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U.S. Department of Education

Wheeled Mobility and Accessible Transportation

**2003
Conference
Proceedings**

Excerpts: Background Papers Related to Vehicle Modification

Wheeled Mobility and Accessible Transportation 2003 Conference Proceedings



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CESSI

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Executive Summary

The “Wheeled Mobility and Accessible Transportation Summit” was the first Interagency Committee on Disability Research (ICDR) meeting held to develop a future research agenda based on identified key issues and priorities. It was conducted on July 22, 2003, in Washington, D.C. The one-day meeting took place in conjunction with an accessible transportation forum commemorating the 13th anniversary of the *Americans with Disabilities Act (ADA)*.

The summit brought together researchers and experts from the fields of rehabilitation science and technology, physical medicine, engineering, architecture and transportation from throughout the country. Attendees included grantees from the National Institute on Disability and Rehabilitation Research (NIDRR) and the Department of Veterans Affairs (VA), as well as policymakers and representatives from disability and transportation-related federal agencies.

Presentations and discussions focused on three main areas related to wheeled mobility and transportation: wheeled mobility usage and interface with the environment; safe and accessible transportation; and standards for public transportation. Topics discussed under usage and interface included: the fit between the user and the chair itself, advanced wheelchair features, and the barriers to full community participation. In the area of safe and accessible transportation, topics discussed were: the use of wheelchairs as seats in motor vehicles, securement systems and safety issues, intelligent transportation systems, and the design for a universal transit system including buses, trains and light rail systems. Topics related to standards issues included: wheelchairs, seating, wheelchair user safety and the Department of Transportation (DOT)’s regulatory process.

After each set of presentations, discussion ensued to better define the research needed to meet intended goals. The discussion focused on: the logistical difficulties in making cutting-edge wheeled mobility and seating systems available and affordable; the need for compatible and appropriate wheeled mobility for paratransit and *ADA*-compliant securement systems; limited access to, or problems associated with, private and public transportation; the need for a universal transit system that will service all people; and the difficulties in coordinating the use of voluntary standards for wheelchairs and seating systems.

Recommendations among the researchers centered on the need for universal standards for wheelchair interface and the need for clinical practice guidelines that comply with reimbursements from Medicare and other third-party insurers. Wheelchairs must also be recognized as a seat in a motor vehicle with federal endorsement for their use in transit. Participants agreed that to better characterize wheeled mobility assistive technology use in transportation, questions in transportation databases must first be modified. Notification of when crashes or incidents occur, through the use of the Food and Drug Administration’s (FDA) medical device reporting system, would further benefit the investigation of people seated in wheelchairs. They also suggested that a registry of wheelchair users be developed to assist researchers in answering pertinent research questions such as: anthropometry of wheeled mobility devices; long-term studies on the cause and prevention of secondary injuries from wheelchairs; analysis of risk versus operational issues; the quality of health care and the cost; and the design of mobility for more than one use.

While significant time was devoted to group discussion, which was designed to reach a consensus on research gaps and future needs, it was determined that further follow-up was necessary. Two subsequent teleconferences, which included many of the participating researchers, were conducted to identify and refine key issues and priorities related to wheeled mobility and accessible transportation research. They are included herein.

Nearly all presenters prepared brief papers to complement their talks. The papers and presentations served as the basis for discussion in each area. A collection of edited papers can be found in Appendix A.

Appendix A: Background Papers by Topical Area

Topic: Safe and Accessible Transportation in Private and Public Vehicles

Securing Wheelchairs: Recent Developments, Future Challenges

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Abstract

The need to accommodate travel by passengers with disabilities on fixed-route transit is increasing. This includes the need to eliminate barriers faced by many individuals in effectively using bus service instead of paratransit. Commercially available on-vehicle wheelchair securement equipment has evolved over the past few years. Several new designs make securement safer and easier to use than the first generations of systems that complied with the *Americans with Disabilities Act (ADA)*.

The evolution of wheelchair design, however, is at odds with some of those improvements. Many new power wheelchairs and scooters do not provide adequate securement points. Recently developed standards to include attachment points on mobility aids are not well known, and the new designs are available on only a fraction of wheelchair models.

Several research and development projects are underway to improve the situation. These include the testing of innovative new securement designs; evaluation of existing securement, occupant restraint and crash testing requirements; and investigation of universal “docking” solutions. Meanwhile, there is a fast-growing need to find a way for wheelchair users, manufacturers, dealers and medical funding agencies to offer and use devices with proper attachment points.

The transit industry has been only marginally involved in these development efforts but continues to be the frontline for dealing with securement problems. It is becoming crucial for transit systems, disability advocates and transportation regulatory bodies to take a leadership role in guiding new research and implementation of standards.

Transit Service Experience and Solutions

Alameda-Contra Costa Transit (AC Transit) traditionally has served a large wheelchair-using customer base and has had a fully accessible bus fleet since the mid-1980s. The system experiences between 600–900 daily wheelchair users out of a total daily ridership of over 225,000. This level of wheelchair usage is similar to other large West Coast transit systems,

many of which were lift-equipped prior to the passage of the *ADA*. Systems in other parts of the country have started to experience more wheelchair demand, which will continue to grow as paratransit and other community resources are stretched.

Issues related to the use of *ADA*-compliant securement systems, along with an increasing general need to improve access by wheelchair users, led AC Transit to explore a variety of approaches including the following projects.

