Wheeled Mobility Device Transportation Safety in Fixed Route and Demand-Responsive Public Transit Vehicles within the United States

Karen L. Frost PhD MBA, Linda van Roosmalen, Gina Bertocci PhD PE & Douglas J. Cross

Accepted author version posted online: 08 Feb 2012. Published online: 06 Jun 2012.


To link to this article: http://dx.doi.org/10.1080/10400435.2012.659325

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the “Content”) contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions
Wheeled Mobility Device Transportation Safety in Fixed Route and Demand-Responsive Public Transit Vehicles within the United States

Karen L. Frost, PhD, MBA,1 Linda van Roosmalen,2 Gina Bertocci, PhD, PE,1 and Douglas J. Cross3
1J.B. Speed School of Engineering, Mechanical Engineering Department, University of Louisville, Louisville, Kentucky
2Rehabilitation Science & Technology, University of Pittsburgh, Pittsburgh, Pennsylvania
3Douglas J. Cross Transportation Consulting, Oakland, California

ABSTRACT An overview of the current status of wheelchair transportation safety in fixed route and demand-responsive, non-rail, public transportation vehicles within the US is presented. A description of each mode of transportation is provided, followed by a discussion of the primary issues affecting safety, accessibility, and usability. Technologies such as lifts, ramps, securement systems, and occupant restraint systems, along with regulations and voluntary industry standards have been implemented with the intent of improving safety and accessibility for individuals who travel while seated in their wheeled mobility device (e.g., wheelchair or scooter). However, across both fixed route and demand-responsive transit systems a myriad of factors such as nonuse and misuse of safety systems, oversized wheeled mobility devices, vehicle space constraints, and inadequate vehicle operator training may place wheeled mobility device (WhMD) users at risk of injury even under non-impact driving conditions. Since WhMD-related incidents also often occur during the boarding and alighting process, the frequency of these events, along with factors associated with these events are described for each transit mode. Recommendations for improving WhMD transportation are discussed given the current state of knowledge.

KEYWORDS public transit, wheelchair, wheelchair transportation safety

INTRODUCTION

This review describes the current environment, research findings, and safety-related issues associated with passengers who remain seated in their wheelchair or scooter (hereinafter referred to as “wheeled mobility device,” or “WhMD”) while traveling in either fixed route or demand-responsive, non-rail, public transportation vehicles.
Although fixed route and demand-responsive transportation differ in terms of services provided, vehicle mass and crash severity environment, both modes of transportation rely on wheelchair tiedown and occupant restraint systems (WTORS) as the primary means of assuring WhMD passenger safety during transit (Figure 1). Additionally, each mode of transportation requires some level of third party assistance to access and use boarding and alighting devices (e.g., lifts and ramps) and WTORS.

This review provides an overview of the environment of each mode of transportation, followed by a discussion of the primary issues affecting safety, accessibility, and usability. Applicable transportation regulations and industry standards are also summarized. Key barriers to achieving balance in terms of safety, usability, and accessibility are highlighted, and strategies for effecting potential change are identified.

**Modes of Public Transportation (Non-Rail)**

**Fixed Route Service**

Large accessible transit vehicles (LATVs) most commonly refer to 40- and 30-foot transit buses intended for use on city streets, highways, and busways. LATVs are a common means of transportation for individuals who have the ability to travel independently or with a caregiver while seated in their WhMD. Anecdotal reports from LATV operators suggest that ridership by scooter users has increased over the past decade. Scooter users may be part-time WhMD users and thus some scooter users may have the ability to transfer to a vehicle seat. Inside the LATV, all WhMD users require assistance from the LATV operator (or a caregiver) to secure their WhMD, and often to apply occupant restraints.

Annual WhMD boardings on fixed route LATVs vary across the US. In a medium size city such as Louisville, KY there may be between 10,000–13,000 WhMD passenger boardings per year. In larger cities, such as Philadelphia, PA, there may be an average of 20,000 WhMD passenger boardings per year (Southeastern Pennsylvania Transportation Authority, 2008); while major cities such as New York City, estimate over 600,000 WhMD passenger boardings per year occur on fixed route LATVs (Metropolitan Transit Authority, 1999).

The continued trend in fixed route transit is the design and manufacture of low-floor LATVs with kneeling capabilities that enable the use of ramps for more efficient ingress/egress. Both mid-entry and front-entry low-floor LATVs are in use today. However, the interior space of LATVs remains limited for those traveling in their WhMDs. Space constraints such as LATV ramp and door width, aisle clearances, and fixed objects (farebox, wheel housing covers) can make it difficult for people in WhMDs to maneuver to a WhMD securement station (Project Action, 2008).

In the US, the ADA allows for the use of both forward-facing or rear-facing wheelchair securement stations in LATVs, provided each wheelchair securement station is equipped with WTORS meeting ADA and Federal Transportation Administration (FTA) requirements (Americans with Disabilities Act, 1990).

