

Wheelchair rider risk in motor vehicles: A technical note

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Abstract—A better understanding of the risk involved in riding different sizes and types of motor vehicles is required to make informed decisions regarding a reasonable level of protection for wheelchair riders. Wheelchair rider accident information that can be used to estimate risk is quite limited. This paper reviewed the resources available, including the National Electronic Injury Surveillance System database. Motor vehicle accident data for the general public were analyzed in order to better characterize wheelchair rider risk. Using the National Safety Council annual transportation mode fatality rates and the (inverse) relationship of vehicle mass and occupant fatality rate, fatality rates for vehicles that transport wheelchair riders (minivans, vans, paratransit vans, and small and large buses) were estimated. Despite the large margins of error that must be assumed for accident data and the conclusions drawn from it, the available information suggests that 1) the majority of wheelchair rider injuries could be prevented by providing protection for abrupt vehicle maneuvers; 2) the type, size, and mass of the vehicle have a substantial effect on the fatality rate, although this effect decreases for heavier (<3,000 kg) vehicles; and 3) wheelchair riders who cannot properly use tiedown and occupant restraint systems or who are frail would face a lower risk of injury if transported in larger vehicles.

Key words: *fatality rates, injuries, motor vehicles, risk, transportation safety, wheelchair.*

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INTRODUCTION

Although there has been an increased awareness regarding wheelchair rider transport safety, there is very little information available regarding the risk of riding in a wheelchair on a motor vehicle. A better understanding of the risk involved in riding different sizes and types of motor vehicles would help transit operators, wheelchair riders, and other interested parties make informed decisions regarding both a reasonable level of protection and an improved access to transportation. Informed decisions could be made regarding special case wheelchair riders who may not be accommodated by current wheelchair tiedowns and occupant restraint systems (WTORS) shown in **Figure 1**. For example, a more accurate understanding of risk may help to determine whether the poor fit of the occupant restraint belt due to alternative sitting posture significantly affects the chance of injury and, therefore, justifies special accommodation.

Background

Since the mid-1970s, laboratory research has dramatically demonstrated the potential danger of an inappropriate WTORS in a vehicle collision (1–5). Based on this research, WTORS have been developed or upgraded, and several safety standards have been implemented or are under development to reduce the risk faced by wheelchair users. These standards include the Americans with Disabilities (ADA), wheelchair tiedown and occupant restraint regulations (49 C.F.R. Vol. 56, No. 173, 9/6/1991), the recently published Society for Automotive Engineers (SAE) Wheelchair Tiedown and Occupant Restraint Systems (WTORS) for Use on Motor Vehicles (SAE

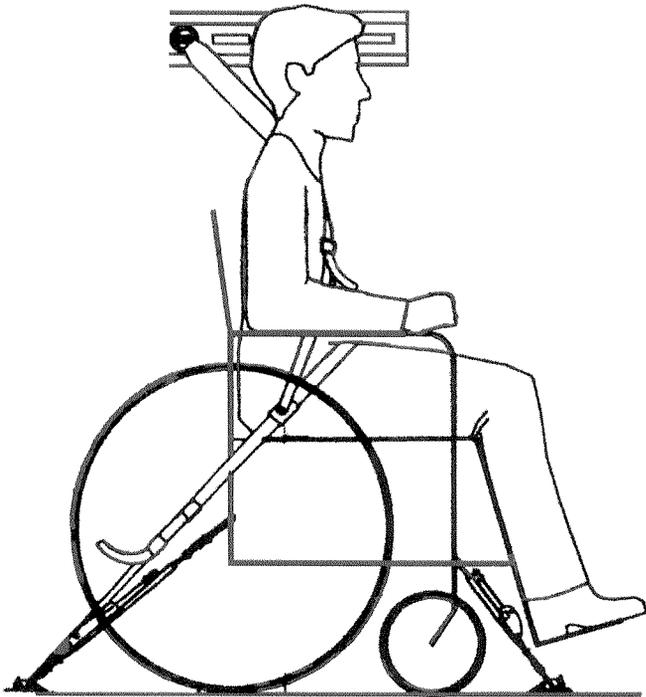


Figure 1.
A typical wheelchair tiedown and occupant restraint system (WTORS).

#J2249), and the American National Standards Institute (ANSI)/RESNA Standard for Wheelchairs Used as Seats on Motor Vehicles (ANSI/RESNA #WC/19). Although the number of vehicles with improved WTORS has increased, there is a wide range of systems currently in use. While new school and transit buses are federally mandated to have WTORS capable of passing a static strength test, many older buses continue to operate with superseded WTORS designs. There are no federal guidelines regarding WTORS in private passenger vans.

Laboratory testing suggests that wheelchair riders could suffer severe or fatal injuries in a crash if not adequately protected. However, in order to fully understand the risk faced by wheelchair riders aboard motor vehicles, it is not only important to know what could happen in a worst case scenario, but also to know the chances of being in such a situation. For example, the fatality rate is quite high for a commercial airliner crash, but, because there are very few crashes, the risk of flying (in terms of deaths per passenger miles; that is, deaths per passenger per mile traveled by vehicle) is 1/20th that of passenger cars (6).