- **Wheelchair Marking and Tether Strap Program**
In 2001, AC Transit began offering a free marking and tether strap program for wheelchair users. Passengers make an appointment to have their chairs examined at AC Transit's offices or at one of several disability-oriented agencies throughout the service area. AC Transit staff who are familiar with wheelchairs and bus securement equipment work with customers to mark appropriate attachment points on their chairs with color-coded tape.

If there is no good place for attachment of belts or hooks, a fabric webbing tether strap is installed permanently on the mobility aid. An informational brochure is distributed to customers and local agencies and is available on the AC Transit Web site: www.actransit.org/pdf/securement.pdf (last accessed Dec. 19, 2004).

The need for this type of program increased with the advent of hook-style securement equipment for fixed-route buses (hooks have been more common on paratransit vehicles). Hooks afford easier one-handed attachment by drivers or attendants in comparison with the older seat-belt-buckle-style straps. Hooks, however, are less versatile and encounter many more situations where there is no adequate attachment point.

- **Cleveland Clinic Foundation (CCF) Securement Prototype**
AC Transit is one of several transit and specialized transportation providers participating in a pilot program of this new system. The CCF design incorporates motorized tensioning of the tie-down straps which eliminates the common failing of manual systems to be properly tightened. Passengers can actuate a nearby electrical switch which both tightens and releases the straps.

Other aspects of the system are designed for those passengers who have some hand and arm ability to perform without assistance. This also gives passengers greater freedom to unsecure themselves where tensioning of straps is not a factor. Field testing and evaluation of the system should be completed in 2003. The National Institutes of Health (NIH) funded the project.

- **European-style Rear-facing Wheelchair Positions**
AC Transit is purchasing European-style low-floor buses for use in new Bus Rapid Transit (BRT) service. This new service will feature boarding at "mini-stations" via multiple bus doors with the goal of faster boarding and limited express stops. AC Transit saw this as an opportunity to try the rear-facing securement style common in Europe and Canada.

Two securement stations are located on the same side of the new bus, with easy access via a ramp in the second door. This eliminates the entry area constrictions common to traditional

front boarding designs. The forward-facing securement area uses traditional belt-type securements. The adjacent rear-facing station features a padded backrest with folding armrest, grab rails and seat belts. This design is intended to provide containment in the event of sudden stops or crashes instead of relying solely on tie-down straps to hold the wheelchair in place.

The rear-facing station is configured also to use *ADA*-style securement straps and to be used as an optional forward-facing station in cases where passengers are not able to ride backward for physical reasons. The regular seating areas throughout the bus feature rear-facing seating in opposing pairs. Therefore, stigmatization of the wheelchair user by being forced to ride backward should not be an issue.

The vehicles were delivered to Oakland in 2003. Initial rides by wheelchair users on two prototype models in late 2002 were very positive, despite some consumer apprehension about how such a different new layout would work. AC Transit expects to participate in research and evaluation of this approach in anticipation of interest in it becoming an accepted United States practice, especially among BRT operators.

- **Retrofitting Newer Securement Equipment**

Over the past few years, manufacturers have improved securement systems. *ADA*-compliant systems typically consist of four tie-down straps. New models have become easier to use and help alleviate frustration among drivers and passengers. New products, such as American Seating's A.R.M, Q'Straint's QRT, Sure-Lok's RTT Solo and TSI's 5200, have features such as remote release levers, automatic tensioning and convenient stowage when not in use. Some of the basic ergonomic problems of strap-type systems, however, have not been solved yet. The physical issues of bending, kneeling, pulling, reaching and grasping to perform securement continue to be barriers to acceptance and can even result in injuries.

AC Transit is considering retrofitting some of its existing fleet with newer equipment and is aware of at least a few other transit systems that have done so. One objective is to foster a more standardized experience for drivers and passengers. The tendency of receiving the "latest and greatest" products with each new bus purchase has resulted in a variety of clamps, straps, hooks, arms and levers for users to decipher. Some of the principles of older systems, such as wheel clamps, are diametrically opposed to the principles of strap-type systems which must not be attached to wheels.

- **Improving Employee Training and Customer Education**

Training and education are keys to proper use and acceptance of wheelchair securement systems. AC Transit has tried a variety of approaches and continually looks for new and better methods. Many transit systems have built practice rigs for use at training centers or in driver rooms. AC Transit was able to employ several retired buses as securement training buses.

One training bus is placed at each bus yard. Each one contains three securement stations with a combination of all of the types of equipment in the fleet. Using actual buses provides the most realistic environment including the space limitations encountered in actual service. The

training buses are used for practice and re-instruction of drivers who have questions or are involved in complaints about securement. In addition, new drivers are trained with a variety of wheelchair styles on each of the types of buses in the fleet.

Some transit systems use a mock or actual bus in consumer travel training programs or for conducting functional assessments of paratransit applicants. AC Transit frequently assists customers who have new wheelchairs or are new to the area by allowing them to practice boarding, maneuvering and securing their wheelchairs on a variety of buses in a bus yard.

Educating passengers about securement is accomplished by many transit systems in a special accessibility guide or brochure. AC Transit uses an interior advertising card on both sides of each bus to explain the six steps of wheelchair securement. The card explains how securement can best be done and that drivers must provide assistance in doing so. It includes a statement that passengers must allow their chairs to be secured, and that seat and shoulder belts are at the passenger's option. This covers recent Federal Transit Administration (FTA) guidance stipulating that transit systems must have a stated policy if they intend to enforce the *ADA* provision to refuse service to any passenger who will not allow their wheelchair to be secured.