Blower et al. estimated that a passenger traveling in an LATV will experience a 5 g or greater crash severity only once every 27 million miles (Blower,
Woodroofe, & Schneider, 2005). A more common occurrence while traveling in an LATV is the experience of an emergency maneuver or sudden braking. During non-crash emergency maneuvers, peak forward accelerations of up to 0.40 g may occur (Zaworski, Hunter-Zaworski, & Baldwin, 2007), and lateral accelerations during emergency turns may reach up to 0.45 g (Turkovich, van Roosmalen, Hobson, & Porach, 2009). Non-crash emergency decelerations during sudden or hard braking may attain up to 0.80 g (Zaworski et al., 2007; Turkovich et al., 2009). A vehicle that experiences these levels of acceleration and deceleration (less than 1 g) is considered a “low-g environment.” When the level of vehicle deceleration is less than 1 g, alternative WhMD securement or containment systems that do not require active securement mechanisms, or action by the vehicle operator, may be feasible to retain the WhMD during transit. Alternative occupant protection systems that allow for independent use by WhMD users may also be an option for low g LATVs.

**Demand-Responsive (Paratransit) Service**

Demand-responsive transportation provides service to passengers who require personal assistance boarding and alighting vehicles, and in some cases, door-to-door service. Demand-responsive transit vehicles commonly used to transport WhMD-seated passengers include (i) full size modified vans with lifts, (ii) mini-buses with lifts (e.g. mini-bus bodies on commercial, dual rear-wheel van chassis), (iii) low-floor mini-buses with ramps (a more recent trend), and (iv) minivans with ramps (often used in accessible taxi fleets). Some large metropolitan areas use vehicles with rear-entry lifts since access to sidewalks and curb cuts may be blocked by parked cars. However, rear-entry lifts require WhMD passengers to drive their WhMD into the street, placing WhMD passengers at risk of injury from passing vehicles.

Although power wheelchairs and scooters are frequently transported in demand-responsive transit vehicles, manual wheelchairs are also commonly transported because they are often provided by nursing homes, care facilities, and hospitals, and may also be provided by the transportation service on a temporary basis. In contrast to boarding an LATV, WhMD passengers cannot board a demand-responsive transit vehicle independently; they are reliant on vehicle operator assistance to operate the lift. Vehicle operator assistance is also needed to implement WTORS prior to transit.

The interior of a demand-responsive transit vehicle is intended to accommodate several ambulatory passengers and one or more WhMD-seated passengers. Modified vans and minivans typically accommodate up to two WhMD-seated passengers, whereas minibuses may accommodate three or more WhMD-seated passengers. Additional WhMD-seated passengers may be accommodated if manufacturers’ vehicle seats are removed, or have the capability of being folded when not in use.

Demand-responsive transit vehicles are considered high-g environments because they have a relatively lower mass (Shaw, 2000) compared to LATVs, resulting in increased crash severity and a greater potential for injury during a crash or emergency maneuvering. The deceleration pulse experienced by paratransit vehicles during frontal impact can be twice as high as those associated with an LATV exposed to the same frontal impact (Transportation Research Board, 2003), requiring the use of WTORS to secure WhMDs, and lap and shoulder occupant restraint belts to ensure occupant protection for WhMD users and nearby passengers.

**WHMD TRANSPORTATION REGULATIONS AND STANDARDS: STATUS, APPLICABILITY, AND LIMITATIONS**

**Regulations—Americans with Disabilities Act**

The Americans with Disabilities Act (Americans with Disabilities Act, 1990) was enacted to assure, in part, that individuals with disabilities were provided equal access to transportation services. The ADA Accessibility Specifications for Transportation Vehicles (49 CFR 38.23) contain requirements related to WhMD boarding and alighting, as well as the WhMD securement and occupant restraint process.

Related to securement, ADA requires that at least two WhMD securement stations be provided in vehicles in excess of 22 ft. (6.71 m) and at least one securement station in vehicles 22 ft. (6.71 m) in length or less. In vehicles greater than 22 ft. (6.71 m) in length, at least one securement station must be capable of securing a WhMD in a forward-facing orientation, while the second securement station can be...
designed to accommodate either a forward or rearward oriented WhMD. Vehicles must be equipped with a WhMD securement and occupant restraint system. ADA requires that WhMD securement systems be capable of securing a “common WhMD” which is defined as a 3- or 4-wheeled device no larger than 30 in. wide × 48 in. long (76.2 cm × 121.92 cm) weighing 600 lb. or less when occupied. Securement system strength performance is evaluated based upon the application of static loading. Additionally, securement systems must limit WhMD movement to less than 2 in. (5.08 cm) during normal driving maneuvers. Securement stations required to accommodate a “common WhMD” must have the minimum dimensions of 30” wide and 48” long (76.2 cm × 121.92 cm). While transit agencies can mandate WhMD securement as a policy under the provisions of ADA, restraint of the occupant (lap and shoulder belts) is at the discretion of the WhMD passenger unless ambulatory passengers are required to use occupant restraints; which is sometimes the case on paratransit vehicles.

To assure accessibility to vehicles, ADA stipulates that vehicles shall be provided with a level changing mechanism or boarding device (e.g., lift, ramp). Lifts or ramps must be capable of withstanding a 600 lb. load with a safety factor of 3. Lifts and ramps must provide a 30 in. (76.2 cm) wide platform, and must include edge barriers (1-1/2 in. [3.81 cm] for lift; 2 in. [5.08 cm] for ramp) to prevent WhMD wheels from slipping off the platform surface. Ramp slopes shall be minimized and shall not exceed a 1:4 slope when deployed to the ground level.