METHODS

Accessible wheelchair rider accident information that can be used to estimate risk is quite limited. In Phase I, we reviewed information available regarding wheelchair user deaths and injuries, including the National Electronic Injury Surveillance System (NEISS) database. In Phase II, in order to provide added insight and to better characterize wheelchair rider risk, we pursued the alternative approach of using fatality rates for all passengers to approximate the risk faced by wheelchair riders. Because there are many more people out of wheelchairs than in them, there is a correspondingly greater amount of accident data that can be used to estimate risk.

Phase I. Information Review: Wheelchair User Deaths and Injuries

We conducted an analysis of NEISS data for the 93-month period from September 1996 through January 1988. The staff of the Consumer Product Safety Commission (CPSC), who maintain the database, provided a list of all injuries involving wheelchairs that occurred on streets and highways. This staff currently collects cases from a sample of 95 of an estimated total of 6,000 hospitals nationwide that either have emergency departments or accommodate emergency visits. The weight factor of **Table 1** is used to approximate the nationwide number of similar cases had all 6,000 hospitals been surveyed. Because NEISS data collection and analysis does not consider cases treated at other medical care facilities, it underestimates the total number of injuries. In addition to searching the NEISS data, other information sources were also reviewed.

Findings

The existing information indicates that there have been very few deaths and hospitalized injury cases involving WTORS. The most readily accessible and only quantifiable information regarding accidents involving wheelchairs on vehicles was found in the NEISS database: **Table 1** lists the 33 wheelchair riders injured while in motor vehicles and seen in hospital emergency rooms. The data indicate that most of these injuries were minor and resulted from inappropriate wheelchair and occupant securement. In 14 of the 33, the wheelchair fell over. In five cases the wheelchair moved in the vehicle. In nine, in which there was no indication of the wheelchair tipping over, the riders fell from the chair. There were an approximately equal number of tips, falls, and reported movement to the front,

Table 1.
Wheelchair rider injuries from 1988 to October 1, 1996.

Yr	Diag	Part	Sev	Wght	Comment
88	ST/SP	L/TRK	2	68.2	Van halted suddenly, patient fell forward.
88	FRACT	L/LEG	3	81	Van stopped suddenly, patient fell out of wheelchair.
89	CT/AB	Head	3	81	Unsecured wheelchair fell over in a transport van.
89	CT/AB	Elbow	2	78.4	Car stopped quickly and patient toppled over.
90	LACR	Face	4	85.7	Wheelchair back came apart and patient fell to floor.
90	CT/AB	SHOUL	2	115.3	Van stopped suddenly, wheelchair tipped over.
91	CT/AB	FINGR	1	16.9	Patient fell out of wheelchair in paratransit van.
91	ST/SP	Neck	3	36	Wheelchair broke when "Mercy" van executed a turn. The patient was thrown forward.
91	CT/AB	SHOUL	2	42.9	wheelchair broke free in dialysis transport van. Wheelchair and patient moved forward.
91	LACR	Head	4	16.9	Patient fell backward in van.
91	LACR	Face	4	36	Four-year old fell out of chair while on the bus.
92	FRACT	U/LEG	3	42.9	Van involved in an accident. Foot and ankle caught in footrests.
93	CT/AB	25-50	6	34.3	Wheelchair fell over in transport van. Patient hit head on padded seat and floor.
93	CT/AB	Face	3	16.9	Wheelchair flipped over in a van.
93	LACR	Ear	2	34.3	Wheelchair flipped in a motor vehicle accident.
93	CT/AB	Arm	2	16.9	Wheelchair rolled forward into the back of the driver's seat in a van.
94	LACR	Head	4	34.3	Wheelchair tipped in van.
94	CT/AB	U/TRK	3	18.2	Patient in paratransit van that was involved in an accident flipped backward out of the Wheelchair.
94	I-O-I	Head	5	18.2	Wheelchair fell over backward in ambulette.
94	ST/SP	Neck	3	42.9	Wheelchair fell over sideways on a bus.
94	ST/SP	L/TRK	2	34.3	Wheelchair tipped over in wheelchair van; patient injured back.
94	CT/AB	L/TRK	2	42.9	Patient fell out of wheelchair and the wheelchair fell on her in a special van.
95	CT/AB	Ankle	2	42.9	Patient was getting on the bus. Before being locked down, the bus turned and the wheelchair trapped the patient's ankle against the bus wall.
95	LACR	L/LEG	2	34.3	Patient released wheelchair lock and the chair rolled into the back of the ambulance.
95	LACR	Face	4	16.9	Patient fell out of wheelchair while riding an ambulance and hit his head on the floor.
95	CT/AB	Head	3	16.9	Wheelchair tipped over in an Interagency transit van.
95	ST/SP	SHOUL	2	16.9	Patient fell out of wheelchair when the van swerved.
95	CT/AB	L/TRK	2	16.9	Wheelchair and patient fell backwards when van accelerated.
96	CT/AB	Head	3	34.3	Van turned too quickly.
96	ST/SP	Foot	1	34.3	Ambulance van turned, causing the wheelchair to roll.
96	FRACT	FINGR	3	34.3	Wheelchair tipped over to the side in a "Mercy" van.
96	Other	L/TRK	0	34.3	Patient was tossed around in van and suffered back spasms.
96	LACR	Head	4	42.9	Wheelchair tipped over on the school bus.

