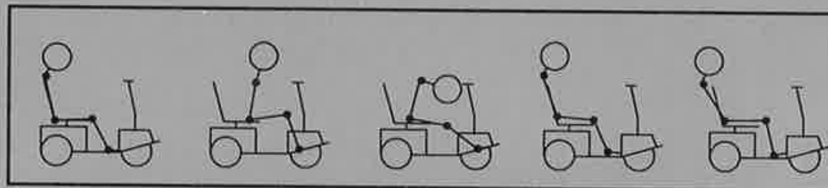
FTA-MA-26-9003-95-1
DOT-VNTSC-FTA-95-8

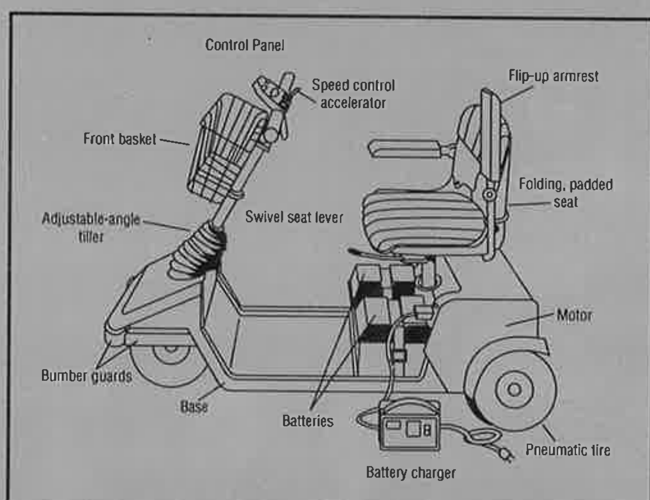
U.S. Department of Transportation
Federal Transit Administration

Tri-Wheeled Scooters Transported on Buses and Vans: Assessment of Securement and Restraint Issues

David Spiller

Research and
Special Programs
Administration
Volpe National
Transportation Systems Center
Cambridge, MA 02142-1093





Final Report
October 1995

Office of Grants Management
Washington, DC 20590

This document is available to the public through the National Technical Information Service, Springfield, VA 22161

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

PB96-132030

2. REPORT DATE
October 1995

3. REPORT TYPE AND DATES COVERED
Final Report
September 1994 - May 1995

4. TITLE AND SUBTITLE
Tri-Wheeled Scooters Transported on Buses and Vans: Assessment of Securement Restraint Issues

5. FUNDING NUMBERS
TM595/U5080

6. AUTHOR(S)
David Spiller

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Department of Transportation
Research and Special Programs Administration
John A. Volpe National Tranportation Systems Center
Kendall Square
Cambridge, MA 02142

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-FTA-95-8

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
US Department of Transportation
Federal Transit Administration
Office of Grants Management
400 7th Street, SW
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
FTA-MA-26-9003-95-1

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

This document is available to the public through the National Technical Information Service, Springfield, VA 22161

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Under the Americans with Disabilities Act (ADA) of 1990, all "common wheelchairs and mobility aids," including tri-wheeled scooters, must be accommodated on buses and vans used in public transit service.

Several transit systems have recently expressed their concerns to the Federal Transit Administration (US DOT/FTA) on the safety of transporting tri-wheeled scooters and their occupants. Responding to these concerns, this report provides, for transit system staff and other interested parties, a comprehensive assessment of securement and restraint issues related to the transport of tri-wheeled scooters and their occupants on buses and vans used in public transit service.

14. SUBJECT TERMS
tri-wheeled scooters, mobility devices, mobility aid securement and occupant restraint (MASOR), transit, occupant

15. NUMBER OF PAGES
178

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

PREFACE

Under the Americans with Disabilities Act (ADA) of 1990, all "common wheelchairs and mobility aids," including tri-wheeled scooters, must be accommodated on buses and vans used in public transit service.

Several transit systems have recently expressed their concerns to the Federal Transit Administration (US DOT/FTA) on the safety of transporting tri-wheeled scooters and their occupants. Responding to these concerns, this report provides, for transit system staff and other interested parties, a comprehensive assessment of securement and restraint issues related to the transport of tri-wheeled scooters and their occupants on buses and vans used in public transit service. This report was prepared under the Federal Transit Administration's Research and Technology Assessment program in support of the Americans with Disabilities Act (ADA) of 1990.

This report was prepared by David Spiller, Service Assessment Division, US DOT/Volpe Center. Extensive contributions were made by a number of individuals for which the author is indebted: Douglas Hobson and Patricia Karg, University of Pittsburgh; Gregory Shaw, University of Virginia; Steven Reger, Cleveland Clinic Foundation; Lou Cheng, Failure Analysis Associates; Katherine Hunter-Zaworski, Oregon State University; William Stokes, The Community Transportation Forum of Phoenix, AZ; Jonathan Belcher, EG&G Dynatrend, Anita Graffeo, EG&G Dynatrend, Richard Feldman, EG&G Dynatrend; and William Henderson, retired.

Federal colleagues include: Louis Molino,US Department of Veteran Affairs, Rehabilitation Research and Development Service; Henri Richardson, Arthur Neill, Gayle Dalrymple and Carl Ragland, all from the National Highway Traffic Safety Administration (US DOT/NHTSA); Jordon Multer, Gordon Plank, Richard Feldman and Walter Gazda, all from US DOT/Volpe Center; Joel Friedman, from the US Consumer Product Safety Commission; and unnamed staff from the National Institute for Disability and Rehabilitation Research (NIDRR), US Department of Education.

The cooperation and collaboration of all the 'key actor' group respondents - from the technical community, the sample of transit systems, the securement and scooter manufacturers, and the sample of mobility aid users - made completion of this report possible. The author is grateful for the contribution of each respondent.

Robert Stout, Office of Grants Management, Federal Transit Administration, and Michael Jacobs, Chief, Service Assessment Division, US DOT/Volpe Center provided overall program direction and guidance.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	= 2.5 centimeters (cm)
1 foot (ft)	= 30 centimeters (cm)
1 yard (yd)	= 0.9 meter (m)
1 mile (mi)	= 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	= 28 grams (gm)
1 pound (lb)	= 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	= 5 milliliters (ml)
1 tablespoon (tbsp)	= 15 milliliters (ml)
1 fluid ounce (fl oz)	= 30 milliliters (ml)
1 cup (c)	= 0.24 liter (l)
1 pint (pt)	= 0.47 liter (l)
1 quart (qt)	= 0.96 liter (l)
1 gallon (gal)	= 3.8 liters (l)
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	= 0.04 inch (in)
1 centimeter (cm)	= 0.4 inch (in)
1 meter (m)	= 3.3 feet (ft)
1 meter (m)	= 1.1 yards (yd)
1 kilometer (k)	= 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	= 1 hectare (he) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	= 0.036 ounce (oz)
1 kilogram (kg)	= 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)	= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 liter (l)	= 2.1 pints (pt)
1 liter (l)	= 1.06 quarts (qt)
1 liter (l)	= 0.26 gallon (gal)
1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION

Inches	0	1	2	3	4	5

Centimeters	0	1	2	3	4	5	6	7	8	9	10	11	12	13

QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 1/23/95

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

EXECUTIVE SUMMARY

Transit systems are required under the Americans with Disabilities Act (ADA) of 1990 to accommodate all *common wheelchairs and mobility aids.* This includes tri-wheeled scooters, provided they meet the dimensional envelope of thirty (30) inches in width and forty-eight (48) inches in length, measured two (2) inches above the ground, which defines a *common wheelchair and mobility aid* under the Act.

Several transit systems have recently expressed their concerns to the Federal Transit Administration (US DOT/FTA) on the safety of transporting tri-wheeled scooters and their occupants on buses and vans used in public transit service. Responding to these concerns, this report provides a comprehensive assessment of securement and restraint issues related to the transport of tri-wheeled scooters and their occupants on buses and vans used in public transit service.

Based on extensive review of research, test reports and the 'expert opinion' of the technical community, the author confirms the following securement and restraint related issues for tri-wheeled scooters as actual or potential problems:

Non-crash Issues: 1. Inaccessible attachment points; 2. Inadequate structural strength of attachment points; 3. Proliferation of scooter models that are incompatible with securement systems;

Crash-related Issues: 1. Inability to restrain the battery in a crash impact; 2. Shearing or fracture of the seat pedestal; 3. Large bending moments that exceed the restraining force of seat designs; 4. Scooter occupant injury from contact with the front tiller.

Two additional confirmed issues that bridge both categories - non-crash and crash-related driving events - are (a) the rollover or tipping instability inherent in the tri-wheeled scooter design; and (b) spillage of battery fluid, unless the scooter battery is of the dry or gel-type.

Within both the technical community and the transit system community, there is consensus that the occupant of the tri-wheeled scooter should transfer to a bus or van seat for maximum occupant protection. Most manufacturers of mobility aids, including manufacturers of tri-wheeled scooters, issue disclaimers against the transportability of the mobility aid on a bus or van.

Recommendations are also made in this report for US DOT-sponsored research, and US DOT administrative action.

US DOT-sponsored Research - Four, high-priority near-term focus areas are recommended:

- A testing, clearinghouse, technical assistance and technology/information transfer program for mobility aid securement and occupant restraint (**MASOR**) systems.

- A comparative retrospective or prospective risk assessment to quantify rigorously the relative risk of mobility aid users, including tri-wheeled scooter occupants, when riding buses and vans used in public transit service.

- A comprehensive, systems-oriented investigation to analyze existing internal designs, including consideration of space requirements and passenger circulation, of fixed-route standard-sized accessible buses, and to search and validate improved designs.

- Research support, under the auspices of the American National Standards Institute and the Rehabilitation Engineering Society of North America (ANSI/RESNA) to develop a 'transportable mobility aid' standard and test protocol.

Two long-term, more basic research efforts are also suggested:

- The design, development and validation of a disabled anthropomorphic test device (ATD).

- The identification and validation of the best parameters for occupant injury determination in dynamic crash tests.

At this time (1995), no change is recommended in the US DOT Final Rule as it relates to the securement and restraint of mobility aids, including tri-wheeled scooters. The very low incidence of injury-producing accidents/incidents, based on the available statistics, does not dictate a need for immediate action.

Instead, a five point US DOT administrative action plan is recommended, the main thrust of which is to proactively support and publicize the work of the ANSI/RESNA Subcommittee on Wheelchairs and Transportation (SOWHAT) in developing the research base, standard and test protocol for a 'transportable mobility aid', and to work with all affected parties towards its acceptability.

1. INTRODUCTION

The Americans with Disabilities Act (ADA) accessibility specification for transportation vehicles (US DOT Final Rule, Part 38, FR Vol. 56, No. 173, Sept. 6, 1991) requires that all new, used or remanufactured buses and vans (except over-the-road buses), purchased after August 25, 1990, provide a level-change mechanism or boarding device (e.g., lift or ramp). Among other specified technical requirements for compliance, this level-change mechanism or boarding device must accommodate all common wheelchairs and mobility aids, **including tri-wheeled scooters**, that comply with the dimensional envelope of thirty (30) inches in width and forty-eight (48) inches in length, measured two (2) inches above the ground.

Several transit systems have recently expressed their concerns to the Federal Transit Administration (US DOT/FTA) on the safety of transporting tri-wheeled scooters and their occupants on buses and vans used in public transit service. Responding to these concerns, this report provides a comprehensive assessment of securement and restraint issues associated with the transport of tri-wheeled scooters and their occupants on buses and vans used in public transit service. This includes fixed route accessible bus service, and complementary paratransit service. The scope of this report is limited to securement and restraint issues as they affect tri-wheeled scooters; several issues, however, have wider applicability to other mobility aids as well.

The report is organized as follows: Section 2 provides preliminary background information on the characteristics of scooters, mobility aid securement and occupant restraint (**MASOR**) systems, and the mobility impaired population. In Section 3, the complexity of the vehicle-mobility aid-mobility aid user system is examined. A discussion and assessment of securement and restraint issues are presented in Section 4. Section 5 reviews current and proposed standards for limitations or restrictions they may impose on the transport of tri-wheeled scooters. An analysis of accident data and securement-related injuries, and a discussion of issues related to the quantification of risk are given in Section 6. Section 7 summarizes additional information provided by the technical community, a sample of transit systems, securement and scooter manufacturers, and a sample of mobility aid users. Key findings of this study are reported and summarized in Section 8. Recommendations for US DOT-sponsored research, and US DOT administrative action are provided in Section 9.

2. PRELIMINARY BACKGROUND

This section presents information on the characteristics of tri-wheeled scooters and how they differ in design from other mobility aids, the generic types of mobility aid securement systems and the specific incidence of these types within the sample of transit systems studied, and a statistical profile of the mobility-impaired population and specific transit usage by this population based on our transit system sample.

2.1 DESCRIPTION AND CHARACTERISTICS OF TRI-WHEELED SCOOTER MOBILITY AIDS

Both the Society of Automotive Engineers (SAE) and the US Architectural and Transportation Barriers Compliance Board's ADA accessibility guidelines (ADAAG) define mobility aids, which include tri-wheeled scooters, as a seating system comprised of a frame, a seat, and wheels that is designed to provide support and mobility for persons with physical disabilities (Society of Automotive Engineers, 1995; US DOT Final Rule, 1991).

Scooters are used primarily by people who have poor endurance and difficulty walking due to disabilities such as arthritis, multiple sclerosis, muscular distrophy, post-polio syndrome, emphysemia, stroke and cardiac conditions (ECRI, 1991). There are over fifty (50) scooter models (three and four-wheeled) currently available for sale in the United States, ranging in price from $1000-$4000 (1991 dollars) (ECRI, 1991).

Major design differences between tri-wheeled scooters and the other generic classes of mobility aids (manual, sport, electric, and powerbase) are:

- A base unit which includes the drive train, the wheels, the floor or platform, and the seat post in lieu of sideframes and cross brace.

- A tiller for steering control, which is often adjustable and collapsable, in lieu of swiveling front castor wheels.

- Smaller diameter, solid hub wheels in lieu of large diameter rear wheels which can be either spoked or solid.

- Lower ground clearance, longer wheel base length, and shorter wheel base width.

Of major significance to the ability to secure tri-wheeled scooters is that the base unit often includes a plastic or metal cowling or shroud that covers the axles and other structural frame members.

Figures 1 and 2 illustrate the two types of tri-wheeled scooters: front wheel drive (FWD) and rear wheel drive (RWD). For FWD scooters, the motor is located over the single front wheel,

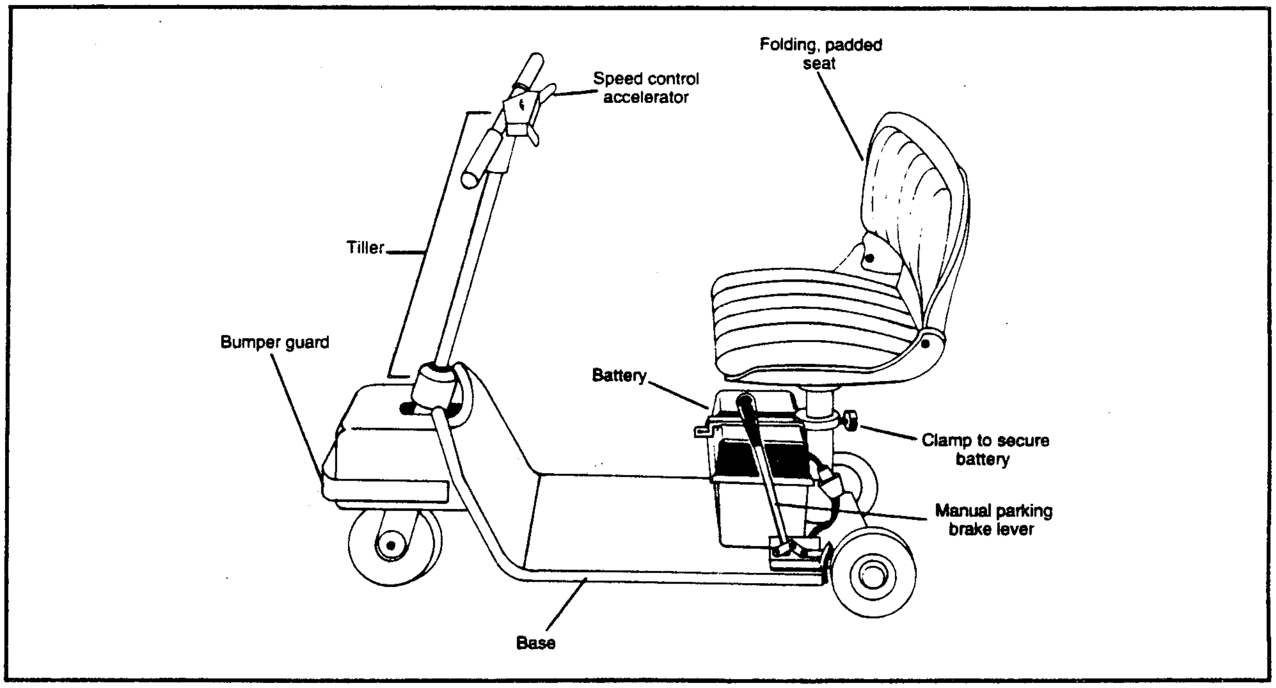


Figure 1. Front Wheel Drive (FWD) Scooter

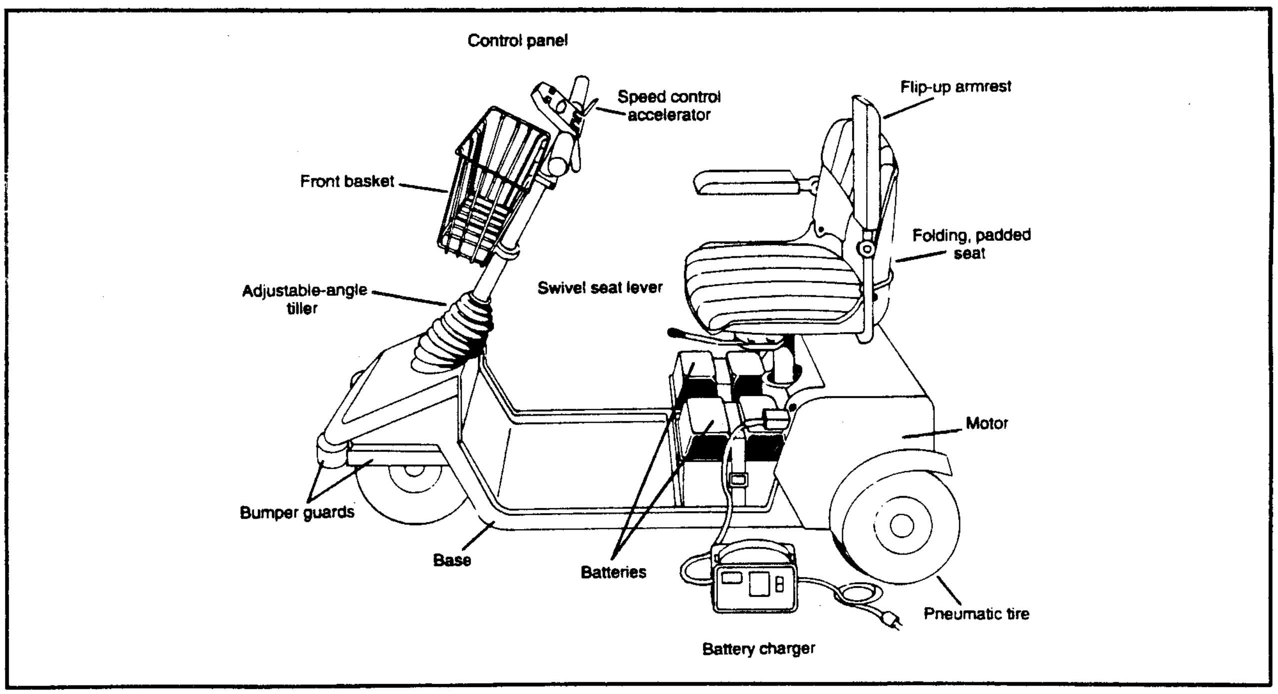


Figure 2. Rear Wheel Drive (RWD) Scooter

Source: ECRI (1991). Reprinted with permission from REquest Product Comparison and Evaluation of Scooters, June 1991.

while the battery is below the seat post. In RWD models, both the battery and motor are below and behind the seat post, with the motor connected to the rear axle. The motor drives both rear wheels as opposed to FWD models where power is provided to just the single front wheel. Weight and center of gravity (CG) measurements for four popular scooter models are given in Table 1.

Table 1. Summary of Weight and Center of Gravity (CG) Measurements for Four Tri-Wheeled Scooter Models

Model	Vertical CG (in/mm)	Horizontal CG (in/mm)	Weight (lbs/kg)
Fortress Scientific 2000FS	9.0 (229)	8.6 (218)	180.5 (82)
Everest and Jennings Carrette	7.5 (190)	9.3 (236)	174.5 (79)
Invacare Tri-Rolls	N/A	8.2 (208)	147.5 (67)
Amigo RWD	7.5 (190)	8.2 (208)	129.0 (59)
Average of four scooters tested	8.0 (203)	8.6 (218)	158.0 (72)

Source: Hunter-Zaworski and Ullman, 1991
Notes: All values in the table have an error band of + 1 in. (25 mm) and + 2 lb. (1 kg). The vertical center of gravity is measured from the floor. The horizontal center of gravity is measured forward from the center of the rear axle.

2.2 GENERIC TYPES OF MOBILITY AID SECUREMENT SYSTEMS

There is general consensus that mobility aid securement system designs installed in public transit vehicles fall into four (4) generic classes: T-bar, rim pin, fender clamp or bracket, and belt systems. There is a fifth class, called a lockdown system whose design is tailored to a specific mobility aid and the repetitive securement of only that mobility aid, that is solely used by mobility aid passengers who drive their own vehicle. Many transit systems use a hybrid approach consisting of a combination of rim pin and belt design.

T- bar systems - The T-bar system consists of a screw rod and a straight bar. The T-bar restraint attaches, by two pressure points, the two lowest horizontal members of the mobility aid to the horizontal member of the T-bar which is located under the crossmembers of the mobility aid. Structurally, the T-bar has only one vertical member to withstand any loads transmitted to it (Red, Hale, McDermott and Mooring, 1982). This vertical member, the screw rod, is tightened to the floor of the vehicle. Because of its design, T-bar systems can not restrain tri-wheeled scooters.

Rim pin systems - These designs use a rod or pin between U-shaped brackets that are attached to either the side wall or floor of the vehicle. Side-wall attachment obviously restrains mobility aid orientation to a sideways orientation, perpendicular to the vehicle's motion. The pins hold the rear wheels of the mobility aid in place, generally at axle height for sidewall mounting and at the bottom of the rims for floor mounted brackets. It is possible that the U-brackets may have spring loaded clamps which automatically lock the wheel rims in place when the mobility aid is backed into them. During the normal motion dynamics of transportation, the cross pins prevent the mobility aid from moving forward while the U-brackets prevent the mobility aid from rolling backwards. Lateral sliding of the mobility aid can occur if the motion dynamics cause lateral forces to exceed the static friction forces between the wheels and floor. Rim pin designs can not be used with mobility aids that have solid magnesium or other metal cast wheels, nor can they work with tri-wheeled scooters.

Fender clamp or bracket systems - The fender clamp or bracket system has brackets mounted either to the wall of the vehicle or to posts installed on the floor of the vehicle. To secure the mobility aid, these brackets are lowered onto the large wheels and hold the top of the wheels in position. These designs also can not be used with the small diameter, lower floor height wheels on tri-wheeled scooters.

Belt systems - These include two, three and four belt systems, often referred to as two, three and four point attachment designs. The belts are adjustable with buckles for quick connection to structural members of the mobility aid and track fittings or anchorages mounted on the vehicle wall and/or vehicle floor. Four belt designs, attaching to four attachment points - two aft and two forward - on the mobility aid provide the most stability against movement of the mobility aid and against rotation. It is important that the belts pass down toward the floor at a limiting angle range betweeen thirty (30) and forty-five (45) degrees aft and a limiting angle range between forty (40) and sixty (60) degrees forward, and pass out to the side at about twenty-five (25) degrees (SAE, 1995). These angles are to insure that there is a sufficient horizontal component to counteract forward, rearward, and sideward forces. The two belts attached at the front of the mobility aid pull forward and counteract the forces induced by rearward acceleration. If all four belts are attached at an angle to the side, they will counteract the forces induced by side-to-side acceleration (Hunter-Zaworski and Ullman, 1992).

2.2.1 Statistical Securement Type Incidence Based on Transit System Sample in Study

Before reporting on the incidence of securement type, we present in Table 2 data that characterize the nature of the transit system sample about which information is presented in this study.

Table 2. Comparison of Transit System Sample to All Public Transit Systems
Sample Passenger Boarding Percentage - Fixed Route and Paratransit

	Fixed Route	Paratransit
Transit System Sample (No. of Observations =44)	70%	25%

Source: Section 15 Database, 1992

Because all large transit systems (> 1000 vehicle fleet) were sampled by design, the percentage of all public transit fixed route passenger boardings represented by the transit system sample in this study is relatively high, at seventy (70) percent. Conversely, no transit system with fewer than two hundred and fifty (250) vehicle fleet size was sampled. Thus, many small systems providing paratransit services are underepresented which is why the transit system sample collectively includes only twenty-five (25) percent of all passenger boardings on public paratransit service.

The data summarizing the incidence of securement type for the transit system sample in this study are illustrated in Table 3.

Table 3. Transit System Sample - Incidence of Securement Type

Securement Type	Number of Responses	Response Rate
a. Rear Wheel Clamp or Pin	18	0.64
b. Belt System (2, 3 or 4 point)	27	0.96
c. T-Bar	-	-
d. Fender Bracket	-	-
e. Other*	-	-

Source: Aggregate Data from Transit System Data Collection Form

Notes:
1. Respondents indicated multiple securement types on their fleets.
2. One respondent didn't indicate securement type.
3. Other category included mention of Q'straint harness, a seat and shoulder belt, and conbination of wheel clamp and belts.

The data in Table 3 indicate that the most prevalent securement system on buses and vans used in public transit service is the Belt System, primarily three (3) and four (4) point attachment designs. This may be because the Belt System is the most universally adaptable to a variety of mobility aids encountered. Universal design systems, such as the Oregon State University (OSU) design and the Cleveland Clinic Foundation design, have not been commercially marketed. None, therefore, are in operational fleets.

2.3 STATISTICAL PROFILE AND CHARACTERISTICS OF MOBILITY-IMPAIRED POPULATION

The incidence of severe disability in the United States has increased dramatically in the twenty-five years from 1966 to 1992, the most recent year of data. Severe disability is defined by the Bureau of Census' Survey of Income and Program Participation (SIPP), which collects the data, as including those persons who are unable to perform one or more activities, or as having one or more specific impairments, or who use a mobility aid other than for short-term use. In terms of prevalence rates, the rate of severe disability increased from 213 people per 10,000 in 1966, to 365 people per 10,000 in 1979, to 957 people per 10,000 in 1992 (DeJong and Lifchez, 1983; McNeil, 1993). In absolute numbers, 24.1 million or 9.6 percent of the US population can be categorized as having a severe disability (McNeil, 1993).

The prevalence of "assistive technology" devices used by the mobility-impaired population derives from the 1990 National Health Interview Survey on Assistive Devices (NHIS-AD), which was cosponsored by the National Center for Health Statistics (NCHS), and the National Institute for Disability and Rehabilitation Research (NIDRR). NCHS is one of the Centers for Disease Control in the Public Health Service, Department of Health and Human Services. NIDRR is an agency in the Office of Special Education and Rehabilitation Services, Department of Education.

Estimates of the number of persons using various types of mobility aids by age cohort are given below in Table 4.

As the data indicate in Table 4, scooters are by far the smallest proportion of mobility aid assistive devices in the population. Prior to 1986, however, scooters were not generally available in the marketplace. There are twenty-two (22) wheelchairs to every scooter. The incidence of each mobility aid device also rises dramatically with age of the population.

An indication of the growth in mobility aid devices used by the mobility-impaired population is given in Table 5. The most notable aspect is the rapid growth in wheelchair usage.

Table 4. Number of Persons Using Mobility Technology Devices by Type of Device and Age of Person (1990)
(Number in Thousands)

	All Ages	24 Years and Under	24-44 Years	45-64 Years	65-74 Years	75 Years and Over
Any Mobility Technology Device	6,403	240	609	1,385	1,435	2,735
Crutch	671	87	173	210	137	64
Cane or walking stick	4,400	*31	319	1,011	1,032	2,007
Walker	1,687	*34	72	276	350	957
Wheelchair	1,411	139	168	304	324	476
Scooter	64	*6	*11	*18	*18	*11
Other mobility technology	254	*18	*28	66	57	85

Source: LaPlante, Hendershot and Moss, 1992.
* - Figure does not meet standard of reliability or precision.

Table 5. Number of Persons Using Mobility Technology Devices and Percent Change from 1980 to 1990
(Number in Thousands)

	1980	1990	Difference between 1980 and Age-adjusted 1990 (percent)
All Persons	217,923	246,099	12.9
Mobility Technology Device			
Crutch	588	590	0.3
Cane or walking stick	2,878	3,626	26.0
Walker	866	1,363	57.4
Wheelchair	720	1,185	64.6

Source: LaPlante, Hendershot and Moss, 1992.
Note: Scooters were not counted prior to the late 1980s.

2.3.1 Statistical Profile of Transit System Usage Based on Transit System Sample in Study

Precise estimates of the number of mobility aid users boarding fixed-route and paratransit vehicles are very hard to come by. The percentage of boardings that involve tri-wheeled scooters is even more uncertain since most transit systems do not track boardings by type of mobility aid. Our best estimates, which are very rough, based on the transit system sample for this study, are summarized in Table 6.

Table 6. Estimate of Transit System Usage by Mobility Aid Users (MAU) Based on Transit System Sample

	Fixed Route		Paratransit	
	Mean Weekly MAU Boarding Rate	Percent Scooters	Mean Weekly MAU Boarding Rate	Percent Scooters
Large Systems (>1000 vehicles) (No. of Obs.)	627 (13)	5.2 (7)	2,292 (15)	11.0 (11)
Medium Systems (500-1000 vehicles) (No. of Obs.)	488 (6)	6.0 (4)	534 (4)	10.5 (3)
Small Systems (250-500 vehicles) (No. of Obs.)	69 (4)	2.0 (3)	1,564 (4)	4.5 (4)

Source: Aggregate Data from Transit System Data Collection Form
Notes: 1. Variances of estimates are large.
2. Source year for data is 1994.

Analysis of the data in Table 6 indicates that:

- The percentage of mean weekly boardings involving scooters on fixed-route service ranges between two (2) and six (6) percent.

- The percentage of mean weekly boardings involving scooters on paratransit service ranges between four (4) and eleven (11) percent.

3. COMPLEXITY OF DESIGN: THE VEHICLE-SECUREMENT-MOBILITY AID-MOBILITY AID USER SYSTEM

For maximum occupant protection of the mobility aid user, it is important to recognize that the vehicle, securement device, occupant restraints, and the mobility aid user jointly define a "system" in which the interactions between the components need to be factored into the design of any one component. This obviously adds to the complexity of design, but failure to acknowledge this reality can have unintended consequences and increase the potential for injury to the mobility aid user as well as to other passengers on public transit vehicles. Some examples of these interactions serve to illustrate these points.

Hard, interior bus and van structures, such as sidewalls and windows, can increase injury to the head upon impact. Padding which can absorb some of the impact energy can reduce head injury levels (generally, measured by Head Injury Code (HIC) values exceeding 1000) by up to 50 percent (Monk and Wilke, 1987; Digges and Dalrymple, 1992) but it is important to realize in designing the vehicle interior within the envelope of the mobility aid location that occupants of mobility aids ride substantially higher than passengers on OEM bus and van seats. Padding of bus and van structures must therefore relate to the most probable locations of impact during a dynamic crash event.

Padding is not universally appropriate, however. Mobility aid designs which incorporate soft seating cushions and/or seat backs can aggravate occupant injury levels, caused by a complex mechanism which also involves occupant restraint design and vehicular design. In a series of twenty-five (25) anthropomorphic test dummy (ATD) sled tests, augmented by four (4) cadaver tests, Kallieris et al. (1981) found that the incidence of "submarining" - in which the occupant or test dummy slides beneath the lap belt restraint - is higher for soft padded materials. This increases lower limb injury as the body moves much further in a frontal crash, including the possibility of striking objects beyond any Frontal Clear Zone (FCZ) (SAE, 1995) associated with the mobility aid securement location on the vehicle that might otherwise have been provided. "Submarining" also increases soft tissue abdominal injury as the lap belt rides up from the pelvic region to the abdominal area. No compressable padding should be placed behind or under the mobility aid user. Soft padding, including pillows and foam, compress on impact and can prevent upper torso restraints, such as is provided by a Type 2 seat-belt system, from maintaining a secure and tight fit on the mobility aid user's body. A dangerous slack can result, and the occupant can be excessively loaded by the restraint belt itself (American Academy of Pediatrics, 1994).

In collisions, forces equivalent to up to 30 times the combined weight of the mobility aid and occupant may be exerted on the restraints in the forwards direction. A mobility aid securement restraint is only as strong as the part of the vehicle capable of withstanding these forces (MDD, 1992). For this reason, Federal Motor Vehicle Safety Standards impose design and performance requirements separately for seat belt assembly hardware, and seat belt anchorages (FMVSS 209, FMVSS 210, respectively). Vehicles may need to be reinforced at anchorages for mobility aid securement and occupant restraints (Fisher, Seeger, and Svensson, 1987; Wevers, 1983; Orne, Barak and Fisch, 1976). Tying the mobility aid securement system directly to structural members of the vehicle itself allows the inertial loads of the mobility aid to be transferred to the parts of the vehicle best able to absorb these forces (Schneider and Melvin, 1978). Static pull tests conducted on the Lane Transit System's uniquely-designed securement system indicated wide variation in the failure load of the several components that comprise the system, ranging from 1882$\pm$10 lbf failure load (in shear) for the anchorage bolts to 5061$\pm$10 and 5078$\pm$10 lbf respectfully for the O-ring and anchor plate (both tensile failure mode) (Tittle, Thompson, and Morehouse, 1991).

It is also critical that the mobility aid securement and the occupant restraints be mutually compatible. If both, for example, use webbing, then the stretch or elongation under load of the mobility aid tiedown should be less than that of the occupant restraint in order to restrict the motion or forward excursion of the mobility aid, under a frontal crash event, to less than the corresponding excursion of the restrained occupant (TCRP, 1994; Seeger and Caudrey, 1983). Otherwise, the mobility aid will impart unduly high loads on the occupant from behind.