Standard for Transit Wheelchairs

The WC-19 standard, Wheelchairs Used as Seats in Motor Vehicles, was approved by the American National Standards Institute (ANSI) in May 2000 and is now a voluntary U.S. national standard. It specifies strength and geometric requirements for at least four securement points, and occupant restraint anchorage points that can withstand the forces of a 20 g and 30 mph impact, as well as geometry that can receive a securement hook. The standard covers design requirements, test procedures and performance criteria related to frontal impact performance and accessibility to motor vehicles and stability during normal vehicle travel.

So far, only a limited number of wheelchair models are available with the securement loops specified by the WC-19. Manufacturers call these models the "Transit Option." It is not generally available on power wheelchairs or scooters that are commonly used by transit passengers. Some consumers have reported medical funding entities denying coverage of the option which has only a marginal additional cost. This is partially due to the lack of understanding of the need for securement while traveling and the fact that wheelchairs have not had such features in the past. The problem is compounded by the fact that manufacturers have traditionally labeled wheelchairs as "non-transportable," wary of liability issues and the high cost of crash testing.

The WC-19 standard was developed by the Standards Committee on Wheelchairs and Transportation (SOWHAT), which is sponsored by the ANSI and the Rehabilitation Engineering and Assistive Technology Society of North America. This group also provides official United States input to the International Organization for Standards. Membership is open to interested parties and consists of wheelchair and securement manufacturers, researchers, disability advocates and transit system staff.

The author of this paper is currently a member. More information is available on the Wheelchair Standards Information Web site (www.wheelchairstandards.pitt.edu).

Transit industry participation in the SOWHAT has been minimal in the past, and the committee has identified the need for a stronger role for transit, especially in the area of educating the public about the need for the WC-19 transit option. Other topics being addressed for new standards are testing of aftermarket wheelchair seat assemblies and design geometry for potential universal docking securement mechanisms.

Research and Development

Wheelchair Safety Research Initiative

Several universities and research organizations have investigated various aspects of securing wheelchairs and restraining wheelchair occupants on public transportation. Some of the researchers also are involved in the standards development described above. In 2001, the National Institute on Disability and Rehabilitation Research (NIDRR) awarded a five-year grant for a Rehabilitation Engineering Research Center (RERC) on Wheelchair Transportation Safety to the University of Pittsburgh and the University of Michigan's Transportation Research Institute.

The RERC program includes a comprehensive research and development effort that involves consumers, manufacturers, students, clinicians, transport providers and rehabilitation technology experts. It also includes information dissemination, training and technology transfer using personnel, media and facilities at the University of Pittsburgh. Information is available on the RERC Web site (www.rercwts.pitt.edu).

RERC tasks include the investigation and development of new wheelchair tie-down and occupant restraint technologies. Included are wheelchair-integrated restraints and universal docking concepts that can enable wheelchair users to independently and quickly secure and release their wheelchairs and use an effective occupant restraint system without the need for assistance.

Researchers at the RERC are considering the development of lower-severity frontal crash-test standards for securement systems used only on large buses. The current standards for wheelchair securement require testing at a severity of 20 g and 30 mph, which is comparable to federal safety standards for personal passenger vehicles including vans and minivans. A lower level of crash severity may be appropriate for larger buses and may allow the development of securement systems which are more acceptable to the operational demands of public transportation systems.

RERC researchers also are investigating the frequency of crash-related injuries on large urban transit buses. This will help determine the potential risks associated with very low-g securement or facing wheelchair occupants backward against padded structures when traveling in city-type buses.

The docking concept holds particular interest for public transit systems. A few early attempts at developing and marketing such systems encountered many issues. Not the least of these issues was the need for a standardized attachment point on an ever-increasing variety of wheelchair shapes and sizes. However, a practical docking system could alleviate many of the drawbacks of traditional tie-down systems.

Study of Transit Industry Securement Issues

The Center for Urban Transportation Research (CUTR) at the University of South Florida recently published the report “Synthesis of Securement Device Options and Strategies” (#416-07) related to securement and barriers among public transit agencies. The CUTR surveyed 270 transit agencies, inquiring about general agency policies, and found that 90 percent have securement policies and 94 percent actively utilize tie-downs. Over half of the respondents reported ongoing difficulties in securing wheelchairs, especially the “scooter”-type (which are both unstable as seats and difficult to secure). The study is available on the CUTR Web site (www.cutr.usf.edu/index2.htm).

In analyzing the reasons for difficulties in securing wheelchairs, the CUTR study found that many people do not understand policies, and wheelchair users are frustrated and uncertain as to whether they should be secured or not. The study concluded that policy clarification from the U.S. Department of Transportation is needed, as well as guidance as to the types of wheelchairs or features that are appropriate for use in transportation such as the WC-19 transit option. This included an observation that voluntary steps will probably not be enough, pointing to the need for some type of mandatory requirements. The study also concluded that more consistency across vehicle securement devices is needed.

Other Research

In addition to the CCF’s NIH-funded development of securement systems, Easter Seals’ Project ACTION and the U.S. Transportation Research Board have funded various securement-related projects. Investigation of the European-style rear-facing securement option currently is being covered in a “Synthesis of Practice” (i.e., a compilation of studies on current practice in the field of highway transportation and transit) study, under the board’s Transit Cooperative Research Program. Other studies have probably been done under the auspices of a variety of organizations, but there is no central clearinghouse for such information as of yet.