Yr=year; Diag=diagnosis; CT/AB=contusion or abrasion; FRACT=fracture; I-O-I=internal organ injury; ST/SP=strain or sprain; Part=body part; FINGR=finger; L/LEG=lower leg; U/LEG= upper leg; L/TRK=lower trunk; U/TRK=upper trunk; SHOUL=shoulder; 25-50=20%-50% of the body; Sev=severity (note that this severity scale is not the same Abbreviated Injury Scale (AIS) used by NHTSA and commonly reported in automotive crash safety literature); 0=unknown; 2-6=geometrically progressive indication of severity; 7=all hospitalized "6" cases; 8=death; Wght=the approximate number of similar cases nationwide.

rear, and side. Based on this 33-case sample, the CPSC estimated that 1,320 such injuries occurred nationwide during this time period. Because the NEISS does not track individuals who sought care at other medical facilities or from individual healthcare workers, and because some cases may have been miscoded, the estimated total number of injuries is low. However, because of the focus on hospital emergency rooms, we assume that the data reflect most of the moderate and severe injuries.

None of these 33 persons required admission to the hospital; all were either treated and released or examined and released. No deaths were reported. Eleven suffered lacerations, contusions, or abrasions to the head and face.

Most NEISS event comments (**Table 1**) specified the type of vehicle involved in the incident. Vans, including paratransit vans, were cited 22 times. Other cases were reported to involve four (van-based) ambulances or ambulettes, three buses, and one school bus.

Observations

Our search of primarily national (US) sources confirmed that only limited information is available. Based on a very brief and incomplete description of the cause of the injuries recorded in the NEISS event comments, tentative conclusions can be drawn regarding the most common injury scenarios. The most common involved a van executing a maneuver that caused the wheelchair to fall over. Ten case descriptions cited vehicle braking or turning as the reason for the injury. Only two indicated that the vehicle had been involved in a crash.

These conclusions parallel those of Richardson (7), who analyzed NEISS data from 1986–1990 and concluded that “improper securement accidents generally occur when the vehicle stops too quickly or makes a sharp turn,” reporting that most of the resulting injuries were relatively minor; none of the estimated 2,200 injuries required hospitalization. Using fatality data from the CPSC Death Certificate File from 1973–1991, he found a record of only one fatality occurring when an occupant fell from the wheelchair in a van due to a sudden stop.

Caution should be exercised when using NEISS comment information, which is condensed (from patient chart intake information gathered by hospital emergency room staff) into a two-line note by data-entry personnel. There is great variation regarding what is, and what is not, recorded. Richardson (7) warned that the CPSC database was not a census of all deaths and that there have been variations in how data were reported.

In the course of our investigation, we found other sources of information. The National Center for Statistics and Analysis division of the National Highway Traffic

Safety Administration (NHTSA), has recently begun collecting more specific information on motor vehicle accidents involving wheelchair occupants. A 1996 fatality, under investigation at the time this was written, involved a wheelchair-seated driver in a minivan.

Although there are anecdotal reports of at least one death, sources at NHTSA, the National School Transportation Association (NSTA), and the bus transport industry were not aware of any wheelchair occupant deaths occurring while the vehicle was in motion in the last 20 years. We were unable to find documentation of wheelchair user injuries aboard school buses (except for the one NEISS case listed in **Table 1**). Anecdotal reports from school transportation departments, school therapists, and school bus providers suggest that most of the injuries, as reported for all vehicle types in NEISS data, are not serious and occur when the occupant either falls out of the wheelchair or the wheelchair tips over during vehicle maneuvers. Most of the injuries have been attributed to the improper use or maintenance of the vehicles' WTORS.

One study of transit buses mentioned that “few fatalities are known to have occurred...,” but did not provide a source for this information. The authors reported little success in finding useful accident data for wheelchair users (8). Examples of transit bus accidents included two cases (#2148 and #2198), documented by the State of New York Public Transportation Safety Board. In one, the wheel lock failed during a turn, causing the chair to overturn and eject the rider. In another, the wheel lock apparently failed during braking, causing the wheelchair to roll forward. In both cases, the riders suffered minor injuries. A 1991 German study stated that there were no accidents in which transit bus wheelchair riders were injured. This information was used to justify the now common German approach of not using WTORS. Protection is provided by backing the rear-facing wheelchair up to a padded bulkhead and locking the brakes (9).

Phase II. Estimating Wheelchair Rider Risk by Using Accident Fatality Data for the General Population

To better define wheelchair user risk, Phase II utilized information from databases specifically designed to track motor vehicle accidents involving the general population. Although NEISS and other data sources provide a perspective regarding the approximate number of incidents and insight as to the kinds of injury-producing situations, they do not provide sufficient specific details, including a consistent reporting and classification of vehicle type, WTORS use, and the death and injury rate per unit of exposure, such as deaths per passenger mile. This information is needed both to establish the risk and to

evaluate the efficacy of risk-reduction efforts.

Ideally, wheelchair rider risk should be defined in terms of both injuries and fatalities. However, due to problems in classifying injury and assigning injury severity, the following Phase II analyses used only the more consistently recorded fatality data. Although it has been generally assumed that the fatality rate is positively correlated with the rate of severe injury for most accident environments, the fatality rate may or may not correlate with the rate of minor or moderate injury.

Approach

We used the annual estimates of passenger vehicle accident fatality rate made by the National Safety Council (NSC). These data, in combination with study results that have established an inverse relationship between vehicle mass and fatality rate (10–13), were used to estimate the fatality risk for passengers aboard specific types of wheelchair transport vehicles. The NSC, using information from the Fatal Accident Reporting System (FARS) database and others, publishes an annual report, summarized in **Table 2**, on unintentional injuries occurring during travel (6).