There is an assertion that rigid securement systems, providing automatic docking capabilities for self-attachment by the mobility aid user, may transfer vehicular vibrations to the mobility aid user increasing the discomfort to the user (Kooi and Janssen, 1988). Rigidity of these systems may alter the natural frequency of the mobility aid-mobility aid user-MASOR system, which may amplify the peak tiedown loads for certain crash pulse deceleration rates (Shaw, Lapidot, Scavnicky, Schneider and Roy, 1994), and increase what is referred to as acceleration amplification - the ratio of the measured acceleration of parts of the occupant, generally head and chest, to the acceleration of the vehicle or simulated vehicle (the sled platform) (Red, Hale, McDermott and Mooring, 1982; TCRP, 1994, at p. 43, Draft Guidelines; Wevers, 1992). There is some experimental support for amplification due to rigidity of one or more subsystems: High-speed film records of the dynamic trials that were run in support of the Australian Standard for Wheelchair Occupant Restraint Assemblies for Motor Vehicles revealed that the dynamic interactions between the dummy and seating were more violent with the rigid test seat than with the wheelchair which deforms under impact (frame and wheels), soaking up some of the crash energy (Fisher, Seeger and Svenson, 1987). The theory that rigid securement systems increase acceleration amplification, however, is not universally accepted (Bauer and Reger, 1992).

The attachment geometry for the occupant restraints, in particular the attachment on the vehicle sidewall, and the full range of shape and size of the disabled population that must be accommodated are intimately related to the performance of the occupant restraint system. Vertical forces are also created in frontal crashes, and if the attachment point for Type 2 seat belt systems that provide upper torso restraint is too low on the vehicle sidewall then excessive compressive forces on the occupant's shoulder can result in spinal and lower back injuries; too high a location, and the occupant can "submarine" under the belt. (Aldman, Brattgard and Hansson, 1974). Type 2 seat belt restraint systems inherently can not be made as effective as in automobiles for the mobility-impaired population for a number of reasons:

- Due to the higher seating position of the mobility aid user, the bands must be made longer and the securing points must be placed at greater distances away from the occupant, increasing as stated above the risk of sliding below the belt, stressing the neck and the lower abdominal region.

- Mobility aid accessories and the armrests on many mobility aid designs make it difficult to properly secure the lap belt (over the pelvic or hip bone).

The above examples, highlighting the mutual dependencies within the vehicle-securement mobility aid-mobility aid user system, could be extended further. The important issue for designers is to recognize, accommodate and coordinate these interdependencies for maximum system performance.

3.1 MULTIPLE OBJECTIVES/REQUIREMENTS

Unquestionably, protection against injury of the mobility aid user and other passengers during normal and abnormal driving events is a key requirement for mobility aid securement and occupant restraint (**MASOR**) systems. But it is not the only objective or requirement! Even considering, for the moment, crashworthiness as the primary objective, no matter how well a particular restraint functions in a laboratory crash test, its real test is in its daily use (Shaw, 1987; Kooi and Janssen, 1988). Use and maintenance should be straightforward. Complex systems invariably lead to misuse or disuse. In the case of child restraints, for example, staff at the University of Tennessee Rehabilitation Engineering Program discovered that 75 percent of the child restraints examined were improperly used, strongly suggesting the need for designs that are easier to use (Physicians for Automotive Safety News, 1983/1984). This author is unaware of a similar study documenting misuse and disuse incidence for the mobility aid user population when riding buses and vans in public transit service, but it is highly likely that the incidence is higher than it should be.

In describing the design, test and development of a wheelchair restraint system for the Wayne State University transportation system, Orne, Barak and Fisch (1976) arrived at a number of design criteria (see Table 7), encompassing the accident environment, the wheelchair itself, the passenger, and a set of general characteristics (e.g., space constraints, fire resistant, aesthetically pleasing).

During the 1981 National Workshop on Wheelchair Securement in Transit Vehicles (Brenner and Giangrande, 1981), design recommendations included:

- For large bus transit, securement designs should restrain the wheelchair (and the passenger) against 20 mph, 10g deceleration impacts, over a 100 millisecond duration; for paratransit vehicles, the corresponding crash event is 30 mph, 20g deceleration, over a 100 millisecond duration.

Table 7. Summary of Design Conditions and Design Criteria for Wheelchair Restraint System (WRS)

A. Accident Environment
   1. Frontal Barrier Equivalent Velocity (BEV) of 30 mph.
   2. Rear BEV of 15 mph.
   3. Side impact and rollover.
   4. Emergency braking.
   5. Normal vehicle handling conditions.

B. Wheelchair
   1. Secured to bus under conditions (A).
   2. No entrapment of passenger in accident.
   3. Battery securement
      a. No beakaway in accident.
      b. No acid spills in accident.
   4. Electric and manual wheelchairs.

C. Passenger
   1. Survive accident conditions (A) with little or no injury.
   2. Lower human tolerance values (HIC) than for able-bodied passengers.
   3. Passive rather than active restraint preferred.
   4. Simple operation of devices.
   5. No unusual muscular effort or coordination needed to engage or release devices.

D. General Characteristics of Wheelchair Restraint Systems
   1. Self contained modular unit.
   2. Fit into most buses.
   3. Fit within space envelope of wheelchair.
   4. Easy to install and remove.
   5. Aesthetically pleasing and integrated into bus interior.
   6. Easy to mass produce - low unit costs.
   7. Fire resistant according to FMVSS 302, non-toxic.

Source: Orne, Barak and Fisch, 1976.

- Securement systems should fit or be readily adaptable to the great majority of in-use mobility aids.

- Ergonomic requirements for operational use of the securement and restraint systems should consider the physical limitations and constraints of the mobility aid population, particularly in reference to force and motion needed to operate the systems.

- Independent securement by the mobility aid user to the maximum extent feasible should be secured by the design.

- Psychological requirements, avoiding a strictly clinical technical appearance, but rather emphasizing more transportation environmental factors - shape, color, touch, materials, surfaces, aesthetics - should be accommodated by the design.

- Maintainability of securement and restraint systems in order to insure vehicle availability (it being assumed that an inoperable securement and restraint system would require the withdrawal of the vehicle from service) should be a critical design constraint.

The Dutch have taken the position that safety, operational requirements and cost must be explicitly balanced in arriving at an optimal solution for local (i.e., Dutch) conditions. They have, for example, rejected the more stringent crash pulse test requirements of the Australians (30 mph impact, 20-30g) on the grounds that designs that are compliant with this standard are relatively complex and expensive as well as difficult to handle. In addition to citing cost and useability concerns, they also consider wider concerns such as passenger comfort, and the effect on loading and discharge operations in relation to the specific combination of securement, occupant restraint and vehicle deployed.

Based on the literature, discussions with individuals and organizations, a survey of the experts on a steering committee and of transit providers, Karg, Yaffe and Berkowitz (1994) have summarized securement and restraint design citeria, ordering the categories in priority, although recognizing the need to tradeoff subcategories in practice:

Safety

- Minimize injury.
- Allow for egress in an emergency situation.
- Simplify use so system is used properly.

Ergonomics/Human Factors

- Simplify use for independent and timely securement.
- Promote the physical and mental comfort of user.

Vehicle Characteristics

- Optimize vehicle capacity.
- Minimize costs.

Using perhaps the most rigorous requirements definition process for the design of mobility aid securement systems, Hunter-Zaworski, Ullman and Herling (1992) identified customer requirements (defining "customer" inclusively to include not only mobility aid users, but also transit operating, engineering, and maintenance staff; securement, vehicle and mobility aid manufacturers; other passengers; standards organizations), and translated these into measurable engineering requirements. Again, customer requirements fall into such categories as performance (e.g., ease of use; energy management during normal operating mode and during abnormal crash or near-crash events), spatial requirements (e.g., passenger orientation in the forward direction corresponding to the motion of the vehicle; non-interference with the seating or movement of other passengers), cost, appearance, emergency operation (e.g., standard and easy identification of emergency release mechanism), and maintenance requirements.

The most useful and practical set of design criteria for securement and restraint systems is that recently developed under a Transit Cooperative Research Program project (TCRP, 1994). We have used this set of design criteria as the basis for soliciting the preference ordering of the transit system community, and as a basis for benchmarking the evaluation of in-use securement and restraint systems experienced by the mobility aid user population. Our results, based on a sample of transit systems and mobility aid users, are reported in Table 8.

Table 8. Transit System Respondents - Number of Observations by Rank Ordering

	Most Important 1	2	3	4	5	6	7	Least Important 8
a. Universal Design	8	2	5	3	1	4	0	2
b. Minimum Crashworthiness Std.	13	4	4	2	0	1	2	0
c. Maximum Securement and Release Time	8	5	3	5	2	0	1	0
d. Vandal-Resistant	1	2	4	2	0	3	6	7
e. Independent Securement by MAU	2	1	4	3	4	4	3	4
f. Cost of System	3	5	1	1	3	3	4	4
g. Ease of Installation and Maintenance	6	3	4	2	6	2	2	0
h. Safety and Ease of Driver Securement	12	5	2	2	2	1	0	0
i. Other *								

*a. Amount of personal space invasion, and method of tightening securement.
b. Design should consider safe and efficient ergonomic process for both driver and customer.
Source: Aggregate data from Transit System Data Collection Form
Notes: 1. Two (2) non-respondents.
2. Some respondents rated design criteria equally important.
3. Some respondents had different rank orderings for paratransit vs. fixed-route service.

Analysis of the data reported in Table 8 suggest the following:

- Meeting a *minimum crashworthiness standard* is the most important design requirement, followed closely by *safety and ease of driver securement*; *universal design* and satisfying a *maximum securement and release time standard* tie for third in rank ordering.

- From the perspective of the transit system community (as represented by our sample), there is no consensus on the relative importance of *independent securement by the mobility aid user (MAU)*: some systems rank it as important, others do not.

- *Vandal Resistant* and *Cost* are relatively unimportant considerations.

The results for our sample of mobility aid users are reported in Table 9.

Table 9. Mobility Aid User Respondents - Number of Observations

Problem?	Agree	Disagree
a. Lack of a universal interface	11	4
b. Excessive operations inspection time (> 3 minutes)	8	7
c. Excessive securement time (> 1 minute fixed route; > 3 minutes paratransit)	10	6
d. Lack of a securement completion signal	9	5
e. Lack of user privacy (reaching components; connecting to mobility aid)	8	6
f. Excessive force needed to secure (> 10 lbs normal use; > 5 lbs for difficult access points; > 1 lb for emergency release)	8	5
g. Lack of redundant release	8	5
h. Excessive mobility aid motion during normal and emergency driving maneuvers (> 2 inches any direction; tipping of mobility aid during cornering)	10	5
i. Lack of securement system integrity (system breaks apart) during crash events	6	7
j. Lack of occupant restraint system	6	6
k. Other*		

*a. Insufficient training and practice by the driver in securement; variety of different systems because of mixed fleets.

b. Securements do not work on scooters; occupant is not restrained.

Source: Aggregate data from Mobility Aid User Data Collection Form

Notes: 1. Some respondents did not rate all problem areas.

Analysis of the data reported in Table 9 support the following conclusions:

- For all evaluation criteria, except item i - *securement system integrity,* more mobility aid users in the sample agree than disagree that existing securement and restraint systems are deficient with respect to these criteria. Since none of the mobility aid users had direct involvement in a crash event (also asked in the Mobility Aid User Data Collection Form), and because most if not all lack the technical expertise to make a judgement concerning securement system integrity during a crash event, the response data reported under item i is probably not significant.

- The most important problem identified by this sample of mobility aid users is the lack of a *universal interface.* This is followed by *excessive securement time,* and *excessive mobility aid motion during normal and emergency driving maneuvers.*

- The number of responses reporting a lack of an occupant restraint system is both surprising and alarming.

To summarize, just as the interactions within the vehicle-securement-mobility aid-mobility aid user system add to the complexity of design, there are a multiple of objectives/requirements that need to be satisfied. While crashworthiness is undoubtedly critical, there are also other factors involved.

3.2 THE PRINCIPLES AND PHILOSOPHY OF UNIVERSAL DESIGN

What is universal design, and how does it apply to the vehicle-securement-mobility aid-mobility aid user system?

Designers* have traditionally based their designs on anthropometric data for "able-bodied" adult males in the prime of life (Wilkoff and Abed, 1994). The needs of children, women, the elderly or persons with disabilities were never explicitly considered. A consequence of this exclusion is that facilities and products are either not useable (i.e., accessible) by a large portion of the population, or are useable but with great difficulty. Universal design redresses this incomplete paradigm by inculcating a sensitivity within the design process to the diverse needs of all of the community. Designs are sought that are safer, more functional, and more convenient for everyone. Removal of barriers within the environment, and sensitivity to the needs of people with varying disabilities are required for the designer to create an accessible solution that truly works for the person with a disability. Universal design, when most successful, extends accessibility into the environment to such a degree that it is accepted by both designers and the public as the norm rather than being viewed as an adaptation for special needs.

---

* Designer is used genericly to include any person who is professionally involved in the design of products, physical sites and spaces; it includes industrial designers, architects, landscape architects, interior designers, etc.

Universal design also has its limitations. Even if persons with disabilities are included in the design process, it is not possible to design products and devices so that they are useable by all such persons. There will always be a "tail" of individuals who are unable to use a given product. Vanderheiden (1990) refers to this phenomemon as the "95th-percentile illusion," arising because there are no 95th-percentile data for specific designs-only data with regard to individual physical or sensory characteristics (e.g., for height, vision, hearing, reach etc.). As a result, it is not possible to determine when a product can be used by 95 percent of the population, but only to estimate when a product can be used by 95 percent of the population along any one dimension. Because people in the 5 percent tail for any one dimension are usually not the same people as those in the 5 percent tail along another dimension (Kroemer, 1987), it is possible to design a product using 95th-percentile data and end up with something that can be used by far less than 95 percent of the population. To compound this, the data from which the 95th-percentile figures are calculated often exclude persons with disabilities!

The National Workshop on Wheelchair Securement in Transit Vehicles acknowledged the importance of designing securement and occupant restraint systems to accommodate the diversity of mobility aids in the population (Brenner and Giangrande, 1981). Universal securement devices necessarily require standardardized fittings at prescribed points on the mobility aid to permit effective coupling to the securement device (Brenner and Giangrande, 1981). Additionally, the Workshop participants recommended that mobility aid manufacturers recognize that their products are being transported and consider modifications or adaptations to current and future designs to facilitate their securement and capacity to sustain occupant loadings generated in dynamic crashes. These modifications or adaptations would include standardized occupant restraint belt attachment points, standardized clearance, and the removal of appurtenances which project from the mobility aid and obstruct or inhibit securement of the mobility aid or restraint of the occupant. The data reported below add further support in identifying at least one element necessary to make universal design realizable: the requirement for a standardized attachment and attachment geometry. (See Table 10.)

It is illogical for placing the locus of responsibility for achieving universal design for the vehicle-securement-mobility-aid-mobility aid user system on only one manufacturing sector. Clearly, the vehicle, securement, mobility aid and occupant restraint manufacturers each have cooperative responsibilities with each other to assure compatibility at the boundaries of each subsystem, and to make the system as a whole adaptable to the diverse needs of the mobility-impaired population who use mobility aids. Some elements, not necessarily complete, which further the application of universal design concepts to the vehicle-securement-mobility aid-mobility aid user system include the following:

- Standards which unambiguously define what the interface should be between subsystems at the boundary; it is reflective to observe that the interconnection of heterogeneous computers (from different vendors) into information networks would be inconceivable without an open system architecture consisting of standards and protocols.

Table 10. Number of Respondents who Asserted the Need for Standardized Attachments and/or a Standard Attachment Geometry for Mobility Aids

Key Actor Group	Number	Response Rate
a. Technical Community	2*	0.25
b. Transit Systems	17	0.63
c. Securement Manufacturers	3	0.60

Source: Aggregate data from Data Collection Forms for each "Key Actor" Group

*Only two (2) respondents asserted the positive requirement for standardized attachments and/or a standardized attachment geometry, but seven (7) out of eight (8) respondents strongly agreed or agreed that attachment points on tri-wheeled scooters are practically inaccessible. It could be argued that, inferentially, these other respondents are also supportive of a standard attachment and an attachment point geometry.

- Vehicle floor structures and a standardized attachment point geometry that jointly exceed performance loads related to worst case crash environments, and can resist forward, aft or sideways motion of the mobility aid, or rotation (Hunter-Zaworski and Ullman, 1991). Although it is recognized that even the identical vehicle model may have differing internal seating configurations at the various transit systems, a standardized attachment point geometry could be defined based on a relative frame of reference using the space dimensions of the mobility aid bay.

- Incorporation of belt pretensioners, webbing lock mechanisms and adjustable anchors for belt-based occupant restraint systems that would make the occupant restraint system adaptable to the wide range in size of occupants, and seating position heights.

3.3 CRASHWORTHINESS DESIGN PRINCIPLES

Before considering crashworthiness design principles in their application to the securement of mobility aids and the restraint of mobility aid users, it is instructive to review briefly what happens in a crash to the vehicle and to passengers riding within the vehicle. The crash dynamics described (Grime, 1979; Viano, 1988; Kulowski, 1960) assume a frontal impact, and collision with a rigid object (i.e., no elasticity or mechanical coupling as would be the case in a vehicle-to-vehicle impact).

The vehicle is rapidly decelerated over a time duration on the order of 0.1 seconds (100 msec), its energy at impact dissipated by the work done in structurally deforming the vehicle. The impact of the vehicle is often refered to as the "first collision." The mean deceleration of the vehicle is proportional to the square of the impact velocity, and inversely proportional to the crush (stopping) distance of the vehicle. During this tenth of a second, the passenger's head and body continue to move forward at very nearly the full speed of the vehicle before the impact. The passenger then strikes the internal structure of the vehicle and/or other passengers at about the instant when the vehicle itself has come to a complete stop. Injury-producing impacts on the unrestrained passengers take place at nearly the speed of the vehicle before impact. This constitutes the "second collision." The same principle also applies to response of the body under a collision impact. Damage to the skull from head impact constitutes the "second collision" while damage to the semi-liquid nature of the brain constitutes in effect a "third collision" as it undergoes sloshing within the bony skull and collides with the inside of the skull (Johnson and Mamalis, 1978; Kulowski, 1960).

To reduce damage during transit, minimum relative velocity between the envelope and its contents, in this case the vehicle and its occupants, is required throughout the whole journey. This is the principle behind occupant restraint systems, such as lap and shoulder belts, which couple the occupant to the vehicle and allow the occupant to "ride down" the crash, increasing both time and distance over which deceleration g forces are experienced (Viano, 1988). This of course lowers the rate (in g's per second) and level of deceleration g force experienced by the occupant. Packaging engineers, well aware of the multi-collision phenomena for transported bodies, give four basic principles (Kulowski, 1960):

- The package (i.e., vehicle) should not open up and spill its contents (i.e., occupants), and should not collapse under reasonable or expected conditions of force and thereby expose objects inside it to damage.

- Packaging structures must be strong and be capable of absorbing energy so as to cushion contents.

- Contents should be held and immobilized inside by "interior packaging" to prevent inside impacts.

- The means for holding an object inside must transmit forces to the strongest parts of the contained objects.

Application of these principles, and a substantial body of tests undertaken to evaluate mobility aid securement and occupant restraint systems (**MASORs**) argue for these guidelines:

1. Independent systems should exist for the securement of the mobility aid, and for the restraint of the mobility aid user (Seeger and Caudry, 1983; Dalrymple, Hsia, Ragland and Dickman, 1990; MDD, 1992; Kooi and Janssen, 1988; Schneider (a), 1981; Schneider (b), 1981; Amendment to FMVSS 222, 1993).

   Both systems should be designed so as to avoid the mobility aid loading being transmitted to the occupant and vice versa in a crash situation. It is possible to still maintain independence of the two subsystems while using the same vehicle anchorage points, provided that the securement hardware of the respective subsystems and the joint anchorage points on the vehicle are properly designed to withstand the combined inertial loads of the mobilty aid and the mobility aid users. FMVSS 222, *School Bus Passenger Seating and Crash Protection,* requires a combined anchorage point to withstand a force of 13.344 kN multiplied by the number of securement devices sharing the anchorage.

2. Mobility aid securement systems should attach to the strongest elements of the mobility aid (Red, Hale, McDermott and Mooring, 1982; Schneider (b), 1981). Mobility aid wheels or tubular crossbars that are generally used to stiffen the mobility aid or provide a collapsable mechanism should not be used as structural attachment points. Tubing joints such as the seat-frame/rear upright junctions are preferable (Seeger and Caudrey, 1983).

3. The best orientation of the mobility aid on a bus or van for protection of the occupant in a frontal crash impact is rearwards, with back and head supports; because most passengers, including mobility aid users, find riding backwards to the forward motion of the vehicle unsettling, the best practical orientation of the mobility aid is in the forward direction. Dynamic tests indicate that neither the mobility aid nor the human body can withstand the force generated in a frontal crash if placed in a side-facing orientation (Schneider, Melvin and Cooney, 1979; Stewart and Reinl, 1981; US DOT Final Rule, 1991; Kooi and Janssen, 1988; Red, Hale, McDermott and Mooring, 1982; Karg, Yaffe and Berkowitz, 1994).

4. Occupant restraint systems should ensure that loads are distributed over the skeletal structures of the body as much as possible. It is the skeletal structures of the body that have the most rigidity and therefore resistance to localized stresses (Kulowski, 1960; Aldman, Brattgard and Hansson, 1974). In a frontal crash situation, the hip acts as a hinge. Provided the lap belt is centered low and over the hip/pelvic bone region, the mobility aid user will "jacknife" (unless restrained by upper torso restraints) as the occupant accelerates in the forward direction. This in itself will not result in injury provided there is sufficient forward clearance to prevent the occupant's head and extremities from striking any object. If, however, the lap belt is improperly placed or rides up, there results severe soft tissue injury in the abdominal region, and/or severe spinal injury due to spinal flexion (Kulowski, 1960; Aldman, Brattgard and Hansson, 1974).

Upper torso restraints should lie midway over the shoulder, and across the chest. The upper anchorage on the vehicle should be behind and approximately 40 mm above shoulder height of the mobility aid user to prevent excessive compressive stress on the spine when the user is thrown forward in a frontal crash (MDD, 1992).

Human tolerance levels to g forces generated in a crash situation for persons with disabilities who use mobility aids is still an unsettled question. Because of reduced neuromuscular control, bone strength, and local tissue load tolerance, a number of investigators over the years have speculated that injury threshold criteria may understate the potential for injury within this subpopulation (Khadilkar, 1986; Clark, 1984; Aldman, Brattgard and Hansson, 1974; Wilkof and Abed, 1994; Technical Community Respondents, 1995). There are no anthropomorphic test dummies (ATDs) to represent disabled persons, and no dynamic test data, known to the author, to provide guidance. Studies of injury patterns and mechanisms arising in actual vehicle crashes involving mobility aid users have also not, to the best of this author's knowledge, been undertaken. It is probably the case, based on inferential information about the pre-condition of this subpopulation, that the risk of injury, for equivalent delta v/ g force crash impulses, is higher for mobility aid users.

4. SECUREMENT AND RESTRAINT ISSUES

This section documents and provides a critical assessment of securement and restraint issues in the transport of tri-wheeled scooters on buses and vans used in public transit services. Assessment is based on research reported in the technical literature, on static and dynamic tests, and on responses of the technical community, securement manufacturers, scooter manufacturers, and transit systems to Data Collection Forms (see Appendices A, B, and C) sent to each of the respective "key actor" groups. Eleven issues, listed below, have been identified:

1. Attachment points, on some scooter models, are inaccessible.
2. Attachment points, on some scooter models, are not structurally strong enough to withstand dynamic loads (both panic stops and crash events).
3. Inability to restrain battery in a crash event.
4. Improper restraint angle on two-point attachment systems to prevent backwards rotation in a crash event.
5. Shearing or fracture of the seat pedestal.
6. Large bending moments that exceed the restraining force of seat designs.
7. Lack of independent securement and occupant restraint systems.
8. Proliferation of scooter models that are incompatible with securement systems.
9. Elastic deformation of the scooter platform imparting large vertical excursions and vertical accelerations.
10. Rollover and tipping instability of scooters.
11. Other issues.

4.1 ISSUE #1: ATTACHMENT POINTS, ON SOME SCOOTER MODELS, ARE INACCESSIBLE

4.1.1 Discussion

Accessible attachment points on mobility aids are critical to the ease and safety of operator-assisted securement, and to the minimization of securement time. The minimization of securement time is important for its consequencial effect on operations, particularly scheduled fixed-route operations. Independent securement by the mobility aid user, for securement designs that can support independent securement, is of course impossible without accessible attachment points (i.e., accessible to the mobility aid user directly, or to an automatic docking mechanism that the mobility aid user can easily attach to by maneuvering his/her aid). In the latter case, what is accessible to the operator may not be for the mobility aid user.

Paradoxically, the most accessible attachment points on tri-wheeled scooters are also the least desireable in terms of structural design strength at the point of attachment, and crash dynamics during a frontal impact (see Issue #2, Section 4.2). As with other mobility aids, attachment points should lie on structural frame members of the scooter platform and should not encompass the wheels, axles, backrest, armrests, steering column tiller, or seat pedestal (Australian Standard, 1994; Layton, Hunter-Zaworski and Safford, 1989). In practice, securement of scooters does encompass use of the seat pedestal and steering column tiller. One major securement system, Q'Strainttm, uses a fifth strap to attach in the rear to a retrofited lift handle for Amigo Basic Classic and Med Special scooter models (material provided by Amigo to the author in its response to the Scooter Data Collection Form).

A visual examination, by the author, of black and white photographs for the major scooter models currently marketed by the scooter manufacturers (i.e., Alpha Mobility, Amigo Mobility, Electric Mobility, Everest and Jennings, Golden Technologies, Invacare Corp., Jubilee Scooters, Motovator, Ortho-Kinetics, and Pride Health Care) indicated that there are no obvious attachment points, *and none specifically designated and marked by the manufacturer*, on or under the platform base unit (ECRI, 1991). The smooth plastic and/or metal surfaces on the platform inhibit any attachment unless the scooter has been retrofited with attachment loops or inset bars that can mate with webbing buckles or other attachment hardware hooks or couplings. Ground clearances for all of the above referenced scooter models are extremely low, ranging from 2.0 in (50 mm) to 4.5 in (115 mm), making it impossible to reach underneath the platform base unit and attach securement straps to any exposed structural frame members, assuming they exist. For some scooter models, the platform is an integral mold, and there are no specific frame members.

Data from the technical community in response to this issue are summarized below in Figure 3.

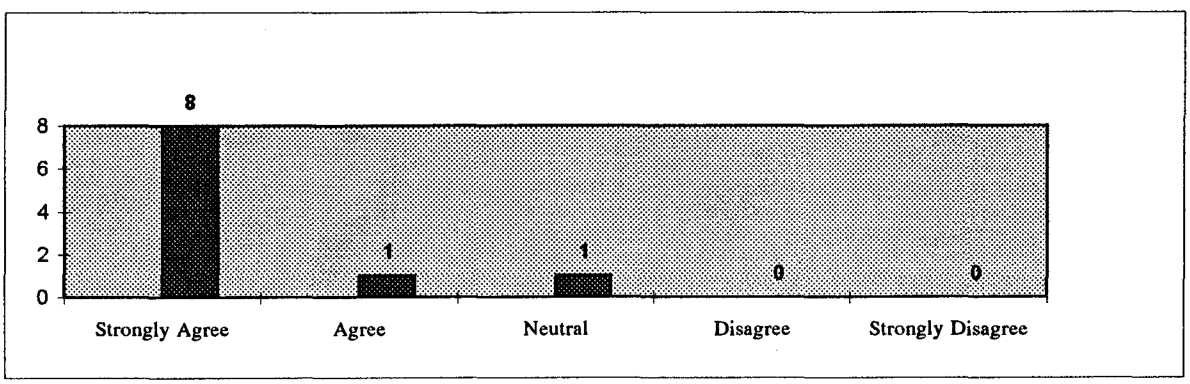


Figure 3. Technical Community Responses to Issue #1:
Inaccessible Attachment Points

Source: Aggregate Data from Technical Community Data Collection Form

More than ninety (90) percent of the technical community responses strongly agree or agree that most scooter models have inaccessible attachment points.

Additionally, minimal clearance between the seat bottom and the top of the battery blocks access to the seat post, while large diameter seat posts (> 2 in (50 mm)) interfere with attachment hooks (Bauer and Reger, 1992; Reger and Adams, 1993).

4.2 ISSUE #2: ATTACHMENT POINTS, ON SOME SCOOTER MODELS, ARE NOT STRUCTURALLY STRONG ENOUGH TO WITHSTAND DYNAMIC LOADS (BOTH PANIC STOPS AND CRASH EVENTS)

4.2.1 Discussion

The Society of Automotive Engineers (SAE) Adaptive Device Subcommittee, the Canadian Standards Association (CSA), and the International Standards Organization (ISO) have each proposed identical dynamic test standards for mobility aid securement and occupant restraint (**MASOR**) systems (SAE, 1995; CAN/CSA-Z605, 1995; ISO 716/19, 1994). The proposed standards, applicable to mobility aids in a forward facing orientation only, specify a 30 mph (48 km/hr) frontal impact test similar to that currently required by FMVSS 213 for child safety seats. In addition to the delta V constraint of 30 mph (48 km/hr), the standards specify a crash pulse corridor that defines the deceleration vs time history (see Figure 4). As Figure 4 illustrates, the maximum deceleration must be no less than 20g, with onset no later than 50 milliseconds, and of duration no less than 20 milliseconds. The total crash duration has to be no less than 100 milliseconds (0.1 second).

Dynamic tests on four-point belt securement systems conducted at internationally known test centers as part of the *Interlaboratory Study of Proposed Compliance Test Protocol for Wheelchair Tiedown and Occupant Restraint Systems* (Shaw, Lapidot, Scavnicky, Schneider and Roy, 1994), in accordance with the above referenced crash pulse corridor and delta V constraint, indicate that the average peak load on the left and right rear tiedown is 4450 lbf each (19.28 kN), and 1530 lbf (6.8 kN) and 1840 lbf (8.17 kN) for the left and right front tiedown, respectively. Assuming that the tiedowns are attached to the structural frame members of the mobility aid at a restraint angle of 45 degrees, the axial loads imposed on the frame member are 3150 lbf (14.01 kN) in the rear, and 1190 lbf (5.3 kN), averaged over left and right positions, in front.

According to calculations made by Red, Hale, McDermott and Mooring (1982), the type of steel tubular frame members used in mobility aids other than scooters can not sustain axial loads exceeding 2200 lbf (10 kN) without sustaining major deformation, with the possibility of frame fracture and securement release. Similar calculations, to the author's knowledge, have not been made for the structural members that form the platform base of tri-wheeled scooters. It is highly likely, due to weight and cost considerations, that tubing of similar material, with similar diameter and crossection dimensions, are also employed. If attachment is to the seat post and front tiller of the scooter, it is the opinion of many in the technical

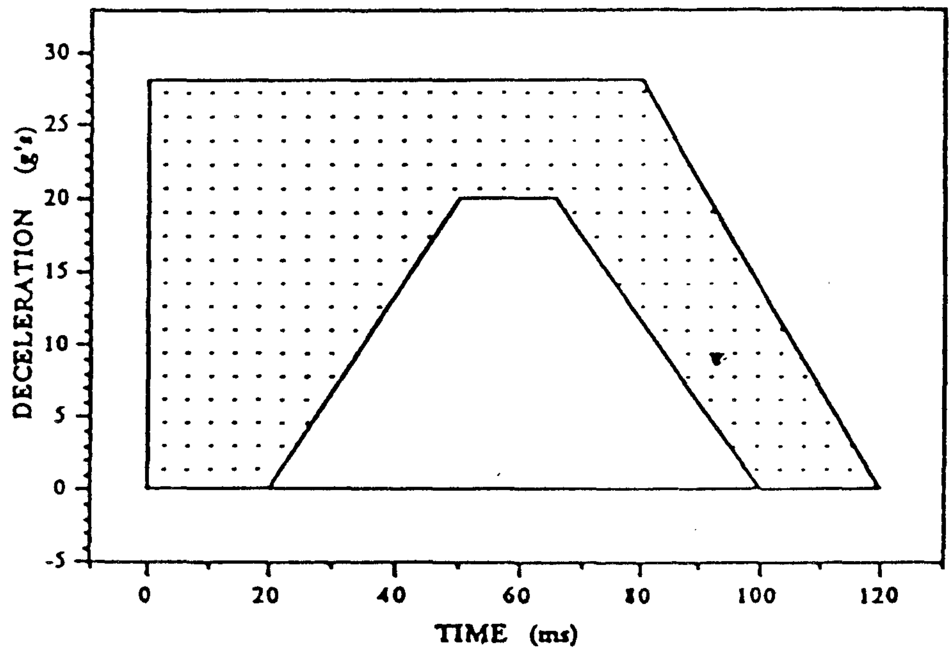


Figure 4. Crash Pulse Corridor as Defined by ISO. The Corridor in Conjunction with the Constraints on Delta V, 48 + 2, -0 km/hr (29.8 - 31.1 mph); Defines the Crash Severity

Source: Shaw, Lapidot, Scavnicky, Schneider and Roy (1994). Preliminary figure reprinted with permission from Shaw et al.

community that neither the seat post nor the tiller has adequate strength to withstand this force level (Technical Community Respondents, 1995; Layton, Hunter-Zaworski and Safford, 1989).

In response to a request for comments on NHTSA's amendment to FMVSS 222, *School Bus Passenger and Crash Protection*, amending FMVSS 222 to require school bus and van vehicles to be equipped with wheelchair securement devices and occupant restraint systems meeting specified performance requirements, Invacare stated categorically that there are no mobility aids currently on the market that have been designed to withstand the DOT crash tests (the 30 mph crash tests used to measure compliance with a variety of standards, even though those standards do not directly apply to mobility aids) (Amendment to FMVSS 222, 1993).

In dynamic crash tests of scooters (delta V of 20 mph, nominal 30 g), scooter strength was sufficient to ensure that there was no complete separation of components, but the strength of individual components or fastenings needed improvement (Little, 1990). A test of an Amigo Classic scooter, secured using an Aeroquip FE 500 series four-point tiedown system with two straps attached to the front bumper and two from the seat to the floor at the rear anchorages, resulted in a broken seat pedestal from the scooter base (Hickling, 1989).

Data from the technical community in response to this issue are summarized below in Figure 5.