Next Steps

Transit systems across the United States are likely to face mounting safety and driver or customer comfort and convenience issues unless wheelchairs and securement technology are brought more in line with each other. The path to “practical and painless” securement of wheelchairs on transit vehicles is not clear. Two things, however, are clearly needed to begin moving in a cohesive direction—dialogue and education.

Dialogue is needed to determine what the priorities should be, what kinds of standards are needed and how any new standards will be implemented. This should stem from an honest evaluation of the risks to which wheelchair-using transit riders are exposed and what kind of protection they need, balanced with the need for freedom of movement that the general public enjoys.

Education on the benefits of proper securement and the need for WC-19-specified “Transit Option” wheelchairs, as well as on other potential improvements, is needed for wheelchair users and manufacturers, securement equipment and vehicle suppliers, transit managers, and medical

funding and regulatory entities. Also needed is leadership and consensus building toward common objectives.

The CUTR report recommendation that some type of mandatory regulation will be needed brings up questions:

1. Who and what should be regulated, and how could it be enforced?
2. Will collaborative efforts be enough?

The transit industry will be on the front line of any of these issues since all wheelchairs meeting the definition of a “common wheelchair” must be transported whether they can be adequately secured or not. The current environment does not allow for draconian enforcement of whom and what are permitted aboard transit vehicles. Likewise, the wheelchair industry and medical insurers are not looking for new ways to complicate their already intricate requirements.

In the absence of a clear starting point, the suggestion can be made that the transit industry needs to reach out to stakeholders to begin formulating an approach. Recent developments at the federal level may point to possible venues. The meeting “National Dialogue on Accessible Transportation,” was held in 2002 in Washington, D.C. The dialogue is being continued through a series of regional meetings in 2003, which could include focus on this topic. Also, a new RERC for accessible public transportation is being proposed by the NIDRR.

These efforts should acknowledge and coordinate the work already underway, hopefully with collaborative guidance from the FTA and its kindred federal agencies, Easter Seals’ Project ACTION and the American Public Transportation Association as well as other interested industry and consumer organizations.

Accessibility and Intelligent Transportation Systems

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Overview

In the past few decades, intelligent transportation systems (ITS) have steadily evolved from research prototypes to successful commercial products. Certain trends in ITS provide key opportunities to reduce the cost of vehicle modification to end-consumers and third-party payers while also increasing the availability of technicians and vehicles.

Recent advances in ITS have been most apparent in passenger vehicles. Telematics (e.g., wireless, in-vehicle voice and data), in-vehicle navigation systems, adaptive or intelligent cruise control, vision enhancement systems, and automatic crash notification systems now are all available in U.S. showrooms. The added functionality of these systems has resulted in large shifts in driver-vehicle interface practices to reduce “button overload” and driver workload. The traditional practice of assigning one physical control per function is no longer an option. As such, the industry is moving toward new interaction models which, in many cases, directly affect accessibility.

Transit ITS applications are also becoming increasingly common. Real-time vehicle arrival estimates, electronic trip planning tools and smart card payment systems are already available in various metro areas around the United States. One of the most interesting and effective applications of traveler accessibility information, however, is the dissemination of out-of-service information for elevators and escalators (e.g., Washington, D.C. Metrorail). The opportunities and potential barriers are best illustrated through the examination of three general ITS trends that directly affect user-vehicle interactions: multifunction controls, voice interfaces and active vehicle controls.

Trend #1: Multifunction Controls

The use of a few controls to manage a large assortment of functions is starting to become common in high-end vehicles (e.g., BMW’s iDrive system). Automobile manufacturers have a vested interest in promoting these new interfaces for branding and marketing purposes. For example, the Infinity Q45’s multifunction system which offers a rear parking camera was the centerpiece of a heavily run advertisement campaign. As with antilock brakes, airbags and compact disc changers, products now available only on high-end vehicles will soon “trickle down” to the general market. The impact of multifunction systems on vehicle accessibility is relatively unknown, especially for drivers who use hand controls or have upper limb impairments.

Trend #2: Voice Interfaces

General Motors’ OnStar[®] system has been the most successful telematics service provider in the United States, with more than 2 million subscribers since their initial deployment in the fall of 1996. Features include: concierge services, roadside assistance, route directions and emergency services. Other capabilities include remote door unlock, airbag deployment notification

(currently about 688 per month) and theft protection. The OnStar[®] system's interface consists of three, closely grouped very small buttons in the car paired with a cellular connection to service centers. The call center uses a mixture of human operators and speech recognition software. All information is presented to the driver via audible speech. Although OnStar[®] could have great benefits to wheeled mobility users; it is not accessible to those with pronounced hearing loss or severe speech impairments. Also, persons with limited dexterity have restricted use due to the very small buttons.

Trend #3: Active Vehicle Control

A variety of vehicle-initiated actuation technologies, such as adaptive cruise control, lane keeping and collision avoidance systems, are already being introduced. The removal of the physical linkage between the steering wheel and the front wheels (drive-by-wire) is also on the horizon. The automotive community has begun the process of developing communications protocols, functions standards, software interfaces and specifications. This technology provides an opportunity to improve current vehicle control conversion methods and techniques by enabling a direct interface between alternative controls and the on-board vehicle control software.