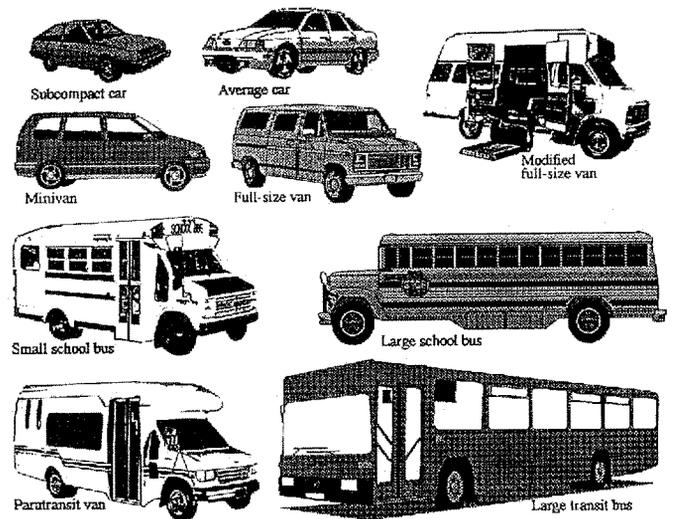


Figure 2.
Vehicle types.

Estimating Occupant Risk for Vans and Small Buses

Although the NSC data allow clear distinctions to be made between vehicles at the extremes of the spectrum, namely passenger cars and large school and transit buses, there is very little information that would allow discriminating between vehicles of intermediate size. Many wheelchair riders use passenger vans, small van-based transit vehicles (paratransit vans), or small van-based school buses (**Figure 2**). In Virginia, most transit systems have contracted paratransit van operators to serve wheelchair

riders. During the period from 1990 to 1995, 19 percent of the school buses sold in the US were van-based or other small buses (13).

Attempts to recreate the NSC analysis for wheelchair transport vehicles from FARS were hampered by its limited specificity in coding small buses and by a lack of passenger/mile information by individual vehicle type. We used an alternative approach involving the inverse relationship between vehicle mass and fatality rate. Starting with the fatality rate for passenger cars (0.95 fatalities per 100 million passenger miles), we used the mass relationship, along with average vehicle-type occupancy rates and annual vehicle mileage, to estimate the fatality rate for minivans,

Table 2.
NSC fatalities per 100 million passenger miles*.

Year	Cars	General Buses	School Buses	Transit Buses	Intercity Buses	Railroad	Scheduled Airlines
1989	1.12	0.04	0.04	^A 4.80×10 ⁻⁹	0.01	0.06	0.04
1990	1.05	0.02	0.01	0.01	^A 4.30×10 ⁻⁹	0.02	3.20×10 ⁻⁹
1991	0.97	0.02	0.01	0.01	0.03	0.06	0.03
1992	0.89	0.02	0.01	0.01	0.03	0.02	0.01
1993	0.82	0.01	0.01	0.02	0.00	0.42	0.01
1994	0.86	0.01	^B 2.10×10 ⁻⁹	0.02	0.02	0.04	0.04
AvgE	0.95	0.02	0.01	0.01	0.02	0.10	0.02

*Data source: National Safety Council. Accident facts (1991-96 editions) Itasca, IL: National Safety Council. A=one death; B=two deaths; C=predominantly large city buses; D=Greyhound, Trailways, etc.; E="NSC data."

vans, and small transit and school buses.

Many researchers have investigated the relationship between passenger car mass and risk of injury and death. Although study results vary in the magnitude of the effect, most agree that heavier vehicles are safer than lighter ones. Evans (10) estimated that the risk of death in a light (900 kg) car was 2.6 that of a heavy car (1,800 kg) in a single vehicle crash and twice (2.0) that of the heavy car in crashes involving two cars of the same mass. For two-car crashes involving a 900 kg car and a 1,800 kg car, the driver of the smaller car is 13 times more likely to die than is the driver of the larger. These relationships were reported to be approximately the same with or without the use of restraint belts. Partyka and Boehly (11), in a review of FARS data, concluded that lighter car occupants suffer more fatalities and injuries than heavier car occupants. The authors fit a regression model to 1978–1987 fatalities per registered vehicle rate data. For all types of accidents the following linear relationship correlates well (R-squared=0.88) for passenger cars weighing 680–2,360 kg:

$$\frac{\text{Fatalities}}{\text{Registrations}} \text{ Per } 100,000 = 39.28 - [0.55824 \times 9 \text{vehicle mass} - \text{in hundreds of kg} \times 2.2]$$

Table 3.
Vehicle parameters.