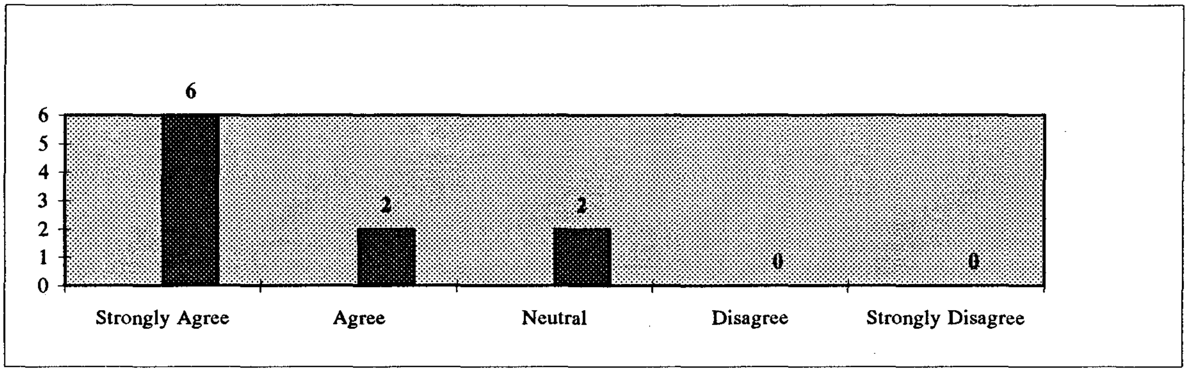


Figure 5. Technical Community Responses to Issue #2:
Structurally Insufficient Attachment Points

Source: Aggregate Data from Technical Community Data Collection Form

Eighty (80) percent of the technical community responses either strongly agree or agree that attachment points, to the extent they exist on the scooter, are structurally insufficient when measured against a standard 30 mph (48 km/hr) delta V/ 20 g frontal impact.

4.3 ISSUE #3: INABILITY TO RESTRAIN BATTERY IN A CRASH EVENT

4.3.1 Discussion

Two generally uncontested facts are worthy of note: No dynamic crash tests have been undertaken without using special tether ropes or straps to prevent the battery(ies) from being hurled uncontrollably during rapid deceleration of the sled (sometimes, the contents of the battery(ies) are also removed, and replaced with equivalent weighted ballast); mobility aid manufacturers do not factor crash force levels as a design constraint for the attachment of the battery(ies) to the mobility aid, including scooters. Depending on the type of crash event and vehicle involved, this force level can equal 20 to 50 times the weight of the battery(ies) (MDD, 1992).

The UK Department of Transport has a general requirement that batteries should be firmly attached to the wheelchair (United Kingdom, Department of Transport, 1987). UK's Medical Devices Directorate, however, in its *Safety Guidelines for Transporting Children in Special Seats*, advises that all loose items should be secured so that they do not act as missiles in the event of a rapid stop or impact. They suggest that all securing devices be capable of resisting a force of fifty (50) times the weight of the stored item (MDD, 1992). Canada requires that portable support equipment or special accessory items be secured at the mounting location to withstand a pulling force of twenty (20) times the weight of the item in any direction (Canadian Standards Association, 1992). Australia, also citing the potential for batteries to become missiles in a crash impact, strongly advises that the battery be securely connected to the wheelchair frame and the whole system of battery restraint be able to withstand a horizontally applied load of twenty-five (25) times the battery weight (Australian Standard, 1994). SAE is silent on the necessary restraint requirement for batteries (Society of Automotive Engineers, 1995), but the American Academy of Pediatrics, Committee on Injury and Poison Prevention, recommends the use of external battery boxes (which would require redesign of most mobility aids) to house and protect batteries during everyday use, transportation and collision (AAP Safe Ride News, 1993).

Batteries should be located as low as possible, consistent with ground clearance. The top of the battery should be below seat level; those powered wheelchairs and scooters with batteries or other components projecting above the level of the seat, and which are not securely connected to the wheelchair frame or scooter platform base are considered unsuitable for transporting by motor vehicle (Australian Standard, 1994). It is important, however, to recognize that powered wheelchairs and scooters with batteries and motors shift the center of gravity (CG) to well below the seat, displacing even further the CG of the mobility aid from that of the occupant. If not properly accounted for by both the securement and the occupant restraint systems (and if each is not compatible with or "tuned" to the other, see Section 3), the mobility aid can back into the occupant, loading the occupant from behind (Wevers, 1992). Several instances of this phenomenon occured in the BC Transit crash tests.

In a dynamic test of the Amigo Classic Tri-wheeled Scooter, the battery box did come free during the test (frontal crash, delta V 30 mph, 20 g) despite being secured in place by a length of belt webbing wrapped around the battery box and the pedestal post (AM 9001, 1990). A main conclusion of the BC Transit crash tests was that battery securement was frequently inadequate (Little, 1990). A battery of sled tests (delta V 20 mph/20 g frontal impact) using an Everest and Jennings Model 3P powered wheelchair, however, indicated that containment and securement of the battery during frontal impacts did not pose any serious problem. In no case did the battery box cover come off, or did the battery itself come completely free of the gimbaled mounts (Schneider, 1981(b)). These good results, however, are due to the unusually good securement design of the battery on this mobility aid.

Data from the technical community in response to this issue are summarized below in Figure 6.

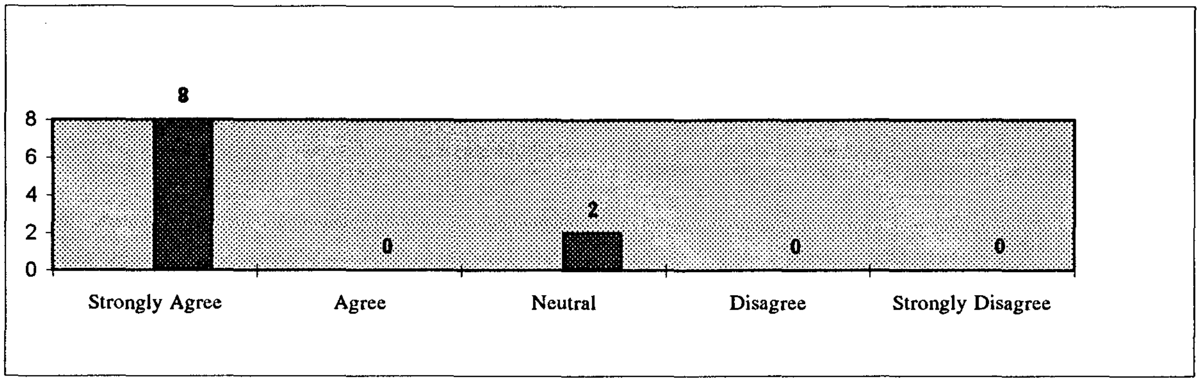


Figure 6. Technical Community Responses to Issue #3: Inability to Restrain Battery in a Crash Impact

Source: Aggregate Data from Technical Community Data Collection Form

Eighty (80) percent of the technical community responses strongly agree that restraints are inadequate for the battery(ies) during a crash impact, irrespective of direction. At least three technical community respondents cited personal observation of battery packs acting as projectiles, based on additional tests conducted at University of Virginia, Transportation Development Center (Toronto, Canada), and the Cleveland Clinic Foundation (dynamic tests actually conducted at the Transportation Research Center, East Liberty, Ohio) (Technical Community Respondents, 1995; Bauer and Reger, 1992). Technical community respondents also cited the use of velcro as a battery strap that would definitely fail in a crash impact, and respondents believe that most scooter battery containment systems would fail dramatically due to configuration and location.

4.4 ISSUE #4: IMPROPER RESTRAINT ANGLE ON TWO-POINT ATTACHMENT SYSTEMS TO PREVENT BACKWARDS ROTATION IN A CRASH EVENT

4.4.1 Discussion

To secure the mobility aid adequately, the securement system must limit translation in three directions and rotation about three axes, during forward, rearward, and sideward acceleration under normal and accident conditions (Hunter-Zaworski and Ullman, 1992). Rotation backwards can occur from either the rebound in a frontal crash impact (and there are no front attachment straps), from a rear crash event, or when the combined center of gravity (CG) of the occupant and mobility aid, secured by only a two-point attachment system, lies below the line of the belt between the attachment point on the mobility aid and its anchorage at the vehicle floor.

Two-belt attachment systems can secure a mobility aid in the forward and rearward directions and limit sideward movement provided that the mobility aid backs up to a rigid partition or flip-up seat, and the belts pass down toward the floor at an angle of between thirty (30) and forty-five (45) degrees, and out to the side at ten (10) degrees for rear attachments, and twenty-five (25) degrees for front attachments (Society of Automotive Engineers, 1995).

Two-point attachment systems are particularly problematic for tri-wheeled scooters because of the difficulty of finding secure attachment points that provide the proper restraint angles to limit rotation or translation. Secure anchoring points on the mobility aid should lie two (2) to six (6) inches (50-150 mm) below reference point P* on the mobility aid to provide user convenience and ensure the proper restraint angles (Wevers, 1992). For scooters, this vertical distance is impossible to achieve. The data collected for the transit sample in this study indicated that no system, in the sample, currently uses a two-point attachment securement system. This issue, therefore, may be more of a theoretical concern.

Data from the technical community in response to this issue are summarized below in Figure 7.

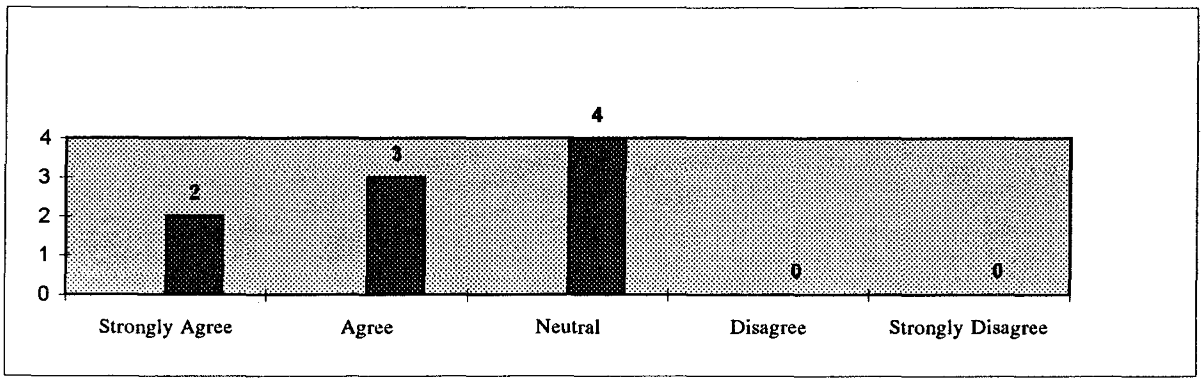


Figure 7. Technical Community Responses to Issue #4: Improper Restraint Angles for Two-Point Attachment Systems

Source: Aggregate Data from Technical Community Data Collection Form

* Reference Point P - Both SAE and the Australian Standard define Reference Point P as a reference point that lies at the cross-sectional center of a 100-mm diameter cylinder positioned with the longitudinal axis perpendicular to the wheelchair reference plane such that the curved surface of the cylinder contacts with the backrest and the upper surface of the seat.

Fifty (50) percent of the technical community responses either strongly agree or agree that improper restraint angles for two-point attachment, with the possibility of backwards rotation of the mobility aid during rapid deceleration, may be a problem at some transit systems. Design factors that are critical to proper mobility aid securement using two-point attachment systems are height and angle of attachment. Proper angle varies as a function of the center of gravity (CG) height, and its fore-aft location (Technical Community Respondents, 1995).

4.5 ISSUE #5: SHEARING OR FRACTURE OF THE SEAT PEDESTAL

4.5.1 Discussion

For tri-wheeled scooters, the seat is supported by a single structural member which is the seat post or pedestal. This sole member, consisting of a thin-walled cylindrical steel or possibly other metal-alloyed material, must sustain all of the loads transmitted to it, including both vertical compressive loads and bending moments induced by a crash impact. Sustaining these loads is unlikely due to the lightweight, weak seat mount which is cited as an inherent design problem for current scooter models (Layton, Hunter-Zaworski, and Safford, 1989).

In a rear impact dynamic test (delta V 30 mph/ 25 g) of an Amigo Classic scooter using an Aeroquip FE500 series four-point attachment system, the seat pedestal broke from the scooter base and flew to the back of the van; it was judged that the anthropomorphic test device (ATD) experienced potentially fatal head and neck injuries (Hickling, 1989). Subsequent testing of the same scooter model, but with an improved and strengthened seat pedestal design (frontal impact, delta V 30 mph/ 20 g, Q'straint four-point tie-down system), yielded the following results: the pedestal remained in place and did not fail although it did flex so that the mid-point of the seat pedestal moved forward about two inches relative to the base during peak loading. The pedestal, although redesigned and strengthened, may have contributed to the submarining or slippage of the ATD below its attached lap belt, since it may lack the stability and support necessary to assist in retaining the dummy's pelvis in place (UMTRI, 1990). A different scooter model (Burke Mobility Scooter No. 1) had its seat post buckled after a similar standard frontal crash impact (Biokinetics, 1991). The BC transit crash tests of buses and vans experienced at least one (1) pedestal failure, with the seat and ATD collapsing downwards (Little, 1990).

Kinedyne, a major manufacturer of mobility aid securement and occupant restraint (**MASOR**) systems, states categorically that the scooter occupant must transfer to a standard vehicle seat, noting that all of the impact testing film and data that they have reviewed demonstrates a higher degree of potential injury that may occur using a scooter as mobile seating device (personal correspondence, R. Jacobson, 1995).

Data from the technical community in response to this issue is summarized below in Figure 8.

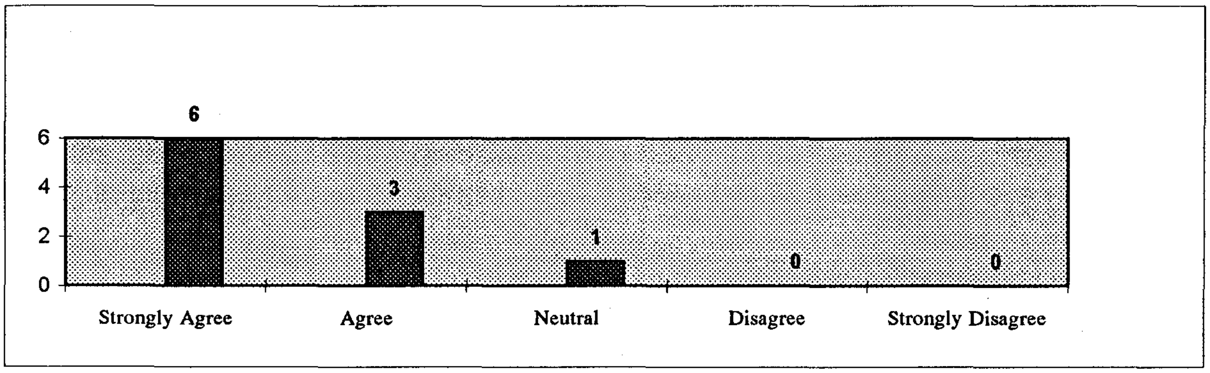


Figure 8. Technical Community Responses to Issue #5: Shearing or Fracture of the Seat Pedestal

Source: Aggregate Data from Technical Community Data Collection Form

Ninety (90) percent of the technical community responses either strongly agree or agree that the seat pedestal or post is very likely to fail under peak loading induced by a standard frontal crash. At least two respondents urged further testing because of the crucial function the seat post plays in occupant motion and potential injury-causing mechanisms, such as slippage of the lap belt from the pelvic region. Two respondents cited test data, from their own direct experience, that found no evidence of seat post failure (at a delta V 20 mph/ 10 g crash impact, scooter model unspecified; at a delta V 30 mph/ 20 g crash impact, on an Everest and Jennings scooter model). Another respondent cited his own personal observation of seat post failure in a dynamic test. Two respondents cited fatigue testing of scooter components, in accordance with test protocols developed by ANSI/RESNA, that indicated that the seat pedestal or post is the weakest part of the scooter structure. Although fatigue life does not correlate directly with ultimate strength, it does indicate structural deficiencies which may be critical during overload conditions. This is corroborated by an incident reported by one respondent in which a heavy rider broke a seat post while operating the scooter in a normal manner.

4.6 ISSUE #6: LARGE BENDING MOMENTS THAT EXCEED RESTRAINING FORCE OF SEAT DESIGNS

4.6.1 Discussion

The seating system for mobility aids generally consists of a seat, a back, and armrests supported by either tubular members in a vertical plane each side of the armrests, or by a single seat pedestal or post as in the case of scooters. Unlike OEM seating systems in motor vehicles (which includes cars, MPVs, trucks and buses), mobility aid seating systems are not required to meet the performance requirements of Federal Motor Vehicle Safety Standard

(FMVSS) 207, *Seating Systems.* FMVSS 207, whose intent is to minimize the possibility of failure of seating system components due to forces acting on them in a crash, dictate that seat assemblies, or a seat back and seat bench individually if they are attached to the vehicle separately, withstand both a rearward and forward force of twenty (20) times its weight, and a thirty-three hundred (3300) inch-pound moment (373 N-m), the force applied to the upper structural member of the seat back, with the moment arm extending to the seating reference point (approximately the occupant's hip joint, which would lie on an axis through reference point P on the mobility aid). It is not known how many mobility aid models, including scooters, can pass these requirements, but it is believed that few can (Digges and Dalrymple, 1992; Red, Hale, McDermott and Mooring, 1982).

Red, Hale, McDermott and Mooring (1982) have calculated that the static load and moment requirements dictated by FMVSS 207 actually grossly understate the actual dynamic loads and moments generated in a crash environment. According to their calculations, assuming that a rear impact imparts 8-10 g accelerations to the occupant, a 50th percentile subject would in turn impart an inertial load of 4.05 kN (910 lbf) at the torso plus head center of gravity, approximately 30 cm above the seating reference point. This would cause a bending moment on the seat of about 1200 N-m, over three times the FMVSS 207 requirement. Based on their experience with many different mobility aid models, it was their opinion that most could not withstand loads of this level. Dynamic tests seem to bear this out.

Because seating system design is rather similar for mobility aids other than scooters, and for scooters, test results for mobility aids other than scooters are reviewed, in addition to dynamic tests on scooter models, for additional insight with respect to this issue. Actually, the single structural support for the seating system in scooters is more compliant than the two rigid supports for the seating systems of mobility aids other than scooters. This implies that the occupant acceleration is amplified (Bauer and Reger, 1991; Red, Hale, McDermott and Mooring, 1982), and therefore force and moment exerted on the seat and seat back are greater. Thus, dynamic tests that indicate seat system failure for mobility aids other than scooters imply almost certain failure for scooter seating system designs subjected to the same crash forces.

In a rear impact (delta V 20 mph/ 10 g), with the wheelchair secured by a frame clamp securement system, the ATD tore through the back of the wheelchair and experienced severe arching of the back (Red, Hale, McDermott and Mooring, 1982). In a dynamic test simulating a frontal impact involving a tri-wheeled scooter, similar occupant motion (i.e., arched back over seat back) involving rapid bending of the seat back and post transpired (see Table 11). In a noncrash test involving a double lane change of the test vehicle (vehicle speed of 75 km/hr, lateral acceleration peaks in the range of 0.8-0.95 g), the seat back and occupant experienced rather large displacements (-17.65 cm to the right, +15.5 cm to the left) (Mercer and Billing, 1990). In a battery of thirty (30) sled tests on an Everest and Jennings power wheelchair (delta V 20 mph/ 20 g, mostly frontal impact), two of the test series resulted in the chair back upholstery torn loose on the ATD rebound, and the rear posts of the chair bent backwards during the impact (Tests 80M002 and 80M010, respectively) (Schneider, 1981(b)).

Table 11. Sequence of Crash Events - Three Wheel Scooter with Belt Restraints

Time After Impact (sec)	Event Description
0.00	The bus, wheelchair and occupant are travelling undisturbed at a constant velocity of 20 mph prior to impact.
0.05	The bus is experiencing its maximum deceleration rate of 10 g's. The bus continues to travel forward at 13.5 mph. The force of impact has not yet been transferred to the occupant, who continues to travel forward at 20 mph. The wheelchair, which was tightly held by the rear restraints, is moving forward at 17 mph within the bus, while loading the rear restraints.
0.130	The bus has stopped moving and the wheelchair has moved forward 5 inches. This is the furthest position forward, and the load on the rear restraints is at its highest level, over 4000 lbs. **The force and angle of the restraint belts are bending the seat post forward.**
0.180	**The elasticity of the seat post and restraints is snapping the wheelchair seat rearward at 4.5 ft/sec. Batteries are breaking loose and flying forward.**
0.260	Wheelchair comes to rest, occupant continues to rebound.
0.500	**Occupant comes to rest, back arched over seat back.**

Source: Bauer and Reger, May-August Progress Report, 1991.
Notes: Items in **bold** provide additional corroboration of Issues #3, and #6.

Data from the technical community in response to this issue are summarized below in Figure 9.

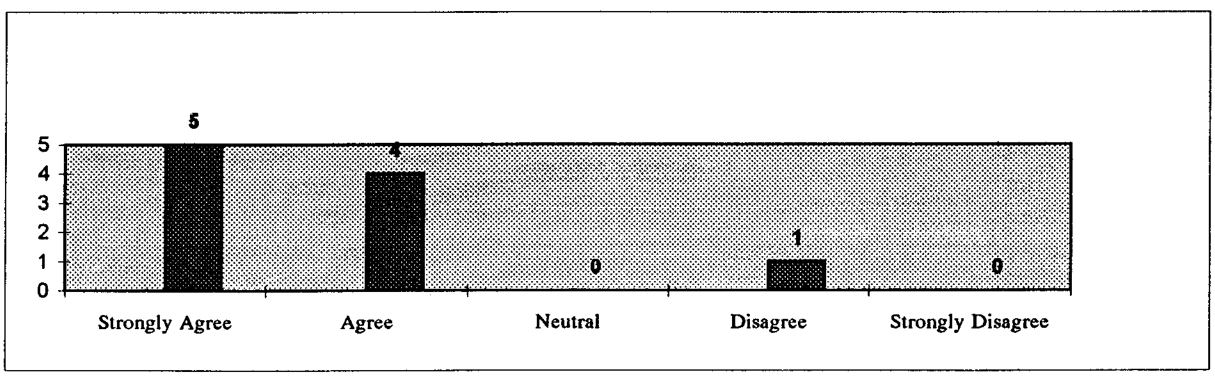


Figure 9. Technical Community Responses to Issue #6: Large Bending Moments that Exceed Restraining Force of Seat Designs

Source: Aggregate Data from Technical Community Data Collection Form

Ninety (90) percent of the technical community responses either strongly agree or agree that seating system designs for scooters are insufficient to resist force and moment levels induced in a standard frontal impact. One respondent cited personal observation of seating system failure due to excessive bending moments in low g tests. Another respondent cited a test of a Fortress scooter which showed significant elastic deformation as the occupant loaded the front of the seat. Based on product evaluations and tests of multiple scooter models, a third respondent believes that the cantilevered seat design on the seat pedestal or post virtually guarantees large bending moments in crash situations, both when the occupant accelerates forward and on the rebound.

4.7 ISSUE #7: LACK OF INDEPENDENT SECUREMENT AND OCCUPANT RESTRAINT SYSTEMS

4.7.1 Discussion

Although not strictly limited to the securement and restraint of scooters and their occupants, this issue is of particular concern and importance to warrant its discusssion here. As discussed in Section 3.3, one of the basic principles in crashworthiness design applied to mobility aid securement on vehicles is to ensure independence between the mobility aid securement system and the occupant restraint system to minimize any possibility that the mobility aid imposes loads on the occupant during vehicle impact (Kooi and Janssen,1988; Schneider, 1990). The transfer of the mobility aid inertia to the occupant's body would create serious injury-causing, possibly fatal, loads on the pelvis and chest of the mobility aid user during the crash. To assure no mobility aid inertia loads on the occupant's body, the forward motion of the mobility aid user must exceed the forward motion of the mobility aid (Bauer and Reger, 1992; Society of Automotive Engineers, 1995). SAE recommends for tests of **MASOR** systems that the ratio of the excursion of the ATD's knee to the excursion of the mobility aid exceed 1.1 (Society of Automotive Engineers, 1995).

The UK Code of Practice, Canada's draft standard for **MASOR** systems, and SAE's draft recommended practice for 'wheelchair tiedown and occupant restraint' (WTOR) systems all, for the reason stated above, recommend functional independence of the two systems, with each anchored separately to the vehicle structure. In response to NHTSA's rule amending FMVSS 222, *School Bus Passenger Seating and Crash Protection*, to require that buses transporting persons with mobility aids to be equipped with mobility aid securement devices and occupant restraint systems meeting certain performance requirements, the Washtenaw Michigan Intermediate School District, Thomas Built Buses, The Massachusetts Department of Public Health, and the American Occupational Therapy Association all endorsed the concept of having the mobility aid secured independently of the occupant.

The occupant restraint should not be designed with anchorages intended to rely on the mobility aid structure to transmit loads unless the **MASOR** is designed for a specific mobility aid and the combination of mobility aid and **MASOR** have been dynamically tested to ensure that the mobility aid structure remains intact and no excessive loads have been placed on the occupant by the mobility aid (Society of Automotive Engineers, 1995). Another reason for having independent systems is that the material strength requirements and dynamic design loads that each system must sustain are substantially lower than for a combined or integrated system in which the mass of the occupant is coupled to that of the mobility aid, and the combined mass must now be restrained by a single system. NHTSA requires, for example, that a specified load of 13.3 kN (2993 lbf) for each system (i.e., mobility aid securement device, and occupant restraint system) be applied **simultaneously** whenever a mobility aid securement device and an occupant restraint share a common anchorage, including occupant restraint designs that attach the occupant restraint to the securement device or the mobility aid. (Note: This is only a static test, which is all that is required under FMVSS 222).

Data from the technical community in response to this issue are summarized below in Figure 10.

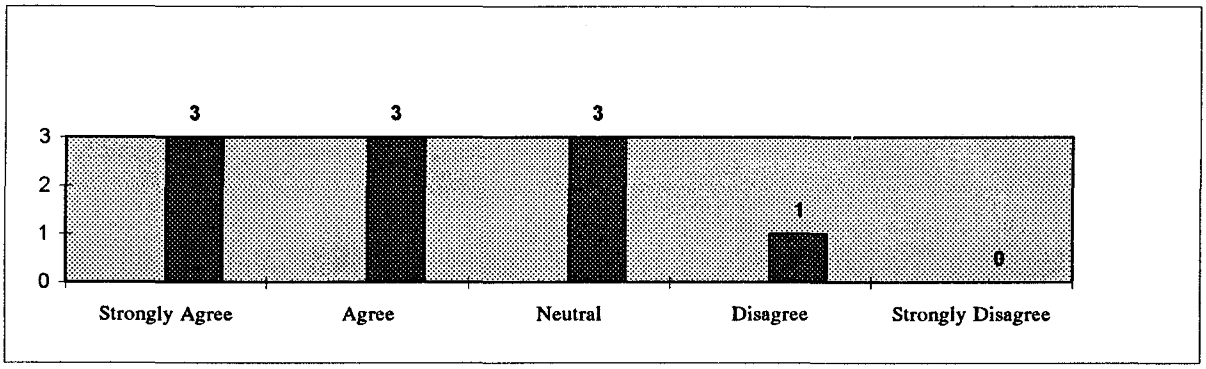


Figure 10. Technical Community Responses to Issue #7: Lack of Independent Securement and Occupant Restraint Systems

Source: Aggregate Data from Technical Community Data Collection Form

Sixty (60) percent of the technical community responses either strongly agree or agree that the lack of independent securement and occupant restraint systems may be a problem on buses and vans that transport mobility aid users. However, none of the technical community respondents could cite specific cases (i.e., specific transit systems, and specific **MASOR** systems that are implicated).

At least two respondents argued that integrated systems are preferable, provided the integrated system as a whole has been tested using a standard frontal crash (delta V 30 mph/ 20 g). Q'Straint^{tm} is such an integrated system (the lap belt is attached to the rear tiedowns) that has passed a standard dynamic frontal crash. Similarly, Kinedyne states that when using its Integrated Lap Belt (FE200595) or its Integrated Combination Belt (FE200727) with its Series L Mobility Aid Securement Systems (FE514 or FE517), only the heavy duty Series L Track (FE744-01 or FE748-01) shall be used for the floor track since only that model has been subjected to and has passed a standard dynamic frontal crash test (Kinedyne, 1994). Another advantage of integrated systems is that when the lap belt is attached to the rear securement tie-downs, the attachment point moves with the extension of the securement tie-downs under load, thereby preventing any transfer of load from the mobility-aid to the occupant (Little, 1990).

One respondent stated that although the concept of independent securement has been thoroughly discussed and has been accepted by most crashworthiness experts, achieving true independence is not straightforward. Many frontal crashes, including those conducted by this respondent, indicate that the measured forces on the rear attachment points are generally higher than estimates based on sled and scooter decelerations. Rear attachment loads have been as high as 3000 lbf (13.4 kN) for each separate rear attachment; tests on Q'Straint[tm] 's integrated system showed even higher forces. These unusually high forces imply that some coupling of the occupant and the mobility aid has occured, even for tests of nominally independent securement and occupant restraint systems.

4.8 ISSUE #8: PROLIFERATION OF SCOOTER MODELS THAT ARE INCOMPATIBLE WITH SECUREMENT SYSTEMS

4.8.1 Discussion

There are many different models for mobility aids driven by the need to satisfy the functional and personal needs of a very diverse population of users. A mobility aid is a substitute for ambulation for the user and is necessary for the user's basic existence (Brenner and Giangrande, 1981). Many mobility aids are prescribed by a clinician (e.g., occupational or physical therapist). From a clinical perspective, the individual's muscular strength, coordination and stability, posture, or ancillary medical problems may dictate the proper 'fit' of the mobility aid to the individual. A review by one investigator of wheelchair data derived from product brochures, catalogs and safety manuals concluded that there is no standard size or configuration or type (Khadilkar, 1986); Everest and Jennings, one of the largest manufacturers, lists over one hundred and fifty (150) different models (Khadilkar, 1986), including:

- adult chairs in standard, large, narrow and tall variations;
- hemiplegic and amputee versions;
- junior and children sizes;
- special back-support models;
- manual driven and power driven chairs.

Any of these models can be purchased with options, such as:

- fixed, adjustable, and specialized types of footrests;
- standard, desk, folding, detachable and other types of armrests;
- spoked, cast and plastic wheels;

- a variety of sizes of wheels;
- conventional, wide, balloon and other types of tires;
- deluxe or basic construction.

At least fifty (50) scooter models, all differing in critical dimensions, are currently sold in the marketplace (ECRI, 1991).

As part of a Project Action investigation, project staff at the Cleveland Clinic Foundation also conducted a systematic review of wheelchairs and scooters, and developed a data base of more than one hundred and fifty types with several sizes for each type (Bauer and Reger, 1992; Transit Cooperative Research Program, 1994). They also concluded that none conform to a standard geometry, lacking conformity even for the frame and a set of identifiable attachment points.

Participants at the National Conference on Wheelchair Securement in Transit Vehicles commented that new mobility aid designs and modifications are developed without taking into consideration the fact that the mobility aids are being used as seats in a variety of transportation systems, and at an increasing rate. Many of these designs are not suitable for use as vehicle seats because of unsound structures, or unsuitable design (Fisher, Seeger and Svensson, 1987; Australian Standard, 1994).

It was also noted that securement and restraint systems are also designed without taking into consideration new designs in mobility aid construction (Brenner and Giangrande, 1981). None of the currently available restraint systems used in public transportation were designed to accommodate new design manual mobility aids or powered scooters, since these designs only started to influence the market after 1986 (Layton, Hunter-Zaworski and Safford, 1989). Certain types of securement systems (e.g., Rim pin, T-bar, Frame clamps) are unuseable with scooters (see Section 2.2). The covered cowlings on scooters often make belt securement systems difficult to attach to the scooter (also, see Section 4.1). Securement and restraint systems that are effective in securing the mobility aid and protecting the occupant in a standard frontal crash (delta V 30 mph/ 20 g) for one type or size of mobility aid may not be equally effective with a different type or even same type but different model of mobility aid (Schneider, 1990). Schneider (1990), citing previous dynamic tests with scooters, noted that no securement system has been found effective at the delta V 30 mph/ 20 g force level due to either failure of the seating system (also, see Section 4.5 and 4.6) or failure of the tie-down hardware. The latter failure is due to the relatively large mass of the scooter generating forces that exceed the strength of the securement hardware.

Only recently have standards been proposed to address the safe transport of mobility aids (Canadian Standards Association, 1994). American National Standards Institute (ANSI), and the Rehabilitation Engineering Society of North America (RESNA), in a joint effort, are in the very early stages of defining a transportable mobility aid standard, similar in concept if not specifics to the draft Canadian standard (CAN/CSA-Z604), for the United States. Standards of this type are difficult to formulate because of the many different types of mobility aids available, and the conflicting requirements that dictate their particular designs. It has been suggested that one of the items that would be relatively easy to standardize in this context concerns the parts on the mobility aid to which the securement systems can be attached (Kooi and Janssen, 1988; Wevers, 1992). Kooi and Janssen (1988) have also suggested that color marking of the attachment points on the mobility aid would help contribute to the correct use and safety of **MASOR** systems (also, see Section 3.1).

One of the primary conclusions of an evaluation documenting the prototype development and field test of a specific Caltrans Wheelchair Safety Securement System (CWSSS), bearing on this issue of the proliferation of mobility aid designs and the incompatibilities between these designs and securement system designs, recommended that no further development of the system be made *until a greater degree of wheelchair frame standardization exists* (Maxwell, 1986). That study found two types of incompatibilities: 1. bracket incompatibility (mobility aid cannot be retrofitted); and 2. device incompatibility (mobility aid can be retrofitted, but is incompatible with the securement device). Only twenty to twenty-five (20-25) percent of the mobility aids transported by public transport were found to be compatible with the CWSSS. Even "universal design" securement systems, in particular the Oregon State University (OSU) system and the Cleveland Clinic Foundation's system, each of which was successful in securing a specific scooter model, are subject to the same types of incompatibilities which can only worsen with the proliferation of new nonstandardized designs. This is why neither "universal design" system is likely to be widely adopted. The CWSSS evaluation concluded, and this author agrees, that without some degree of mobility aid standardization for transportability on vehicles, it is highly unlikely that any standard securement system can be designed to replace belt securement systems (Maxwell, 1986; Garland and Dorion, 1989; Dalrymple, Hsia, Ragland and Dickman, 1990; Cheng, Werner, Vogler, Jewett and Carnell, 1993).