Recommendations for Research

There has been considerable research on the usability and utility of ITS, and researchers often include older subjects in their studies. However, these volunteers are not representative of young and middle-aged users with disabilities. As such, the accessibility of ITS applications is largely unexplored. Furthermore, little effort has been devoted toward documenting and measuring interaction paradigms for appropriate and safe use by drivers and passengers with disabilities. Methodologies for detailed examination should include a mixture of proven techniques including, but not limited to, identification of user needs, guideline development, basic research, reference designs and prototype testing, and standards development.

Research is needed in the following areas to insure that new ITS adopted by industry are universally accessible. Some important topics in a research agenda should include the following:

- Multifunction dashboard controls that support safe use by drivers whose vehicles have hand controls or have upper limb impairment or have both. The opportunity to develop universal or easily modified interfaces is enhanced by the shift toward software-defined interfaces with generic physical controls. Methods and practices should be identified before standards and original equipment manufacturer practices are solidified.
- Driver-vehicle interfaces which support safe interaction by drivers who are deaf, hard of hearing or have speech impediments. As we have experienced with telematics and in-vehicle navigation systems, the advocates of accessibility and universal design have already missed having an impact on the first wave of products.
- Active vehicle control and drive-by-wire. As a long-range plan, the vehicle modification industry will benefit from early integration of alternative vehicle control software and hardware interfaces into active vehicle control and drive-by-wire standards.
- Accessible transit information. As transit agencies fall under the *Americans with Disabilities Act*, they have made concerted efforts to provide travelers' information in accessible formats.

Successful practices should be identified and disseminated within the industry to promote broader application.

There are significant opportunities for leveraging mainstream efforts and enthusiasm for new technologies to provide greater access to all travelers. ITS applications have the potential to be powerful enablers but, as demonstrated in the computer industry, barriers can be introduced inadvertently or can be a result of inadequate effort in identifying accessible solutions. A dedicated effort by policy and research entities to emphasize accessibility in the early stages of development will produce a significant benefit down the road.

Ingress and Egress From Vehicles

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Experience with the *Americans with Disabilities Act (ADA)* has demonstrated that providing accessibility for wheeled mobility devices is clearly feasible. But transit agencies and critics in the United States argue that the mandate to improve accessibility, combined with no increases or only minimal increases in budgets, hampers the ability of mass transit to compete with the private automobile. Although this may not be an accurate statement of fact, it is a perception that advocates and practitioners of accessible transportation have to address. Universal design is perhaps the way to counter this perception. Those in the accessibility movement must ally themselves closely with the advocates of mass transit in general because improving services and convenience for everyone are shared goals. Universal design includes traditional accessibility as required by the *ADA* and other laws, but that accessibility is provided in a way that benefits all customers not just the riders with disabilities.

A good example of universal design is the “stepless” bus. Conventional lift-equipped buses require special considerations for loading and unloading a wheeled mobility user. No one else benefits from those provisions. In fact, lifts do not even help people who have other disabilities. The stepless bus, equipped with a low floor, “kneeling” suspension and ramp access makes it easier for all riders to enter and exit, not just wheeled mobility users. It makes riding the bus more attractive to all customers and it makes the wheeled mobility user an independent rather than dependent participant.

We have definitely learned that accessible ingress and egress depends not only on the design of the vehicle but on the context in which the vehicle operates (e.g., station design, types of services provided and operating policies). Solutions that address both may be the most difficult to plan and implement but the benefits are worth it. For example, in Helsinki, Poland, the city has an extensive light rail system. Most of the major stops were located in the middle of the street on islands. A new tram was designed which had a low floor and wide midcar entry. A new fare system includes automated pay stations at each entry so all passengers can enter any door. The midstreet stops were raised off the ground to be flush with the low floor of the tram, and ramps were built at each end of the platforms. Another good example of universal design, this system increases safety and convenience in fare payment, and ingress and egress for all passengers.

Commuter and intercity rail systems present one of the greatest challenges to accessibility. There are a number of serious problems making these systems fully accessible. First, to increase the capacity of the system to a maximum, passenger cars are completely filled with seats, leaving only minimal room for luggage and wheeled mobility devices. Second, all compartments have stair access, often on two levels. Third, there can be a large gap between the train and the platform. Lastly, in some cases there also may be differences in the platform height from station to station. The new train that operates across the bridge from Denmark to Sweden is a good example of universal design. It has a low floor and a main entry in the middle of the car at the same level as the station platforms. Stairs lead from the middle to compartments at either end. The middle compartment is equipped with folding seats to provide more general room at peak periods for standing riders and also room for wheeled mobility devices, carriages, rolling

luggage carts and bicycles. An accessible restroom is provided at that level. The entrance is equipped with a no-step entry, telescoping gangway to bridge the horizontal gap between train and platform, and a wide, automated entry door.

The graying of America will soon fuel a need to rethink how mass transportation services are provided on a communitywide level, especially in the low-density suburban areas of our cities. These projects will become the new frontier of accessible mass transportation. Two examples point the way to solutions for low-density communities.

In Curitiba, Brazil, the city planners wanted a system that would be so convenient that no one would want to use private automobiles. The heart of the system is a dedicated busway with vehicles that hold up to 350 passengers. This capacity is achieved by having a minimum number of seats and “bus trains” with up to three articulated cars connected together. The bus trains travel on radial routes to the city center and a system of feeder buses bring passengers to the bus train terminals. The feeder buses are equipped with lifts for loading from street level, but once an individual is up at the floor level of the bus they can remain at that level using platform boarding at the terminals and at local downtown stops equipped with ramps or lifts. The Curitiba system is a very cost-effective approach that can be adapted to existing low-density areas where streets are wide enough to provide the dedicated busways. It could also be adopted on old railroad rights-of-way.