The ADA vehicle guidelines are in the process of being updated (Architectural and Transportation Barriers Compliance Board, 2010) however, the current version of the ADA has a number of limitations that present challenges to the provision of safe and accessible WhMD transportation. Key limitations are described below:

- Performance requirements for securement and occupant restraint systems used in paratransit vehicles do not provide an adequate level of crash protection given the high g crash severity conditions that may be encountered. Securement and occupant systems for use in paratransit vehicles should be required to comply with SAE RP J2249 Wheelchair Tiedowns and Occupant Restraints for Use in Motor Vehicles which requires that WTORS be dynamically tested to a 20 g/30 mph frontal impact crash severity; a crash severity level which may be encountered in these lower mass vehicles.
- The space allocated for securement stations (30 in. × 48 in.; 76.2 cm × 121.92 cm) is not able to accommodate “common wheelchairs” or larger WhMDs. These space constraints, along with configuration of the securement station in some cases, present extreme difficulty for vehicle operators when attempting to secure most wheelchairs and scooters, regardless of physical WhMD size. Such conditions can lead to misuse and disuse of securement and occupant restraint systems (Frost & Bertocci, 2009b).
- For lower g environments, such as LATVs used in fixed route transit, ADA securement and occupant restraint system design and testing requirements are overly conservative, requiring that these systems perform at a level that exceeds crash severity conditions expected to be encountered in this vehicle environment. These requirements tend to limit and/or discourage the design and provision of innovative wheelchair securement and occupant restraint systems that may enhance usability and WhMD independence.
- Ramp-related ADA requirements do not provide an environment that can be safely negotiated by WhMD users during boarding and alighting. Such conditions have led to difficulty and adverse incidents during WhMD passenger boarding and alighting from LATVs (Sison, Frost, & Bertocci, 2008; Frost, Bertocci, & Sison, 2010b). Three primary requirements of concern were identified by Sison et al.:
  1. The current minimum ramp width requirement of 30 in. (76.2 cm) is too narrow to allow for safe WhMD navigation. Given the physical configuration of some bus stops, circumstances often prevent WhMD users from aligning their WhMD with the ramp. WhMD users must therefore orchestrate a turn onto the ramp surface requiring that their wheels travel onto or over the edge barriers creating an unsafe condition.
  2. The 1:4 ramp slope permitted by ADA is too steep for safe WhMD boarding and alighting. Such a slope introduces an extreme WhMD pitch when traversing the ramp that can lead to tipping of the WhMD and occupant.
  3. Edge barrier minimum height requirements (2 in.; 5.08 cm) for ramps do not prevent WhMD users
Voluntary Industry Standards

While ADA primarily addresses vehicle accessibility related to WhMD transportation, there are no comprehensive federal regulations addressing after-market WhMD securement and occupant restraint systems. A number of voluntary WhMD transportation safety industry standards have been developed and adopted nationally by SAE, ANSI/RESNA, and internationally by ISO. These voluntary standards can be categorized into those addressing securement and occupant restraint systems and WhMDs, and are summarized herein.

SAE RP J2249—Wheelchair Tiedowns and Occupant Restraints for Use in Motor Vehicles

SAE RP J2249, and its equivalent international standard ISO 10542, provide design requirements, instructions for use, testing requirements and performance criteria for WTORS. The hallmark of these standards is the requirement for dynamic testing of WTORS to a 20 g/30 mph frontal impact crash severity. WTORS complying with these standards will provide suitable WhMD securement and occupant crash protection in all vehicle environments, including small vans.

ANSI/RESNA WC19—Wheelchairs Used as Seats in Motor Vehicles

ANSI/RESNA WC19, and the equivalent international standard, ISO 7176-19, provide design requirements, instructions for use, test methods and performance criteria for WhMDs that are intended to serve as vehicle seats when traveling in a motor vehicle. WhMDs complying with ANSI/RESNA WC19 must be equipped with four securement points of a specified geometry that interface with tiedown end-fittings that are intended to improve the ease of WhMD securement. Additionally, WhMDs must be dynamically tested (under 20 g/30 mph frontal impact crash conditions) with an integrated lap belt anchored to the WhMD. WhMDs complying with ANSI/RESNA WC19 and ISO 7176-19 are capable of serving as a vehicle seat in all vehicle environments.

Since the LATV environment has been shown to be a low g environment consisting largely of intra-city travel, alternative means of providing safe and accessible WhMD transportation can be considered. Accordingly, ISO standard, ISO 10865: Wheelchair Containment And Occupant Retention Systems For Rearward Facing Wheelchair-Seated Passengers, is currently under development. This standard describes design requirements and test methods for rear-facing wheelchair passenger stations (RF-WPS) which are currently being used in Canada and European countries (Figure 2). The fundamental principle behind the concept of a RF-WPS use in LATVs is that passive (no action required by WhMD user or driver) containment of an occupied WhMD during normal travel and emergency vehicle maneuvers is sufficient to provide a reasonable level of transportation safety to WhMD-seated passengers. WhMD movement toward the front of the vehicle is limited when the WhMD is positioned against a forward excursion barrier. The goal of a RF-WPS station is to promote independent WhMD

FIGURE 2 Rear-facing WhMD containment station showing padded backrest and aisle-side stanchion (color figure available online).
containment and occupant retention in a manner that is compatible with the demands of fixed route transport.