Data from the technical community in response to this issue are summarized below in Figure 11.

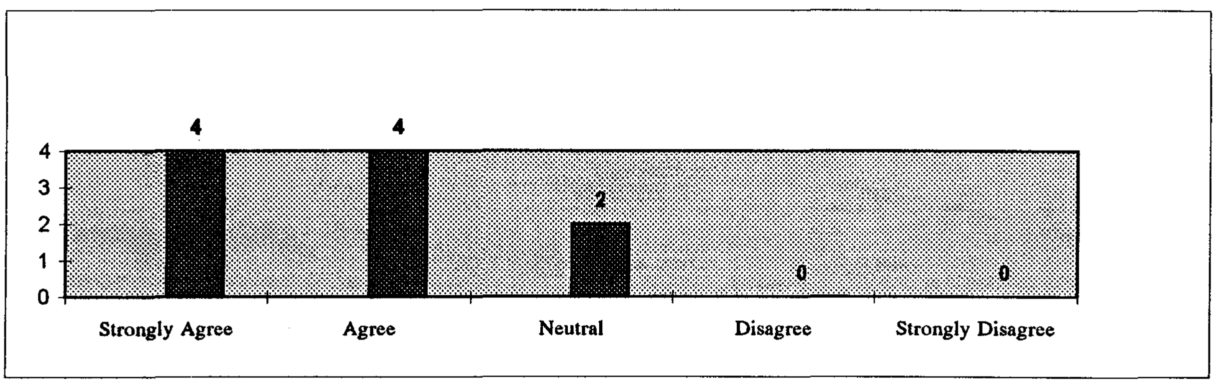


Figure 11. Technical Community Responses to Issue #8: Proliferation of Scooter Models Incompatible with Securement Systems

Source: Aggregate Data from Technical Community Data Collection Form

Eighty (80) percent of the technical community responses either strongly agree or agree that the proliferation of new scooter designs poses a major incompatibility problem with **MASOR** systems. One respondent commented that incompatibility is a problem across the board, not just with new models. Another respondent suggested that manufacturers should be encouraged to dynamically test their mobility aids with a **MASOR** system of their choice. Those that pass would be allowed to display a sticker, similar to the SNELL and DOT stickers that are used for bicycle and motorcycle helmets respectively. In this way, proliferation of untested and incompatible designs with be kept to a minimum, if not totally eliminated. Another respondent pointed out that a **MASOR** is typically designed to be compatible with a general class of mobility aids with similar physical characteristics. When these characteristics are not present, it is difficult to utilize the system effectively. This is the reason why the draft SAE Wheelchair Tiedown and Occupant Restraint (WTOR) standard specifies design and location of securement points. The ANSI/RESNA Transport Wheelchair Working Group is beginning activities to define securement point location and design on wheelchairs. Hopefully, the scope of this effort will include all types of mobility aids, including scooters.

4.9 ISSUE #9: ELASTIC DEFORMATION OF THE SCOOTER PLATFORM IMPARTING LARGE VERTICAL EXCURSIONS AND VERTICAL ACCELERATIONS

4.9.1 <u>Discussion</u>

Because of the angularity of securement and restraint belts, it is known that vertical loads on the occupant and the mobility aid are imposed in a frontal crash. The occupant's load is additive to that of the mobility aid. The only way to determine whether there is elastic deformation, however, and whether it can impart a large vertical excursion and acceleration to the occupant of the scooter in a frontal crash is to measure both in an actual crash, or in a simulated crash using a dynamic sled test. It has been noted that some crash characteristics can only be known from actual crash tests (Hunter-Zaworski, 1990). BC Transit has conducted the only known (at least to this author) actual crash tests involving the transport of mobility aids, using accelerometers and high-speed video as measurement instrumentation.

Three different wheelchairs and thirteen scooters of seven different models were crash tested in seven paratransit vans and one full-size transit bus. The paratransit vans used a 100-ton barrier target in six tests and the transit bus as a target vehicle in one test. All tests, including the van/bus crash, were head-on. The first test was a delta V 25 mph/ 30 g impact, while the remaining six tests were delta V 20 mph/ 30 g impacts. Because of the stiffness of the vans, with very little crush deformation on impact, peak g's were greatly accelerated beyond nominal values, in the range of 50 g.

BC Transit reported the following results from these tests (Little, 1990): In general, the securement strap angularity was in the range of 30° to 45° to the floor of the van, and the downward component of the strap tension was sufficient in many cases to compress the scooter structure and suspension to the point where the underside of the scooter platform was in contact with the floor, or nearly so. Because of low ground clearance, compression of the platform base for ground contact need be only two (2) to four (4) inches for most scooter models. In the case of a scooter weighing no more than 45 kg (100 lb), experiencing an impact not over 20 g would involve a downward load of the order of 4.4 - 8.8 kN (1000-2000 lbf), depending upon securement strap angle. This structural compression was predominantly elastic, and the rebound as the compression and bending energy was released was sufficient to launch some of the scooters off the floor of the van to heights varying up to as much as ten (10) to twelve (12) inches (25-30 cm), accompanying by pitching.

In the high-speed video sequences, angular movement of the handlebar post gave an indication of the large elastic deformation experienced by the scooter platform. The other main source of compression energy that contributed to the vertical rebound was the tires. During the rebound, the upward velocity of the ATD was sufficient to separate it from the seat. This may have contributed to the rearward flexure of the dummy when it came back down into the seat at the end of the rebound. Both the rebound and rearward flexure were thought to be severe enough to cause serious injury or fatality to the occupant.

Further evidence of the elastic nature of the scooter platform for most models was indicated by the test results of one run in which the rear wheel and axle deformed from the compressive load, damaging them sufficiently to release the compression energy before the vertical rebound developed. That scooter model had a more rigid monocoque structure, in contrast to the other models. As a result of all these tests, BC Transit concluded that control of compression energy is essential to prevent tethered flight of the scooter; further, the scooter and occupant displacements observed would be sufficient to cause interference between adjacent scooters and occupants, other passengers on the vehicle, and with the vehicle structure.

In a dynamic frontal crash test of a Burke Mobility Scooter (delta V 30 mph/ 20 g), the sequence of events noted from the video indicated that the seat post attachment bracket buckled and the ATD and the seat were pulled downward, followed by the rebound, with maximum head excursion and continued ATD rebound at 0.1 seconds after initial acceleration of the sled (Biokinetics, 1991). A frontal crash test (delta V 20 mph / 10 g) of a Mobie II scooter, with the Oregon State University (OSU) "universal design" Independent Locking Securement System (ILSS), however, indicated very little motion of the scooter through the course of the crash, including upwards motion resulting from both the crash and the rebound of the compressed wheels. This was thought to be particularly significant because the design of the ILSS uses only a rigid attachment at the rear of the mobility aid (i.e., no front attachment restraints to prevent excessive rebound), relying on the rear attachment point being slightly above the center of mass of the mobility aid for stability during a crash (Hunter-Zaworski, Zaworski and Clarke, 1992). The ILSS crash test is indicative of forces generated in a crash for a large transit bus, but not representative of crash forces involving a small paratransit bus or van.

Assessment of an Everest and Jennings "Carrette" scooter under severe driving conditions indicated that roll angle and displacement of the scooter were very sensitive to scooter tire pressure as well as tie-down pretensioning (Mercer and Billing, 1990). A combination of these two variables, within the bounds of the severe driving tests, almost doubled the roll and displacement response of the scooter, supporting the findings of BC Transit concerning the elastic rebound of the wheels as one contributing factor to large vertical excursion and acceleration.

Data from the technical community in response to this issue are summarized below in Figure 12.

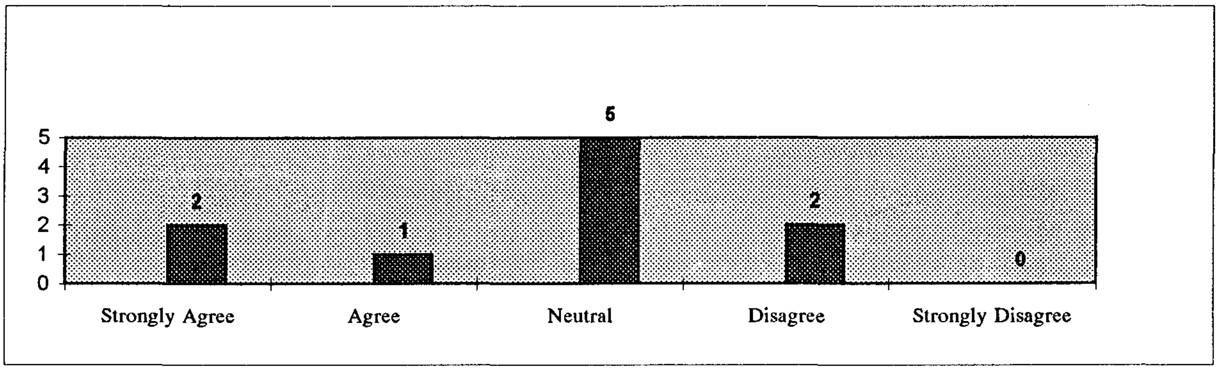


Figure 12. Technical Community Responses to Issue #9: Elastic Deformation of the Scooter Platform Imparting Large Vertical Excursion and Acceleration

Source: Aggregate Data from Technical Community Data Collection Form

Only thirty (30) percent of the technical community responses either strongly agree or agree that scooters in a frontal crash elastically deform, resulting in large vertical excursion and acceleration of the occupant on the rebound. It is interesting to note that this issue had the least unanimity of opinion, with the largest number of responses indicating a neutral opinion because of no direct knowledge of this phenomenon. One respondent commented that only through instrumented testing could this phenomenon be known. Another respondent did not find any evidence of it in tests that he conducted. A third respondent thought that it was not an issue. Several, however, cited the BC Transit tests, which as described above, were strongly in agreement that the current designs of scooters do not mitigate against elastic deformation in a crash environment.

4.10 ISSUE #10: ROLLOVER AND TIPPING INSTABILITY OF SCOOTERS

4.10.1 Discussion

Small diameter wheels and a tricycle geometry make scooters inherently more unstable than other mobility aids (Layton, Hunter-Zaworski and Safford, 1989; Haynes, Stroud and

Thompson, 1986). Comparison of the turning radius of a powered scooter vs a powerbase wheelchair, when moving at a given speed either under its own power or when transported on a vehicle, indicates that the required radius of curvature to prevent rollover, for any given speed, is 2.5 times higher for the tri-wheeled scooter (Haynes, Stroud and Thompson, 1986).

The higher seating height of the scooter occupant results in a combined center of gravity (CG) of the occupant and scooter which is higher than for other mobility aids; this increases the tendency of the scooter to rollover under lateral acceleration. The reactive forces through the wheels are not large enough to balance the tipping moment produced when the scooter is subjected to horizontal forces experienced by the scooter when on a vehicle that is traversing a curve. The tests cited below of a scooter on a vehicle operating under extreme driving conditions confirms this behavior. The height of the occupant above the platform base and the cantilevered design of the seating system also tends to produce a tipping moment in the fore-aft axis of the scooter. In a survey of thirty-eight (38) transit systems nationwide to determine their accessibility policies, problems, and solutions, fourteen (14) of the twenty (20) responses received reported having significant problems and safety concerns with the top-heaviness of tri-wheeled scooters (Hunter-Zaworski, 1990).

Static vertical stability is a function of the length and width of the platform, measured by the distance between the rear axle and the front wheel, and the rear axle length, respectively (ECRI, 1991; Hunter-Zaworski, 1990). The longer and narrower the scooter, the less stable it is. Tests of static stability conducted by ECRI showed that the tri-wheeled scooter models had a maximum tilt angle range between 10° - 14.5° before sideways slippage compared to tilt angles greater than 20° for four-wheeled scooter models (ECRI, 1991).

Four-point attachment of the securement system to the scooter, and with the proper side angles, is critical to preventing the scooter from tipping backwards during the rebound phase in a frontal crash (Hunter-Zaworski and Ullman, 1992; Bauer and Reger, 1992) (also, see Section 4.4).

During a series of tests using a typical scooter, with a seated rider and a typical tie-down system, the results of the severe driving tests involving lateral acceleration (the tests included a double lane change maneuver, a spiral turn, a constant radius turn and a J-turn) showed the following: the base of the scooter moved up to 2.25 cm (1 inch) laterally, and the upper portion of the seat moved up to 18 cm (7.2 inches) laterally, from an initial upright position. The upper portion of the scooter and the ATD swayed large amounts under lateral loads, and the ATD came very close to the inner wall of the vehicle at various times. The frequency and amplitude of the swaying motion might, in the long-term, give rise to complaints by seated riders about the ride quality of the vehicle, *even though it is almost entirely due to the characteristics of the scooter* (Mercer and Billing, 1990). It was also noted that in all the tests the rider was restrained, and the scooter and rider returned close to their original positions.

Similar extreme-condition driving tests (0.35 g lateral acceleration during a turn) conducted by Oregon State University (OSU) for its Independent Locking Securement System (ILSS) showed that while the ILSS could halt the tipping motion of a Mobie II scooter (with a rider approximating a 95 percentile male), nevertheless the rear wheel of the occupied scooter had a vertical displacement of three-fourths (3/4) of an inch from contact with the vehicle floor. There was, however, no sideways motion or slipping of the scooter in any of the maximum rate turn tests (Hunter-Zaworski, Zaworski and Clarke, 1992). The scooter and securement system were compliant with the ADA limits on displacement during normal driving conditions.

Data from the technical community in response to this issue are summarized below in Figure 13.

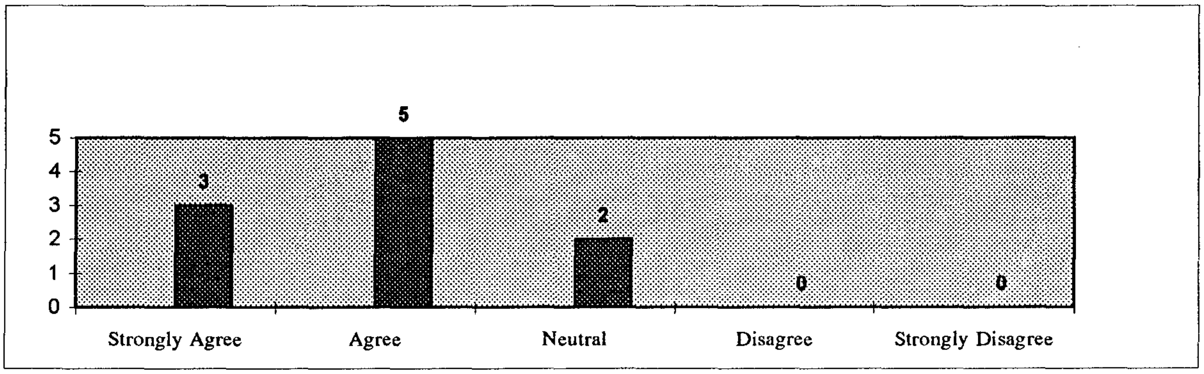


Figure 13. Technical Community Responses to Issue #10: Rollover or Tipping Instability of Scooters for Side-Impact Crash and Extreme Cornering Events

Source: Aggregate Data from Technical Community Data Collection Form

Eighty (80) percent of the technical community responses either strongly agree or agree that side-impact crash and extreme vehicle cornering events are likely to produce rollover and/or tipping of scooters due to the inherent instability of the tri-wheeled scooter. Two respondents stated that good **MASORS** and four-point attachments should minimize this problem. One respondent commented on the need for additional laboratory tests to develop appropriate standards, noting that very little useful work to date has been done on this issue. One respondent stated that docking type systems that secure the mobility aid down low may present more of a problem in this regard for scooters. One respondent commented that **MASORS** are designed to protect against frontal impacts. Side impacts are just starting to be looked at for vehicles. Although dealing with this issue for side-impact crashes may be premature, the issue of stability of the scooter on a vehicle subject to normal and extreme driving dynamics is relevant. One respondent felt that the two inch (5 cm) excursion limit under normal driving conditions permitted under ADA rules should ensure stability of the scooter on the vehicle.

4.11 OTHER ISSUES

Several other issues related to the transport of scooters and their occupants on public transit buses and vans were raised by the technical community. The list below simply summarizes the additional comments provided by technical respondents, with the exception of the last two issues for which we provide additional elaboration. These issues are:

- The need for a universal interface between scooter technology (platform bases) and docking-type (vehicle) securement systems.

- Failure of the scooter manufacturers to design for transportability (i.e., lack of attachment points), including designing for crash conditions.

- The potential for scooters to jump or climb over lift-edge barriers.

- Proper location and adjustment of the shoulder belt anchorage for occupants of scooters (who ride higher than other mobility aid users who also do not transfer to the vehicle seat).

- The size (too short) of the ADA specified mobility aid bay for most scooters.

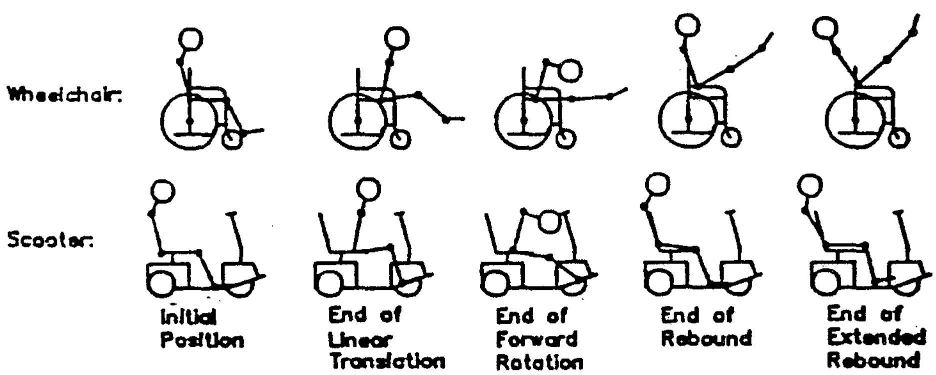
- The platform lifts, which are not designed to accommodate scooters: 1. the lifts are not long enough. Although transit operators are only required to transport mobility aids that fit the 30" x 48" envelope, in reality this results in either the rejection of most scooter models or a hazardous situation when the operator errs in the judgement of size. 2. no guard rails are present to protect against rollover or tipping of the scooter due to its instability.

- The potential for spillage of battery fluids.

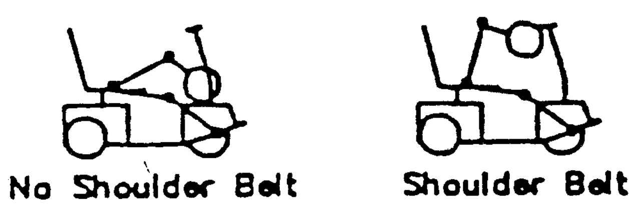
- Scooter occupant injury due to contact with the tiller in a frontal crash.

Potential spillage of battery fluid - If the battery of a scooter (or any powered mobility aid) uses a liquid electrolyte, any motion of the scooter from its upright position, arising from either crash conditions or extreme driving conditions (see Section 4.10), could rather easily result in spills involving acid burns to the scooter occupant and/or other passengers on the vehicle. A number of public school systems that transport children on buses and vans allow battery powered mobility aids, including scooters, only if the mobility aids use dry cell or gel-type batteries (Washtenaw, 1993; Portland, 1987). The American Academy of Pediatrics, Committee on Injury and Poison Prevention, strongly recommends gel-cell or dry- cell batteries for mobility aids that are transported on vehicles (AAP Safe Ride News, 1993).

Scooter occupant injury due to contact with tiller - The kinematics of a seated body in a wheelchair and in a scooter during crash simulation tests were studied by Adams, Sauer and Reger (1992). The results were obtained by an analysis of body motion using high speed cinematography taken during crash simulation tests (with a Hyge Impact Simulator) using various restraints on the mobility aids and a seated, instrumented ATD. The four phases that were identified are graphically depicted in Figures 14 (a) and 14 (b), for a wheelchair and scooter, with and without an occupant shoulder belt. Because of the angularity of the tiller, and the fact that it impinges on the Frontal Clear Zone (FCZ) that is critical to accommodate any forward motion of the occupant (SAE recommended dimension is 650 mm with upper torso restraint, and 950 mm when only pelvic restraint is used), it is clear that even with shoulder belts for the scooter occupant that serious head and chest injury is probable.



(a) Kinematics of a seated body in a restrained wheelchair during a simulated vehicle crash. Lap and shoulder belts are applied.



(b) Effect of a shoulder belt in limiting forward chest motion.

Figure 14. Occupant Kinematics in a Crash Event

Source: Adams, Sauer and Reger (1992). Reprinted with permission from authors.

5. COMPARATIVE REVIEW OF STANDARDS

This section focuses on a comparative review of standards, both draft or proposed and adopted standards. The scope of this section, however, is limited solely to mandatory and advisory guidelines related to the type of mobility aid allowed, and any performance requirements and restrictions that relate specifically to the securement and restraint of scooters and their occupants. For a more general comparison of national and international standards, refer to Karg, Yaffe, and Berkowitz (1994), Dalrymple, Hsia, Ragland and Dickman (1990), Hunter-Zaworski (1989), as well as the latest versions of the standards.

Americans with Disabilities Act (ADA)(1990) - Section 1192.23 (d) (3) states that the securement system shall secure common wheelchairs and mobility aids and shall either be automatic or easily attached by a person familiar with the system and mobility aid and having average dexterity. Under Subpart A - General - *common wheelchairs and mobility aids* are defined as belonging to a class of three or four wheeled devices, usable indoors, designed for and used by persons with mobility impairments which do not exceed thirty (30) inches in width and forty-eight (48) inches in length, measured two (2) inches above the ground, and do not weigh more than six hundred (600) pounds when occupied. Accordingly, transit systems, under the ADA, must transport tri-wheeled scooters provided they comply with the dimensional envelope, and the combined weight of the scooter and occupant does not exceed the weight limit of six hundred (600) pounds.

The dimensional envelope and weight limits were established by the Access Board to include the vast majority of mobility aids in use. Accessibility was the sole objective, not whether the mobility aid could be secured on the vehicle nor whether the mobility aid, once secured, could withstand crash level forces that could reasonably be expected given the operating mode of the vehicle (e.g., 10 g for fixed-route, large bus operations; and 20-30 g for demand-responsive, small van operations).

Australia AS 2942 (1994) - The Australian standard is the only standard that identifies explicitly certain types of mobility aids that are considered, under the standard, to be undesireable for use in vehicles, owing to potentially hazardous projections, unsuitable seating height, weak frame components or supporting surfaces, unsuitable battery position, or means of restraining the battery. Specifically listed and identified in a graphic figure are scooter-type wheelchairs with front projection (AS 2942, Appendix A, 1994). The list of mobility aids and the *Guidelines for Users of Wheelchair Occupant Restraint Assemblies (Appendix A)*, however, are only advisory, being contained in an informative appendix only.
According to the preface of the 1994 standard, the earlier 1987 version of the *Guidelines* was amended as its recommendations were subject to misinterpretation, resulting in refusal to permit a mobility aid occupant to travel in a vehicle in their usual mobility aid. The 1994 version has been changed to recognize that a mobility aid that best serves the overall needs of its owner may not be ideal for restraint in motor vehicles, and that prohibiting the use of such mobility aids in a vehicle is not practical despite some additional risks of injury (AS 2942,

1994). Restriction of scooter type mobility aids could still occur, however, if no securement system, attached to the scooter, can pass the dynamic front, side and rear impact tests required under the standard.

United Kingdom Code of Practice (1987) - The UK Code of Practice adopts a concept very similar to the *common wheelchair and mobility aid* approach used under the ADA. The Code advises that a vehicle used for general purposes design accommodation for mobility aids around the dimensions of a Size A chair, specified in British Standard 5568:1978 for folding wheelchairs, as having overall dimensions of 1065 mm (41.5 inches) long by 660 mm (25.7 inches) wide. Approximately ninety (90) percent of wheelchairs in use in the UK fall within this envelope. No explicit consideration of accommodation, performance requirements, or restrictions is provided for scooters.

SAE Recommended Practice for WTORS (draft, 1995) - SAE's recommended practice defines a wheelchair as a seating system comprised of a frame, a seat, and wheels that is designed to provide support and mobility for persons with physical disabilities. It explicitly notes that this definition (and therefore applicability of the recommended practice) encompasses standard manual wheelchairs, powered wheelchairs, power-based wheelchairs, *three-wheel scooter-type wheelchairs*, and specialized seating bases. Like the Australian standard, SAE cautions against the provisions of the *Recommended Practice* from being used to discourage people with disabilities from using motor vehicle transportation or to limit access to, and availability of, motor vehicle transportation to mobility aid users.

Appendix F of the Recommended Practice, which at this stage is only advisory (i.e., informative as opposed to normative), provides for geometric guidelines for mobility aid securement points to ensure compatibility between the mobility aid and Wheelchair Tiedown and Occupant Restraint (WTOR) system hardware. The guidelines apply either for securement points that are integral to the frame structure, that is, OEM design, or to securement add-on components that are retrofitted to mobility aids in use. These guidelines, if adhered to by scooter manufacturers, would greatly facilitate engagement and disengagement of securement systems to the scooter, and ensure proper location and angle for securement. SAE briefly refers to ongoing ANSI/RESNA activity to define design and performance standards for the mobility aid, in contrast to standards and/or recommended practice for the design and performance of **MASOR** systems.

Canada, CAN/CSA-Z604, Transportable Mobility Aids for Occupancy in Moving Vehicles (draft, 1994) - The Canadian 'standard', which is only a draft proposal at this point and not an official standard, is the first such effort to prescribe a performance envelope along multiple dimensions to determine the suitability of mobility aids for transport on a moving vehicle. It recognizes that few current models can comply immediately with its requirements, and expects that it will take time before models of mobility aids appear in the marketplace that do comply with the standard.

The standard, according to its preface, is based on the current best practice for mobility aids, including manual wheelchairs, powered wheelchairs, and *scooters*, with respect to safety, including crashworthiness, as it existed on the date of publication. Safety, according to the standard, is the safe conveyance of all persons inside the vehicle; crashworthiness is the ability of the mobility aid to withstand the stresses of a frontal impact to the transporting vehicle without presenting undue risk to mobility aid or other vehicle occupants. The standard only applies to vehicles less than 10,000 kg GVW.

To get an idea of the encompassing nature of the performance envelope, we list the items below:

- General
- Overall dimensions
- Ground clearance
- Escort handholds
- Flammability
- Corrosion protection
- Parking brake
- Dynamic brake
- Stability
- Obstacle climbing
- Attachment points
- Compatibility with occupant restraint system
- Dynamic crashworthiness

The standard recognizes two types of mobility aids that can be compliant with the standard, Type O and Type V which are defined, respectively, as a mobility aid which is intended to be transported while occupied (and in a forward-facing orientation), and a mobility aid which is intended to be transported unoccupied (vacant). The standard, however, only implicitly defines each type by the tests which the mobility aid passes and fails. For example, a scooter when tested with an ATD that passes the securement-related tests but fails at least one of the excursion and force loading limits for the ATD would presumably be classified as a Type V mobility aid. Conversely, another model of a scooter that passes all tests, including those related to the ATD (thereby simulating the scooter occupant), would qualify for and be classified as a Type O scooter model.

6. ACCIDENT DATA AND THE QUANTITATIVE MEASUREMENT OF RISK

The collection of accident data and its analysis for the purposes of measuring the effect of safety countermeasures, or setting a minimum crashworthiness standard, or the initial quantification of safety risk is neither trivial nor an academic exercise. The Federal Motor Vehicle Safety Standards (FMVSS) issued by US DOT/NHTSA, unless supported by the best possible science on force loadings, the kinematics of vehicles and occupants, the biomechanics of injury and the estimation of the injury-reducing effect of a given standard, are subject to petitions for reconsideration which would probably prevail. With no rational basis for a standard, the governmental action to enforce it would be deemed arbitrary and capricious, a constitutional violation of the due process clause.

Under the Americans with Disabilities Act (ADA) of 1990, and Section 504 of the Rehabilitation Act of 1973, discrimination against persons with disabilities in programs, services, and facilities (public and private) is disallowed unless an individual poses a "direct threat" to the health or safety of others. A "direct threat" is a significant risk to the health or safety of others that cannot be eliminated by a modification of policies, practices or procedures, or by the provision of auxiliary aids or services. Any change to the ADA Final Rule by the US DOT that might introduce a safety or crashworthiness contraint on the transport of common wheelchairs and mobility aids must take heed of the test set forth by the US Supreme Court in *School Board of Nassau County v. Arline* (480 U.S. 273, 1987), which was also reiterated by the US DOJ in its Final Rule implementing Title III, Public Accommodations, under the ADA. The Court, reiterated by the US DOJ, have stated that the determination that a person poses a direct threat to the health or safety of others may not be based on generalizations or stereotypes about the effects of a particular disability. It must be based on an individualized assessment, based on reasonable judgement that relies on medical evidence or on the best available objective evidence, to determine: the nature, duration, and severity of the risk; the probability that the potential injury will actually occur; and whether reasonable modifications of policies, practices, or procedures will mitigate the risk (FR Vol. 56, No. 144, Friday, July 26, 1991; *School Board of Nassau County v. Arline*, 480 U.S. 273, 1987). In other words, alleged liability problems of transporting scooters and their occupants by a single transit system, or even by multiple transit systems, unless substantiated by objective evidence, would fail to meet the test as set forth by the US Supreme Court were the US DOT to solely rely on that testimony in amending the rule.

An ideal assessment of risk as it relates to the transport of scooters and their occupants should consider two basic comparisons: the relative risk of serious injury or fatality to scooter occupants in a crash impact versus occupants of mobility aids other than scooters; and the relative risk of serious injury or fatality to scooter occupants in a crash impact versus other seated passengers. A third comparison, which lumps all mobility aids including scooters together, and compares the incidence of serious and fatal injuries to mobility aid occupants versus other seated passengers may also be quite informative. Either a comparative retrospective study should be made, based on the random sampling of accident events for fixed-route operations and paratransit operations, taken separately; or a comparative prospective study, tracking accident outcomes in the future, having randomly preselected the transit systems to be followed. In theory, a comparative retrospective study could be undertaken now, although the rareity of accident events probably would require the pooling of several years of data to increase sample sizes. A prospective study would have to wait to 1997 to begin, when ADA implementation is complete, because transit usage (and therefore exposure) by mobility aid users is not stable or constant.

The most widely accepted metric for comparing relative risk (i.e., the three comparisons referenced above) is to compute the sample odds ratio (Fleiss, 1981). The odds ratio is equal to one (1) if there is no differential risk, and not equal to one if there is a difference. Table 12 illustrates how the data might be organized for a comparative retrospective study.

Table 12. Association between Serious and Fatal Occupant Injury and Seating System Design: Comparative Retrospective Study Fixed-Route Transit Operations

Occupant Outcome	Seating System Design Scooter A	 OEM Seat A'	Total	Proportion Using Scooter Seating System
Serious and Fatal Injury (AIC > 2) B	n_{11}	n_{12}	$n_{1.}$	$n_{11} / n_{1.}$ (= P(A|B)
Uninjured (AIC< 2) B'	n_{21}	n_{22}	$n_{2.}$	$n_{21} / n_{2.}$ (=P(A|B')
Total	$n_{.1}$	$n_{.2}$	$n_{..}$	

The odds ratio calculation is illustrated below in Table 13. It should also be noted that, like any statistic, both a standard error and a 95 percent confidence interval can also be calculated.

A comparative retrospective study, such as is outlined above, is not readily done. None of the US DOT/NHTSA national databases (e.g., GES, FARS, NASS) have the requisite level of detail to address these questions. It may be possible from a combination of motor vehicle police report records, locally-collected transit system accident records, and insurance claim records.

Another reason mitigating against undertaking this type of study is that, fortunately, the general incidence of serious and fatal accidents involving mobility aids irrespective of whether on a motor vehicle or not is quite low. Only 3.3 percent of all mobility aid users have a serious wheelchair-related accident each year, the vast majority being falls from the

Table 13. Comparative Risk of Scooter vs. OEM Seating System Design: Calculation of the Odds Ratio

Scenario	Odds Ratio
Scooter v. OEM Design	$o = P(A|B) \times P(A'|B') / P(A'|B) \times P(A|B')$
	$= (n_{11}n_{22} / n_{12}n_{21})$

mobility aid at home or in a public institution (Calder and Kirby, 1990). An analysis of fatal mobility aid accidents indicated that only one (1) fatality, representing 0.1 percent of the seven hundred and seventy (770) fatal mobility aid accidents identified nationally from 1973-1987, were on a vehicle (Calder and Kirby, 1990). Using data from the National Electronic Injury Surveillance System from the National Information Clearinghouse of the Consumer Product Safety Commission, Richardson (1991) was able to calculate national estimates of mobility aid occupants injured in motor vehicle-related accidents, by type of mobility aid accident and body type of motor vehicle. He found that only two thousand, two hundred and two (2202) accidents, representing 1.5 percent of all mobility aid accidents (148,671) during 1986-1990, involved improper securement. However, improper securement of the mobility aid/occupant represented almost sixty (60) percent of the four categories of motor vehicle-related accidents for which he calculated the national estimates (hydraulic lift; securement; fell off ramp; and transferring to/from the vehicle). The vast majority of mobility aid users (87 percent) were either examined and released without treatment, or had minor and moderate injuries. We collected the same data as Richardson, but for the years 1991-1993, giving the following corresponding results: one thousand, one hundred and thirty three (1133) improper securement-related accidents, representing 0.6 percent of all mobility aid accidents (180,679) during 1991-1993. We note that the number of improper securement-related accidents fell relative to the expected number for the smaller three year period, possibly due to both a "regression-to-the-mean" effect and more emphasis on operator training after ADA implementation. However, the estimate of the total number of mobility aid accidents during the three year period almost doubled relative to its expected value, a result that remains unexplainable.

An analysis of insurance record claims for accidents involving paratransit vehicles by a major insurance agency that insures transit systems indicated that in 1992 only twenty-nine (29) accidents involved an improperly restrained mobility aid/occupant, representing 4.1 percent of all its accident claims (TD Safety Report, 1994). However, it was noted that these mishaps are the most expensive, averaging $32,000 per occurence.

As part of the request for data from the "key actor" groups, we included a common question, across all groups (see Table 14), that asked for descriptive statistics for accident events involving scooters. None of the ten (10) technical community respondents had collected nor could they provide this accident data, nor did any conduct any accident analysis related to the transport of mobility aids, including scooters, on public transit buses and vans (Technical Community Respondents, 1995). Likewise, securement and scooter manufacturers also did not provide any of the data in Table 14. Mobility aid users were asked similar information for accident events in which the respondent had personal knowledge because he/she was a party to litigation arising from the accident. Only one respondent could provide such information; but the sample of respondents was extremely small (14).