Vehicle Type	Curb Weight	Occupancy	Miles	NSC Rate	Calc. Rate
Subcompact car	900	1.48	12,000	N/A	1.25
Passenger car	1,400	1.52	12,000	0.95	—
Minivan	1,800	1.90	12,000	N/A	0.59
Van	2,400	2.23	12,000	N/A	0.29
Small school bus	3,200	7	9,800	N/A	0.10
Paratransit van	4,100	4	21,000	N/A	0.06
Large school bus	7,300	N/E	N/E	0.01	—
Large transit bus	10,700	N/E	N/E	0.01	—

Curb weight=approximate averages either from 1987 fleet weights or estimated from manufacturer's information in kg; Occupancy=average per vehicle, derived from 1992-95 NASS data for accidents of cars and vans in which a vehicle was towed away; occupancy rates for other vehicles estimated by local transit providers; Miles=estimated annual mileage for cars and vans from data in (13); annual mileage for other vehicles estimated by local transit providers; NSC Rate=fatalities for 100 million passenger miles in passenger cars and large buses reported in (6); Calc. Rate=calculated rate of fatalities for 100 million passenger miles calculated using the effect of vehicle mass; fatality rate for subcompact car calculated using the effect of vehicle mass; fatality rate for subcompact car calculated using Equation 1; fatality rates for minivans and vans calculated using Equation 2; N/A=not available; N/E=not estimated.

This relationship, modified by adding average vehicle occupancy information (Table 3), was used to estimate per-passenger-mile fatality rates for vehicles, including minivans and vans, under 2,600 kg. Greater average vehicle occupancy, by increasing the number of passenger miles for a given vehicle type, decreases the fatality rate per passenger mile for a given number of vehicle miles traveled. For example, a passenger van may have the same fatality rate per vehicle mile as a particular passenger car, but, because of its larger occupancy, its per-passenger-mile fatality rate would be lower.

In order to estimate a fatality rate (deaths per 100 million passenger miles) using the (inverse) mass relationship for passenger cars, minivans, and vans, the NSC rate for all passenger cars, 0.95, was multiplied by a factor that reflected a vehicle's deviation from the mass and by another factor that reflected deviation from the average occupancy of the average car (1,400 kg, 1.7 occupants; see Table 3). The mass factor was derived from Partyka and Boehly data (11).

The fatality rate for any vehicle can be expressed as:

$$A \times B \times C = D$$

A= Average passenger car fleet fatality rate = 0.95 deaths per 100 million passenger miles vehicles

B= Mass factor = 0.95 deaths per 100 million passenger miles vehicles
 fatalities per 100,000 average passenger cars (1400 kg)

C= Occupancy factor = average occupancy of the ave. passenger car (1.52)
 average occupancy of the vehicle

D= Calculated vehicle fatality rate = Expressed in deaths per 100 million passenger miles

[1]

For a full-size van with a curb weight of 2,600 kg and an average occupancy of 2.23, the calculated vehicle fatality rate, D, equals 0.29 where

$$A = 0.95$$

$$B = 9.7 / 21.9 = 0.44$$

$$C = 1.52 / 2.23 = 0.68.$$

Because a similar FARS analysis has not been conducted for larger vehicles (-2,600 kg), such as small school buses and paratransit vehicles, we employed a relationship developed by Grime and Hutchinson (12) using a relatively small accident data set from Great Britain 1969–1972. The authors investigated the effect of mass ratio between two colliding vehicles on driver injury for light passenger cars and heavy commercial vehicles up to 13,600 kg. They found that mass ratio has the greatest effect (inverse relationship) on fatalities and a lesser effect on injuries. Unlike Evans (10) and Partyka and Boehly (11), they did not study mass effects in single vehicle crashes. The Grime and Hutchinson study, that only examined two-vehicle collisions, was used to approximate a fatality rate for heavier vehicles for all accident situations. We made the following assumptions in deriving a mass factor.

- 60 percent of fatal accidents are multiple vehicle accidents (14)
- 40 percent of fatal accidents, the majority of which are single vehicle accidents, do not show evidence of a weight/risk relationship
- The estimated average weight of a collision partner is 1,800 kg. This approximation was based on the average curb weights of the most common vehicles that comprise roughly 95 percent of the vehicles on the road, passenger cars (1,300 kg) and light trucks (1,700 kg)¹. Additional mass was added to the estimate to account for the effect of medium and heavy trucks.

In order to estimate a fatality rate (deaths per 100 million passenger miles) for modified vans, small school buses, and paratransit vans, the fatality rate calculated for the van (0.29) was multiplied by a mass factor derived from the Grime and Hutchinson data and by an occupancy factor. The average vehicle occupancy information was approximated from information provided by local transit authorities and the public school transportation department. An additional factor was required to account for differences in the number of annual miles traveled for the vehicle types.

The average annual mileage information was approximated by using US school bus fleet information (13) and information provided by local transit authorities.

The resulting fatality rate for the larger vehicles can be expressed relative to the fatality rate for a full-size van (0.29) calculated using Equation 1:

[2]

$$0.29 \times F \times G \times H = D$$

$$F = \text{Mass factor}^A = 0.0558 (M1/M2)^2 0.5774 \\ (M1/M2) + 1.5324$$

where

M1 = mass of vehicle

M2 = mass of full-size van (2,600 kg)

$$G = \text{Occupancy factor} = \frac{\text{average occupancy of the full-size van (2.23)}}{\text{average occupancy of the vehicle}}$$

$$H = \text{Milage factor} = \frac{\text{average annual milage of the full-size van (12,000)}}{\text{average annual milage of the vehicle}}$$

$$D = \text{Calculated vehicle fatality rate} = \text{expressed in deaths per 100 million passenger miles}$$

^A Mass factor derived from Grimes and Hutchinson data (12).