Further building upon the possibilities for enhanced independence in WhMD transportation in a low g vehicle environment, both ANSI/RESNA and ISO are in the early stages of developing a standard addressing forward-facing WhMD containment and occupant retention in low g vehicles. Given the demands associated with fixed route transportation, the goal of this standard will be to advance innovative solutions that will improve usability and accessibility in WhMD transportation while maintaining safety.

**PRIMARY ISSUES AFFECTING SAFETY, ACCESSIBILITY AND USABILITY**

During the past five years, data regarding incidents and injury risk to WhMD-seated passengers traveling in public transit vehicles has become available yielding a number of important findings (Songer, Fitzgerald, & Rotko, 2004; Fitzgerald, Songer, Rotko, & Karg, 2007; Frost & Bertocci, 2010a; Frost et al., 2010b; Wretstrand, Bylund, Petzall, & Falkmer, 2010). Two primary safety issues affecting WhMD users of both fixed route and demand-responsive public transit vehicles are (1) incidents associated with boarding and alighting using a lift or ramp, and (2) exposure to injury risk during normal and emergency maneuvers (e.g., sudden braking or swerving). Reports indicate that injuries resulting from non-crash situations (e.g., quick or sudden braking, sudden or sharp turning and quick acceleration) are common among WhMD users (Shaw, 2000; Songer et al., 2004; Fitzgerald et al., 2007; Wretstrand et al., 2010). Key factors needing to be addressed in conjunction with these safety issues are discussed in this section.

**Boarding and Alighting Using a Ramp—Fixed Route Transit Vehicles**

Safety during boarding and alighting depends on a number of environmental, adaptive equipment (i.e., ramp), and assistive technology factors. In a retrospective study of transit operator incident reports analyzed over a six-year period for a single mid-sized transit agency, Frost et al. found that 43% of WhMD-related incidents occurred during the boarding and alighting process (Frost & Bertocci, 2010a). Forty-four percent (44%) of all injuries in this same study were associated with the boarding/alighting process. Limited sidewalk space, parked cars, uneven terrain, the built environment (street furniture, light poles, mailboxes), and narrow ramp width affect proper alignment of WhMDs with the ramp prior to boarding (Frost et al., 2010b). During alighting, these same factors can require WhMD users to turn prematurely (e.g., before rear wheels have cleared the ramp), increasing the potential for the rear wheels to drive over the ramp edge barrier, potentially causing the WhMD to tilt or tip over the side of the ramp. Ramp slope and width, as well as thresholds and edge barriers, have been implicated in boarding and alighting incidents (Sison et al., 2008; Frost et al., 2010b). Ramp slope varies based on vehicle floor height, ramp length and design, the level onto which the ramp is deployed (street or sidewalk), and the extent of LATV kneeling provided (if available) (Figure 3). Vehicle operators typically seek to board passengers from the sidewalk whenever possible to reduce ramp slope (Project Action, 2008;}

![Ramp angle associated with boarding and alighting (color figure available online).](image-url)
Frost et al., 2010b). Although ADA vehicle accessibility guidelines restrict maximum ramp slope to 1:4, traversing a 1:4 slope may be difficult or hazardous for some WhMD passengers, with inclement weather further compounding the level of difficulty. Indeed, the U.S. Access Board has proposed changing the maximum ramp slope to 1:6 (Architectural and Transportation Barriers Compliance Board, 2010). The majority of WhMD users enter the vehicle using a forward-facing orientation (Sison et al., 2008). For these passengers, personal belongings carried on the rear of the mobility device may shift the center of gravity of the combined WhMD and passenger rearward. This situation increases the risk of rearward tipping when ascending the ramp, with increasing ramp slope further increasing risk. WhMD-seated passengers who ascend the ramp using a rear-facing orientation (moving rearward up the ramp) are faced with multiple challenges. Physical impairments involving the torso, neck, and head can limit the ability of WhMD users to see behind themselves, making it difficult to maintain proper wheel alignment on the ramp. Regardless of the WhMD orientation on the ramp (rear-facing or forward-facing), obesity and/or the presence of backpacks, bags, and other items attached to armrests and push handles can limit a passenger’s visibility of casters or rear wheels, affecting proper wheel alignment.

Depending on the width of the WhMD, ramp width may provide as little as 1/2 to 1-in. (1.27 to 2.54 cm) clearance on either side of the WhMD. Thresholds intended to allow for easy transition between outdoor terrain and the ramp are often constructed of flexible, rubber material. With age, ramps and thresholds may deform, resulting in warped ramp thresholds that are not even with the ground, making it difficult for WhMD wheels to ascend edge transitions (Figure 4). This can present an even greater challenge when combined with uneven terrain or limited sidewalk space (Sison et al., 2008). Power WhMD users and scooters users who try to “power over” ramp thresholds by increasing speed sometimes place themselves at risk of driving over the ramp edge barrier if their wheels are not aligned within and parallel to the edge barriers. Ramp edge barriers must be a minimum 2 in. (5.08 cm) high for compliance with ADA, a height that can easily be overridden by most power WhMDs.