Table 14. Summary of Sample Accident Events Involving Scooters Transported on Public Transit Buses and Vans (Number of Events in Sample)

Total Number in Sample	_____
a. the crash event was frontal	_____
b. the securement system failed	_____
c. the scooter deformed	_____
d. the scooter excursion exceeded 2" in any direction	_____
e. the scooter occupant was injured/killed	_____
f. the battery pack separated	_____
g. the seat pedestal sheared or fractured	_____
h. the scooter tipped or rolled laterally	_____

Source: "Key Actor" Groups Data Collection Forms

6.1 SUMMARY OF CRASH AND NEAR-CRASH EVENT DATA BASED ON TRANSIT SYSTEM SAMPLE IN STUDY

Transit systems were also requested to provide data on accident/incident events involving all mobility aids, including scooters. Table 15, below, reports on the cumulative and average number of reported accidents/incidents (1990-1994) involving mobility aid occupant injury on

Table 15. Cumulative and Average Number of Reported Accidents/Incidents (1990-94) Involving Mobility Aid Occupant Injury on Buses and Vans in Public Transit Service by Size of System

	Cumulative Number	Average Number
Large System (> 1000 vehicles) (No. of Obs. = 13)	345	27
Intermediate-Sized System (500-1000 vehicles) (No. of Obs. = 4)	80	20
Small System (250-500 vehciles) (No. of Obs. =4)	33	8

Source: Aggregate Data from Transit System Data Collection Form

buses and vans in public transit service, by size of transit system. We caution that the information summarized in Table 15, and also subsequently in Table 16, apply only to this sample of transit systems, and should not be used to infer national estimates. Also, the data reported includes all mobility aid accidents/incidents, not just securement and restraint related. The data also suffer from a number of potential problems including: differing time periods between respondents; response bias, in which systems with few accidents/incidents provided detail characteristics (summarized in Table 16), whereas those with relatively large numbers of accident/incident events did not report details because of the substantial reporting burden in manually reviewing their files; and inconsistency between systems in reporting thresholds and the ability to track accident/incident events involving mobility aids. For a description of the transit system sample frame, see Section 7.

Characteristics of the mobility aid related accidents/incidents are summarized below in Table 16. The number of accidents/incidents reported in Table 16 do not sum to the total reported in Table 15 for some of the reasons reported above.

Even acknowledging some of the data problems underlying the results reported in Table 16, it is nevertheless of interest to note the following:

- The vast majority of mobility aid-related accidents/incidents involve no impact; the great majority result from excessive braking or sharp cornering events, or involve lift operations.

Table 16. Number of Reported Mobility Aid-Related Accidents/Incidents (1990-94), Reported by Transit System Sample, Having Certain Characteristics

a. Direction of impact:	23 Front	14 Side	11 Rear	179 No Impact
b. Bus/van in motion?:	135 Yes	88 No	11 Unknown	
c. Securement system failed?:	66 Yes	167 No	1 Unknown	
d. Degree of injury to mobility aid occupant:		149 None or Minor	53 Moderate	4 Severe
e. Other passengers injured as a direct result of securement or restraint failure:	7 Yes	215 No		
f. Degree of injury to other passengers when injured as a direct result of securement or restraint failure:		7 Minor	0 Moderate	0 Severe

Source: Aggregate Data from Transit System Data Collection Form

- Over seventy (70) percent of the accidents/incidents reported by the sample of transit systems either did not involve securement system failure, or were not securement system-related.

- The vast majority of mobility aid-related accidents/incidents, reported by the sample, did not have any injury consequences for other passengers on board the bus or van.

7. SUMMARY OF 'KEY ACTOR' GROUP SURVEY RESPONSES

This section provides a summary of 'key actor' group comments, not otherwise presented previously, germane to the issues considered in this report, namely, the securement and restraint of scooters and their occupants. More general mobility aid securement and occupant restraint (**MASOR**) issues, as identified by 'key actor' group respondents, are also presented here. The 'key actor' groups include, in the order of presentation: the Technical Community; Transit Systems; Securement Manufacturers; Scooter Manufacturers; and Mobility-Aid Users. Also presented here are the reaction of the Technical Community to potential focus areas by the US DOT for research, development, test and evaluation (RDT&E), and the reaction of each of the 'key actor' groups to hypothetical changes in the US DOT Final Rule related to the requirement to secure all "common wheelchairs and mobility aids."

Nature of the 'key actor' samples - The sample frame for the technical community was determined by identifying all persons within the technical community who are or had been principle investigators on a research project related to **MASOR** systems, or who are conducting or had conducted dynamic sled tests of **MASOR** systems, or who are or were involved in **MASOR** system or mobility aid standards development. The transit system sample frame consisted of all large transit systems (> 1000 vehicles), and a random selection of intermediate-sized transit systems (500-1000 vehicles), and small transit systems (250-500 vehicles). As was stated in Section 2.2.1, transit systems with fewer than 250 vehicles were not sampled at all. The sample frames for securement and scooter manufacturers consisted of all known (based on previous lists, and trade registers) manufacturers of securement devices and scooters respectively. The sample frame for mobility aid users consisted of sending ten (10) data collection forms to each of five organizations (three national organizations; two regional organizations) representing persons with disabilities; each organization was asked to transmit the data collection forms to mobility aid users who could and were willing to provide the information requested. Subsequently, one of the organizations representing persons with disabilities requested five (5) additional data collection forms for distribution. All of the 'key actor' group lists are documented in Appendix B. The 'key actor' group sample characteristics are summarized below in Table 17.

7.1 TECHNICAL COMMUNITY

The technical community was asked to respond to three broader issues related to **MASOR** systems. The technical community response to the first of these, *lack of dynamically tested transit system securement designs*, is presented below in Figure 15. Transit systems in our sample were also asked whether the transit system had designed its own securement system, and if so, what tests were run to confirm its performance. However, of twenty-eight (28) transit system respondents, only four (4) indicated that they had designed and installed their own **MASOR** system; none of these four (4) used dynamic crash tests to check performance of the complete system. Either a static pull test (for strength of components) was used, or a qualitative checklist related to time and ease of use, or the measurement of scooter excursion

Table 17. 'Key Actor' Group Sample Characteristics

	Total Forms Sent	Total Forms Received	Response Rate
a. Technical Community	19	10	0.53
b. Transit Systems	44	28	0.64
c. Securement Manufacturers	24	5	0.21
d. Scooter Manufacturers	8	2	0.25
e. Mobility Aid Users	55	17	0.31

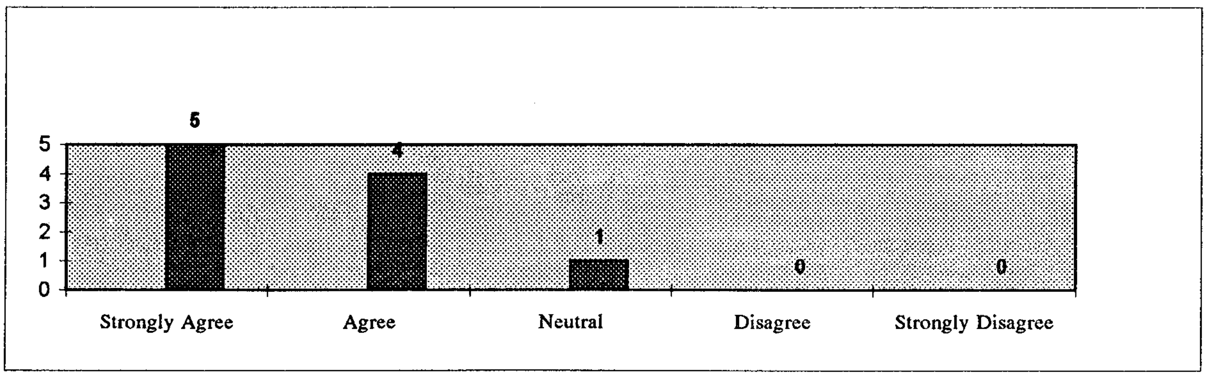


Figure 15. Technical Community Responses - Issue: Lack of Dynamically Tested Transit System Securement Designs

Source: Aggregate Data from Technical Community Data Collection Form

(< 2") under normal driving conditions and maneuvers, or no test was made. Ninety (90) percent of the technical community responses either strongly agree or agree that the lack of dynamically tested transit system securement designs is a problem. One technical respondent pointed out that both ADA and the US DOT/NHTSA school bus standard (FMVSS 222) only require static load tests. All ten of the technical community respondents were unanimously in agreement, however, that dynamic crash tests are critical to truly determine performance of **MASOR** systems (see, also, Red, Hale, McDermott and Mooring, 1982). At least one respondent cited his own dynamic tests that indicated force levels exceeding 22.3 kN (5000 lbf) in the rear tiedown straps, securing a 185 lb (84 kg) mobility aid, in a standard delta V 30 mph/ 20 g frontal crash. Measured force loads were twice the static load standard. Other crash tests have also confirmed these findings (see Section 4). It is also possible that an anchor system that can withstand static forces will not meet dynamic testing requirements. Several Dutch anchoring systems passed a quasi-static test at a horizontal force of 16.0 kN (3590 lbf). In spite of this, these systems failed completely in a series of dynamic tests (Kooi and Janssen, 1988). Kooi and Janssen (1988) concluded that this emphasizes the importance of carrying out driving tests and crash tests to assess the stability and strength of **MASOR** systems. Another technical respondent cited his own transit system survey which confirmed our own results reported above, namely the lack of dynamic crash tests for transit system-designed securement systems.

The second broader issue, for which the technical community provided a response, is *insufficient determination of occupant injury in dynamic tests of securement systems.* These results are reported below in Figure 16.

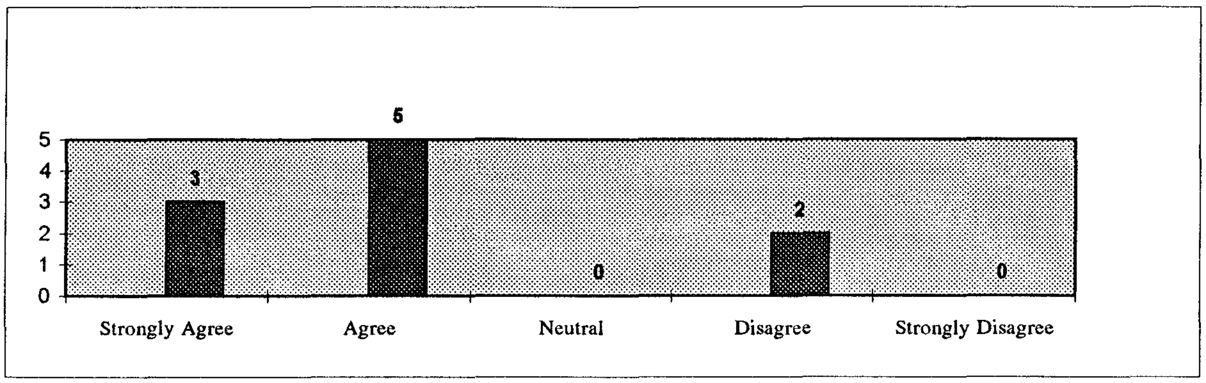


Figure 16. Technical Community Responses - Issue: Insufficient Determination of Occupant Injury in Dynamic Tests of Securement Systems

Source: Aggregate Data from Technical Community Data Collection Form

Eighty (80) percent of the technical community responses either strongly agree or agree that there is insufficient determination of occupant injury in dynamic tests of securement systems. The draft SAE and ISO test protocols (SAE, 1995; ISO 7176/19, 1994) utilize excursion of the anthropomorphic test device (ATD) and the mobility aid as the performance criteria. The draft Canadian test protocol (CAN/CSA-Z604, 1994) also uses excursion of the ATD and mobility aid, but includes a determination of force loads, if any, imposed on the occupant based on an analysis of high-speed film. This is to test for functional independence between the securement system for the mobility aid and the restraint system for the occupant. Zero force load on the occupant, therefore, is the criterion for acceptance.

Several respondents noted that measurement of head acceleration, and the calculation of the Head Injury Criterion (HIC) value, such as is mandated as a performance measurement under FMVSS 208 - Frontal Occupant Protection - is not very useful or relevant since dynamic sled tests of **MASOR** systems do not simulate the interior compartment of the vehicle. HIC values have meaning only when the head makes contact with the interior structure of the vehicle. Since FMVSS 208 requires a full production crash test of a vehicle, the HIC threshold value (> 1000) for injury determination does have value. For **MASOR** systems that incorporate a head restraint, the Australian test protocol (AS 2942, 1994) does require measurement of HIC since the head can contact the head restraint on the crash rebound. Several respondents, however, noted that chest G, which is also a performance criterion under FMVSS 208, is a potentially useful measurement for dynamic tests of **MASOR** systems. Other respondents suggested that belt loads on the occupant, femur loads (as required under FMVSS 208), pelvic acceleration, force loads on the neck and lumbar spine, and vertical occupant excursion are all potentially useful measurements for occupant injury determination that would probably not add excessive cost to the tests. One respondent commented that dynamic sled tests of **MASOR** systems will not provide accurate information on occupant injury for the disabled population until a realistic and validated disabled antropomorphic test device (ATD) and a surrogate mobility aid become available. Several technical respondents commented on the need for further research on the best parameters to measure for occupant injury determination in dynamic crash tests.

The last broad issue that the technical community was asked to react to is *inconsistency of MASOR test protocols*. The results are presented below in Figure 17.

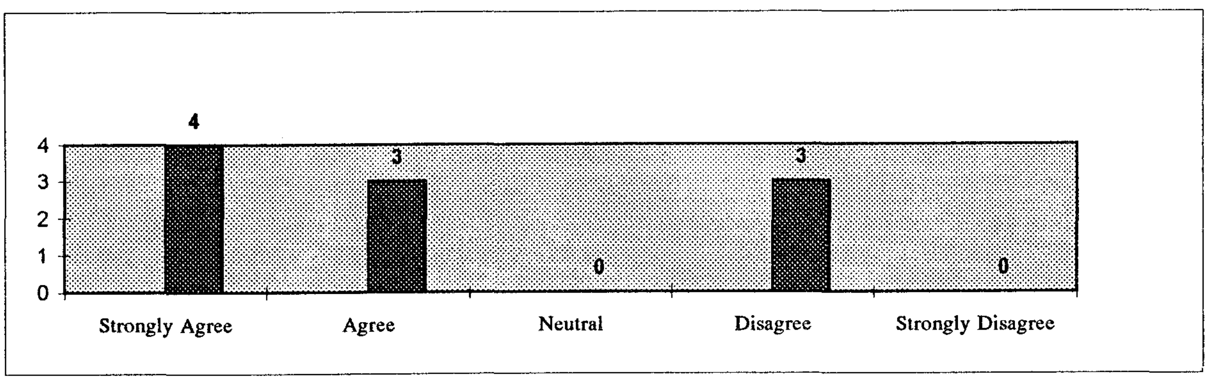


Figure 17. Technical Community Responses - Issue: Inconsistency of MASOR Test Protocols

Source: Aggregate Data from Technical Community Data Collection Form

Seventy (70) percent of the technical community responses either strongly agree or agree that inconsistency of test protocols for **MASOR** systems complicates interpretation and comparability of test results. The problem may not be as bad as these numbers seem to indicate, however. Early tests (1979-1987) were conducted with a variety of different test protocols. One respondent commented on the use of a fifth strap in tests of an Amigo scooter at UMTRI. ECRI, in a review of seven (7) major studies, found that basic test conditions, such as delta V and g deceleration force experienced in the simulated crash, varied between 10-30 mph and 5-20 g, respectively (see Table 3.8, ECRI, 1994). Test measurements for the ATD also varied greatly. No controls were imposed on initial ATD and mobility aid positions, belt slack, etc.

Current draft versions of the SAE, ISO, and the Canadian test protocols indicate close convergence for dynamic crash tests. Each requires a standard frontal dynamic crash test of delta V 30 mph/ 20 g. Variations in the crash pulse shape or duration, provided the basic crash parameters are standardized at delta V 30 mph/ 20 g, have little effect on key peak output values of the test (e.g., peak force loads in the rear and front attachment tiedowns) (Shaw, Lapidot, Scavnicky, Schneider and Roy, 1994). The surrogate wheelchair is the same for the SAE and ISO protocols, but different from other protocols (e.g., Australia). Australia uses a frontal simulated crash of delta V 22 mph/ 30 g, and also requires side and rear dynamic crash tests, which is not proposed for SAE/ISO. As mentioned before, ADA and FMVSS 222 - School Bus Passenger Seating and Crash Protection - require similar static tests.

The draft Transit Cooperative Research Program (TCRP) test protocol, developed by the Cleveland Clinic Foundation (Transit Cooperative Research Program, 1994), is extremely important in this regard since it includes the SAE/ISO dynamic crash tests as a subseries of tests, adopts FMVSS 208 standards for injury determination, applies to all mobility aids (including the explicit consideration of scooters), includes normal and adverse driving condition tests as well, and is the only test protocol that considers other functional requirements of both the transit system operators and mobility aid users.

Research - The technical community was also asked to respond to potential focus areas for US DOT-sponsored research. The focus areas covered four (4) broad areas: 1. research to support the development of a 'transportable mobility aid' standard and test protocol; 2. implementation of a national mobility aid securement and occupant restraint (**MASOR**) testing, clearinghouse-function, and technology/information/training program; 3. research to evaluate existing, and to develop new "universal design" **MASOR** systems; and 4. other, related research, including human factor studies on securement, and research on bus interior space design (including access to mobility aid securement bays, and manueverability of mobility aids within the bus interior). The technical community responses are reported in Tables 18-21 below.

Ninety (90) percent of the technical community responses either strongly agree or agree that the US DOT should support the development of a 'transportable' mobility aid standard and test protocol, including the underlying research base to support the standard and accompanying test protocol. The best mechanism to accomplish this, in the author's opinion, is under the auspices of the ANSI/RESNA Subcommitee on Wheelchairs and Transportation (SOWHAT) which is just getting underway. The draft Canadian standard for transportable mobility aids (CAN/CSA-Z604, 1994) can serve as the starting basis for this effort. Of the eleven specific research items that the technical community was asked to react to, this had the highest perecentage of responses under the category *strongly agree.* This research focus area also was one of only three research items - the other two were respectively, *improve training*

Table 18. Technical Community Responses for Research Area 1

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a. Develop a national standard for 'transportable' mobility aids	7	2	1	0	0

Source: Aggregate Data from Technical Community Data Collection Form

materials and information transfer to bus/van operators (see Table 19), and *investigate better internal circulation for buses/vans* (see Table 21) - for which there were no technical community respondents who either disagree or strongly disagree that this should be a focus area for US DOT-sponsored research.

Table 19. Technical Community Responses for Research Area 2

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a. Design and develop standard battery of **MASOR** tests	2	4	1	2	1
b. Conduct **MASOR** system test program	1	6	2	0	1
c. Develop national clearinghouse for **MASOR** system tests	0	7	2	0	1
d. Improve training materials and information transfer to bus/van operators	5	4	1	0	0

Source: Aggregate Data from Technical Community Data Collection Form

Between sixty (60) and ninety (90) percent of the technical community respondents endorsed the concept of a proactive, national program consisting of **MASOR** system testing, a clearinghouse for such tests, and the development and distribution of both specific and general training materials, technical assistance, and information transfer materials (e.g., videos, manuals, interactive computer-aided training modules, etc.). The item with the most support (90 percent, who strongly agree or agree) is the information transfer (including technical assistance) function. The element with the most disagreement is the development of a standard battery of **MASOR** tests.

As was discussed above (see Figure 17, and following discussion), the draft SAE and ISO test protocols are closely in agreement on the essential features for a dynamic frontal crash test. Also, the draft TCRP guidelines, which include the SAE/ISO crash tests as a subseries, could well serve a national testing program. The only aspect that, in this author's opinion, warrants US DOT support is the development of the underlying research base and the specific testing protocols for rear, side and rollover crash tests. This is a long-term effort, and the concept of a national testing, clearinghouse, technical assistance and information transfer program for **MASOR** systems can proceed independently of this long-term effort.

Only thirty (30) percent of the technical community respondents felt it was of value to underwrite a new competition for a new "universal design" **MASOR** system (see Table 20). In contrast, seventy (70) percent of the technical community responses either strongly agree or agree that the two existing "universal design" securement systems - the OSU Independent Locking Securement System (ILSS) and the Cleveland Clinic Foundation's Cleveland Securement System - should be evaluated in a national, large-scale operational test using a common evaluation framework. This might determine which of the two, or neither, is operationally suitable in a transit environment. Such a national, large-scale evaluation could help determine whether either or both will proceed to commercial development.

Table 20. Technical Community Responses for Research Area 3

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a. Conduct national, large-scale operational tests of competing "universal design" **MASOR** systems	3	4	0	0	1
b. Conduct new competition for a new **MASOR** system "universal design"	2	1	1	2	2

Source: Aggregate Data from Technical Community Data Collection Form

The last research focus area includes several items related to **MASOR** systems. The technical community responses are summarized below in Table 21.

Table 21. Technical Community Responses for Research Area 4

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a. Human factor tests of independent securement by mobility aid users (e.g., time, motion, energy studies)	3	3	0	3	1
b. Human factor tests of bus/van operator-assisted securement (e.g., time, motion, energy studies)	2	4	2	2	0
c. Investigate better internal circulation of buses/vans	2	5	3	0	0
d. Characterize bus crash environment, including occupant injury mechanisms	4	3	1	1	0

Source: Aggregate Data from Technical Community Data Collection Form

Of the four **MASOR** system related research areas, the investigation of the interior space design of the bus is the only item with no disagreement among the technical community. Several of the transit system respondents also commented on the difficulty of manuevering scooters within the bus, insufficient dimensions for the mobility aid securement bay, or accessibility problems in going from the lift to the mobility aid securement bay (Transit System Respondents, 1995). Whether mobility aids are boarded inwards or outwards (i.e., away from the door entrance) is also a major factor. Rethinking the whole concept of interior space layout and design of the standard transit bus used in fixed-route operations - from an accessibility perspective - appears to be a useful area for new US DOT-sponsored research. This may be especially timely as intelligent transportation system (ITS) equipment is added to the bus.

While generally supported by a majority of the technical community respondents, initiation of new human factor studies for both independent and operator-assisted securement is not universally held to be useful. Several technical respondents stated that these studies have already been done, and that no new information is likely to be gained.

On the last item, bus crash testing and occupant injury determination using full-scale bus crash tests, most technical community respondents thought that additional work in this area could be useful. The only known full-scale bus crash tests undertaken to date is the US DOT/NHTSA-sponsored work in 1980-81 by Minicars (Khadikar, Will and Costa, 1981).

Finally, all technical community respondents were asked to comment on any other Federal RDT&E areas that should be initiated, identifying the issue or problem to be addressed, describing what RDT&E should be done, and what the federal role should be. Items identified by the technical community are summarized below:

- Conduct research towards new docking securement devices that incorporate a "universal" interface.

- Use the national testing program to verify manufacturers' certification of compliance with a 'transportable' mobility aid standard, once such a standard is developed and adopted by the national standards organizations.

- Develop tests to assure that scooters (all mobility aids) stay secured when a vehicle is on its side or upside down.

- Determine and assess whether scooters can jump or climb lift edge barriers; evaluate alternative solutions.

- Risk assessment/cost-benefit analysis for different transit vehicles - i.e., can a simpler **MASOR** system be used in a full-sized transit bus?

- Explore ways to assess non-lethal injury due to occupant non-contact kinematics, e.g., due to belt loads, due to mobility aid imposed loads on the occupant, neck whiplash, etc.

- Develop occupant injury tolerance for disabled and elderly.

- Development of disabled body kinematics and dynamic response to driving and crash-related forces.

- Design, development and validation of a disabled anthropomorphic test device (ATD).

- Development of a surrogate wheelchair that preserves realistic body kinematics.

- Reassess the 30" x 48" specification for the minimum wheelchair bay requirement; since this corresponds with the "common wheelchair" envelope, it makes use of **MASORs** that much more difficult.

Hypothetical US DOT Rulemaking - Technical community respondents were also asked to react to hypothetical changes to the US DOT Final Rule as it relates to mobility aid securement, including the securement of tri-wheeled scooters. These results are reported below in Table 22.

Table 22. Technical Community Responses for Hypothetical Rulemaking

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a. Scooter occupants must transfer to a bus/van seat	3	2	1	2	2
b. Adopting a "certified list" of transportable mobility aids in lieu of the "common wheelchair" concept	3	3	1	2	1
c. Conditioning federal financial assistance for the purchase of a mobility aid that complies with a transportable mobility aid standard	1	3	1	3	2
d. Restriction of "common wheelchair" to four-wheeled mobility aids	1	1	0	6	2
e. No change to Final Rule with respect to securement of mobility aids, including tri-wheeled scooters	2	0	3	2	3

Source: Aggregate Data from Technical Community Data Collection Form

Although virtually all technical respondents agree that scooter occupants are at greater risk of injury than were they to transfer to the bus/van seat, only half of the respondents felt that this should be mandated on public transit vehicles. Sixty (60) percent of the technical respondents, a greater percentage than for any other hypothetical rulemaking change, either strongly agree or agree that a certified list, based on a transportable mobility aid standard, should substitute for the current "common wheelchair and mobility aid" concept. The great majority of respondents (50 and 80 percent, respectively) were opposed, however, to conditioning federal financial assistance on whether the mobility aid prescribed by a clinician to the individual complies with a transportable mobility aid standard, or to restricting the definition of "common wheelchair and mobility aid" to four-wheeled mobility aids (thereby excluding the more unstable tri-wheeled scooters).

Only twenty (20) percent of the technical community respondents felt that there should be no change to the US DOT Final Rule as it relates to mobility aid securement; fifty (50) percent of the technical community responses either disagree or strongly disagree that the Final Rule should stand as it is. Some of the changes recommended include:

- Securement and occupant devices should be subjected to dynamic tests, unless the static tests can be shown to reflect real-world accidents and the crash-related forces induced in such accidents.

- Mobility aids that pose an increased risk should be identified, with both the transit community and the user community informed of the risk.

- Restrict the size of the combined weight of the mobility aid and occupant to < 250 lbs, as the Canadians do.

- Increase the size of the mobility aid securement bay to fifty six (56) inches in length.

- Require drivers to offer assistance to secure the mobility aid if requested.

7.2 TRANSIT SYSTEMS

Transit systems were asked to respond to several operational, engineering and maintenance issues. In addition, transit system respondents also were asked to react to hypothetical US DOT Final Rule changes related to the securement and restraint of scooters and scooter occupants, respectively.

Crash testing has indicated that the scooter occupant is at risk in a crash environment (see Section 4). Transit system respondents indicated a number of operational problems in attempting to restrain the occupant on the scooter, including: inability to reach or extend the restraint straps due to the forward position of the occupant on the scooter; inability to properly tighten the occupant restraint straps; close physical contact between the operator and occupant often detering or inhibiting use of the occupant restraints; the extra time and delay also detering use of the restraints; high position and center of gravity of occupant contributing to instability and tipping of the scooter during vehicle cornering; and difficulty in achieving functional independence of the securement of the scooter and the restraint of the occupant (Transit System Respondents, 1995). Almost all of the respondents recommend or support the transfer of the occupant to a bus/van seat as a measure that would reduce the risk of injury to the occupant and to other passengers on board the bus/van, but most systems do not make the request (see Table 23). Approximately three-fourths of the respondents think that transfering should be mandated (see Table 25).

The results reported in Table 23 stand in contrast to earlier survey results (1988) from a US DOT Rural Transportation and Training Program (RTAP) survey. In that survey, the majority of respondents (55 percent) required their passengers to transfer to a regular bus seat or another wheelchair (Hunter-Zaworski, 1990). The difference in results, however, may be explained by the difference in the nature of the sample of systems surveyed (rural vs predominantly urban), and that, under ADA, transit agencies are not permitted to require a transfer.

Table 23. Transit System Responses: Operational Issues

a. Are scooter occupants requested to transfer to a bus/van seat?	9 Yes	21 No
b. Average compliance rate	0.54	
c. Are there detailed user instructions on the vehicle for the mobility aid securement and occupant restraint (**MASOR**) system?	18 Yes	12 No

Source: Aggregate Data from Transit System Data Collection Form
Notes: Total does not equal total number of respondents because some systems have different policies for fixed route vs paratransit operations.

The location for detailed user instructions for the **MASOR** system on the vehicle is generally within the securement bay, under the flip-up seat or on the interior side wall. Some systems simply provide a manual or pocket guide to the driver. Of note, however, is that twelve (12) respondents, representing forty (40) percent of the sample respondents, have no detailed user instructions on the vehicle.

All twenty-eight (28) respondents provide training to their operators, but the nature of the training (e.g., number of hours; subject areas; new vs recurrent) varies. Most systems do have a practicum or hands-on portion of training related to both lift operations and use of the **MASOR** system. Many have adopted the national Passenger Assistance Training (PAT) module as a component of their program. Many have a sensitivity component. One system includes role-playing, including having operators use mobility aids while their peers assist them in boarding the vehicle and securing the mobility aid. One system requires a sign off by the operator that he/she is familiar with the securement system. Not all systems, however, have periodic refresher training, even for experienced operators.

The policies with regard to operator assistance in securement and occupant restraint also vary among the transit system respondents. For paratransit operations, almost all place the responsibility for the securement of the mobility aid and the restraint of the occupant on the driver. Drivers are instructed not to move the vehicle unless and until both are properly secured (based on driver's judgement). One system instructs the operator to secure with only four-point belts. Many systems, for fixed-route operations, instruct the driver to provide assistance if necessary or if requested by the passenger. This may include assistance in transfering to a bus/van seat. In at least one system, the passenger is instructed to move the tiller "out of harms way." Many systems commented that securement systems that are designed to meet the ADA requirements (primarily four-point belt systems) are impossible to use independently by the mobility aid user. The amount of twisting, turning and stooping required, for example, to reach the ends of a four-point belt system and to secure the mobility device with the proper restraint angles and tensioning precludes its use by the mobility aid occupant from his/her seating position on the mobility aid. These ergonomic factors (i.e., the amount of twisting, bending, tightening, etc.) are also of great concern in terms of the potential for driver injury during the securement and release operations. Many systems require a priority dispatch to the dispatcher if the driver encounters a mobility aid that the driver can not secure.

Other operational issues and/or problems cited by the sample of transit system respondents include:

- The lack of uniformity of design of mobility aids, which poses a challenge to the operator in figuring out how best to secure the device.

- Damage caused by four-point securement systems to the scooter (e.g., steering post and controls; battery and wiring).

- The inability to accommodate four (4) scooters in vehicles with four (4) tiedown positions.

- Instability of scooters, with resultant tipping during vehicle cornering, or in boarding and alighting operations.

- Where best to attach to scooters for the best securement.

- Available space for securement and access to the tiedowns due to oversized scooters which span the complete securement bay envelope.

- Inability to use any other securement system other than belts, and a belief that even belt systems are largely ineffective.

- Excessive length of scooters, which render the securement and restraint system less effective due to an inability to provide the proper pre-tensioning or proper restraint angles.

- Inability to evacuate the scooter in an emergency.

- Uncomfortable intrusion into the personal space of the occupant to effect securement and restraint, and release.

- Problems in keeping belt retractors operating properly.

- Refusal on the part of some mobility aid users to use securement system, believing that their own brakes are sufficient to secure the mobility device on the vehicle.

- Manuverability of scooters within the bus, particularly for inboard loading in which the scooter is facing towards the door but must turn to access the securement bay;

long wheelbases, and pre-set turning-locks installed to assist in the stability of the scooter when maneuvering on the ground only compound this problem. Four-wheeled scooters also compound this problem.

One system, however, has designed an adjustment in its securement procedures which significantly improves the stability of the securement. That change involves leaving the forward facing seat in the down position, allowing for a more effective securement angle (45 degrees, +/- 15 degrees). In addition, this system requires that the passenger either remove or tilt the tiller to prevent potential secondary injuries in the event of a severe forward lurch such as would occur in a rear-end collision or rapid deceleration. This is particularly important because occupant restraints can not be mandated for use by the occupant.

Another system has used its bus wheel chock to keep the scooter from moving.

Engineering and Maintenance Issues - One of the engineering and maintenance issues that was asked of the sample of transit systems has to do with the nature of the acceptance tests that transit systems require for commercial-off-the-shelf **MASOR** systems that they specify in their bus/van procurements. The results are reported in Table 24.

Transit system were also asked to identify specific mobility aid models or classes of mobility aids that are particularly difficult to secure, and the reasons or problems involved. In general, there was substantial agreement that oversize and overweight mobility aids are a problem; also problematic are scooters with small diameter and/or solid wheels; scooters with plastic cowlings or fenders over the wheels; scooters with large rear overhangs that make attachment of the rear tiedowns very difficult; new or modified mobility aid designs that have smooth, curved tubular frames with no "intersections" appropriate for attaching securement belts; child stroller wheelchairs; reclining wheelchairs; mobility aids with extra wide tires, or oversized batteries or accessories in the rear; and sport wheelchairs with cambered wheels (Transit System Respondents, 1995).

Engineering and maintenance issues cited by the sample of transit system respondents include:

- The need for standards for mobility aid designs that provide for universal, well marked attachment points (e.g., D-ring or other standardized securement hardware on the mobility aid; and a consistent, standard geometry); a standard geometry might include height from floor, securement hardware dimensions, distance between securement hardware points, and other specifications that uniquely fix attachment point locations.

- The need for certification by the manufacturer of the mobility aid that the mobility aid is transportable or is not transportable in a vehicle; consequently, the need on the part of the mobility aid manufacturer to design for crash forces, including reinforcement of the seat design. At least one respondent cited cases in which three wheeled scooters have completely come apart during an accident (collapse of the steering column and seat)(no additional documentation was provided to the author).

Table 24. Transit System Responses: Acceptance Tests of Commercial-off-the-shelf **MASOR** Systems

a. Manufacturer must design device to meet Federal, state and local standards and safety requirements;
b. Meet ADA standards as well as reliability, maintainability and ease of use;
c. Documented engineering tests and certification by PE that specific installation meets the requirements of California regulations;
d. Must meet Minnesota guidelines and have demonstrated compliance with the minimum requirements as set forth by the Commissioner of Public Safety;
e. Certification by vendor of applicable tests in FTA publication, DOT-T-93-03 (Guideline Specifications for Passive Lifts, Active Lifts, Wheelchair Ramps and Securement Devices);
f. Certification by PE that equipment complies with DOT and ADA standards, including that manufacturers have followed all testing procedures;
g. Certification of compliance with ADA and FMVSS;
h. Meet SAE, FMVSS, ADA and ASTM standards; also, pass useability tests which include quick securement and release, minimum use of belts, and use of retractors;
i. University of Michigan pull test;
j. Method of tightening reduces potential injury to operator;
k. Van anchoring system must pass 30 mph/ 20 g crash impact test;
l. Entire wheelchair restraint system must be tested and certfied by manufacturer supplier of paratransit vehicle;
m. Local user group must demonstrate it and approve of its use on their mobility aids;
n. No acceptance tests required;
o. Wheelchair is used to randomly test 1-2 buses from the fleet to ensure that securement and restraint system is working properly.