Findings in **Table 3** and **Figure 3** summarize the results of modifying the NSC data to approximate the fatality rate for wheelchair transport vehicles. As vehicle mass increases, the fatality rate, D, decreases in a manner approximated by a power function:

$$1E + 07M^{-2.2822} = D$$

where

M= Vehicle mass in kg

D= fatality rate expressed in deaths per 100 million passenger miles

[3]

The fatality rate for very heavy vehicles such as standard (large) school buses and transit buses (0.01) is much lower than that for minivans (0.59). However, for heavier vehicles

¹Kuhane C. Relationships between vehicle size and fatality risk in model year 1985\N93 passenger cars and light trucks. Washington, DC: NHTSA Evaluation Division, Plans and Policy. Unpublished draft report; 1995.

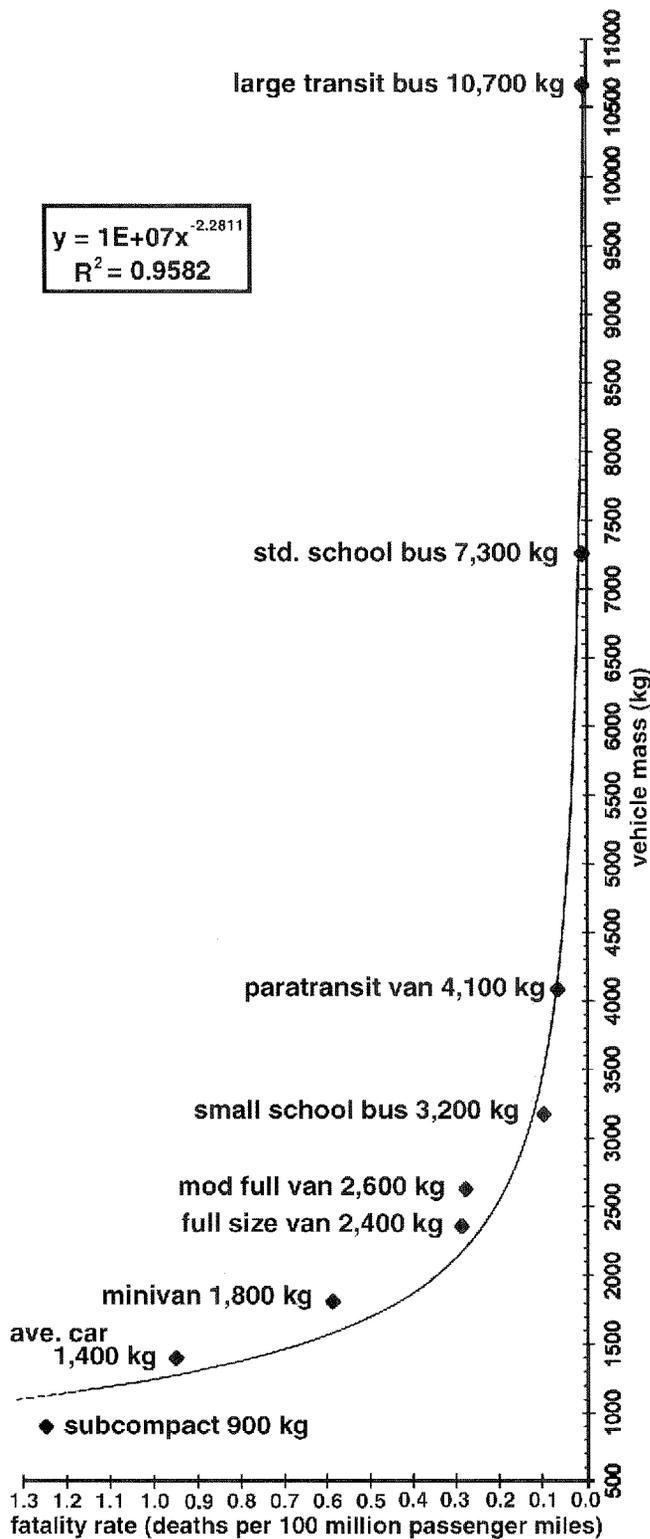


Figure 3. Fatality rate as a function of vehicle mass. See **Table 2** for a description of the plotted data.

(-3,000 kg), the benefit of additional weight is diminished. Note that the NSC data report identical fatality rates (0.01) for the 7,300 kg school bus and for the 10,700 kg transit bus.

Observations

As expected, we found a greater amount of accident data for all vehicle passengers than for the subset of wheelchair riders. While the search of data sources containing information on wheelchair riders contained only one documented fatality from 1973–1991 (7), the FARS database recorded over 880,000 fatalities for all motor vehicles occupants for the same period. This relative wealth of data allowed us to estimate the fatality rate for passengers aboard vehicles used to transport wheelchair riders. Although we are confident that the fatality rate for all passengers is a reasonable indication of the risk of injury or death faced by the wheelchair rider sub-group, several limitations should be acknowledged.

Although the NSC method of reporting the death rate, deaths per mile traveled by each passenger, allows comparisons across vehicle types, calculating the exposure is problematic. There is little reliable information regarding vehicle occupancy. In the case of fixed route buses that continually load and unload passengers, the number of passengers on board, and hence the number of passenger miles, varies constantly. An NSC statistician acknowledged that, due to assumptions that had to be made in calculating passenger miles, there is an unquantified level of uncertainty regarding the estimated death rate.