**Boarding and Alighting Using a Lift—Demand-Responsive Vehicles (Paratransit)**

WhMD lifts are the predominant means for WhMD passengers to board demand-responsive transit vehicles (Figure 5). (Mini-vans used as paratransit vehicles may be an exception since they typically are equipped with ramps for WhMD access.) This is due to the higher vehicle floor of full-size vans and mini-buses. Although lifts must meet federally mandated performance requirements (National Highway Traffic Safety Administration) related to capacity, roll stops, and retention devices, incidents involving WhMD passengers when using lifts are not uncommon. A study of injuries experienced by WhMD passengers using demand-responsive services found that 19% of all
Injuries occurred during the boarding or alighting process (Wretstrand et al., 2010); 92% of these injuries were classified as Maximum Abbreviated Injury Scale (MAIS) 1 and 8% were classified as MAIS 2+ injury severity (MAIS 1 = minor injury; MAIS 2 = moderate injury).

WhMD incidents involving the use of lifts most often occur when the WhMD passenger is exiting, or alighting, the vehicle (Wretstrand et al., 2010). A recent study found that lift incidents resulted in a greater number of injuries compared to ramp incidents, and that most incidents involved power WhMD users who maneuvered from the vehicle compartment onto the lift platform in a rearward-facing orientation and rolled beyond the lift rollstop (Wretstrand et al., 2010). This process requires a high degree of passenger driving skills and adequate visibility and/or assistance from the vehicle operator to safely transfer to the lift platform. Vehicle operators must be adequately trained to understand the safety risks of boarding/alighting using the lift, and should have experience steering/maneuvering many different wheelchairs to provide assistance in a safe manner when needed.

Incidents may also occur during alighting when the lift platform is not level with the vehicle floor. Lift platforms that are positioned slightly lower than the vehicle floor result in a stepped transition that can cause the WhMD and occupant to drop suddenly, leading to increased risk of injury. The Federal Motor Vehicle Safety Standard, 49 CFR 571—Platform Lift Systems for Accessible Motor Vehicles addresses this problem through the requirement of threshold warning systems that alert the WhMD user when the lift platform level is 1 in. or more below the vehicle floor level. However, older lifts that do not comply with these lift requirements continue to be used in many vehicles. In addition to these safety issues there is also a need for vehicle operator training, as illustrated by ongoing questions amongst operators regarding WhMD orientation (i.e., forward facing versus rearward facing) during boarding, and whether or not it is safe for the operator to accompany a WhMD on the lift platform.

Vehicle Environment and WhMD Securement Issues—Fixed Route Vehicles

Almost 20 years after the ADA regulations were implemented requiring that securement and occupant restraint systems be installed in all public transportation vehicles, four-point, strap-type tiedown systems remain the WhMD securement technology that is most commonly available in fixed-route transit vehicles across the U.S. Widespread use of the four-point tiedown system is due to its ability to secure a wide range of wheelchair types sizes. Over the years, improvements in commercial tiedown systems, such as hook-type end fittings and automatic-tensioning retractors have made securing a WhMD easier, aiding vehicle operators charged with this task. Additionally, wheelchair marking and tether strap programs implemented at some transit agencies have aided vehicle operators in identifying and accessing appropriate securement points on wheelchairs and scooters. The availability of ANSI (American National Standards Institute) WC19-compliant transit WhMDs with visibly marked securement points also improves the ease of effectively securing WhMDs using tiedown straps (Schneider, Manary, Hobson, & Bertocci, 2008). Unfortunately, few consumers and transit agencies are
familiar with WC19 compliant WhMDs. Additionally, the use of WTORS appears to vary among transit agencies throughout the U.S. (Buning, Getchell, Bertocci, & Fitzgerald, 2007; Frost & Bertocci, 2009b). Many transit agencies have implemented policies mandating the use of WhMD tethers, but not the use of occupant restraint systems, based on the rationale that other passengers in the vehicle are not required to use occupant restraints, or even provided with belt restraints. Since most WhMD users cannot independently implement WTORS, passengers must rely upon vehicle operators to initiate securement of their WhMD and positioning of the occupant restraints, or they must request that operators do so. A recent nationwide survey of 283 WhMD users found that 39% of respondents never requested to have their WhMD secured, mostly because the vehicle operator seemed unwilling to take the time (Buning et al., 2007). Other reasons included not wanting to delay the schedule or be treated differently than other passengers.

Despite modest improvements in WTORS, the incidence rate of injuries for WhMD-seated passengers using fixed route transportation is estimated at 5.2 injuries per 100,000 miles traveled, compared to an incidence rate of 0.6 injuries per 100,000 miles for passengers who transfer to a vehicle seat (Songer et al., 2004). Frost and Bertocci reported a <1% WhMD-related incident rate per WhMD trip based upon a retrospective study of a single transit agency’s incident reports, with 33% of these incidents leading to injuries (Frost & Bertocci, 2010a). A nationwide survey of WhMD users conducted by Fitzgerald and Songer (Fitzgerald et al., 2007) found that 14% of WhMD passengers who used fixed-route transportation reported receiving an injury from a non-crash event, such as quick or sudden braking, sudden or sharp turning, or quick acceleration. Frost and Bertocci further found that 20% of WhMD-related incidents occurred during normal driving, while 6% occurred during emergency driving. No crash-related incidents involving WhMD-seated passengers were reported in this same study over the six-year period (Frost et al., 2010a). More recently, Frost and Bertocci (2009b) reviewed 117 video recordings of trips by WhMD-seated passengers on fixed route buses from one metropolitan transit agency and found that the majority of WhMDs (76%) were unsecured (no WhMD tether straps were used) during transport. They also reported that the occupant restraint system was used to restrain the WhMD-seated passenger during only 20% of trips, and in all cases, only the lap belt was used. Misuse of the lap belt was observed in at least 44% of the trips, and consisted of vehicle operators routing the lap belt around the WhMD seatback to secure the WhMD instead of over the WhMD passenger’s pelvic region.