Source: Aggregate Data from Transit System Data Collection Form

- Maintainability and serviceability of the securement and restraint system is an issue.

- Difficulty in restraining the scooter occupant who choses not to transfer for many of the reasons cited above (e.g., inability to pre-tension the restraints properly; not able to extend the restraining straps).

- Low platform scooters preclude achieving the proper restraint angles on the rear and forward tiedowns.

Hypothetical US DOT Rulemaking - Transit systems were also asked to react to the same hypothetical changes to the US DOT Final Rule as it relates to the securement and restraint of mobility aids. These results are reported below in Table 25.

Table 25. Transit System Responses

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a. Scooter occupants must transfer to a bus/van seat	9	5	6	4	5
b. Adopting a "certified list" of transportable mobility aids in lieu of the "common wheelchair" concept	12	11	3	3	0
c. Conditioning federal financial assistance for the purchase of a mobility aid that complies with a transportable mobility aid standard	6	11	7	3	2
d. Restriction of "common wheelchair" to four-wheeled mobility aids	5	3	8	12	1
e. No change to Final Rule with respect to securement of mobility aids, including tri-wheeled scooters	0	2	7	10	9

Source: Aggregate Data from Transit System Data Collection Form

Analysis of the results reported in Table 25 indicate that more than eighty (80) percent of the transit system responses either strongly agree or agree for the need to develop a transportable mobility aid standard, and to adopt a "certified list" based on compliance with that standard. Also, more than sixty-seven (67) percent of the transit system responses either disagree or strongly disagree that there should be no change in the US DOT Final Rule as it relates to the securement and restraint of mobility aids, including tri-wheeled scooters. A caution, issued by one respondent, however is worth heeding: in order for local transit agencies to adequately address safety, training and liability issues, the Final Rule needs to be all encompassing or leave areas open to local policy decisions. Neither option is likely to address and satisfy the concerns of all interested parties.

7.3 SECUREMENT MANUFACTURERS

Securement manufacturers were asked to provide a compatibility matrix of tri-wheeled scooter models and the securement system(s) that each manufacturer markets, illustrating also the appropriate attachment points for each scooter model listed. None of the five (5) securement manufacturer respondents, however, could provide this information. Each of the respondents does collect data on problems reported with the use of its securement system. Although the sample is quite small, some insight into the nature of the problems associated with the securement systems marketed by these respondents is reported below in Table 26.

Table 26. Securement Manufacturer Responses

a. Collect data on problems with the use of your securement system?	5 Yes	0 No
Category of Problems (No. of Obs.)		
a. Lack of a universal interface		4
b. Excessive operations inspection time (> 3 minutes)		1
c. Excessive securement time (> 1 minute fixed route; > 3 minutes paratransit)		3
d. Lack of a securement completion signal		0
e. Lack of user privacy (reaching components; connecting to mobility aid)		1
f. Excessive force needed to secure (> 10 lbs normal use; > 5 lbs for difficult access points; > 1 lb for emergency release)		0
g. Lack of redundant release		0
h. Excessive mobility aid motion (> 2" in any direction; tipping of mobility aid during cornering)		1
i. Securement system integrity (no fragmentation) during crash events)		0

Source: Aggregate Data from Securement Manufactuers Data Collection Form

Securement manufacturer respondents also noted that the types of tests conducted for their securement system(s) include the ADA-specified static load tests, and a test to determine compliance with the ADA-specified criterion for mobility aid movement under "normal operating conditions."

Hypothetical US DOT Rulemaking - Securement manufacturers were also asked to react to the same hypothetical US DOT Final Rule changes. These results are reported below in Table 27.

Table 27. Securement Manufacturer Responses for Hypothetical Rulemaking

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a. Scooter occupants must transfer to a bus/van seat	2	2	0	0	1
b. Adopting a "certified list" of transportable mobility aids in lieu of the "common wheelchair" concept	3	1	0	1	0
c. Conditioning federal financial assistance for the purchase of a mobility aid that complies with a transportable mobility aid standard	1	1	1	1	0
d. Restriction of "common wheelchair" to four-wheeled mobility aids	1	0	0	2	1
e. No change to Final Rule with respect to securement of mobility aids, including tri-wheeled scooters	0	0	1	2	1

Source: Aggregate Data from Securement Manufacturer Data Collection Form

Eighty (80) percent of the securement manufacturer responses either strongly agree or agree that (a) the scooter occupant must transfer to a bus/van seat; and (b) on the need for a standard for 'transportable mobility aids', including common attachment points. Ultimately, the Final Rule should adopt a concept of a certified list of mobility aids that are compliant with the established standard.

7.4 SCOOTER MANUFACTURERS

Only two (2) scooter manufacturers responded to our data collection form. Both respondents recommend that the scooter occupant transfer to the OEM bus/van seat when transported.

Hypothetical US DOT Rulemaking - For comparison purposes with the other 'key actor' groups, we report the responses of both scooter manufacturer respondents to the same hypothetical US DOT Final Rule changes below in Table 28.

Table 28. Scooter Manufacturer Responses

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a. Scooter occupants must transfer to a bus/van seat	1	0	1	0	0
b. Adopting a "certified list" of transportable mobility aids in lieu of the "common wheelchair" concept	1	0	0	1	0
c. Conditioning federal financial assistance for the purchase of a mobility aid that complies with a transportable mobility aid standard	1	1	0	0	0
d. Restriction of "common wheelchair" to four-wheeled mobility aids	1	0	0	0	1
e. No change to Final Rule with respect to securement of mobility aids, including tri-wheeled scooters	0	1	0	1	0

Source: Aggregate Data from Scooter Manufacturer Data Collection Form

7.5 MOBILITY AID USERS

Mobility Aid Users were asked to provide information characterizing the direction of boarding, whether or not operator assistance is required in the securement operation, and whether detailed **MASOR** system user instructions are available on the bus/van in an accessible location to the user. Many of these issues are directly relevant to the efficiency and effectiveness of transit boarding and securement operations. Most transit operators, for example, would prefer outward boarding in which the mobility aid is boarded on the lift facing away from the bus/van door. The reasons for this are twofold: 1. the mobility aid on the lift is more stable, since the center of gravity is shifted towards the vehicle, reducing the magnitude of the bending moment on the lift itself; 2. the mobility aid can be more easily manuevered within the confining space of the vehicle along an accessible path (pass the fare collection equipment) to the forward-facing securement bay, without the need to turn the mobility aid. The results of these operational-related questions by the Mobility Aid User respondents are presented below in Table 29.

Table 29. Mobility Aid Users Responses: Operational-Related Issues

a. Boarding bus/van facing towards door	7	
b. Boarding bus/van facing away from door	11	
c. Able to independently secure mobility aid?	4 Yes	14 No
d. Detailed user instructions for the securement system on the bus/van?	4 Yes	13 No

Source: Aggregate Data from Mobility Aid User Data Collection Form
Notes: One respondent boarded fixed-route in a outward facing direction, and paratransit in an inward facing direction.

Mobility Aid Users were also asked to identify and comment on problems in the securement of scooters on buses and vans. Table 30, below, summarizes the problems noted by the respondents.

The three primary concerns noted are respectively, the ease and independent use of currently installed **MASOR** systems, and concern related to the safety of the scooter occupant when riding on buses and vans used in public transit service.

Hypothetical US DOT Rulemaking - As with the other 'key actor' groups, Mobility Aid Users were asked to react to the same hypothetical US DOT Final Rule changes. These results are reported below in Table 31.

The most interesting result reported in Table 31 is that sixty-eight (68) percent of the Mobility Aid User responses either strongly agree or agree on the need for a standard for 'transportable mobility aids', including common attachment points, and that the Final Rule should adopt a concept of a certified list of mobility aids that are compliant with the established standard. The Canadian concept of a Type O mobility aid, a 'transportable mobility aid' certified as such with the occupant in place, is prefered to simply mandating that scooter occupants transfer to a bus/van seat. Mandating scooter occupants to transfer to a bus/van seat engendered the most opposition (eight (8) respondents, representing fifty (50) percent of the Mobility Aid User sample who strongly disagreed.

Table 30. Mobility Aid User Responses

	Category of Problem (No. of Obs.)
a. Ease of use of securement system	9
b. Independent use by occupant	6
c. Close physical space between driver and user during securement and release	5
d. Reluctance to use securement and restraint systems	3
e. Access to and from securement locations	5
f. Emergency evacuation	5
g. Safety of scooter occupant	6
h. Safety of other occupants	4

Source: Aggregate Data from Mobility Aid User Data Collection Form

Table 31. Mobility Aid User Responses for Hypothetical Rulemaking

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
a. Scooter occupants must transfer to a bus/van seat	1	2	5	0	8
b. Adopting a "certified list" of transportable mobility aids in lieu of the "common wheelchair" concept	6	5	3	0	2
c. Conditioning federal financial assistance for the purchase of a mobility aid that complies with a transportable mobility aid standard	3	4	2	2	4
d. Restriction of "common wheelchair" to four-wheeled mobility aids	2	2	4	2	6
e. No change to Final Rule with respect to securement of mobility aids, including tri-wheeled scooters	1	2	6	4	2

Source: Aggregate Data from Mobility Aid User Data Collection Form

8. SUMMARY OF FINDINGS

This section provides a summary of key findings of this study. These findings are listed in their order of presentation.

1. More than ninety-five (95) percent of the Transit System sample in this study use a two, three or four-point belt system to secure mobility aids. Almost two-thirds of the sample also use a rear wheel clamp when able to do so. The sample in this study collectively represent seventy (70) percent of annual fixed route trips, and twenty-five (25) percent of annual paratransit trips completed.

2. The incidence of severe disability in the United States has increased dramatically in the twenty-five years from 1966 to 1992, the most recent year of data. In terms of prevalence rates, the rate of severe disability increased from 213 people per 10,000 in 1966, to 365 people per 10,000 in 1979, to 957 people per 10,000 in 1992. In absolute numbers, 24.1 million or 9.6 percent of the US population can be categorized as having a severe disability.

3. Sixty-four (64) thousand persons are estimated to use scooters as a mobility aid (1990 estimate). There are, however, twenty-two (22) wheelchairs to every scooter. The number of persons who use mobility aids of any kind, however, has grown by almost sixty-five (65) percent between 1980 and 1990.

4. For the sample of transit systems in this study, the mean weekly boarding rate of mobility aid users on fixed-route accessible buses ranges between sixty-nine (69) and six hundred and twenty-seven (627), depending on size of system. The percent of these boardings that comprise scooters ranges between two (2) and five (5) percent.

Corresponding numbers for complementary paratransit service are the following: mean weekly boarding rate of mobility aid users between five hundred and thirty-four (534) and two thousand two hundred and ninety-two (2292), and the percent that comprise scooters ranging between four and one half (4.5) percent and eleven (11) percent.

5. The vehicle, securement device, occupant restraints, and the mobility aid user jointly define a complex system. Failure to acknowledge this reality can have unintended consequences and increase the potential for injury to the mobility aid user as well as to other passengers on public transit vehicles.

6. Protection against injury of the mobility aid user and other passengers during normal and abnormal driving events is a key requirement for mobility aid securement and occupant restraint (**MASOR**) systems, but it is not the only requirement. Additional engineering and functional requirements for both transit systems and mobility aid users add to the complexity of design and the difficulty in arriving at acceptable solutions.

7. Based on extensive review of research, test reports and the 'expert opinion' of the technical community, we have confirmed the following securement and restraint related issues for tri-wheeled scooters as actual or potential problems:

Non-Crash Issues: 1. Inaccessible attachment points; 2. Inadequate structural strength of attachment points; 3. Proliferation of scooter models that are incompatible with securement systems.

Crash-related Issues: 1. Inability to restrain the battery in a crash impact; 2. Shearing or fracture of the seat pedestal; 3. Large bending moments that exceed the restraining force of seat designs; 4. Scooter occupant injury from contact with the front tiller.

Two additional confirmed issues that bridge both categories - non-crash and crash-related driving events - are (a) the rollover or tipping instability inherent in the tri-wheeled scooter design; and (b) spillage of battery fluid, unless the scooter battery is of the dry or gel-type.

8. A review of proposed and current standards indicates that only the Australian standard explicitly recommends against the transport of tri-wheeled scooters; the Canadian proposed standard for 'transportable mobility aids' imposes certain tests that tri-wheeled scooters would have to comply with before being certified as transportable with or without an occupant (Type O, and Type V, respectively).

9. There are no known formal studies of the quantitative measurement of risk to mobility aid users, including persons who use scooters, based on actual accident experience from riding on buses and vans used in public transit service. US DOT/NHTSA national databases do not provide the requisite level of detail to undertake such a study. It will require special, locally-collected data to complete a study of this kind. Allegations that scooter occupants represent a "direct threat" to justify any access restrictions, however, must pass the test set forth by the US Supreme Court in *School Board of Nassau County v. Arline* (480 U.S. 273, 1987) that such action be based on the best available objective evidence to determine: the nature, duration, and severity of the risk; the probability that the potential injury will actually occur; and whether reasonable modifications of policies, practices, or procedures will mitigate the risk.

All available accident statistics, however, indicate a very low incidence of securement-related injuries to mobility aid users. National estimates are two thousand, two hundred and two (2202) for the period 1986-1990, representing 1.5 percent of all mobility aid accidents, and one thousand, one hundred and thirty-three (1133) for 1991-1993, representing 0.6 percent of all mobility aid accidents.

Analysis of accident data associated with the transit system sample for this study indicate a five year cumulative number of accidents/incidents involving injury to the mobility aid user ranging between thirty-three (33) and three hundred and forty-five (345), depending on size of system. The vast majority of these accidents/incidents involved no impact (i.e., excessive braking or sharp cornering events, or involve lift operations). Over seventy (70) percent of the accidents/incidents reported by the sample did not involve securement system failure, or were not securement system-related. The vast majority resulted in only minor injuries to the mobility aid occupant, and no injuries to other passengers on board the bus or van.

10. Within both the technical community and the transit system community, there is consensus that the occupant of the tri-wheeled scooter should transfer to a bus or van seat for maximum occupant protection. Crash testing confirms that the scooter occupant is at greater risk in a crash environment. Most manufacturers of mobility aids, including manufacturers of tri-wheeled scooters, issue disclaimers against the transportability of the mobility aid on a bus or van.

11. All of the 'key actor' groups - Technical Community, Transit Systems, Securement Manufacturers, Scooter Manufacturers, and Mobility Aid Users - were asked to provide their input on a number of other issues, including to react to certain hypothetical US DOT Final Rule changes as they relate to the securement and restraint of tri-wheeled scooters on buses and vans used in public transit services. Significant results are:

- Ninety (90) percent of technical community respondents believe that the lack of dynamically tested transit system securement designs is a problem.

- Eighty (80) percent of the technical community respondents believe there is insufficient determination of occupant injury in dynamic tests of securement systems.

- Ninety (90) percent of the technical community endorse US DOT-sponsored research support for the development of a standard and test protocol for a 'transportable mobility aid', and sixty (60) percent support the concept of a certifiable list based on that standard. Corresponding percentages supporting the concept of a certifiable list based on a 'transportable mobility aid' standard and test protocol for the other 'key actor' groups are: eighty (80) percent of transit system respondents; eighty (80) percent of the securement manufacturer respondents; fifty (50) percent of the scooter manufacturers; and sixty-eight (68) percent of the mobility aid user respondents.

9. RECOMMENDATIONS

This section provides recommendations under two broad categories: **US DOT-sponsored research** to increase our knowledgebase where information is currently lacking or uncertain and to support the Agency decision-making process, and **US DOT administrative action,** which includes rulemaking. More detailed research program descriptions are provided in Appendix D.

US DOT-sponsored Research - Four, high-priority near-term focus areas are recommended for initiation by US DOT/FTA:

- A testing, clearinghouse, technical assistance and technology/information transfer program for mobility aid securement and occupant restraint (**MASOR**) systems.

- A comparative retrospective or prospective risk assessment to quantify rigorously the relative risk of mobility aid users, including tri-wheeled scooter occupants, when riding buses and vans used in public transit service.

- A comprehensive, systems-oriented investigation to analyze existing internal designs, including consideration of space requirements and passenger circulation, of fixed-route standard-sized accessible buses, and to search and validate improved designs.

- Research support, under the auspices of the American National Standards Institute and the Rehabilitation Engineering Society of North America (ANSI/RESNA) to develop a 'transportable mobility aid' standard and test protocol.

In addition to the above, two long-term, more basic research efforts should also be initiated by US DOT/NHTSA:

- The design, development and validation of a disabled anthropomorphic test device (ATD).

- The identification and validation of the best parameters for occupant injury determination in dynamic crash tests.

Discussion - The first focus area - a national program for testing, clearinghouse, technical assistance and technology/information transfer - could be implemented using existing administrative structures; specifically, day-to-day management could be effected through the University Transportation Centers. All reputable testing facilities could participate under contract via the University Transportation Centers. A US DOT/FTA-sponsored technical advisory committee may also be helpful for general oversight and policy guidance. Equitable cost-sharing arrangements should be worked out among all interested parties, including a determination of equitable cost-shares for the US DOT/FTA, transit systems, securement and restraint manufacturers, and mobility aid manufacturers. All testing results would be widely publicized.

The importance of a technical assistance, and technology/information transfer program should not be minimized. It has been found that, in the area of accessible design, providing technical assistance, including the wide publication of tests results and the assessment of comparative risks, often minimizes unnecessary conflict and often encourages mutual problem solving and cooperation (DeJong and Lifchez, 1983). This proposal is consistent with the statutory provisions of the Architectural and Transportation Barriers Compliance Board which recognizes the role of technical assistance.

The second and third near-term focus areas, because each involves special locally-collected data collection efforts and close involvement with local transit systems and with bus manufacturers, are ideal candidates for the Transit Cooperative Research Program (TCRP).

Additional comment on the fourth near-term focus area is provided below, under US DOT administrative action.

US DOT Administrative Action - No change to the US DOT Final Rule as it relates to the securement of mobility aids, including tri-wheeled scooters, is recommended at this time (1995). Instead, we recommend the following US DOT administrative action plan:

1. The Federal Transit Administration (US DOT/FTA) should join as an equal partner with the National Highway Traffic Safety Administration (US DOT/NHTSA) in supporting the creation of a strong research base, standard and test protocol for a 'transportable mobility aid' under the auspices of the ANSI/RESNA Subcommittee on Wheelchairs and Transportation (SOWHAT). Currently, US DOT/NHTSA is providing $100,000; US DOT/FTA should match this amount.

2. The US DOT/FTA and US DOT/NHTSA should proactively and publicly support the above effort. In particular, the US DOT should have a federal presence as observers on the ANSI/RESNA SOWHAT (e.g., a professional staff person from US DOT/OST, US DOT/FTA, US DOT/NHTSA, and US DOT/RSPA).

   A 'transportable mobility aid' standard and test protocol must be the end product of an open, inclusionary and participatory standards process. It must arise from consensus and mutual accommodation of all affected parties. The US DOT cannot nor should it dictate the contents of this standard.

3. The US DOT/FTA should convene a National Workshop one year after completion of the ANSI/RESNA SOWHAT committee effort to evaluate and to suggest revisions, if necessary, to the standard and test protocol for a 'transportable mobility aid'.

4. The US DOT should join with other Federal agencies (e.g., Department of Veterans Affairs, US Public Health Service, National Institute for Disability and Rehabilitation Research (NIDRR) in developing and implementing an inter-agency monitoring and assessment program to track the success of clinicians across the nation in prescribing mobility aids that are compliant with the 'transportable mobility aid' standard.

Manufacturers would be allowed to display a certification sticker on all mobility aids that pass the test protocol.

5. Depending on the success or failure of voluntary compliance, the US DOT should consider changing the Final Rule to adopt the concept of a certifiable list of mobility aids that are compliant with the 'transportable mobility aid' standard. Transit systems would have to transport these mobility aids. The Department could make it permissive, at the discretion of local option, for transit agencies to transport all other mobility aids.

This action would be consistent with the US DOT's historic, and primary mission to protect the safety of the riding public, including persons with disabilities. This action achieves a reasonable, and reasoned balance between the rights of access and the safe transport of the public, including crashworthiness considerations.

REFERENCES

AAP Safe Ride News (1993), *Policy Statement: Transporting Children with Special Needs,* American Academy of Pediatrics, Committee on Injury and Poison Prevention.

Abernethy, C., Jacobs, H., Plank, G., Stocklosa, J., and Sussman, E. (1977), *Maximum Deceleration and Jerk Levels That Allow Retention of Unrestrained, Seated Transit Passengers,* Transportation Research Record 774.

Adams, T., Sauer, B., and Reger, S. (1992), *Kinematics of the Wheelchair Seated Body in Crash Simulation,* Proceedings RESNA International '92.

Aldman, B., Brattgard, S., and Hansson, S. (1974), *Safety During Special Transportation Service Trips,* Volume 1: Transportation in Vehicles Designed for the Handicapped, translation, UMTA-CA-06-0098-78-2.

AM 9001 (1990), *Test of Amigo Classic Tri-Wheeled Scooter.*

Amendment to FMVSS 222 (1993), *School Bus Passenger Seating and Crash Protection,* Federal Register, Vol. 58, No. 10, Friday, January 15, 1993.

American Academy of Pediatrics (1994), *School Bus Transportation of Children with Special Needs,* Committee on Injury and Poison prevention, Pediatrics, Vol. 93, No. 1, January 1994.

American Seating (1992), Test Reports, TR # 92-42-TT14 and TR # 92-28-TT14.

Ardoino, P. (1982), *Capability of the Car to Minimize the Global Damage in Road Accidents,* International Center for Transportation Studies, Vol. 2, Proceedings Series.

Australian Standard (1994), **Wheelchair Occupant Restraint Assemblies for Motor Vehicles**, AS 2942.

Battelle Columbus Division and ATE Management & Service Co. (1986), **National Workshop on Bus-Wheelchair Accessibility: Guideline Specifications for Wheelchair Securement Devices**, UMTA-IT-06-0322-87-4.

Bauer, W., and Reger, S. (1991), Services for Independent Living, Inc., Project ACTION Report, February 15, 1991 to May 15, 1991.

Bauer, W. and Reger, S. (1991), Services for Independent Living, Inc., Project ACTION Report, May 15, 1991 to August 15, 1991.

Bauer, W., and Reger, S. (1991), Services for Independent Living, Inc., Project ACTION Report, August 15, 1991 to November 15, 1991.

Bauer, W., and Reger, S. (1992), Services for Independent Living, Inc., Project ACTION, Final Report 1992.

Baumeister, T., Avallone, E., and Baumeister III, T. (eds.) (1987), **Marks' Standard Handbook for Mechanical Engineers**, Chapter 5, Mechanics of Materials.

Benson, J., and Schneider, L. (1985), *Improving the Crashworthiness of Restraints for Handicapped Children*, SAE Paper.

Beusenberg, M. and Goudswaard, P. (1989), *Several Comments and Recommendations of the Dutch Delegation of ISO/TC173/WG6: "Wheelchair and Occupant Restraint Systems" to this Working Group.*

Biokinetics and Associates, Ltd. (1991), **Development of a Dynamic Test Procedure for Transportable Mobility Aids and Securement Devices**, Volume 1: Summary and Recommendations, Document R91-12/jm.

Biokinetics and Associates, Ltd. (1991), **Development of a Dynamic Test Procedure for Transportable Mobility Aids and Securement Devices**, Volume 4, Test Procedure and Results, Document R91-15/jm.

Blanchet, R., and Bety, J. (1988), **Compendium of Accessible Vehicles**, TP-7310E.

Brenner, E. and Giangrande, R. (1981), **Wheelchair Securement Systems in Transit Vehicles: A Summary Report**, DOT-TSC-UMTA-81-43.

Brereton, W., Dutchak, R., et al. (1984), *Occupant Restraint for Vans*, Proceedings of the 2nd International Conference on Rehabilitation Engineering, Ottawa, Canada.

Bull, M., Stroup, K., and Doll, J. (Eds.) (1991), **Transporting Children with Special Needs: Research and Resource Manual**, Automotive Safety for Children Program, James Whitcomb Riley Hospital, Indianapolis, Indiana.

Calder, C., and Kirby, R. (1990), *Fatal Wheelchair-related Accidents in the United States,* American Journal of Physical Medicine and Rehabilitation, Vol. 69, No. 4.

Canadian Standards Association (1990), *Report of the Ad Hoc Group on Wheelchair Securement to ISO TC-173 WG6.*

Canadian Standards Association (1992), **Motor Vehicles for the Transportation of Persons with Physical Disabilities**, CAN/CSA-D409-92.

Canadian Standards Association (1994), **Transportable Mobility Aids for Occupancy in Moving Vehicles**, CAN/CSA-Z604, Draft.

Canadian Standards Association (1995), **Mobility Aid Securement and Occupant Restraint (MASOR) Systems for Motor Vehicles**, CAN/CSA-Z605, Draft.

Cheng, L., Werner, S., Vogler, M., Jewett, C., and Carnell, P. (1993), **Wheelchair/Occupant Securement System (California)**, FTA/DMT CA-08-PB93-140747.

Clark, C. (1984), **Crash Protection of Children, the Elderly and the Handicapped and the Design of Inflatable Compartmentalized Controlled Deformation Protective Systems for Them**, NHTSA-NRD-12-CC-84105.

Coburn, N., Martin, C., Thompson, R., and Norstrom, D. (1992), **Guidelines for Improvements to Transit Accessibility for People with Disabilities**, DOT-T-93-04.

Dalrymple, G., Hsia, H., Ragland, C., and Dickman, F. (1990), **Wheelchair and Occupant Restraint on School Buses**, DOT-HS-807-570.

DeJong, G. and Lifchez, R. (1983), *Physical Disability and Public Policy*, Scientific American, Vol. 248, No. 6.

Digges, K., and Dalrymple, G. (1992), *Applying the Intent of Federal Motor Vehicle Safety Standards to Vehicles Modified for the Use of Disabled Persons*, SAE Paper 920563.

Dong, V., and Smith, R. (1981), **Wheelchair Securement on Bus and Paratransit Vehicles**, CA-06-0098-82-2.

ECRI (1991), **Product Comparison and Evaluation: Scooters.**

ECRI (1993), *Powered Wheelchairs*, Health Devices, Special Issue, Vol. 22, No. 10.

ECRI (1994), **Positioning and Securing Riders with Disabilities and Their Mobility Aids in Transit Vehicles: Designing an Evaluation Program**, Project ACTION.

ECRI (1994), **Healthcare Product Comparison System: Wheelchairs, Nonpowered.**

Elkind, J. (1990), *The Incidence of Disabilities in the United States*, Human Factors, Vol. 32, No. 4.

Ficke, R. (1992), **Digest of Data on Persons with Disabilities**, US Department of Education, National Institute on Disability and Rehabilitation Research.

Fisher, W., Seeger, B., and Svensson, N. (1987), *Development of an Australian Standard for Wheelchair Occupant Restraint Assemblies for Motor Vehicles,* Journal of Rehabilitation Research and Development, Vol. 24, No. 3, 1987.

Fleiss, J. (1981), **Statistical Methods for Rates and Proportions**, Second edition.

Francis, G., and Norstrom, D. (1992), **Guideline Specifications for Passive Lifts, Active Lifts, Wheelchair ramps, and Securement Devices**, DOT-T-93-03.

Garland, L., and Dorion, S. (1989), **Development of a Wheelchair Securement System for Vans and Small Buses**, Document TP9758E.

Gearhart, K., Russell, R., and Hood, C. (1994), *Transporting Disabled Children: How to Secure Car Safety Seats, Medical Equipment, Lap Trays*, School Bus Fleet, June/July 1994.

Graham, C. (1986), **Transporting Handicapped Children Safely: Research Summary**, prepared for New York Association for Pupil Transportation.

Grime, G. (1979), *A Review of Research on the Protection Afforded to Occupants of Cars by Seat Belts Which Provide Upper Torso Restraint*, Accident Analysis & Prevention, Vol. 11.

Hackett, L. (1978), **Guidelines for the Identification of the Transportation Needs of the Elderly and Handicapped**, UMTA-CA-09-8002-79-1.

Hale, K., Mooring, B., Red, W., and McDermott, M. (1982), *Design of an Impact Facility to Test Wheelchair Restraint Devices*, ASME Paper 82-DET-50.

Hamann, C. (1994), *Transporting Disabled Children: Special Needs Seating Poses Challenges for the Industry*, School Bus Fleet, December/January 1994.

Hartman, R., and Kurtz, E. (1994), **The Stakeholders' Forum: Taking the Pulse in Representative American Communities to Measure How ADA Compliance in Public Transportation is Going**, Project ACTION.

Hauer, E. (1983), *Reflections on Methods of Statistical Inference Research on the Effect of Safety Countermeasures*, Accident Analysis & Prevention, Vol. 15, No. 4.

Hauer, E. (1986), *On the Estimation of the Expected Number of Accidents*, Accident Analysis & Prevention, Vol. 18, No. 1.

Haynes, C., Stroud, S., and Thompson, C. (1986), *The Three Wheeler (Adult Tricycle): An Unstable, Dangerous Machine*, The Journal of Trauma, Vol. 26, No. 7.

Hedlund, J. (1984), *Comments on Hauer's Approach to Statistical Inference*, Accident Analysis & Prevention, Vol. 16, No. 3.

Henderson, W. (1990), *Safety Analysis of Mobility Aids: A Proposed Method for* Use *by Transportation Systems*, Appendix F in Hunter-Zaworski, K., **Securement of Non-Traditional Style Wheelchairs on Public Transit Vehicles**.

Hickling, Inc. (1989), **Crash Test of a Three-Wheel Scooter.**

Hunter-Zaworski, K. (1989), **The Status of Wheelchair Occupant Restraint Standards for Motor Vehicle: Transportable Devices**, Transporation Research Institute, Oregon State University.

Hunter-Zaworski, K. (1990), **Securement of Non-Traditional Style Wheelchairs on Public Transit Vehicles**, 1990.

Hunter-Zaworski, K. and Ullman, D. (1992), *Mechanics of Mobility Aid Securement and Restraint on Public Transportation Vehicles,* Transportation Research Record 1378.

Hunter-Zaworski, K., Zaworski, J., and Clarke, G. (1992), **The Development of an Independent Locking Securement System for Mobility Aids on Public Transportation Vehicles**, DOT-T-93-08.

Hunter-Zaworski, K., Ullman, D., and Herling, D. (1992), **Application of the Quality Functional Deployment Method in Mobility Aid Securement System Design,** DOT-T-93-22.

Johnson, W., and Mamalis, A. (1978), **Crashworthiness of Vehicles**, Mechanical Engineering Publications Ltd., London.

Joksch, H. (1993), *Velocity Change and Fatality Risk in a Crash - A Rule of Thumb,* Accident Analysis & Prevention, Vol. 25, No. 1.

Kallieris, D., Mattern, R., Schmidt, G., Glitsch, G., Harres, M., and Leis, B. (1981), *Behavior and Response of Wheelchair, Passenger and Restraint Systems Used in Buses During Impac*t, Proceedings of the 25th Stapp Car Crash Conference, SAE.

Karg, P., Yaffe, K., and Berkowitz, D. (1994), *Positioning and Securement of Riders and Their Mobility Aids in Transit Vehicles: An Analytical Review,* Assistive Technology, Vol. 6.

Khadilkar, A., Will, E., and Costa, V. (1981), **Crash Protection Systems for Handicapped School Bus Occupants**, DOT-HS-805-828, Vols. 1, 2, and 3.

Khadilkar, A. (1986), **Summary of Information and Practices Relative to Wheelchair Occupant Protection in Motor Vehicles, For Use in Developing SAE Documents by the Adaptive Devices Subcommittee (AD-3a)**, Final Report, submitted to SAE.

Kinedyne (1994), **Mobility Aid Securement and Occupant Restraint Systems Application Guide.**

Kinedyne Corp. (1995), personal communications.

Kooi, J., and Janssen, E. (1988), *Wheelchair Occupant Protection Systems: Safety During Transport*, Journal of Rehabilitation Sciences, Vol. 1, No. 3.

Kraus, L., and Stoddard, S. (1989), **Chartbook on Disability in the United States**, US Department of Education, National Institute on Disability and Rehabilitation Research.

Kroemer, K. (1987), *Engineering Anthropometry*, in Handbook of Human Factors, Salvendy, G., Ed.

Kulmala, R. (1994), *Measuring the Safety Effect of Road Measures at Junctions*, Accident Analysis & Prevention, Vol. 26, No. 6.

Kulowski, J. (1960), **Crash Injuries: The Integrated Medical Aspects of Automobile Injuries and Deaths**, Charles C. Thomas, Publisher.

LaPlante, M. (1988), **Data on Disability from the National Health Interview Survey, 1983-85**, US Department of Education, National Institute on Disability and Rehabilitation Research.

LaPlante, M., Hendershot, G., and Moss, A. (1992), *Assistive Technology Devices and Home Accessibility Features: Prevalence, Payment, Need and Trends*, US Department of Health and Human Services, Public Health Service, Centers for Disease Control, National Center for Health Statistics, Advance Data, No. 217, September 16, 1992.

Layton, R., Hunter-Zaworski, K., and Safford, R. (1989), **A Study of the Human Factors in Public Transportation Safety**, OR-11-0005, UMTA University Research and Training Program.

Little, A. (1990), **BC Transit Barrier Crash Tests of 3-Wheeled Scooters and Wheelchairs in Paratransit Vans**, Interim Report.

Little, A. (1990), **BC Transit Barrier Crash Tests of 3-Wheeled Scooters and Wheelchairs in Paratransit Vans**, Final Report.

Maxwell, J. (1986), **Wheelchair Safety Securement System Demonstration and Evaluation**, UMTA-CA-MI-86-151.

McCown, R. (1991), Wheelchair Securement, unpublished presentation given to Oregon State University.

McNeil, J. (1993), **Americans with Disabilities: 1991-92: Data From the Survey of Income and Program Participation**, Current Population Reports, Houshold Economic Studies, P70-33, December 1993.