The lack of single source information necessitated a number of assumptions and approximations and the use of several data sources in order to construct the mass/fatality relationship depicted in **Figure 2**. This unavoidable approach introduced a substantial, unquantified level of uncertainty in the results. This uncertainty prevents confident discrimination between vehicles of similar masses. Fatality estimates using the Partyka and Boehly (11) data for passenger cars and vans, derived from FARS, required fewer assumptions than did the fatality estimates for modified vans, small school buses, and paratransit vehicles that used the Grime and Hutchinson (12) data. However, the values calculated using Grime and Hutchinson data were found to be a reasonably good fit with the trend indicated by values calculated for passenger cars and vans and those reported by the NSC for large school and transit buses. Moreover, a similar mass/fatality rate relationship can be constructed without incorporating the Grime and Hutchinson-calculated values.

Using accident data for all passengers to approximate that of wheelchair riders assumes that wheelchair riders enjoy a level of protection similar to that of passengers who ride on the vehicle seats (or stand in the aisles) on transit buses. Clearly, in relation to vehicle-seat passengers with a comparable level of occupant restraint, wheelchair riders face an increased risk if the wheelchair moves or tips. This can happen in low-g vehicle maneuvers if the wheelchair is not tied down or if the tiedowns used are either too weak or inappropriately secured. In high-g crash conditions, the average wheelchair user also faces an increased risk, even if the wheelchair is appropriately secured. This is because most wheelchairs, unlike vehicle seats, are not designed to provide occupant protection in the event of a collision.

Therefore, on average, the wheelchair rider faces an increased risk of injury or death with respect to passengers who ride on vehicle seats. The risk disparity is greatest when the wheelchair is inappropriately secured: it can be reduced by the use of appropriate tiedowns and wheelchairs designed for transit use. Unfortunately, there is no information that allows quantification of the increase in risk faced by wheelchair riders.

A final consideration in estimating wheelchair rider risk involves the rider's physical condition in comparison to that of the general population. Because the average wheelchair user is more frail or physically compromised than the average vehicle seat passenger, his/her risk of injury is somewhat greater. The magnitude of this increased risk has not been defined.

Wheelchair Rider Risk by Vehicle Type

Available evidence strongly suggests that large heavy and slow vehicles that are typically driven conservatively, are safer (for the occupants) than are smaller, lighter and faster vehicles. The following discussions of risk associated with different vehicle types use the fatality rates calculated for passengers who sit on vehicle seats as a way to establish relative risk. As indicated above, the actual fatality rate (risk) for wheelchair users will be higher.

Passenger Vans

As the smallest, lightest, and fastest of vehicles that transport wheelchair riders, modified passenger minivans and vans represent a worst case in terms of accident severity. Due to the relatively small number of wheelchair vans, their correspondingly small number of accidents, and the limitations of the National Accident Sampling System (NASS) in identifying passengers as wheelchair users, there is virtually no information specific to wheelchair van collisions.

The fatality rate for minivans (0.59) and vans (0.29) is lower than the 0.95 passenger car average (**Table 3** and **Figure 2**). The difference is even more pronounced when comparing vans to subcompact cars (900 kg), calculated to have a fatality rate of 1.25. The lower van fatality rate is due both to greater mass and a higher-than-average occupancy rate.

School Buses

All evidence suggests that the school bus is a very safe form of transportation. Due to the high level of public and governmental concern for the safety of school children, fairly comprehensive accident information has been recorded and stringent safety regulations have been mandated (Federal Motor Vehicle Safety Standard #222). From 1985 to 1995, an average of 12 school bus passengers were killed per year. Riding on the bus was safer than getting to the bus or disembarking: an average of 27 children were killed annually getting on or off the bus (15).

Because the majority of the school bus fleet is composed of large (37+-passenger) buses (13), the very low (0.01) fatality rate reflects the risk faced by large school bus passengers more accurately than it does that faced by small (~19-passenger) school bus occupants. Using the mass/fatality relationship described in Equation 2, we calculated the fatality rate of small (3,200 kg) buses to be 0.10. However, other considerations suggest that the actual fatality rate is closer to that of large school buses. A NHTSA representative suggested that, while the larger bus would be safer, the advantage would be negligible because of the excellent overall school bus safety record, in part a product of stringent federal safety regulations.

How and when a vehicle is driven can significantly affect its fatality rate. Small school buses, because they are usually driven slowly during daylight hours on fixed routes, are likely to have a lower fatality rate than the average small truck of a similar mass. Evidence for this can be found in the fatality data published by the Insurance Institute for Highway Safety (16) for passenger cars and light trucks, which show fatality rates for passenger car models to be generally lower as vehicle mass increases. However, the fatality rates for station wagons have been substantially lower than for sedan or coupe versions of the same car. For example, the driver fatality rate for the 1996 Chevrolet Caprice wagon (2,040 kg), was approximately 30 percent of that of the 1,860 kg sedan. However, the Partyka and Boehly mass relationship predicts a wagon fatality rate that is 84 percent of the sedan. In this case, the 180 kg weight differential accounts for only 23 percent of the observed difference in fatality rate. The way the station wagon is

driven partially explains the residual difference. Station wagons are used in much the same way as small school buses. They are generally driven at slower speeds during the safest (daylight) hours by the population with the lowest accident rate: sober, middle-aged adults.

Transit Buses

Although their safety requirements are not as stringent as those for school buses, the average size, weight, and relatively low speeds of transit buses combine to limit the chance of injury and death; their fatality rate (0.01) is the same as that of school buses, and is also much lower than that of passenger cars (Table 3 and Figure 2). Other sources confirm their relative safety.