The time required to properly secure a WhMD and apply occupant restraints is often considered to be the primary impediment to proper securement/restraint. Interviews with vehicle operators reveal that the increased time required to secure WhMDs is primarily driven by ergonomic factors of space, reach and visibility (Frost, 2009a). WhMDs with backpacks secured to the seatback, scooters and oversized WhMDs leave limited space for vehicle operators to maneuver within the WhMD securement station to access and apply tethers. Vehicle operators frequently report that they cannot see or reach the tether assembly; nor can they see or reach appropriate securement points on the WhMD frame, especially on the vehicle wall side. Additionally, vehicle operators report their own functional limitations (e.g., knee, hip, back and shoulder pain, or range-of-motion limitations), and concerns regarding potential injuries to extremities as reasons for not fully or properly securing wheeled mobility devices. Discomfort regarding violation of passenger personal space is also a concern repeatedly voiced by vehicle operators.

Because emergency maneuvers in LATVs are considered low-g events, alternative means of providing WhMD-seated passenger safety may be feasible. A new development available in select U.S. fixed-route transit systems, as well as Canadian and European transit systems, is the rear-facing WhMD containment and passenger retention system (Figure 5). These designs, which rely upon a rear-facing WhMD orientation, allow WhMD passengers to independently enter the containment area and travel facing the rear of the vehicle. During vehicle stops the WhMD and occupant are contained by a forward excursion barrier (FEB), or padded bulkhead. However, the FEB may not contain the WhMD during sharp vehicle turns and lateral accelerations, and an aisle-side barrier is typically needed to prevent the WhMD and passenger from tipping over or rotating into the aisle (Shaw & Gillispie, 2003; Turkovich et al., 2009). An additional concern with this containment system is that some WhMD-seated passengers have expressed discomfort traveling facing rearward (Turkovich et al., 2009). Additional
research is needed to gain an improved understanding of WhMD-seated passenger safety and rider comfort when using rear-facing containment systems during transit.

Auto-docking systems were developed with the intent of providing WhMD-seated passengers with an option for independent WhMD securement (Hobson & van Roosmalen, 2007). Docking systems automatically secure WhMDs through the use of a latching mechanism mounted to the vehicle (usually the floor) that engages with interface hardware mounted on the WhMD when the passenger maneuvers the WhMD into position. However, the adoption of auto-docking systems by fixed route-transit agencies has been minimal. The primary barrier has been that each WhMD requires specialized interface hardware mounted to the frame that engages with the docking securement device in the vehicle. Efforts by one of the authors (L. van Roosmalen) are currently underway to develop alternative WhMD low-g containment and occupant retention technologies that can be independently used by WhMD users to protect them during forward facing travel in LATVs without the use of a specialized WhMD adapter.

Vehicle Environment and WhMD Securement Issues—Demand-Responsive Vehicles

As stated previously, in contrast to large fixed-route transit vehicles, demand-responsive vehicles will experience a higher crash severity for a given event since they have a lower vehicle mass (Shaw, 2000). Currently, there is a paucity of data available regarding adverse incidents and injuries that occur to WhMD passengers during transport in demand-responsive vehicles. The injury incidence rate for WhMD-seated passengers is estimated between 9.7 to 10.1 injuries per 100,000 trips, compared to an incidence rate of 1.5 to 5.6 injuries per 100,000 trips for all passengers (i.e., passengers seated in OEM vehicle seats and WhMD-seated passengers) (Wretstrand et al., 2010). WhMD-seated passengers where found to incur MAIS 1 and MAIS 2+ level injuries resulting from incidents when the vehicle was stopped (MAIS 1 = 92%; MAIS 2+ = 8%) and in motion (MAIS 1 = 75%; MAIS 2+ = 25%). Additionally, this same study found that 89% of incidents that occurred when the vehicle was in motion consisted of non-crash events. Wretstrand et al. also estimated the cost to Swedish society of injuries and adverse incidents involving WhMD-seated passengers traveling in demand-responsive vehicles at $23 million USD (Wretstrand et al., 2010).

A nationwide survey of Swedish WhMD-seated passengers found that 12% of WhMD passengers reported being involved in an incident while using paratransit services (Wretstrand, Petzall, & Stahl, 2004). Over half of these incidents occurred during transport (versus when the vehicle was stopped). The most common cause of adverse incidents was vehicle braking or acceleration during non-crash events (64% of incidents occurred during normal driving or sudden maneuvering), followed by incidents that occurred during boarding/alighting procedures (19%). Injuries varied from minor to severe, but the majority of passengers received medical treatment. Interestingly, 94% of passengers stated that their WhMD was always secured, and 78% reported always using the occupant restraint system. However, this study was not able to verify whether WTORS were properly used. This information indicates that, despite a high reported usage rate of WTORS in paratransit vehicles, adverse incidents and injury risk remain high. Although not indicated by the authors, other potential reasons for these adverse incidents and associated injuries include the misuse of tiedowns and improper or incomplete use and positioning of lap and shoulder belts.