MDD (1992), **Safety Guidelines for Transporting Children in Special Seats,** MDD/92/07, United Kingdom, Department of Health, Medical Devices Directorate.

Mercer, W., and Billing, J. (1990), **Assessment of a Severe Transportable Mobility Aid in Severe Driving Conditions - An Exploratory Test**, CV-90-03, Vehicle Technology Office, Ministry of Transportation of Ontario, Canada.

Monk and Willke (1987), *Energy Absorption Material Selection Methodology for Head/A-Pillar*, Proceedings of the 30th Stapp Car Crash Conference, SAE.

Mount, L., and Lieljuris, G. (1982), **Study on Wheelchair Tie-Downs, Occupant Restraint Systems, and Legislation vs Handicapped Transportation as a State of the Art.**

National Highway Traffic Safety Administration (1994), unpublished data from GES and CDS files.

National Transportation Safety Board (1987), **Safety Study: Crashworthiness of Large Poststandard School Buses**, NTSB/SS-87/01.

National Transportation Safety Board (1989), **Safety Study: Crashworthiness of Small Poststandard School Buses**, NTSB/SS-89/02.

Orne, D., Barak, E., and Fisch, R. (1976), *Design, Test and Development of a Wheelchair Restraint System for Use in Buses*, Proceedings of the 20th Stapp Car Crash Conference, SAE.

Petty, S., and Chatfield, A. (1983), **Static and Dynamic Tests of Wheelchair Restraints for Use in Public Service Vehicles**, Transport and Road Research Laboratory, TRRL Laboratory Report 1087.

Petty, S. (1985), *The Safe Transportation of Wheelchair Occupants in the United Kingdom*, Proceedings of the Tenth International Technical Conference on Experimental Vehicles.

Physicians for Automotive Safety News (1983/1984).

Portland Public Schools (1987), **Wheelchair and Safety Tie-Down Procedures for Physically Handicapped Transportation.**

Q'Straint (1993), The Training Manual: Wheelchair and Occupant Restraint System.

Red, E., Hale, K., McDermott, M., and Mooring, B. (1982), *Wheelchair Restraint Systems, Dynamic Test Results and the Development of Standards*, SAE Paper 821161.

Reger, S., and Adams, T. (1993), **Comparative Field Testing of the Cleveland Securement System**, Project ACTION.

Richardson, H. (1991), *Wheelchair Occupants Injured in Motor Vehicle-Related Accidents*, National Center for Statistics and Analysis, Mathematical Analysis Division, National Highway Traffic Safety Administration (NHTSA), Technical Note.

Roy, P. (1990), *Summary of Impact Performance of Three Types of Standard Wheelchair*, paper presented to WG6, ISO.

Sanders, M. (1978), **A Requirements Analysis Document for Transit Vehicle Wheelchair Lift Devices**, UMTA-CA-06-0101-79-1.

Schneider, L., and Melvin, J. (1978), **Impact Testing of Restraint Devices Used With Handicapped Children in Bus Seats and Wheelchairs**, UM-HSRI-78-52.

Schneider, L., and Melvin, J. (1978), **Sled Test Evaluation of a Wheelchair Restraint System for Use by Handicapped Drivers**, UM-HSRI-78-57.

Schneider, L., Melvin, J., and Cooney, C. (1979), *Impact Sled Test Evaluation of Restraint Systems Used in Transportation of Handicapped Children*, SAE Paper 790074.

Schneider, L., (1980), *A Wheelchair Restraint System for Handicapped Drivers and Passengers*, Proceedings of the 1st International Conference on Rehabilitation Engineering, Toronto, Canada.

Schneider, L. (1981(a)), *Protection for the Severely Disabled - A New Challenge in Occupant Restraint*, Proceedings of International Symposium on Occupant Restraint, Toronto, Ontario, Canada, June 1-3, 1981, Green, R. and Petrucelli, E., co-editors, American Association for Automotive Medicine.

Schneider, L. (1981(b)), **Dynamic Testing of Restraint Systems and Tie-Downs for Use With Vehicle Occupants Seated in Powered Wheelchairs**, UM-HSRI-81-18.

Schneider, L. (1982), *Occupant Protection for Wheelchair Travelers*, Physical Disabilities Special Interest Section Newsletter, American Occupational Therapy Association, Vol. 5, No. 2.

Schneider, L. (1982), *Motor Vehicle Safety for Occupants in Wheelchairs: Progress and Future Needs*, Proceedings of the 5th Annual Conference on Rehabilitation Engineering, Houston, Texas.

Schneider, L. (1985), **Sled Impact Test of Wheelchair Tie-Down Systems for Handicapped Drivers**, UMTRI-85-19.

Schneider, L. (1990), *Transportation of Wheelchair-Seated Students*, chapter 10 in **Physical Management of Multiple Handicaps: A Professional's Guide,** Second edition, Fraser, B., Hensinger, R., and Phelps, J., eds.

Schneider, L. (1991), **Rationale, Historical Synopsis of the Literature, and** *Bibliography*, Volume 2, Biokinetics and Associates, Ltd., Document R91-13.

School Board of Nassau County v. Arline (1987), 480 U.S. 273, 1987.

School Bus Fleet (1982), *California DOT Completes Wheelchair Studies*, School Bus Fleet, Vol. 27, No. 5, October/November, 1982.

School Bus Fleet (1986), *Is Handicapped pupil Transportation Facing Foward?*, School Bus Fleet, Vol. 31, No. 4, August/September, 1986.

School Bus Fleet (1987), *Ensuring Safety of Handicapped*, School Bus Fleet, Vol. 32, No. 1, February/March 1987.

School Bus Fleet (1987), *Study on Handicapped Transportation Underway*, School Bus Fleet, Vol 32, No. 4, August/September 1987.

School Bus Fleet (1988), *Wheelchair Tie-Down Systems Evolve*, Vol. 33, No. 3, June/July, 1988.

School Bus Fleet (1990), *Conference Develops Handicapped Standards*, School Bus Fleet, Vol. 36, N0. 4, August/September, 1990.

Seeger, B., and Caudry, D. (1983), *Special Article. Crashworthiness of Restraints for Physically Disabled Children in Buses*, Rehabilitation Literature, Vol. 44, No. 11-12.

Seeger, B., and Luxton, R. (1984), *A Crashworthy Restraint System for Disabled People in Wheelchairs in Motor Vehicles*, Proceedings of the 2nd International Conference on Rehabilitation Engineering,

Severy, D., Brink, H., and Blaisdell, D. (1971), *Smaller Vehicle versus Larger Vehicle Collisions*, Proceedings of the 15th Stapp Car Crash Conference, SAE.

Shaw, G. (1987), *Vehicular Transport Safety for the Child With Disabilities*, The American Journal of Occupational Therapy, Vol. 41, No. 1, January 1987.

Shaw, G., Lapidot, A., Scavnicky, M., Schneider, L., and Roy, P., (1994), *Interlaboratory Study of Proposed Compliance Test Protocol for Wheelchair Tiedown and Occupant Restraint Systems*, SAE Paper 942229.

Siegal, A., Nahum, A., and Runge, D. (1971), *Bus Collision Causation and Injury Patterns*, Proceedings of the 15th Stapp Car Crash Conference, SAE.

Smith, B., and Nishizaki, R. (1981), **Compendium of Transportation Equipment for Disabled Persons**, TP-3618E.

Smith, B. (1988), *Wheelchair Securement and Passenger Restraint: Issues, Principles and Initiatives*, unpublished presentation, Transportation Development Centre, Montreal, Quebec, Canada.

Society of Automotive Engineers (1995), **Wheelchair Tiedown and Occupant Restraint Systems for Use in Motor Vehicles**, SAE Jxxxx, Draft SAE Recommended Practice.

Souders, M. (19), **The Engineer's Companion: A Concise Handbook of Engineering Fundamentals**, John Wiley and Sons, Inc.

Staff (1983/84), *Observed Misuse of Child Restraints*, Physicians for Automotive Safety News.

Stewart, C., and Reinl, H. (1976), *Loading and Securing Wheelchairs in Transporting Students,* Transportation Research Record 578.

Stewart, C., and Reinl, H. (1981), **Wheelchair Securement on Bus and Paratransit Vehicles**, UMTA-CA-06-0098-81-1.

Stewart, C., and Reinl, H. (1980), **Wheelchair Securement on Bus and Paratransit Vehicles**, Interim Report Number 1, CA-06-0098-79-1.

Stewart, D. (1993), **Special Care on the School Bus: Getting Your Child with Special Needs To and From School Safely - A Parents' Guide**, Automotive Safety for Children Program at Riley Hospital for Children, Indianapolis, Indiana.

Stewart, D. (1993), **Special Care on the School Bus: Getting Your Child with Special Needs To and From School Safely - A Manual for School Transportation Professionals,** Automotive Safety for Children Program at Riley Hospital for Children, Indianapolis, Indiana.

Stout, J., Bull, M., Stroup, K., Goldsmith, J., Doll, J., and Russell, R. (1993), *A Survey of Transportation Services for Children with Disabilities*, The American Journal of Occupational Therapy, Vol. 47, No. 9, September 1993.

Stroup, K. (1993), *Transporting Disabled Children: Modified Preschool Restraints Must Survive Crash Test*, School Bus Fleet, February/March 1993.

Suen, L., and Geehan, T. (1993), *Transportation Technologies for Improving Independence in Canada*, Transportation Research Record 1378.

TD Safety Report (1994), Vol. 2, Nos. 8, 9, 10, 13, 18,19, 20, 21, 22.

Telovsky, W. (1995), **Transporting the Disabled: Using Wheelchairs as Seating Devices in Moving Vehicles: A Legislative Study with Recommendations**, A Report to the New York Legislature by the Legislative Commission on Critical Transportation Choices.

Tie Tech, Inc. (1989), **Documentation for Sled Test as Conducted at Transportation Research Center of Ohio.**

Tittle, B., Thompson, J., and Morehouse, D. (1991), *Failure Strength of an Electric Scooter Restraint System*, unpublished paper, Course ME 439x, Oregon State University.

Transit Cooperative Research Program (1992), *Personal Mobility Aid Securement and Passenger Restraint on Transit Vehicles*, Research Project Statement, TCRP Project C-1, FY '92.

Transit Cooperative Research Program (1994), **Personal Mobility Aid Securement and Passenger Restraint on Transit Vehicles**, Interim Report, Transportation Research Board, National Academy of Sciences.

Transportation Systems Center, Research and Special Programs Administration (1986), **National Workshop on Bus-Wheelchair Accessibility**, Proceedings, DOT-I-87-11.

UMTRI (1986), **Sled Impact Test WK-8602: Constantin Transit Vehicles and "E.Z. Lock" Wheelchair Tiedown.**

UMTRI (1991), Sled Impact Test OS 9102, Orthosafe Systems Protector System with Retractor and 50th Percentile Male Dummy.

United Kingdom, Department of Transport (1987), **The Safety of Passengers in Wheelchairs on Buses**, Code of Practice, VSE 87/1.

United Kingdom (1993), Mobility Unit: 1993/94 Review, Department of Transport.

United States Architectural & Transportation Barriers Compliance Board (1986), **Lifts and Wheelchair Securement.**

United States Architectural & Transportation Barriers Compliance Board (1990), **Securement of Wheelchairs and Other Mobility Aids on Transit Vehicles.**

United States Architectural & Transportation Barriers Compliance Board (1992), **Buses, Vans & Systems: Technical Assistance Manual.**

University of Michigan Transportation Research Institute (1990), **Sled Impact Test AM-9001.**

University of Virginia (1994), *UVA Transportable Wheelchair Standard Contribution,* unpublished.

US Consumer Product Safety Administration (1995), unpublished data from the National Electronic Injury Surveillance System.

US DOT Final Rule, Americans with Disabilities Act of 1990 (ADA), Federal Register, Vol. 56, No. 173, Friday, September 6, 1991.

Vanderheiden, G. (1990), *Thirty-Something Million: Should They be Exceptions?,* Human Factors, Vol. 32, No. 4.

Viano, D. (1988), *Limits and Challenges of Crash Protection,* Accident Analysis & Prevention, Vol. 20, No. 6.

Walsh, M., and Segal, D. (1989), *Side Facing Wheelchair Occupant Safety: A Sled Testing and Computer Simulation Study*, Proceedings of the Eighteenth Annual International Workshop on Human Subjects for Biomechanical Research.

Washtenaw Intermediate School District (1993), **Transportation of Students with Disabilities**, Seating Study Committee Report and Pre-school Guidelines.

Wevers, H. (1983), *Wheelchair and Occupant Restraint System for Transportation of Handicapped Passengers*, Archives of Physical Medicine and Rehabilitation, Vol. 64, August 1983.

Wevers, H. (1992), Final Report for the Canadian Standards Association CAN/CSA- Z605, **Mobility Aid Securement and Occupant Restraint Systems for Motor Vehicles**.

Wheelchair Development, Standards, Progress and Issues: A Discussion with Colin McLaurin, Sc. D., Journal of Rehabilitation Research & Development, Vol. 23, No. 2, April, 1986.

Wilkoff, W. and Abed, L. (1994), **Practicing Universal Design: An Interpretation of the ADA**.

Appendix A - Sample Cover Letters

U.S. Department
of Transportation

**Research and
Special Programs
Administration**

John A. Volpe
National Transportation
Systems Center

Kendall Square
Cambridge, Massachusetts 02142

12/15/94

The US Department of Transportation's Volpe Center is working with the Federal Transit Administration (FTA) to identify issues pertaining to the securement of three-wheeled scooters and the restraint of their occupants on buses and vans used in the provision of public transit services, both fixed-route and complementary paratransit services.

As you are well aware, the Americans with Disabilities Act (ADA) accessibility specification for transportation vehicles (Part 38, FR Vol. 56, No. 173, Sept. 6, 1991) requires that all new, used or remanufactured buses and vans (except over-the-road buses), purchased after August 25, 1990, provide a level-change mechanism or boarding device (e.g., lift or ramp). Among other specified technical requirements for compliance, this level-change mechanism or boarding device must accommodate all common wheelchairs and mobility aids, including three-wheeled scooters that comply with the dimensional envelope of 30 inches in width and 48 inches in length, measured 2 inches above the ground.

This study will not only identify issues, but help shape, in a collaborative effort with you, future Federal research and a possible rule-making agenda directed at these issues. **Your input to this process is critical!** We have enclosed a data collection instrument for this purpose. Your individual responses, at your request, will be kept confidential. We will be glad to share the collective results with you. Please let me know if you would like a copy of the report when the study is complete. You may fax your response to me at FAX: 617-494-3260, or you may send it back in the enclosed, stamped envelope. If you have any questions, please call me at 617-494-2252. **Your response is requested by January 12, 1995.**

Thank you for your cooperation.

Sincerely,

David Spiller, MS Trans. Eng.
Principle Investigator

Enclosure

U.S. Department
of Transportation

**Research and
Special Programs
Administration**

John A. Volpe
National Transportation
Systems Center

Kendall Square
Cambridge, Massachusetts 02142

12/29/94

The US Department of Transportation's Volpe Center is working with the Federal Transit Administration (FTA) to identify issues pertaining to the securement of three-wheeled scooters and the restraint of their occupants on buses and vans used in the provision of public transit services, both fixed-route and complementary paratransit services.

As you are well aware, the Americans with Disabilities Act (ADA) accessibility specification for transportation vehicles (Part 38, FR Vol. 56, No. 173, Sept. 6, 1991) requires that all new, used or remanufactured buses and vans (except over-the-road buses), purchased after August 25, 1990, provide a level-change mechanism or boarding device (e.g., lift or ramp). Among other specified technical requirements for compliance, this level-change mechanism or boarding device must accommodate all common wheelchairs and mobility aids, including three-wheeled scooters that comply with the dimensional envelope of 30 inches in width and 48 inches in length, measured 2 inches above the ground.

This study will not only identify issues, but help shape, in a collaborative effort with you, future Federal research and a possible rule-making agenda directed at these issues. **Your input to this process is critical!** We have enclosed ten (10) copies of a data collection instrument for this purpose. We are asking that you distribute these forms to those whom you think can provide the information requested. The individual responses will be kept confidential. We will be glad to share the collective results with you. Please let me know if you would like a copy of the report when the study is complete. Completed forms may be sent back to me in the enclosed, stamped envelopes. If you have any questions, please call me at 617-494-2252. **Your response is requested by January 19, 1995.**

Thank you for your cooperation.

Sincerely,

David Spiller, MS Trans. Eng.
Principle Investigator

Enclosure

Appendix B - 'Key Actor" Group Lists

Technical Community List

1. Katherine M. Hunter-Zaworski, Ph.D., P.E.
   Transportation Research Institute
   100 Merryfield Hall
   Corvallis, Oregon 97331-4304

2. Steven Reger, Ph.D.
   The Cleveland Clinic Foundation
   9500 Euclid Avenue
   Cleveland, Ohio 44195

3. Barbara Smith
   Transport Canada
   Transportation Development Centre (TDC)
   800 Rene Levesque Blvd. W.
   6th Floor Montreal, Quebec H3b 1x9

4. Gerald A. Francis
   Battelle
   505 King Street
   Columbus, Ohio 43201-2693

5. David Norstrom, MS
   Battelle
   505 King Street
   Columbus, Ohio 43201-2693

6. Lawrence W. Schneider, Ph.D.
   University of Michigan
   Transportation research Institute
   2901 Baxter Road
   Ann Arbor, Michigan 48109-2150

7. Louis Cheng, Ph.D.
   Failure Analysis Associates
   149 Commonwealth Drive
   Menlo Park, California 94205

8. Anil V. Khadilkar, Ph. D.
   Minicars, Inc.
   55 Depot Road
   Goleta, CA 93117

9. Carl F. Stewart
California Department of Transportation
Planning and Full Mobility Branch
Division of Mass Transportation
1120 "N" Street, Room 4202
Sacramento, California

10. W. Mercer, P. Eng.
Research Engineer
Vehicle Technology Office
Transportation Technology and Energy Branch
Ministry of Transportation of Ontario
1201 Wilson Avenue
Downsview, Ontario
M3M 1J8

11. Dennis Cannon
US Architectual and Transportation Barriers Compliance Board
1331 F Street, N.W., Suite 1000
Washington, DC 20004-1111

12. Gayle D. Dalrymple, MS
National Highway Traffic Safety Administration
Crash Avoidance Division/NRM-11
400 7th Street, SW
Washington, DC 20590

13. Carl Ragland, MS
National Highway Traffic Safety Administration
Safety Systems Engineering and Analysis Division/NRD-11
400 7th Street, SW
Washington, DC 20590

14. Make McDermott, Jr., Ph. D.
Texas A&M University
Mechanical Engineering Department
College Station, TX 77843

15. Edward Red, Ph. D.
Texas A&M University
Mechanical Engineering Department
College Station, TX 77843

16. Jeffrey Lerner, Ph.D
Emergency Care Research Institute (ECRI)
Philadelphia, PA

17. John Balog, MS
Ketron
Great Valley Corporate Center
350 Technology Drive
Malvern, PA 19355-1370

18. Greg Shaw, MS
University of Virginia
Automobile Safety Laboratory
1011 Linden Avenue
Charlottsville, VA 22901

19. Douglas Hobson, Ph.D.
School of Health and Rehabilitation Sciences
University of Pittsburgh
915 William Pitt Way
Pittsburgh, PA 15238

Transit System List

1. Carolyn J. Purnell, Executive Director
Seattle Metro
821 Second Avenue
Exchange Building
Seattle , WA 98104-1598

2. Robert Allen Schweim, Executive Director
Spokane Transit Authority
West 1230 Boone Avenue
Spokane, WA 99201-2686

3. Don S. Monroe, Executive Director
Pierce Transit
3701 96th Street, S.W.
P.O.Box 99070
Tacoma, WA 98499-0070

4. Tom Walsh, General Manager
TRI-MET
4012 Southeast 17th Avenue
Portland. OR 97202-3993

5. John J. Haley, Jr., General Manager
MBTA
10 Park Plaza
Boston, MA 02116

6. Marlene B. Connor, Administrator
Pioneer Valley Transit Authority
2808 Main Street
Springfield, MA 01107

7. Dennis J. Fitzgerald, Executive Director
Capital District Transportation Authority
110 Watervliet Avenue
Albany, NY 12206

8. Anthony J. Schill, General Manager
Niagara Frontier Transportation Authority
181 Ellicott Street
P.O. Box 5008
Buffalo, NY 14205

9. Alan F. Kiepper, President
NYCTA
370 Jay Street
Brooklyn, NY 11201-3878

10. Joseph A. Calabrese, Executive Director
CNY Centro
One Centro Center
P.O. Box 820
Syracuse, NY 13205-0820

11. Shirley A. DeLibero, Executive Director
NJ Transit
One Penn Plaza East
Newark, NJ 07105-2246

12. James C. Echols, Executive Director
Tidewater Transportation District Commission
P.O. Box 2096
Norfolk, VA 23501

13. Rollo C. Axton, General Manager
Greater Richmond Transit Company
101 South Davis Avenue
P.O. Box 27323
Richmond, VA 23261-7323

14. Louis J. Gambaccini, Chief Operating Officer/Gen Mgr
SEPTA
The Sovereign Building
714 Market Street
Philadelphia, PA 19106

15. William W. Millar, Executive Director
Port Authority of Allegheny County
2235 Beaver Avenue
Pittsburgh, PA 15233

16. Lawrence G. Reuter, General Manager
WMATA
600 Fifth Street, N.W.
Washington, DC 20001

17. John A. Agro, Jr., Administrator
Mass Transit Administration of Maryland
300 West Lexington Street
Baltimore, MD 21201-3415

18. Graham J. Norton, Director Transportation
Montgomery County Transit Services
110 North Washington Street
Suite 200
Rockville, MD 20850

19. William Hudson, Jr., General Manager
Memphis Area Transit Authority
1370 Levee Road
Memphis, TN 38108

20. David B. Arnett, Executive Director
Transit Authority of River City (TARC)
1000 West Broadway
Louisville, KY 40203

21. Richard J. Simonetta, General Manager
MARTA
2424 Piedmont Road, N.E.
Atlanta, GA 30324-3330

22. Michael J. Scanlon, Director
Broward County Division of Mass Transit
3201 West Copans Road
Pompano Beach, FL 33069-5199

23. Chester Colby, Director
Metro-Dade Transit Agency
111 N.W. First Street, 9th Floor
Miami, FL 33128

24. Sharon Dent, Executive Director
Hillsborough Area Regional Transit Authority
4305 East 21st Avenue
Tampa, FL 33605

25. Paul Larrousse, General Manager
Madison Metro Transit System
1101 East Washington Avenue
Madison, WI 53703

26. Thomas P. Kujawa, Managing Director
Milwaukee County Transit System
1942 North 17th Street
Milwaukee, WI 53205

27. Paul Jablonski, General Manager
Southwest Ohio Regional Transit Authority
Metro Operating Division
Kroger Building - Suite 2000
1014 Vine Street
Cincinnati, OH 45202-1122

28. Ronald J. Tober, General Manager
Greater Cleveland Regional Transit Authority
615 Superior Avenue, W.
Cleveland, OH 44113-1877

29. Glenna L. Watson, General Manager
Central Ohio Transit Authority
1600 McKinley Avenue
Columbus, OH 43222

30. Thomas R. Sather, Chief Administrator/Gen Mgr.
Metropolitan Transit Commission
560 Sixth Avenue North
Minneapolis, MN 55411-4398

31. Ted J. Rieck, General Manager
Indianapolis Public Transportation Corporation
1501 West Washington Street
P.O. Box 2383
Indianapolis, IN 46206-2383

32. Robert Belcaster, President
Chicago Transit Authority (CTA)
Merchandise Mart Plaza
P.O. Box 3555
Chicago, IL 60654-0555

33. Robert G. MacLennan, P.E., General Manager
Metropolitan Transit Authority of Harris County
1201 Louisiana
P.O. Box 61429
Houston, TX 77208-1429

34. Wayne A. Dupre, Executive Director
Regional Transit Authority
6700 Plaza Drive
New Orleans, LA 70127-2677

35. Roger Snoble, Executive Director
Dallas Area Rapid Transit (DART)
1401 Pacific Avenue
P.O. Box 660163
Dallas, TX 75266-0163

36. Richard F. Davis, General Manager
Kansas City Area Transportation Authority
1200 East 18th Street
Kansas City, MO 64108

37. John K. Leary, Jr., Executive Director
Bi-State Development Agency
707 North First Street
St. Louis, MO 63102-2595

38. John C. Pingree, General Manager
Utah Transit Authority
3600 South 700 West
P.O. Box 30810
Salt Lake City, UT 84130-0810

39. Peter M. Cipolla, General Manager
Regional Transportation District (RTD)
1600 Blake Street
Denver, CO 80202

40. Gerald T. Haugh, General Manager
San Mateo County Transit District (SAMTRANS)
1250 San Carlos Avenue
P.O. Box 3006
San Carlos, CA 94070-1306

41. Sharon D. Banks, General Manager
AC Transit
1600 Franklin Street
Oakland, CA 94612

42. Ronald H. Yagura, General Manager
San Diego Transit Corporation
P.O. Box 2511
San Diego, CA 92112-2511

43. Franklin E. White, Chief Executive Officer
Los Angeles County Metropolitan Transportation Authority
818 West Seventh Street
Los Angeles, CA 90017

44. Stanley T. Oftelie, Chief Executive Officer
Orange County Transportation Authority
550 South Main Street
P.O. Box 14184
Orange, CA 92613-1584

Securement Manufacturer List

1. Advanced Mobility, Inc.
   15912 Arminta Street
   Van Nuys, CA 91406

2. Aeroquip Corporation
   Industrial Division
   1225 West Main Street
   Van Wert, OH 45891

3. American Seating Co.
   401 American Seating Center
   Grand Rapids, MI 49504-4499

4. Am-Safe Seat Belt Systems
   240 N. 48th Ave.
   Phoenix, AZ 85043

5. The Braun Corp.
   1014 South Monticello St.
   Winamac, IN 46996

6. Bud Industries, Inc.
   100 West Pulaski Street
   West Warwick, RI 02893

7. Chas. Olsen & Sons
   677 Transfer Road
   St. Paul, MN 55114

8. Coach and Car Equipment Corp.
   1951 Arthur Avenue
   Elk Grove Village, IL 60007

9. Collins Industries, Inc.
   Special Products Division
   P.O. Box 58
   Hutchinson, KS 67501

10. Creative Controls, Inc.
    1354-I Combermere
    Troy, MI 48084

11. Crow River Industries, Inc.
1415 East Wayzata Blvd.
Wayzata, MN 55391

12. Drive-Master Corporation
16 Andrews Drive
West Paterson, NJ 07424

13. Dynamic Mobilities, Inc.
P.O. Box 1493
2070 Helena Street
Madison, WI 53704

14. Electro Van Lift, Inc.
140 Concord
St. Paul, MN 55107

15. Fred Scott & Sons
1444 W. Rand Road
Des Plaines, IL 60016

16. Gresham Driving Aids, Inc.
P.O. Box 405
30800 Wixom Road
Wixom, MI 48096

17. Handicaps, Inc.
4335 S. Santa Fe Drive
Denver, CO 80110

18. Handi-Ramp, Inc.
P.O. Box 745
1414 Armour Blvd.
Mundelein, IL 60060

19. Kinedyne Corporation
3701 greenway Circle
Lawrence, KS 66046

20. Mobility Dynamics, Inc.
21029 Itasca Avenue
Chatsworth, CA 91311

21. Q'Straint
3085 Southwestern Blvd.
Orchard Park, NY 14127

22. Reb Lifts & Ramps by Reb Mfg Co., Inc.
2327 SR 568-W, P.O. Box 276
Carey, OH 43316-0276

23. Skillcraft Industries, Inc.
1270 Ogden Road
Venice, FL 33595

24. Target Industries, Inc.
55 Newberry Road
Warehouse Point, CT 06088

Scooter Manufacturer List

1. Amigo Sales, Inc.
   6693 Dixie Hwy.
   Bridgeport, MI 48722

2. Dunlap Export Co., Inc.
   P.O. Box 5357
   Akron, OH 44334

3. Everest and Jennings, Inc.
   3233 E. Mission Oak Blvd.
   Camarillo, CA 93012

4. Fortress Scientific Ltd.
   1100 Finch Ave. W.
   Downsville, Ont., Canada

5. Invacare Corp.
   899 Cleveland st.
   Elyria, OH 44035

6. Ortho Kinetics, Inc.
   P.O. Box 436
   Waukesha, WI 53187

7. Orthopedic Appliance Co., Inc.
   2101 8th Ave. S.
   Birmingham, AL 35233

8. Ortho Safe System, Inc.
   P.O. Box 9435
   Trenton, NJ 08650

Mobility Aid User Organization List

1. Ms. Maureen McCloskey, Director of Advocacy
   Paralyzed Veterans of America (PVA)
   801 18th Street, N.W.
   Washington, DC 20006

2. Mr. Speed Davis, Executive Director
   National Council on Disability
   1331 F Street, N.W., Suite 1050
   Washington, DC 20004

3. Mr. Alan Reich, President
   National Organization on Disability
   910 16th Street, N. W.
   Washington, DC 20006

4. Mr. Bill Stokes, Jr., Technical Analyst
   The Community Transportation Forum
   1515 East Osborn Road
   Phoenix, AZ 85014

5. Ms. Susan Herz, Executive Director
   Disability Law Center of Boston
   11 Beacon Street
   Boston, MA 02108

Appendix C - 'Key Actor' Group Data Collection Forms

Technical Community Data Collection Form

This data collection form is being circulated within the technical community to support a US Department of Transportation study to identify issues related to the securement of three-wheeled scooters and the restraint of their occupants when transported on buses and vans used in the provision of public transit services.

In Section I, you are asked to react to **potential** issues using a five (5) point rating scale, with 1= STRONGLY AGREE, 2= AGREE, 3 = NEUTRAL, 4 = DISAGREE, and 5 = STRONGLY DISAGREE. In Section II, you are asked to defend your rating by providing substantive evidence and argument for it! Section III asks you to provide accident data if you have completed an accident analysis. Sections IV and V ask that you react, using the same five-point rating scale, to focus areas for Federal research, development, test and evaluation (RDT&E), and specific changes to the DOT Final Rule implementing the Americans with Disabilities Act (ADA) as it relates to *mobility aid securement and occupant restraint* (**MASOR**) systems.

