The Americans with Disabilities Act (ADA) and Individuals with Disabilities Education Act (IDEA), have provided, among many other things, more opportunities for all persons using wheelchairs to gain better access to public transportation. Advances in vehicle modifications and driving adaptions, specifically for vans, have increased the numbers of wheelchair users that utilize personal vehicles as either passengers or drivers. Because many people either elect to or must remain in their wheelchairs while riding in a vehicle, a number of issues related to the safety and security of the wheelchair-seated person are raised, especially in the event of a vehicle collision.

What Are the Issues?

Motor vehicle safety research has a long history involving governments and the motor vehicle industry throughout the western world. This research has clearly established a number of fundamental principles of vehicle occupant protection that, through implementation in vehicle design and industry testing standards, have drastically reduced the number of fatalities and injuries. In summary, these principles stipulate that occupant injury prevention must be considered as a system that includes the vehicle seat, the occupant restraints, and the interior of the vehicle. Since approximately 60 percent of vehicle collisions that lead to fatality or severe injury are frontal impacts, protection systems have been optimized to protect the occupant from injurious forces that can result from frontal impacts.

One critical design aspect of the occupant protection system is the relationship between the vehicle seat, the occupant, and the occupant restraint (lap belt, shoulder belt, and air bag). First, the seat is securely fastened to the vehicle and designed to hold the occupant in a limited range of body positions relative to the occupant restraint device(s). Second, this system is designed to limit and control the motion of the occupant relative to the interior of the vehicle.

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During an impact event. When a person substitutes a wheelchair for a regular vehicle seat this protection system no longer functions as designed and the wheelchair occupant may be at significant increased risk of serious injury. In the case of a public transit vehicle, other passengers are also at increased risk if the wheelchair is not fastened securely to the vehicle, especially in the case of a heavy powered wheelchair.

Until most recently, wheelchairs have not been designed to also serve as occupant-protecting seats in a motor vehicle. For example, armrests and other frame structures often pre-
vent the attainment of effective fit of the occup-

pant restraint belts. In most cases the seat and
wheel assemblies will not sustain the crash
loads necessary to hold the person in the posi-
tion necessary for effective occupant restraint.
Accessories, such as seat inserts, positioning
supports, and tray-mounted devices are often
added to the wheelchair after they leave the
manufacturer. These add-on accessories also are
not designed with crash injury prevention as a
goal. Many frame designs lack locations and the
necessary strength for the attachment of the
tiedown straps required to secure the wheelchair
to the vehicle. And finally, until recently, there
have been no industry standards to which the
wheelchairs and their tiedown devices could be
tested in order to ensure a level of injury pre-
vention that approaches that achieved for per-
sons using OEM vehicle seats and occupant
restraints.

Prior to 1999, the wheelchair industry, large-
ly for reasons of liability, elected to place stickers
on their wheelchairs stating that their product
should not be used as a seat in a motor vehicle.
This placed many parents, school bus trans-
porters, education systems, and transit authori-
ties in a difficult legal position. For example,
IDEA mandates that all children with disabilities
must be transported to educational settings. The
ADA mandates that all wheelchair users be
given access to public transit. Insurance compa-

nies for transporters were increasing rates and
denying coverage because of the increased lia-

bility they then faced. Parents were raising ques-
tions about the safety of their children on school
buses.

The ADA stipulates that occupied wheel-
chairs on public transit vehicles must be secured
to the vehicle in specified wheelchair stations
and occupant restraints must be provided, but
their use is optional. Given that the evolved
industry standard for wheelchair securement is
the four-point strap-type system, this now
means that the vehicle operator must leave the
operator station to secure and unsecure the
wheelchair for each wheelchair rider. With no
standard locations to attach the four straps to
the wheelchair frame, securement is often inade-
quate and in some cases does not occur at all.

Finally, operator unions are less than supportive
of this additional role of the transit vehicle oper-
ator as mandated by the ADA.

Clearly, there was (and still is) a complex
mix of issues that have been crying out for solu-
tions for many years. Solutions are now evolv-
ing based on research and standards develop-
ment that are involving a broad cross-section of
people and organizations. One overarching con-
cept has been that, to the extent possible, the
solutions should be offered as safety options to
wheelchairs users, since personal safety is most
often an individual choice. And clearly, these
evolving safety options must not be used as a
means to limit access to transportation by tran-
sit authorities, but rather as a means to allow
wheelchairs users, or their guardians, to
increase their transport safety.