A Department of Transportation Urban Mass Transit Administration (now the Federal Transit Administration) study that surveyed 18 percent of the total US transit bus ridership, concluded that "the urban transit bus is an extremely safe transportation mode choice...(17)." As was found in the NEISS data, most injuries were minor ones. The most common cause (56 percent) of passenger injuries was found to be bus deceleration that can reach 0.75 g during hard braking. Drivers reported that 50 percent of these incidents occurred when they braked to avoid a collision.

The evidence we have collected indicates that transit buses represent an exceedingly safe form of transportation. The overwhelming majority of passenger injuries that occur while the bus is in motion do so during normal vehicle operation or during emergency braking and are not the result of traffic accidents. There is little information regarding traffic accidents and passenger injury, due to the difficulty in obtaining such data and the infrequency of injury-causing events.

While large transit buses are very safe, smaller buses, such as paratransit vans, are lighter, and are calculated to have a somewhat higher fatality rate. For a typical 17 passenger van-based paratransit vehicle weighing 4,100 kg, we calculated the fatality rate to be 0.08. Note that this rate is still well below that of passenger cars and vans.

DISCUSSION

Because of errors in wheelchair injury data, the paucity of data regarding wheelchair incidents, and the unsubstantiated assumptions required to use data from the general population to approximate wheelchair rider risk,

accident data is most useful in identifying general trends, i.e., the mass/fatality rate relationship. Available accident data will not support fine discrimination between the risk associated with riding in vehicles of similar mass, nor will it support attempts to evaluate the efficacy of different wheelchair tiedown and occupant restraint systems.

Although often limited by quantity, quality, and specificity, real-world accident data is the most credible basis for estimating transport risk. Estimating a general risk level provides a basis for decision making regarding the requirements for safety interventions, including the selection of WTORS.

Recommendations for Further Research

Accident data and laboratory crash testing performed to date provide little definitive information regarding crash severity for wheelchair transport vehicles. In order to design wheelchair safety systems and to develop guidelines for their use, it is important to establish a frequency distribution of crashes relative to severity and chance of occurrence. For example, the NEISS data suggest that the most common injury-producing events are low-g vehicle maneuvers. Safety systems and procedures designed to protect wheelchair riders during these events would provide substantial benefit in terms of risk reduction. The severity/frequency of occurrence distribution also would allow the identification of a "reasonable worst case" crash severity level for each vehicle type. For passenger cars and passenger vans this level has been defined by a 48 km/h collision into a rigid barrier. A NASS database search found that approximately 96 percent of all frontal collisions have been less severe (18). Therefore, in this case, "reasonable" is defined as providing protection for all but 4 percent of typical crashes. Minimizing the risk of injury for this crash environment requires WTORS constructed to the newly published SAE standard (J2249) that includes crash-testing at 48 km/h. The majority of laboratory crash testing has been conducted at this challenging level and has clearly demonstrated the necessity of using a well-designed, properly installed, and carefully applied WTORS.

Unfortunately, information to establish definitive severity/frequency distributions and worst-case severity levels for vehicles larger than passenger vans does not exist or is inaccessible. The accident data that are available suggest that severity levels for larger vehicles are lower. If confirmed and found to be substantial, this relationship would facilitate transport safety decisions and WTORS development and selection. For wheelchair riders

susceptible to injury because of frailty or inability to use standard occupant restraints, it may be advisable to choose a larger transport vehicle. For example, the increased injury potential of poor lap belt placement for a frail wheelchair rider would be much lower aboard a transit bus than aboard a passenger van. WTORS designed to a lower large bus crash severity level could be simpler and more user-friendly than those designed for passenger vans. One example of an easy-to-use wheelchair rider protection is the increasingly common European practice of restraining a transit bus wheelchair simply by backing it up to a padded bulkhead and applying the brakes (9). Transit safety recommendations and WTORS decisions could be made more credibly after better defining a target crash severity level. Research is required to confirm and quantify reasonable worst-case crash severity levels for both small and large buses.

CONCLUSIONS

A better understanding of transport risk is useful in making informed decisions regarding reasonable levels of protection while improving access to transportation in terms of improved WTORS. Despite the large margins of error that must be assumed for accident data and the conclusions drawn from it, the available information supports the following statements:

1. The majority of wheelchair rider injuries could be prevented by providing protection for abrupt vehicle maneuvers, such as hard braking or turning.
2. Large public transit vehicles and school buses are substantially safer than passenger vans. The type, size, and mass of the vehicle have a substantial effect on the fatality rate. The fatality rate for large transit and school buses (0.01 deaths per 100 million passenger miles) is only 1.7 to 3.5 percent of that estimated for passenger vans (0.28–0.59). Limited information suggests that small school buses and van-based transit buses (estimated fatality rates 0.10 and 0.06 respectively) are safer than passenger vans, but not as safe as large buses.
3. For heavy vehicles (~3,000 kg), as vehicle weight increases, vehicle mass becomes less of a factor in determining the fatality rate. Other factors such as how, when, and where the vehicle is driven, average vehicle speed, vehicle safety features, and safety regulations become more important. 4. Wheelchair riders who cannot properly use WTORS or are frail would face a lower risk of injury if transported in a larger vehicle.

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