Can we follow up with a telephone call? YES____ NO____

Name: ________________________________

Adress: ________________________________

____

____

Tel #: ________________________________

FAX #: ________________________________

US Department of Transportation
Volpe National Transportation Systems Center
Kendall Square, DTS-49
Cambridge, MA 02142

David Spiller
US DOT/Volpe Center DTS-49
Kendall Square
Cambridge, MA 02142

I. Potential issues related to the securement of three-wheeled scooters and the restraint of their occupants on buses and vans used in public transit services

Please circle your response.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. Attachment points, on some scooter models, are inaccessible	1	2	3	4	5
2. Attachment points, on some scooter models, are not structurally strong enough to withstand dynamic loads (both panic stops and crash events)	1	2	3	4	5
3. Inability to restrain the battery pack from acting as a projectile in a crash, even when the scooter itself can be restrained by the securement system	1	2	3	4	5
4. Transit systems not installing two-point attachment systems with the proper angle to restrain the scooter from rotation backwards (rear crash event) with respect to its rear axle	1	2	3	4	5
5. Shearing or fracture of the seat pedestal	1	2	3	4	5
6. Large bending moments on the scooter seats, exceeding the restraining force of the seat design, from the inertial loads imposed by the torso of the occupant during a dynamic crash environment	1	2	3	4	5

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
7. Lack of independence of the occupant restraint system and the securement system for the scooter for some transit systems, thereby coupling the mass of the occupant and the scooter and exceeding the design loads of the securement system	1	2	3	4	5
8. Proliferation of new models not compatible with existing securement and occupant restraint systems	1	2	3	4	5
9. Inconsistency of test protocols for **MASOR** systems	1	2	3	4	5
10. Transit-designed **MASOR** systems that have not been rigorously tested, including dynamic sled tests	1	2	3	4	5
11. Insufficient test instrumentation (inadequate test protocol) to adequately determine occupant injury potential, in dynamic tests of **MASOR** systems	1	2	3	4	5
12. Elastic deformation of the scooter platform in a crash event (bottoming out on the bus/van floor) which imparts an excessive vertical excursion and acceleration to the scooter's occupant	1	2	3	4	5
13. Rollover or tipping instability during side impact crash events and/or sharp, high speed cornering maneuvers	1	2	3	4	5

14. Please comment on any other scooter securement and occupant restraint issues and/or problems not otherwise specified (use additional sheets, if necessary)

II. Supporting information for issues related to the securement of three-wheeled scooters and the restraint of their occupants on buses and vans

1. Attachment points, on some scooter models, are inaccessible

   Comments (e.g., laboratory and/or field test data; citation of other research reports; specificity as to scooter makes and models): (use additional sheets, if necessary)

2. Attachment points, on some scooter models, are not structurally strong enough to withstand dynamic loads (both panic stops and crash events)

   Comments (e.g., laboratory and/or field test data; modeling calculations; citation of other research reports; specificity as to scooter makes and models): (use additional sheets, if necessary)

3. Inability to restrain the battery pack from acting as a projectile in a crash, even when the scooter itself can be restrained by the securement system

   Comments (e.g., laboratory and/or field test data; crash event data and post-crash analysis; modeling calculations; citation of other research reports; specificity as to scooter makes and models): (use additional sheets, if necessary)

4. Transit systems not installing two-point attachment systems with the proper angle to restrain the scooter from rotation backwards (rear crash event) with respect to its rear axle

   Comments (e.g., transit field surveys; crash event data and post-crash analysis; citation of other research reports; specificity as to bus/van and securement system makes and models, and securement location on bus/van): (use additional sheets, if necessary)

   ____
   ____
   ____
   ____
   ____
   ____
   ____

5. Shearing or fracture of the seat pedestal

   Comments (e.g., laboratory test data; crash event data and post-crash analysis; modeling calculations; citation of other research reports; specificity as to scooter makes and models, and deceleration force) (use additional sheets, if necessary)

   ____
   ____
   ____
   ____
   ____
   ____
   ____

6. Large bending moments on the scooter seats, exceeding the restraining force of the seat design, from the inertial loads imposed by the torso of the occupant during a dynamic crash environment

   Comments (e.g., laboratory test data; crash event data and post-crash analysis; modeling calculations; citation of other research reports; specificity as to scooter makes and models, and limiting bending moment) (use additional sheets, if necessary)

   ____
   ____
   ____
   ____
   ____
   ____
   ____

7. Lack of independence of the occupant restraint system and the securement system for the scooter for some transit systems, thereby coupling the mass of the occupant and the scooter and exceeding the design loads of the securement system

   Comments (e.g., transit field surveys; crash event data and post-crash analysis; specificity as to securement system makes and models that might be most susceptible due to low design loads) (use additional sheets, if necessary)

8. Proliferation of new models not compatible with existing securement and occupant restraint systems

   Comments (e.g., example incompatibility matrix between specific scooter makes and models, and commercially available *mobility aid securement and occupant restraint* (MASOR) systems) (use additional sheets, if necessary)

9. Inconsistency of test protocols for MASOR systems

   Comments (e.g., citation of specific tests using different test protocols; citation of specific scooter sled tests that are not comparable due to inconsistent test protocols; recommended test protocols that should be used for static and dynamic tests) (use additional sheets, if necessary)

10. Transit-designed **MASOR** systems that have not been rigorously tested, including dynamic sled tests

Comments (e.g., transit field surveys; transit engineering department test reports; crash event data and post-crash analysis) (use additional sheets, if necessary)

11. Insufficient test instrumentation (inadequate test protocol) to adequately determine occupant injury potential, in dynamic tests of **MASOR** systems

Comments (e.g., citation of inadequate test instrumentation, non-adherence to SAE and FMVSS standards, and inappropriate and/or inadequate measurement of anthropomorphic body response in prior test reports) (use additional sheets, if necessary)

12. Elastic deformation of the scooter platform in a crash event (bottoming out on the bus/van floor) which imparts an excessive vertical excursion and acceleration to the scooter's occupant

Comments (e.g., laboratory test data; crash event data and post-crash analysis; modeling calculations; citation of other research reports; specificity as to scooter makes and models, bus/van makes and models, floor stiffness measurements, and attachment point geometries) (use additional sheets, if necessary)

13. Rollover or tipping instability during side impact crash events and/or sharp, high speed cornering maneuvers

Comments (e.g., laboratory test data; field test data; crash event data and post-crash analysis; modeling calculations; citation of other research reports; specificity as to scooter makes and models, and **MASOR** systems that provide inadequate rollover restraints) (use additional sheets, if necessary)

III. Accident data related to the securement of three-wheeled scooters on buses and vans used in the provision of public transit services

Have you ever conducted an accident analysis, published or unpublished, related to the securement of three-wheeled scooters on buses and vans used in the provision of public transit services? YES_____ NO_____

If YES, how many accident events were involved in the sample? _____

Based on this sample of accident events, involving the transport of the scooter on a bus/van in public transit service, please indicate the number of accident events in which:

a. the crash event was a frontal impact ____
b. the crash event was a rear impact ____
c. the crash event was a side impact ____
d. the securement system failed ____
e. the scooter deformed ____
f. the scooter excursion beyond its securement location was greater than 2" in any direction ____
g. the scooter occupant was injured or killed ____
h. other passengers were injured or killed as a result of scooter or scooter occupant movement ____
i. the battery pack separated from the scooter ____
j. the seat pedestal sheared or fractured ____

IV. Potential topics for Federally-sponsored research, development, test and evaluation (RDT&E)

Please circle your response.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. Conduct national, large-scale operational tests (at multiple sites) of competing universal designs for **MASOR** systems using a common evaluation framework	1	2	3	4	5
2. Conduct national competition for a new **MASOR** system universal design	1	2	3	4	5
3. Conduct human factor investigations and experiments for independent securement by persons with mobility impairments (including time, motion, energy studies)	1	2	3	4	5
4. Conduct human factor investigations and experiments for bus operator securement of mobility devices, including scooters (including time, motion, energy studies)	1	2	3	4	5
5. Investigate better internal circulation for buses and vans used in public transit services (including internal flow of passengers, seating, stanchion and securement locations, access paths, location of fare collection and ITS equipment)	1	2	3	4	5

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
6. Improve training materials, and information transfer for bus/van operators (including crashworthiness design, and principles of securement)	1	2	3	4	5
7. Develop national clearinghouse for tests of **MASOR** systems	1	2	3	4	5
8. Design and develop standard battery of static and dynamic tests of **MASOR** systems	1	2	3	4	5
9. Conduct **MASOR** systems test program (using standard battery of tests)	1	2	3	4	5
10. Characterize bus crash environment, including occupant injury mechanisms, using full and model-scaled bus/van crash tests	1	2	3	4	5
11. Develop a national standard for transportable mobility aids (similar to Canadian Standards Association (CSA) Z604)	1	2	3	4	5

12. Please comment on any other RDT&E topics, identifying the issue and/or problem to be addressed, description of the RDT&E to be done, and what the federal role should be. (use additional sheets, if necessary)

V. Potential changes to the US DOT Final Rule implementing the Americans with Disabilities Act of 1990 (ADA)

Please circle your response.

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. Scooter occupants must transfer to a bus/van seat	1	2	3	4	5
2. Adopting a "certified list" of transportable mobility aids in lieu of the "common wheelchair" concept	1	2	3	4	5
3. Conditioning federal financial assistance to individuals for the purchase of a mobility aid to mobility aids that comply with a transportable mobility aid standard (a "certified list")	1	2	3	4	5
4. Restriction of "common wheelchair" to four-wheeled mobility aids	1	2	3	4	5
5. No change to Final Rule with respect to securement of mobility aids, including scooters	1	2	3	4	5

6. Please comment on any other changes, that you deem necessary, to the Final Rule related to **MASOR** systems (use additional sheets, if necessary)

____

____

____

____

____

____

____

THANK YOU FOR YOUR COOPERATION IN COMPLETING THIS DATA COLLECTION FORM!

Transit System Data Collection Form

This data collection form is being sent to a sample of transit systems to elicit information to support a US Department of Transportation study to identify issues related to the securement of three-wheeled scooters and the restraint of their occupants when transported on buses and vans used in the provision of public transit services.

In Section I, you are asked to provide background data that describe your system and the intensity of use by persons with mobility aids, including three-wheeled scooters. Section II addresses operational issues pertaining to the transport of three-wheeled scooters on buses and vans, and Section III asks that you provide information on engineering and maintenance issues. In Section IV, you are asked to react to **potential** changes to the US DOT Final Rule implementing the Americans with Disabilities Act of 1990 (ADA) as it relates to *mobility aid securement and occupant restraint* (**MASOR**) systems using a five (5) point rating scale, with 1=STRONGLY AGREE, 2=AGREE, 3=NEUTRAL, 4=DISAGREE, and 5=STRONGLY DISAGREE.

Can we follow up with a telephone call? YES____ NO____

Name: ______________________________

Address: ______________________________

____

____

____

Tel #: ______________________________

Fax #: ______________________________

US Department of Transportation
Volpe National Transportation Systems Center
Kendall Square, DTS-49
Cambridge, MA 02142

David Spiller
US DOT/Volpe Center DTS-49
Kendall Square
Cambridge, MA 02142

I. Background

1. Please provide the following information:
   a. number of buses in fixed route service in the peak period ______
   b. number of vehicles in complementary paratransit service in the peak period ______
   c. percent of fixed route fleet that is ADA accessible ______

2. On average, how many wheelchair boardings are on the fixed route bus system per week? ______

3. What percent of the average wheelchair boardings per week on the fixed route bus system involve three-wheeled scooters? ______

4. On average, how many wheelchair boardings are on the complementary paratransit service per week? ______

5. What percent of the average wheelchair boardings per week on the complementary paratransit service involve three-wheeled scooters? ______

II. Operational Issues

1. Are occupants of three-wheeled scooters, after boarding the bus or van, requested to transfer to a seat? YES____ NO___

2. Of those occupants who are requested to transfer to a seat, what percent comply? ____

3. Are there detailed user instructions for the mobility aid securement system on the vehicle? YES____ NO___

   If YES, please identify the location on the vehicle of the user instructions.

   ___
   ___
   ___

3. Are drivers given training in the securement of mobility aids and the restraint of their occupants? YES____ NO___

   If YES, please describe.

   ___
   ___
   ___
   ___
   ___
   ___
   ___

4. In the last five years, how many accidents/incidents have there been on buses and vans in your system involving injuries/fatalities to occupants of mobility aids? _____

Please describe, for each accident/incident event (use additional sheets, if necessary):

a. whether the direction of impact was front, side, or rear
b. whether the bus/van was in motion
c. whether the securement system failed
d. identification of type of securement sytem and mobility aid
e. body location and degree of injury (minor, moderate, severe) to mobility aid occupant

f. whether other passengers were injured as a direct result of securement failure of the mobility aid, and/or restraint failure of the mobility aid occupant
g. body location and degree of injury (minor, moderate, severe) to other passengers as a direct result of securement/restraint failure of the mobility aid and its occupant

____

5. In the last five years, how many legal tort claims have been filed against your system related to injuries claimed in the failure to secure mobility aids and to restrain the occupants of those mobility aids? _____

   Please describe each case (use additional sheets, if necessary)

____

6. Please describe operational policy concerning driver assistance in the securement of mobility aids and the restraint of their occupants.

____
____
____
____
____
____
____

7. Please identify the type (s) of securement systems used on your fixed-route buses, and on your vehicles used in the provision of complementary paratransit service:

a. Rear wheel clamps or pins (wheel lock device)	Y	N
b. Belt system (two-, three-, or four-point)	Y	N
c. T-bar ("T"-shaped bar which attaches wheelchair frame to floor)	Y	N
d. Fender brackets (brackets over top of rear wheels)	Y	N
e. Other (please specify)______________________________		

8. Please describe and comment on any other operational issues related to the securement of the three-wheeled scooters on buses and vans (e.g., ease of use of securement system, independent use by occupant, close physical space between driver and user during securement and release, resistance to use of securement and restraint system, access to and from securement location, emergency evacuation, safety of scooter occupant and other passengers, etc.) (use additional sheets, if necessary).

____
____
____
____
____
____
____

III. Engineering and Maintenance Issues

1. Do you specify, in new bus/van procurements, and use in your current fleet of buses and vans commercial-off-the-shelf *mobility aid securement and occupant restraint* (**MASOR**) systems? YES____ NO____

2. What tests of commercial-of-the-shelf **MASOR** systems do you require before acceptance by you?

____
____
____
____
____
____
____

3. Have you designed and installed on your buses/vans your own **MASOR** system? YES____ NO____

   If YES, please describe (use additional sheets, if necessary).

____
____
____
____
____
____
____

4. Please describe all tests conducted on your uniquely designed **MASOR** system.

____
____
____
____
____
____
____

5. Please identify the type (e.g., manual, powered, sport, scooter), manufacturer and model of any mobility aids that are particularly difficult to secure on your buses and vans. Please describe the specific problems encountered for these mobility aids.

____
____
____
____
____
____
____

6. Please indicate your ranking of the following engineering, maintenance and functional requirements that a mobility-aid securement and occupant restraint (**MASOR**) system should satisfy, with 1="most important", 2="next most important", etc.

a. Universal design ____
b. Minimum crashworthiness standard ____
c. Maximum securement and release time ____
d. Vandal-resistant ____
e. Independent securement by mobility-aid occupant ____
f. Cost of system ____
g. Ease of installation and maintenance ____
h Safety and ease of driver-assisted securement ____
i. Other ______________________
____
____

7. Please describe any other engineering or maintenance issue related to the securement of three-wheeled scooters on buses and vans (use additional sheets, if necessary).

____
____
____
____
____
____
____

IV. Potential changes to the US DOT Final Rule implementing the Americans with Disabilities Act of 1990 (ADA)

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. Scooter occupants must transfer to a bus/van seat	1	2	3	4	5
2. Adopting a "certified list" of transportable mobility aids in lieu of the "common wheelchair" concept	1	2	3	4	5
3. Conditioning federal financial assistance to individuals for the purchase of a mobility aid to mobility aids that comply with a transportable mobility aid standard (a "certified list")	1	2	3	4	5
4. Restriction of "common wheelchair" to four-wheeled mobility aids	1	2	3	4	5
5. No change to Final Rule with respect to securement of mobility aids, including scooters	1	2	3	4	5

6. Please comment on any other changes, that you deem necessary, to the Final Rule related to MASOR systems (use additional sheets, if necessary)

____
____
____
____
____
____
____

THANK YOU FOR YOUR COOPERATION IN COMPLETING THIS FORM!

Securement Manufacturer Data Collection Form

This data collection form is being sent to manufacturers of securement systems to elicit information to support a US Department of Transportation study to identify issues related to the securement of three-wheeled scooters and the restraint of their occupants when transported on buses and vans used in the provision of public transit services.

In Section I, you are asked to provide information on your securement system(s), including its compatibility with the securement of three-wheeled scooter models, issues associated with the usage of your securement systems, and any accident data involving known securement system failure. In Section II, you are asked to react to **potential** changes to the US DOT Final Rule implementing the Americans with Disabilities Act of 1990 (ADA) as it relates to *mobility aid securement and occupant restraint* (**MASOR**) systems using a five (5) point rating scale, with 1=STRONGLY AGREE, 2=AGREE, 3=NEUTRAL, 4=DISAGREE, and 5=STRONGLY DISAGREE.

Can we follow up with a telephone call? YES____ NO____

Name: ______________________________

Address: ______________________________

____

____

____

Tel #: ______________________________

Fax #: ______________________________

US Department of Transportation
Volpe National Transportation Systems Center
Kendall Square, DTS-49
Cambridge, MA 02142

David Spiller
US DOT/Volpe Center DTS-49
Kendall Square
Cambridge, MA 02142

I. Mobility Aid Securement System Issues

1. Please list and describe the mobility aid securement system(s) that your company is actively selling in the market for use on buses and vans used in the provision of public transit services.

____
____
____
____
____
____
____

Please attach a technical brochure and specification for each securement system described above.

2. For each securement system described in question 1, please indicate whether the system is suitable for use with three-wheeled scooters. If suitable, please indicate specific scooter make(s) and model(s).

____
____
____
____
____
____
____

3. For each scooter make and model that is compatible with your securement system(s), please describe or provide a schematic of the proper attachment points.

____
____
____
____
____
____
____

4. What types of tests are conducted during product research, engineering and development before the securement system(s) are sold in the marketplace?

____
____
____
____
____
____
____

For the securement system(s) described in question 1, please provide engineering test reports involving dynamic crashworthiness tests.

5. Do you collect data on problems with the use of your securement system(s)? YES____ NO____

If YES, please indicate which of the following categories has been reported to you concerning your securement system(s):

a. Lack of a universal interface ____
b. Excessive operations inspection time (> 3 minutes) ____
c. Excessive securement time (> 1 minute fixed-route; >3 minutes paratransit) ____
d. Lack of a securement completion signal ____
e. Lack of user privacy (reaching components; connecting to mobility aid) ____
f. Excessive force needed to secure (> 10 lbs normal use; >5 lbs for difficult access points; >1 lb for emergency release) ____
g. Lack of redundant release ____
h. Excessive mobility aid motion during normal and emergency driving maneuvers (> 2 inches any direction; tipping of mobility aid during cornering) ____
i. Securement system integrity (no fragmentation) during crash events ____

6. Do you collect data on securement system failures during crash or near-crash events? YES____ NO____

If YES, for each accident/incident event, please describe the following (use additional sheets, if necessary):

a. Whether the direction of impact was front, side, or rear
b. Whether the bus/van was in motion
c. Whether the securement system failed
d. Identification of type of securement system and mobility aid
e. Body location and degree of injury (minor, moderate, severe) to mobility aid occupant
f. Whether other passengers were injured as a direct result of securement failure of the mobility aid, and/or restraint failure of the mobility aid occupant
g. Body location and degree of injury (minor, moderate, severe) to other passengers as a direct result of securement/restraint failure of the mobility aid and its occupant

II. Potential changes to the US DOT Final Rule implementing the Americans with Disabilities Act of 1990 (ADA)

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1. Scooter occupants must transfer to a bus/van seat	1	2	3	4	5
2. Adopting a "certified list" of transportable mobility aids in lieu of the "common wheelchair" concept	1	2	3	4	5
3. Conditioning federal financial assistance to individuals for the purchase of a mobility aid to mobility aids that comply with a transportable mobility aid standard (a "certified list")	1	2	3	4	5
4. Restriction of "common wheelchair" to four-wheeled mobility aids	1	2	3	4	5
5. No change to Final Rule with respect to securement of mobility aids, including scooters	1	2	3	4	5

6. Please comment on any other changes, that you deem necessary, to the Final Rule related to *mobility aid securement and occupant restraint* (**MASOR**) systems (use additional sheets, if necessary).

____

THANK YOU FOR YOUR COOPERATION IN COMPLETING THIS FORM!

Scooter Manufacturer Data Collection Form

This data collection form is being sent to manufacturers of three-wheeled scooters to elicit information to support a US Department of Transportation study to identify issues related to the securement of three-wheeled scooters and the restraint of their occupants when transported on buses and vans used in the provision of public transit services.

In Section I, you are asked to provide information on your three-wheeled scooter models, including whether they can be transported on buses and vans, and the best way for securing them while being transported. In Section II, you are asked to react to **potential** changes to the US DOT Final Rule implementing the Americans with Disabilities Act of 1990 (ADA) as it relates to *mobility aid securement and occupant restraint* (**MASOR**) systems using a five (5) point rating scale, with 1=STRONGLY AGREE, 2=AGREE, 3=NEUTRAL, 4=DISAGREE, and 5=STRONGLY DISAGREE.

Can we follow up with a telephone call? YES____ NO____

Name: ____________________

Address: ____________________

____

____

____

Tel #: ____________________

Fax #: ____________________

US Department of Transportation
Volpe National Transportation Systems Center
Kendall Square, DTS-49
Cambridge, MA 02142

David Spiller
US DOT/Volpe Center DTS-49
Kendall Square
Cambridge, MA 02142

I. Mobility Aid Securement System Issues

1. Please list your most popular three-wheeled scooter models that you sell in the marketplace, and the approximate number of sales for the last three years.

____

____

____

____

____

____

____

Please provide a technical brochure and specification for the models listed.

2. Are the models listed in question 1 capable of being transported on buses and vans used in the provision of public transit services? YES____ NO____

If YES, please describe or provide a schematic, for each model listed, of the best attachment points for securement. What type of securement system do you recommend for these models?

____

____

____

____

____

____

____

3. Do you recommend that occupants of scooters that are transported on buses/vans transfer to a seat?
YES____ NO____ NO OPINION____

4. Of the models that you list that are capable of being transported on a vehicle, please describe the tests that you conduct to insure the crashworthiness of the models when transported on a vehicle.

____
____
____
____
____
____
____

5. Of the models that you list that are capable of being transported on a vehicle, what type of occupant restraint system do you recommend?

____
____
____
____
____
____
____

6. Do you collect accident event data for you scooter models? YES____ NO____

If YES, how many accident events, in the last five years, involved the transport of the scooter on a bus/van in public transit service? ____

Based on this sample of accident events, involving the transport of the scooter on a bus/van in public transit service, please indicate the number of accident events in which:

a. the crash event was frontal _____
b. the securement system failed _____
c. the scooter deformed _____
d. the scooter excursion beyond its securement location was greater than 2" in any direction _____
e. the scooter occupant was injured/killed _____
f. the battery pack separated from the scooter _____
g. the seat pedestal sheared or fractured _____
h. the scooter tipped or rolled laterally _____

II. Potential changes to the US DOT Final Rule implementing the Americans with Disabilities Act of 1990 (ADA)

		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1.	Scooter occupants must transfer to a bus/van seat	1	2	3	4	5
2.	Adopting a "certified list" of transportable mobility aids in lieu of the "common wheelchair" concept	1	2	3	4	5
3.	Conditioning federal financial assistance to individuals for the purchase of a mobility aid to mobility aids that comply with a transportable mobility aid standard (a "certified list")	1	2	3	4	5
4.	Restriction of "common wheelchair" to four-wheeled mobility aids	1	2	3	4	5
5.	No change to Final Rule with respect to securement of mobility aids, including scooters	1	2	3	4	5

6. Please comment on any other changes, that you deem necessary, to the Final Rule related to *mobility aid securement and occupant restraint* (**MASOR**) systems (use additional sheets, if necessary)

____
____
____
____
____
____
____

THANK YOU FOR YOUR COOPERATION IN COMPLETING THIS FORM!

Mobility Aid Users Data Collection Form

This data collection form is being sent to a sample of mobility aid users, and to organizations that represent mobility aid users. The purpose is to elicit information to support a US Department of Transportation study to identify issues related to the securement of three-wheeled scooters and the restraint of their occupants when transported on buses and vans used in the provision of public transit services.

In Section I, you are asked to provide background data that describe your frequency of use of public transit services, the type of mobility aid that you use, and the direction of boarding.

Section II asks you to indicate whether you agree or disagree with a list of items that apply to securing wheelchairs, scooters, etc. on buses and vans.

Section III asks you how you feel about **potential** changes to the US Department of Transportation (DOT) Final Rule implementing the Americans with Disabilities Act of 1990 (ADA) as it relates to *mobility aid securement and occupant restraint* (**MASOR**) systems using a five (5) point rating scale, with 1=STRONGLY AGREE, 2=AGREE, 3=NEUTRAL, 4=DISAGREE, and 5=STRONGLY DISAGREE.

Section IV asks you to provide information about securement system failures if you have **direct knowledge** of these failures.

Can we follow up with a telephone call? YES____ NO____

Name: ____________________

Address: ____________________

____

____

____

Tel #: ____________________

Fax #: ____________________

US Department of Transportation
Volpe National Transportation Systems Center
Kendall Square, DTS-49
Cambridge, MA 02142

David Spiller
US DOT/Volpe Center DTS-49
Kendall Square
Cambridge, MA 02142

I. Background

1. On average, how frequently do you board a bus or van used in public transit services?
   ____ less than 1 time per week
   ____ 1-5 times per week
   ____ greater than 5 times per week

2. Please list the type (e.g., manual wheelchair, powered wheelchair, sport, three-wheeled scooter, etc.), manufacturer and model of your mobility aid.

Type	Manufacturer	Model
Manual Wheelchair	________	________
Powered Wheelchair	________	________
Sport Wheelchair	________	________
Three-wheeled Scooter	________	________
Four-wheeled Scooter	________	________
Other ____________	________	________

3. Do you face towards or away from the door opening when boarding the bus or van? ____ Towards Door ____ Away from Door

II. Mobility Aid Securement System Issues

1. From your **direct experience** with mobility aid securement systems, please check whether you AGREE or DISAGREE that the following items are problems with mobility aid securement systems that are currently installed on buses and vans used in public transit services:

PROBLEM ?	AGREE	DISAGREE
a. Lack of a universal interface	____	____
b. Excessive operations inspection time (>3 minutes)	____	____
c. Excessive securement time (> 1 minute fixed route; > 3 minutes paratransit)	____	____
d. Lack of a securement completion signal	____	____
e. Lack of user privacy (reaching components; connecting to mobility aid)	____	____
f. Excessive force needed to secure (> 10 lbs normal use; > 5 lbs for difficult access points; > 1 lb for emergency release)	____	____
g. Lack of redundant (i.e., second) release	____	____
h. Excessive mobility aid motion during normal and emergency driving manuevers (> 2 inches any direction; tipping of mobility aid during cornering)	____	____
i. Lack of securement system integrity (system breaks apart) during crash events	____	____
j. Lack of occupant restraint system	____	____
k. Other (please describe)		

____

____

____

____

____

____

____

2. Are there detailed instructions for using the mobility aid securement system on the buses and vans that you board? ____YES ____NO

   If YES, is the location an accessible location for you? ____YES ____NO

3. Are you able to independently secure your mobility aid or do you require operator assistance? ____Secure Myself ____Require Assistance

4. Please check and comment on these issues for securing three-wheeled scooters on buses and vans used in public transit services that you feel are important. Please comment on any other issues that you feel are important.

   a. Ease of use of securement system: ____
   b. Independent use by occupant: ____
   c. Close physical space between driver and user during securement and release: ____
   d. Reluctance to use securement and restraint systems: ____
   e. Access to and from securement locations: ____
   f. Emergency evacuation: ____
   g. Safety of scooter occupant: ____
   h. Safety of other passengers: ____

Comments:

III. Potential changes to the US DOT Final Rule implementing the Americans with Disabilities Act of 1990 (ADA)

Please circle your response:

		Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
1.	Scooter occupants must transfer to a bus/van seat	1	2	3	4	5
2.	Adopting a "certified list" of transportable mobility aids in lieu of the "common wheelchair" concept	1	2	3	4	5
3.	Conditioning federal financial assistance to individuals for the purchase of a mobility aid to mobility aids that comply with a transportable mobility aid standard (a "certified list")	1	2	3	4	5
4.	Restriction of "common wheelchair" to four-wheeled mobility aids	1	2	3	4	5
5.	No change to Final Rule with respect to securement of mobility aids, including scooters	1	2	3	4	5

6. Please comment on any other changes, that you think are important, to the Final Rule related to *mobility securement and occupant restraint* (MASOR) systems

____

____

____

____

____

____

____

____

____

____

IV. Mobility Aid Securement System Failure

1. Do you have **direct knowledge** (e.g., involvement in a lawsuit) of a mobility aid securement system failure during a crash or near-crash event? ____YES ____NO

   If YES, for each crash or near-crash event, please describe the following (use additional sheets, if necessary):

   a. Direction of impact: ___ Front ___ Side ___ Rear
   b. Bus/van in motion?: ___ YES ___ NO
   c. Describe securement system failure: ______________________________
      ____
      ____
      ____
   d. Identification of type of securement system: ______________________________
      Type of occupant restraint system: ______________________________
      Type of mobility aid: ______________________________
      Orientation of mobility aid: ___ Front ___ Back ___ Side
   e. Body location of injury to mobility aid occupant: ______________________
      Degree of injury (minor, moderate, severe) to mobility aid occupant: ___ Minor ___ Moderate ___ Severe
   f. Other passengers injured as a direct result of securement failure of the mobility aid, and/or restraint failure of the mobility aid occupant?: ___ YES ___ NO
   g. Body location of injury to other passengers as a direct result of securement/restraint failure of the mobility aid and its occupant: ______________________________
      Degree of injury (minor, moderate, severe) to other passengers as a direct result of securement/restraint failure of the mobility aid and its occupant: ___ Minor ___ Moderate ___ Severe
   h. Other comments:

____
____
____
____

THANK YOU FOR YOUR COOPERATION IN COMPLETING THIS FORM!

Appendix D - Research Program Description

A. Implementation of a Mobility Aid Securement and Occupant Restraint (**MASOR**) Testing and Clearinghouse Function

Project Description: This program would use existing administrative structures - the University Transportation Centers - to provide a coordinated set of services that include:

- Issuance of formal test reports of **MASOR** systems, using the recently developed TCRP guidelines as a common comprehensive test protocol.

- Development of information and technology transfer media (e.g., technical memoranda; research synthesis reports; newsletters; videos; interactive computer-based training modules; manuals; brochures; internet WWW access; etc.) on such topics as mobility aid securement; occupant restraint; securement-related accidents; crashworthiness design principles; etc.

- Short-term technical assistance via a peer-to-peer network of individuals.

- Telephone and fax "hotline" support for questions.

Justification: Between sixty (60) and ninety (90) percent of the technical community respondents (the differing percentage is related to what type of services might be offered) endorsed the concept of a proactive, national program consisting of **MASOR** system testing, a clearinghouse for such tests, and the development and distribution of both specific and general training materials, technical assistance, and information transfer media.

There are also good economic reasons for having a coordinated, national program: Testing is expensive, but once a specific **MASOR** system has been tested, the marginal cost of providing the information to all interested parties is relatively minor. Yet all interested parties, in particular transit system operators and consumers, i.e., transit system users, require such information, including the assessment of relative risks, in order to make good decisions. There is currently no centralized database of **MASOR** tests that a transit system can access and query. With an equitable cost-sharing arrangement, economies can also result to all parties for the initial testing as well. In addition, a national coordinated program can make use of existing testing facilities across the nation, and produce consistent, comparative results by testing to a common test protocol. Once a "transportable mobility aid" standard has been developed, a coordinated, national program can also support a certification process.

Providing information transfer and technical assistance will provide substantial benefits to the nation as "best practices" and state-of-the art technology is introduced and widely disseminated to the nation's transit systems and their communities.

B. Comparative Risk Assessment of Tri-wheeled Scooters Transported on Buses and Vans

Project Description: This research study would undertake a formal retrospective or possibly prospective risk assessment of the transport of tri-wheeled scooters and their occupants on buses and vans used in the provision of public transit services. Three types of comparative analyses would be undertaken:

- Comparison of tri-wheeled scooter occupant risk to other mobility-aid occupants.

- Comparison of tri-wheeled scooter occupants to passengers using bus and van seats.

- Comparison of all mobility-aid occupants (including tri-wheeled scooter occupants) to passengers using bus and van seats.

Specific tasks would include:

a. Design a sampling plan and experimental design (Note: Table 22 in Section 6.0 is one possible approach).

b. Identify the set of risk metrics (Note: Table 23, Section 6.0, showing a calculation of the odds ratio is one of several risk metrics that should be included).

c. Collect the appropriate data from police accident files, insurance claims, and transit system accident files.

d. Prepare risk assessment report.

This study recommends that the Transit Cooperative Research Program (TCRP), of the National Academy of Sciences, Transportation Research Board, undertake sponsorship of this effort.

Justification: Both the responses from the technical community and the transit system community, in addition to a review of the literature, indicate that no formal risk assessment addressing these issues has ever been done.

To impose any sort of crashworthiness constraint on the regulatory requirement to transport "all common wheelchairs and mobility aids," and to satisfy the test set forth by the US Supreme Court in *School Board of Nassau County v. Arline* (480 U.S. 273, 1987), which was also reiterated by the US DOJ in its Final Rule implementing Title III, Public Accommodations, under the ADA, the US DOT would have to undertake a formal risk assessment study as described above. Either the study would substantiate a "direct threat," justifying further regulatory action, or effort to undertake such a study might establish that it is infeasible to complete a formal risk assessment, and that other factors, such as "expert judgement" and crash and laboratory testing, can suffice to meet the Supreme Court test requiring objective, scientific evidence. Failure, however, to attempt such a study would open the US DOT to legal challenge.

C. Analysis and Design of Improved Space Layout and Interior Circulation of Transit Buses

Project Description: This research project is intended to provide a comprehensive and systematic investigation of a number of interrelated issues: accessible design; interior passenger circulation; space and seating layout; on-board equipment and hardware, including information and communication systems, **MASOR** systems, fare collection systems, and intelligent transportation system hardware. Improved interior bus designs that account for the various tradeoffs in an acceptable, if not optimal, manner are urgently needed.

There have been substantial advances, in recent years, in the application of 3D scientific visualization. Much of this has also been interfaced to simulation and CADD systems. This project is an ideal application for these technologies, both in the analysis of existing interior bus designs and in the search for alternative, improved designs. Specific tasks include:

a. Measurement instrumentation, including video taping, to collect data on the performance of existing interior bus designs, including boarding, alighting, fare paying, and interior circulation operations.

b. Use of 3D visualization, simulation and CADD technologies to analyze existing interior bus designs.

c. Use of the same technologies to search for alternative, improved designs (incorporating new on-board hardware and equipment expected to be in place by the year 2000).

d. Validation of the best design(s) by actual bus mockups, and off-road dynamic tests using actual passengers.

e. Preparation of plans, drawings, specifications and a report suitable for bus manufacturers to use.

This study recommends that the Transit Cooperative Research Program (TCRP), of the National Academy of Sciences, Transportation Research Board, undertake sponsorship of this effort.

Justification: Of the four **MASOR** system related research areas, the investigation of the interior space design of the bus is the only item with no disagreement among the technical community (see Section 7.1, Technical Community). Several of the transit system respondents also commented on the difficulty of maneuvering scooters within the bus, insufficient dimensions for the mobility aid securement bay, or accessibility problems in going from the lift to the mobility aid securement bay. Whether mobility aids are boarded inwards or outwards (i.e., away from the door entrance) is also a major factor.

Examining these issues in a piecemeal fashion will only perpetuate poor design. There is currently a flurry of technical activity in the areas of Advanced Public Transportation Systems - the Intelligent Transportation System concept applied to public transit; accessible design, including low-floor buses, and new **MASOR** systems; and the search for a 'transportable mobility aid standard'. All of this activity needs to be coordinated, and this study can be a useful 'vehicle' for achieving a coordinated, comprehensive attack on these issues.

D. Research Support, under the Auspices of the American National Standards Institute and the Rehabilitation Engineering Society of North America (ANSI/RESNA), to Develop a 'Transportable Mobility Aid' Standard and Test Protocol

Project Description: This project involves the US DOT/FTA joining with the US DOT/NHTSA in providing financial support to the ANSI/RESNA SOWHAT committee to develop a 'transportable mobility aid' standard and test protocol. This effort is just getting underway and it is unclear precisely what tasks need to be accomplished to establish a sound, scientific research base for a standard and test protocol. The Canadian draft standard -Z604- is an initial starting point for this effort. It is anticipated, however, that additional laboratory testing, drive tests,and crash testing of all types of mobility aids, including tri-wheeled scooters, and of **MASOR** systems in combination with these mobility aids will be necessary.

Justification: This study has established that: Ninety (90) percent of the technical community endorse US DOT-sponsored research support for the development of a standard and test protocol for a 'transportable mobility aid', and sixty (60) percent support the concept of a certifiable list based on that standard, in lieu of the regulatory requirement by transit systems to transport "all common wheelchairs and mobility aids." Corresponding percentages supporting the concept of a certifiable list based on a 'transportable mobility aid' standard and test protocol for the other 'key actor' groups are: eighty (80) percent of transit system respondents; eighty (80) percent of the securement manufacturer respondents; fifty (50) percent of the scooter manufacturers; and sixty eight (68) percent of the mobility aid user respondents.

For tri-wheeled scooters, this study confirms: inaccessible attachment points; inadequate structural strength of attachment points; inability to restrain the battery in a crash impact; shearing or fracture of the seat pedestal; inadequate restraining force of seat designs; scooter occupant injury from contact with the front tiller; and rollover or tipping instability. Many of these issues also apply to other types of mobility aids. Proliferation of mobility aid designs poses a major compatibility problem for **MASOR** systems. All of these issues would be addressed by a 'transportable mobility aid' standard.

Despite substantial research effort to develop a 'universal design' **MASOR** system - such as the Oregon State University Independent Locking Securement System (ILSS), and the Cleveland Clinic Foundation's system - the dominant opinion, now, within the technical and transit system communities is that these efforts are not going to solve all of the issues involved, including compatibility with new mobility aid designs and the crashworthiness of the mobility aid itself when transported on buses and vans. The most promising approach to address these issues, in the opinion of both the technical and transit system communities, is the development and widespread adoption of a 'transportable mobility aid' standard and test protocol.