The Evolving Options

The Organizational Structure

In order to begin to address the diverse
range of above issues and have the resulting out-
comes implemented in a way that would make a
lasting difference, a forum for discussion, con-
sensus decision-making, and ideally worldwide
implementation was necessary. The existing
standards development activities within RESNA,
the Society for Automotive Engineers (SAE) and
the International Standards Organization (ISO)
have proven to be an excellent forum in which to
tackle these multiple issues. The standards devel-

opment forum brings together the key people,
such as researchers, the involved industry repre-

sentatives, wheelchair users, and clinicians. The
agreed-upon scope of the standard focuses the
discussion. An imposed timetable stimulates clo-
csure on debate and the reaching of consensus. It
can focus and facilitate collaboration of research
efforts at both the national and international lev-
els, as well as across the industries that market
wheelchair products. In the case of transport
safety, the common goal has been to develop
industry-wide performance and testing standards
that are based on the fundamental principles of
vehicle safety research with emphasis focused
on the safety needs of the wheelchair-seated
riding.
The author was elected to lead the transport safety working groups within each of the three standards-setting organizations, which served to facilitate harmonization across the three working groups. In 1997, the SAE group completed the SAE Recommended Practice J2249, Wheelchair Tiedown and Occupant Restraint Systems (WTORS), which is now used by all major manufacturers producing four-point strap-type securement systems. The RESNA group completed the ANSI/RESNA WC-19 Wheelchairs for Use in Motor Vehicles in April 2000. The ISO-TC173/SC-1-WG-6 group has completed parallel standards for WTORS (ISO 10542, parts 1 and 2), and is in the final stages on ISO7176/19, Wheelchairs for Use in Motor Vehicles. Although there are some differences between the U.S. and ISO standards, harmonization has been achieved on the major requirements and performance tests. Wheelchair manufacturers have been actively testing their products to the WC-19 and 7176/19 standards and now have tested products available on the market. The “don’t use on vehicles” stickers are no longer being placed on most wheelchairs.

The Early Research Efforts

To date, the research in support of the transport standards development has been a collaboration between research and test facilities in the United States, the Netherlands, Sweden, Australia, and England. In the United States this work has been pioneered by the University of Michigan Transportation Institute, directed by Larry Schneider, the RERC at the University of Pittsburgh, co-directed by Douglas Hobson and Gina Bertocci, and in the early stages, the University of Virginia, led by Greg Shaw. In the U.S., funding support has been obtained from multiple federal, foundation, and private sources. This collaborative effort has led to significant results to date. The background, current status, and work in progress are summarized below. Details of current research efforts are presented elsewhere in this issue.

A primary research focus has been to translate and verify the time-tested safety principles established by the motor vehicle industry to the situation of the wheelchair-seated vehicle occupant. The seminal test is the simulated crash test using an actual vehicle and instrumented test dummies (ATDs), which are subjected to a crash pulse of a predefined “g” and velocity change (delta V). The crash pulse used throughout the motor vehicle industry, and specified within the U.S. Federal Motor Vehicle Safety Standards (FMVSS), is 20 g, 30 mph (48 km/h) delta V. Measures of deceleration loads experienced by the ATD and displacement values are used to quantify the vehicle and occupant safety system performance.

For wheelchairs and their securement devices, a less expensive testing regime had to be developed and validated if it was to be acceptable as an industry performance standard. It was decided to use the same crash pulse (20 g, 30 mph) as the motor vehicle industry but generated by a dynamic impact sled, available at several collaborating laboratories. Displacement measures of a 50th-percentile male ATD and the occupied wheelchair during the simulated crash event, along with obvious structural failures, would be used to quantify the performance of both the tiedown and occupant restraint devices (WTORS), and the transport wheelchairs.