In Sweden, future projections for the aging of the population indicated that the economic burden of paratransit for local transit systems would be immense. Therefore, the county’s transportation agencies are implementing communitywide services using a mix of accessible vehicles. The most interesting are on-demand “flex routes” and “service routes.” In the former, small buses with lifts travel a designated route in local areas picking up individuals at bus stops. The drivers are in communication with a dispatcher. When a request is received, the closest driver deviates from his route and picks up the passenger at the closest stop to their residence. On service routes, small buses carry up to 12 people or six wheelchairs. These buses are low-floor vehicles that also have lifts at a rear door. They follow a route that serves facilities frequented by frail, older people like rehabilitation hospitals, senior centers and senior housing facilities. The local neighborhood buses feed riders to stops where they can pick up these service route buses.

Citizens and governments are recognizing the importance of good mass transportation even in the United States—the most automobile-oriented country in the world. This new awareness offers opportunities to make strategic improvements in the accessibility of systems for wheeled mobility devices. There is much we can learn from the experiences in other countries where these issues are being addressed already. But as we move ahead, there is an important trend in wheeled mobility that must be addressed. Larger and heavier wheeled mobility devices are being used more frequently. Even lightweight wheelchairs, if they have cambered wheels, are wider than conventional models. Scooters and powered wheelchairs in particular have improved personal mobility for millions of people, but they also present problems in ingress and egress to mass transit vehicles. Ramps and lifts may not have the capacity for the occupied weight of some devices; there are bottoming-out problems when exiting ramps; the clearances inside the entries of the vehicles are not sufficient; and drivers cannot safely assist people with heavy devices to

get up ramps and onto lifts. Thus, there is a need to start communications between consumer advocates, wheeled mobility device manufacturers, vehicle manufacturers and transit agencies to identify solutions to this growing problem. Some of the examples described above are good solutions (e.g., platform loading and low-floor center compartments). Nevertheless, other solutions are still needed such as design standards, operating guidelines and public education.

Categorization and Identification of Critical Research in Wheeled Mobility and Accessible Transportation

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In considering what research to pursue for wheeled mobility and accessible transportation it is worthwhile to categorize the different types of work that are needed. First, we identify engineering research as the research that must be done before an effective technology can be produced. Two examples of this are: 1) A likely candidate for improved wheelchair propulsion systems includes the use of mesoscale hydraulic actuators (a lifting cylinder powered by liquid under pressure with a variable range of extension) but before these actuators can be produced, there are varying fluid dynamics that must be understood and 2) To better understand the control system interface for a powered wheelchair control, more needs to be known about the human-machine interface, particularly with differences in user ability, before the control systems can be optimized.

Second is the area of design. The difference between engineering research and engineering design, in this context, is that useful products can be developed using formalized design procedures with what we currently know. For an example of something needing this type of design effort, consider a vehicle that is purpose-built from the original inception to be utilized by people using wheelchairs. More basic vehicle research is not necessary; however, in order to optimize the resultant vehicle design, formalized design methods are required.

Third is the area of clinical research. Clinical research is needed to ensure that a particular device, improvement or treatment, for example, is in fact resulting in the desired improvement. Much of the technology being considered here would benefit from clinical research; however, good design procedures ensure that user requirements are paramount in the resultant design, so perhaps there is overlap here that is unnecessary and costly.

Fourth is the area of sustainable production. If a device can be produced in a sustainable manner, then it is likely all sorts of things are true of that device. It must mean that it has consumer acceptance, medical and health insurance system acceptance, and in addition, an entity is able to produce it and survive financially. The primary goals of the engineering research, design or clinical research for wheeled mobility and accessible transportation are devices that are produced in a sustainable manner. The primary goal is not the generation of new knowledge. There are many other ways to generate new knowledge, and these methods should (and will be) fostered. The specific needs for wheeled mobility users are of sufficient magnitude and the resources sufficiently scarce that the focus should be on products and devices capable of sustainable production.

Finally, the fifth area of categorization is called state of the art. Technologies for wheeled mobility and accessible transportation will improve when there is a paradigm shift from good enough to state of the art. The INDEPENDENCE[®] iBOT[™] 3000 mobility system is the best example of this in that the researchers and designers used the platform of a powered wheelchair

to develop a device that led to the development of a new type of dynamic system. This paradigm shift will be beneficial for many reasons but there are two principal causes worth mentioning:

- This philosophy is a great motivator for both the developers and the users; and
- Multiple-use technologies are a result, with all of the benefits that occur from having devices that are useful to more than one audience.

One additional comment: There is no difference in the level of complexity, or the skill needed, or the creativity required between good engineering research, design, clinical research or development of products capable of sustainable production. The implication of this is important for selecting which projects to pursue. Decisions should not be based on which of the activities is the most academic—most scholarly—or of most immediate use to a user. The process should include an assessment of capability to complete the task, and an evaluation of the contribution of the project to a larger viewpoint of how the effort will impact the goal of sustainable production of devices.

Shown in the table below are lists of areas in wheeled mobility and accessible transportation that need attention. Space limits comments and descriptions, however, examination of the table will illustrate one set of ideas on how to prioritize work in this area. For example, when considering power systems for use in powered wheelchairs, effort is needed in all of the areas previously described; yet, it would be the best use of resources to do the research and design first and then follow with the other necessary work to produce a usable product.