Educational and Training Issues

Education related to the benefits of proper securement and use of WC19 wheelchairs is needed for WhMD users and the various stakeholder groups involved in WhMD transportation. A recently published survey found that less than 20% of WhMD users, caregivers, and professionals who prescribe WhMDs were aware of voluntary equipment standards, that is, Society of Automotive Engineers’ Recommended Practice (SAE RP) J2249 (Wheelchair Tiedown and Occupant Restraint Systems for Use in Motor Vehicles), or RESNA WC19 (Wheelchairs Used as Seats in Motor Vehicles) (Brinkey, Savoie, Hurvitz, & Flannagan, 2009). This finding is consistent with the authors’ experience working with transit agencies and WhMD users, and in providing WhMD transportation safety training to vehicle operators. Fixed route vehicle operators express uncertainty about advising WhMD passengers on safe boarding techniques, and demand-responsive
vehicle operators have on-going questions regarding WhMD orientation on the lift (i.e., forward facing versus rearward facing), and whether or not it is safe for the operator to accompany a WhMD on the lift platform. There is also a need to recognize that stakeholder groups may not be equally knowledgeable about the issues. For example, Easter Seals Project ACTION reports that it is not uncommon for third-party funding sources to deny coverage for WC19-compliant features, requiring WhMD users to decline these features or pay for them out-of-pocket (Project Action, 2008). Thus, education efforts must strive for a consistent level of knowledge that can be shared among all stakeholders.

**RECOMMENDATIONS FOR IMPROVING WHMD TRANSPORTATION SAFETY**

We have summarized current challenges in wheelchair transportation safety, along with barriers to WhMD accessibility, usability and safety in the fixed route and demand-responsive public transportation settings. We have also set forth a number of potential directions for improvement. The issues identified affect WhMD users and transit agencies, as well as caregivers, assistive technology providers and suppliers, vehicle operators, manufacturers of vehicle and adaptive equipment, and policy makers. These stakeholders are an interconnected group, and a lack of shared knowledge and priorities can impede or delay needed improvements in WhMD transportation safety. Thus, every effort must be made to achieve equal stakeholder participation in the development of priorities and strategies to improve WhMD transportation safety. Potential strategies that may be considered for implementation are described below.

**Development of Industry Standards and WhMD Transportation Safety Technology**

The development of new standards applicable to low g environments (fixed route) may promote development of innovative technologies that can be used independently by WhMD-seated passengers. New technologies that synergistically address usability, accessibility, and safety can potentially resolve challenges with the use of existing WhMD securement and occupant restraint systems, as well as with existing lifts (demand-responsive) and ramps (fixed route).

**Development of WhMD Transportation Safety Best Practice Guidelines**

Best practice guidelines need to be developed for both fixed route and demand-responsive environments to reduce incidents involving WhMD-seated passengers, and to educate vehicle operators in the handling of passengers who travel seated in their WhMDs. Best practices need to incorporate ergonomic issues facing vehicle operators, along with suggestions for applying WTORS in a safe and effective manner.

In addition to information on proper WhMD securement and use of occupant restraint systems, such as provided in the RideSafe brochure (http://www.travelsafer.org), a best practice guide for public transit vehicles should also include proper boarding and alighting procedures. “How-to” guides and/or interior signage displayed in vehicles could benefit both vehicle operators and WhMD-seated passengers.

**Development of Standardized WhMD Transportation Safety Training Tools**

Standardized training tools based on best practices need to be developed for transit safety personnel and vehicle operators. These training materials should include basic information on crash safety, the rationale for wheelchair securement and occupant restraint systems, proper use of WTORS and the consequences of misuse and disuse of transportation safety technologies, and should be targeted at the educational and knowledge level of vehicle operators. One suggestion is to complement existing training modules, such as CEVO (Coaching the Emergency Vehicle Operator) training with modules on proper WTORS usage and boarding and alighting procedures. Incorporating videos that demonstrate consequences when WTORS are not used properly, and coordinating with local assistive technology suppliers to provide a variety of WhMDs during hands-on training sessions can enhance training.
In addition to standardized training tools, WhMD marking and tether strap programs can be used to supplement vehicle operator training and educate WhMD passengers in identifying appropriate WhMD securement points. Finally, transit agencies should consider incorporating random monitoring programs that include an evaluation of the vehicle operator’s ability to safely and effectively secure WhMDs and restrain users.

**Implementation of Vehicle Operator Disability Awareness Training**

Vehicle operator training should also include disability awareness training that incorporates an experiential learning component. One of the most effective means of imparting knowledge to the operators as to scenarios that WhMD users encounter when using public transportation is to have each operator board/alight the vehicle at various ramp slopes, maneuver the WhMD through the vehicle to the securement station, and undergo the WhMD securement and occupant restraint process while seated in a WhMD. This experience will enhance operator awareness as to the challenges experienced by WhMD users related to ramp navigation, maneuvering a WhMD within vehicle space constraints, and the intrusion of personal space experienced by WhMD users during the securement and occupant restraint process. Moreover, vehicle operators should have the opportunity to experience normal and emergency driving while seated in a WhMD under various securement and occupant restraint conditions so as to illustrate the instability that WhMD users may encounter during transport.

