions are that most of the reported noncollision events happened on scheduled (transit) buses, and that the injury descriptors are comparable, i.e., MAIS 1 equals ~slight and MAIS 3 equals ~severe.

Implications for WTORS and WTORS Standards Development

This study found little justification for the ADA-mandated level of frontal impact protection in terms of published crash and injury data. No reported analyses of actual crashes were found, nor reports of severe crashes equivalent to the 32 km/h, 8 g to 10 g frontal barrier crash that formed the basis for the ADA WTORS requirements.

Table 4.

Number of injured bus occupants in bus incidents.

Noncollision*			Collision: Bus†/Car			Collision: Bus†/Truck		
MAIS 1	MAIS 3	Ratio of MAIS 3 to MAIS 1 Injuries	Slight‡	Serious‡	Ratio of Serious to Slight Injuries	Slight	Serious	Ratio of Serious to Slight Injuries
58	8	0.14	25	1	0.04	62	10	0.16

*Both scheduled and over the road.

†Scheduled bus only.

‡MAIS level not indicated. MAIS: indicating the highest AIS score for an injury for a given person, vehicle, or event. AIS Coding: 1 = Minor, 2 = Moderate, 3 = Serious, 4 = Severe, 5 = Critical, 6 = Maximum [30].

Table 5.

Peak vehicle compartment acceleration during severe maneuvers.

Maneuver	Large Fixed-Route Bus (g) [*]	Van-Based School Bus (g) [†]
Acceleration	0.2	0.33
Braking	0.4	0.77
Lane Change	0.1	0.80

^{*}Data from Oregon State researcher Hunter-Zaworski as summarized in the ECRI Project Action report [7]. Values were estimated for both normal and emergency maneuvers.

[†]Data from *Assessment of a Transportable Mobility Aid in Severe Driving Conditions* [31]. Data were recorded from accelerometers placed on a van-based school bus. Peak values were "average maximums" and did not include transient peaks of short duration.

Some researchers proposed that protection up to the 1 g level would be appropriate for large transit buses, so protected wheelchair riders would be secure in relatively common evasive maneuvers. Dejeammes and Bonicel indicated that providing protection for a serious crash is not reasonable but that it is appropriate to ensure "safety for wheelchair users equivalent to other passengers, either seated or standing [13]. These forces are sharp braking and bends (turns)." White and Dennis reviewed bus safety in Britain and came to a similar conclusion [12]. A Canadian researcher suggested that the number of standees injured would be much greater if a substantial number of transit bus collisions exceeded 1 g.^{*}

Such a protection level may be adequate for most bus and/or car collisions and many bus and/or truck collisions, although, as previously indicated in the analysis of the Langweider et al. paper [19], supporting data for this conclusion are very limited. Although the results of this study indicate that protection at the 1 g level is more justifiable than the ADA-implied 8 g to 10 g level, we advocate further investigation of the rare transit bus crashes that exceed 1 g. Several sources recommended that individual transit providers be contacted for more complete crash and injury information [7].[†]

Although resource-intensive, procuring data directly from transit providers appears to be the only viable near-term strategy to find the information required to characterize the transit bus crash environment.

The goal of this further investigation would be to quantify the frequency of these events in terms of occur-

rence per passenger mile and to estimate the magnitude and direction of the forces acting on the wheelchair and rider. This information would be valuable to developers and policy makers when establishing criteria for an improved WTORS, and it would help to weigh the advantages of protection in events that exceed 1 g against factors such as cost, convenience, and user acceptance.

For example, the most convenient current system, the rear-facing bulkhead arrangement, has been tested in both vehicle maneuvers (less than 1 g) and in a series of 10 to 30 km/h in 2 to 12 frontal collisions [13,32,33]. This design, which allows wheelchair riders to independently wheel into the securement space and set the brakes (an automatic feature of most power wheelchairs), provides protection in frontal crashes that exceed 1 g. A Canadian study suggests that some wheelchair riders prefer to ride forward-facing in the securement space, and a system is being considered to better accommodate this user preference, albeit with the use of strap tie-downs [18]. Although we are aware of no crash test data for the forward-facing orientation without securement straps or hardware attached to the wheelchair, we believe that a forward-facing system as convenient as the existing rear-facing arrangement would be significantly less protective for frontal collisions that exceed 1 g. In this case, a better understanding of the frequency and severity of frontal transit bus collisions would help to decide if the benefit of increased user acceptance of the forward-facing orientation is worth the penalty of reduced crash protection.

CONCLUSIONS

The primary finding of this study is that very little published information regarding transit bus safety and crash environment exists. No information was found to suggest that wheelchair riders face undue risks aboard

^{*}Personal communication with Brandon Hemily, formerly of CUTA, March 2002.

[†]Personal communication with Charles Zegeer, University of North Carolina Highway Safety Research Institute, January 2002, and with James Gardner, Transport Canada, February 2002.

transit buses. The focus of most reported wheelchair incidents has been on noncollision events in which a wheelchair was inappropriately secured or an unrestrained rider was injured.

This lack of information for wheelchair rider crashes and injuries was anticipated and is due, in large part, to two factors: (1) Wheelchair riders comprise less than 0.3 percent of bus passengers and, presumably, comprise a similar percentage of bus passenger miles. A similar relationship should exist for the relative number of injuries. (2) The number of injurious transit bus crashes and noncollision events is quite small. Studies spanning 30 years confirm that the transit bus is an exceedingly safe form of transportation. Therefore, improving passenger safety has not been a priority of the transit industry.

We found no estimates of crash environment severity in terms of g-levels in the passenger compartment for incidents involving either wheelchair riders or other passengers. Although most injuries caused by collisions have been minor, some are classified as serious. Only a few of the incidents were reported to have fatalities. The crash conditions for the apparently rare severe events are not adequately described. Serious injuries and fatalities were associated with bus and/or truck collisions in which the most seriously injured passengers were seated near the area of impact. We found no descriptions of individual incidents in which one or more passengers were seriously injured or killed.

Much more information was found for more commonly occurring noncollision incidents. Noncollision incidents have been the focus of research efforts designed to characterize the g-levels associated with vehicle motion in normal operation and during evasive maneuvers. Reported deceleration/acceleration levels range from 0.3 g to 0.8g.

The results of this study indicate that protection at the 1 g level is more justifiable than the ADA implied 8 g to 10 g level. However, before a reduction in the protection level is recommended, further information is needed regarding transit bus crashes that exceed 1 g. Future efforts should establish the frequency, severity, and principal impact direction of these events. Only then can an appropriate WTORS protection level be identified. If this level is substantially lower than 8 g to 10 g, we anticipate the development of WTORS that would provide a reasonable level of occupant protection as well as improved efficiency, convenience, user acceptance, and cost.

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