Wheeled Mobility and Accessible Transportation: Selected Research Areas

Device	Area Needing Improvement	Type of Improvement Needed	Type of Effort Needed Now
Power Wheelchair	Power System	Weight, Size, Power Density, Cost, Range and Power	Research and Design
	Actuators	Weight, Size, Cost and Power	Research and Design
	Modularity	Ease of Customization and Transportability	Design and Sustainable Production
	Energy Storage System	Power, Range and Refueling	Design and Sustainable Production
	Control of Dynamics	INDEPENDENCE® iBOT™ 3000 Mobility System	Research and Design
	Wheelchair Restraint	User-activated and Standardized	Design and Sustainable Production
	Control Interface	Adaptability, Configurability and Feedback	Research
Personal Vehicle	Suitability	Original Equipment Manufacturer (OEM) Manufactured	Design and Sustainable Production
	Reliability	Same	Same
	Safety	Beyond Normal Vehicles	Same
	Cost	Consistent With the Equipment	Same
	Dual-use	OEM Manufactured	Same
Personal Restraint System	Safety	Beyond Normal Restraint Systems	Research and Design
	Usability	User-attachable	Design
	Aesthetics	Obvious	Design
	Cost	Consistent With Normal Restraint System Costs	Design
Public Transportation	Taxis	Entry and Exit	Design
	Buses	Restraint	Design
	Trains	Entry, Exit and In-wheelchair Seating	Design and Sustainable Production
	Airplanes	Entry, Exit, Wheelchair Transport and In-wheelchair Seating	Design and Sustainable Production

Topic: Standards for Public Transportation

Wheelchairs as Seats in Motor Vehicles

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Transit Wheelchair Standards

Wheelchair users who are unable to transfer to a motor vehicle seat during transport must rely upon their wheelchair to function as a vehicle seat. Wheelchair crashworthiness is addressed nationally through the American National Standards Institute/Rehabilitation Engineering and Assistive Technology Society of North America (ANSI/RESNA) WC-19 Wheelchairs Used as Motor Vehicle Seats standard, and internationally through the International Organization for Standardization (ISO) 7176/19 Wheelchairs Used as Motor Vehicle Seats standard (ANSI/RESNA 2000 and ISO 2000). These standards, which focus on the use of a wheelchair as a motor vehicle seat, propose design requirements, instructions to users and test procedures for wheelchairs intended for transportation. A significant design requirement established by these standards is the addition of four securement points on transport-safe wheelchairs which are compatible with end fittings of strap-type tie-down securement systems. This requirement was defined in response to difficulty in properly identifying locations on the wheelchair for attachment of tie-downs. Frontal impact crash testing is also required by the ANSI/RESNA WC-19 and ISO 7176/19 standards. This tested an appropriately sized, wheelchair-seated test dummy to a 20-g and 48-kilometer-per-hour frontal impact crash test. In the ANSI/RESNA WC-19 test protocol, the wheelchair is secured and the occupant is restrained using a reusable wheelchair tie-down and occupant restraint system. The ISO 7176/19-DIS test protocol permits wheelchair securement and occupant restraint using a commercial wheelchair tie-down and occupant restraint system. The ANSI/RESNA WC-19 and ISO 7176/19 test criteria assess wheelchair integrity, as well as occupant and wheelchair kinematics. Many manufacturers now offer transit option wheelchairs in the United States. Roughly 63 WC-19 tests of wheelchairs have been conducted over the past two years at the University of Michigan's Transportation Research Institute—the primary laboratory in the United States for WC-19 testing.

Despite the purpose of the ANSI/RESNA WC-19 and the ISO 7176/19 standards being used to evaluate wheelchair crashworthiness, the addition of aftermarket or optional wheelchair seating systems would invalidate wheelchair testing conducted with an original equipment manufacturer (OEM) seat. Consequently, wheelchairs utilizing aftermarket seating systems may not be crash tested to evaluate their ability to withstand crash-level forces. Additionally, replacement seating systems provided in the field, which differ from those provided with a WC-19- or ISO 7176/19-approved wheelchair, would invalidate compliance and will not be tested. Therefore, methods to evaluate wheelchair seating system crashworthiness, independent of different wheelchair frames, with which they may be coupled in the field are desirable. Toward this end, both the international and national standards groups have organized efforts to address aftermarket, transport-safe wheelchair seating. The ISO 16840-4 and the ANSI/RESNA's seating devices for use in motor vehicles working groups have been working toward such a standard. Both of these groups have agreed to pursue development of independent dynamic seating test methods. Efforts led to the

development of a reusable wheelchair base, which is capable of crash testing commercial wheelchair seating systems independent of a specific wheelchair frame. Validation of the reusable wheelchair base is currently underway.