**Requirement of Wheelchair Transportation Safety Certification of Vehicle Operators**

To ensure proper training and adherence to best practices, a certification process that establishes a benchmark of required knowledge and identifies adequately trained operators should be explored. A certification process that provides ongoing operator evaluation and includes follow-up training on new transportation safety technologies may reduce the risk of vehicle operator and WhMD passenger incidents and injuries.

**Modification of Legislation and Policies to Recognize Differences in Transportation Modes**

Current legislation, such as ADA, does not recognize state of the art WhMD transportation industry standards. As currently written, the ADA takes a one-size-fits-all approach to design requirements and testing of WTORS. This approach does not differentiate between modes of transport, that is, low-\(g\) (LATV) and high-\(g\) (paratransit) vehicle environments, and therefore falls short in optimizing usability, independence, and safety in WTORS design and provision. Future modifications to the ADA that incorporate current practices need to be adopted and implemented by appropriate legislative bodies.

**SUMMARY**

This paper highlights issues affecting safety, usability, and accessibility in fixed route and demand-responsive WhMD transportation. Despite the shortcomings of ADA, the US offers relatively safe and accessible public transportation systems. Both LATVs and paratransit vehicles are equipped with transportation safety technologies that allow WhMD passengers to engage in community life. Technologies such as lifts, ramps, securement systems, and occupant restraint systems, along with voluntary industry standards have been implemented with the intent to improve safety and accessibility for individuals who travel while seated in their WhMD. However, across both fixed route and demand-responsive transit systems, nonuse and misuse of safety systems, oversized WhMDs, vehicle space constraints, inadequate vehicle operator training and the lack of best practice guidelines and standardized training tools place WhMD users at risk of injury even under non-impact driving conditions. During boarding and alighting using a ramp in fixed route transit vehicles, steep ramp slope and narrow ramp width play a key role in WhMD-related incidents (Frost et al., 2010b). When utilizing lifts in demand-responsive vehicles, employing a rearward-facing WhMD orientation when traversing from the vehicle to the lift platform has led to incidents of overdriving the lift roll stop; an extremely hazardous condition (Wretstrand et al., 2010). In LATVs, disuse and misuse of WTORS are often the underlying cause of incidents and injuries when the vehicle is in motion (Frost & Bertocci, 2009b). Table 1 below provides a brief comparative...
### TABLE 1  WhMD-seated passenger injury incidence and distribution associated with various activities and vehicle conditions in demand-responsive and fixed route transportation

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Injury incidence, (per 100,000 trips)</th>
<th>Injuries associated with boarding/alighting, (%)</th>
<th>Injuries associated with normal &amp; emergency driving, (%)</th>
<th>Injuries associated with crash events, (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand responsive¹</td>
<td>10</td>
<td>22%</td>
<td>32%</td>
<td>5%</td>
</tr>
<tr>
<td>Fixed route²</td>
<td>56</td>
<td>43%</td>
<td>43%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Note: Given varying outcome measures determined in previous studies, only two studies having similar outcome measures were able to be compared. Comparisons across studies should be interpreted with caution since differing sources, methodologies, geographical regions and transit agency characteristics were used to obtain data. Additionally, geographical diversity and generalizability was limited in these studies.

¹Wretstrand et al., 2010.
²Frost & Bertocci, 2010a.
summary of incidents involving WhMD-seated passengers traveling in demand-responsive and fixed route transit. With the exception of crash events, the data suggest that more incidents and injuries are occurring in fixed route transit. Without an in-depth assessment to determine the causal factors associated with these incidents and injuries it is difficult to attribute this difference to a specific cause or causes. However, it is likely that the higher level of WhMD user independence associated with traveling on fixed route transit may contribute to the increased frequency of incidents and injuries as compared to that of demand-responsive travel where WhMD passengers are afforded increased operator assistance.

Despite the initial findings related to WhMD passenger challenges associated with fixed route and demand-responsive transport described herein, additional research is greatly needed to advance the identification and understanding of causal factors that underline the safety and accessibility in these vehicle environments. However, the further development and adoption of industry standards, the advancement of WhMD safety technologies, the development of WhMD transportation best practice guidelines, and the standardization of WhMD safety technologies, the development of WhMD transportation best practice guidelines, and the standardization of WhMD safety training tools will further aid in the protection of WhMD passengers when traveling using fixed route and demand-responsive transportation.

ACKNOWLEDGMENTS

This study was funded by the National Institute on Disability and Rehabilitation Research (NIDRR) and the Rehabilitation Engineering Research Center (RERC) on Wheelchair Transportation, Grant #H133E060064. The opinions expressed herein are those of the authors and do not necessarily reflect NIDRR opinions.

NOTE

1. ADA excerpt: Wheelchair means a mobility aid belonging to any class of three or four-wheeled devices, usable indoors, designed for, and used by, individuals with mobility impairments, whether operated manually or powered. A “common wheelchair” is such a device that does not exceed 30 inches in width and 48 inches in length measured two inches above the ground, and does not weigh more than 600 pounds when occupied.

REFERENCES