Published Research

Although most injury research and prevention fields are driven by epidemiology-based studies detailing accident statistics, only limited data on accidents involving persons using wheelchairs as seats in motor vehicle crashes are available (Calder and Kirby 1990, 184–90; National Highway Traffic Safety Administration 1997; Shaw 2000, 89–100; and Ummat and Kirby 1994, 163–67). Early wheelchair transportation research has primarily focused on efforts needed to advance standards development. These early studies worked toward the development of a repeatable frontal impact test using a reusable wheelchair (Shaw et al. 1994). As a part of the standards effort, a computer simulation model was used to investigate the effects of different elements (e.g., seated posture outcomes on wheelchair tie-down and occupant restraint systems and occupant crash response) (Kang and Pilkey 1998, 73–84). A number of studies have also attempted to investigate the injury risk associated with using a wheelchair as a motor vehicle seat, investigating the effects of crash pulse (Kang and Pilkey 1998, 73–84), securement point location (Bertocci, Diggs, and Hobson 2000, 126–39 and Kang and Pilkey 1998, 73–84), restraint configuration (Bertocci, Diggs, and Hobson 1996, 279–89; Bertocci and Evans 2000, 573–89; and Gu and Roy 1996), and seated posture (Kang and Pilkey 1998, 73–84).

Supporting the fact that wheelchairs are not typically designed to sustain crash-level forces, component testing studies have shown that casters—seat attachment hardware and seat support surfaces—often fail at loads similar to those imposed in a frontal impact crash (Bertocci, Ha, Deemer, et al. 2001, 534–40; Bertocci, Ha, van Roosmalen, et al. 2001, 249–57; Bertocci et al. 1999, 32–41; and Ha et al. 2000, 555–63). Unfortunately, design criteria to guide manufacturers in the development of transport-safe wheelchairs and wheelchair seating systems are relatively scarce. Information that exists in the literature has largely been derived from computer simulation of frontal impact events (Bertocci, Szobota, et al. 2000, 565–72; Bertocci et al., 1996, 171–81; and Gu and Roy 1996). These studies have shown that numerous factors (e.g., rear wheelchair securement location, seat stiffness and seat angle) can influence loads that wheelchairs are exposed to in a crash. These findings suggest that manufacturer design decisions can greatly impact the crashworthiness of wheelchairs. While performance of all wheelchair components is key to occupant crash protection, seat design and integrity are of particular concern since vehicle seat characteristics and failure have been linked directly to injury risk in motor vehicle crashes (Adomeit 1979; Aibe et al. 1982; Blaisdell et al. 1993, 109–19; National Highway Traffic Safety Administration 1997; Saczalski et al. 1993; Strother and James 1987, 225–43; Viano 1992; and Warner et al. 1991). Frontal impact crash tests (20 g and 48 kilometer per hour) of commercial wheelchairs have shown seating system failures to be relatively common (Schneider and Manary 2001). Seat attachment hardware, seat support surfaces and seat backs (on rebound) are among the most common components to fail under frontal impact conditions.

Previous studies which have attempted to elucidate wheelchair seat loading under crash conditions have consisted of both computer simulation studies and limited crash testing. Computer simulation studies have shown that frontal impact seat forces are dependent upon

crash pulse, rear securement point location, seat characteristics and restraint configuration (Bertocci, Szobota, et al. 2000, 565–72; Bertocci et al., 1996, 171–81; Gu and Roy 1996; and Kang and Pilkey 1998, 73–84). A limited series of frontal impact crash tests conducted by Gu and Roy, with disc-type load cells (i.e., sensors in the load cell family dedicated to force measurement) incorporated into the ISO reusable wheelchair and using a Hybrid III 50th percentile male test dummy (i.e., a crash testing dummy measuring 5 feet 9 inches tall and 170 pounds, representing a man of average size), measured seat loads (Gu and Roy 1996). Shaw also estimated seat loading in frontal impact crash testing using pressure-sensitive film placed on the seat and load cells located beneath the front wheels of commercial manual wheelchairs with various types of seating systems (e.g., sling or rigid foam mounted on plywood) (ANSI/RESNA 1996). In these tests, Shaw estimated vertical seat loads and found that higher loads were associated with more rigid seating systems. Frontal impact testing (four tests) conducted by Bertocci and Manary, using the Society of Automotive Engineers reusable wheelchair, evaluated seat loads using disc-type load cells incorporated into the wheelchair seat and also evaluated the effects of rear securement-point location (Bertocci, Manary, and Ha 2001, 679–85). This recent series of crash tests provided validation to a previously conducted computer simulation study (Bertocci et al., 1996, 171–81).

While these previous studies represent a preliminary effort toward the development of transport-safe wheelchairs and wheelchair seating, additional efforts are needed to advance safe wheelchair transportation. Testing and computer simulations to date were conducted with a 50th percentile male test dummy; no published studies exist that have evaluated seating loads associated with child-sized test dummies. Recently the Rehabilitation Engineering Research Center (RERC) on Wheelchair Transportation Safety (RERC-WTS) has conducted such tests and is currently analyzing the data. Furthermore, previous studies evaluated seat loading in frontal impact conditions alone—only recently has the RERC-WTS begun to study seat loading under rear impact conditions that are likely to impose very different loading conditions. Failure of seat backs during the rebound phase of frontal impact testing also has led to efforts to evaluate seat back loading conditions within the RERC-WTS. Wheelchair seat backs also are subjected to unique loading conditions in rear impact crashes. Preliminary tests have been conducted by the RERC-WTS to evaluate seat back and wheelchair strength in rear impact collisions. Postural supports also present a unique challenge during transport but, unfortunately, have received very little attention related to transit-safe design. Clearly, additional guidance is needed to provide wheelchair and seating manufacturers with guidance related to the design of transport-safe wheelchairs. As more transit wheelchairs become available, wheelchair user safety will approach levels similar to that provided to OEM vehicle seat users—a scenario that must occur for equivalency in public accommodation.

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