Because the WTORS industry is small, a method for crash testing WTORS had to be developed that did not require the destruction of a new wheelchair with each test. After considerable debate, agreement was reached on the design specifications for a surrogate wheelchair, that when occupied by the ATD and subjected to the standard crash pulse, would apply repeatable loads to WTORS devices being tested. Passing this performance test meant that the WTORS could be considered tested safe for use with any wheelchair up to a specified mass. After a two-year, multi-laboratory validation testing period this approach was accepted and is now the key test in both the SAE J2249-Recommended Practice and ISO 10542 standard.

Specifications for the Surrogate Wheelchair Used in the Dynamic Testing of Wheelchair Tiedown and Occupant Restraint Systems

Design requirements and performance testing of wheelchairs intended for use as seats in motor vehicles involves even more complex
In an effort to reduce the number of issues being initially addressed by the standard, it was decided to only include those wheelchair-seating devices that were provided by the wheelchair manufacturer. That is, work on third-party seating add-ons, for example, and other accessories was deferred and is now being addressed as a separate effort.

Finally, many of the principles being embedded in the design requirements of the standards were new concepts to the involved industries and their marketplaces. Therefore, the research team has been committed to developing guidelines that will assist designers in future designs, and clinicians and wheelchair users in the utilization of the standards. Application guidelines have been produced for the WTORS (J2249) standard, and those for the transport wheelchair standard (WC-19) are currently in process. A website (<http://www.rerc.upmc.edu/>) has been developed by the RERC on Wheeled Mobility from which the latest working group draft standards and the J2249 application guideline can be downloaded. Others will be added as they become available.

**Current Research Efforts**

Current research efforts in support of improved wheelchair transport safety and related standards focus on those issues that were either deferred during the initiation of earlier work or have arisen during the development and implementation of the above standards. Four articles in this issue address several of these remaining issues.

One difficult question is, Who will bear the product liability if a second manufacturer’s seat insert is added to the WC-19-tested wheelchair after production, which is a common clinical occurrence, especially in pediatric specialized seating? A way forward seems to be to have a seat component strength test that is acceptable to both industries. Research is now investigating how strong wheelchair seating components (seat, back, and attachment hardware) need to be in order to maintain a stable occupant support surface and hold the occupant in an appropriate position during a crash event so that the occupant restraint will function as intended. Again, the research is attempting to identify tests that will be valid, but not prohibitively expensive to implement for the involved industry as a test standard.

Specifications for the Surrogate Wheelchair used in the dynamic testing of wheelchair tiedown and occupant restraint systems

![Diagram of Surrogate Wheelchair](image-url)
Obtaining proper occupant restraint fit when using a wheelchair as a motor vehicle seat is often difficult to attain with vehicle-mounted restraint systems. For example, rarely are the anchor points for the shoulder belt in the correct position on the vehicle wall to obtain proper body fit, especially for children. Offering both lap and shoulder belt for occupant restraint as an optional accessory on-board the wheelchair would allow customized body fit, and also give the user an increased degree of independence during transport. Research issues involve questions regarding the necessary strength of the seat back and wheelchair frame components to withstand the increased loads, and how the effectiveness of an integrated restraint system will be measured in a performance test standard.

As indicated, the four-point strap design is the worldwide industry standard for securing wheelchairs in motor vehicles. This approach evolved over many years as a practical solution within an environment in which there were no cross-industry communications or standards. Four-point strap securement has many inherent limitations, not the least of which is the limitation to transport independence of the wheelchair user. Today, we have a forum for cross-industry standards development, so alternate approaches to the wheelchair securement issue can be seriously considered. For example, research combined with prototype development has demonstrated the practicality of having a universal interface device (UID) that could be added as an optional accessory to the rear of any WC-19-designed wheelchair. Docking devices located within wheelchair stations in transport vehicles could be designed to dock with the standard UID. This approach opens the real possibility of independent wheelchair securement by the wheelchair occupant. That is, docking securement combined with integrated occupant restraint could free the wheelchair rider from any personal involvement with an attendant or the vehicle operator. Also, in all likelihood, this development would improve the level of safety and reduce the time required for wheelchair ingress and egress in public transit. Research work continues on this approach and early cross-industry standards development discussions have been initiated.

The Standards to Date

Space does not permit a detailed discourse on what has been implemented to date in the various industry standards related to wheelchair transport safety. As indicated, minor differences exist between the current U.S., Canadian and ISO versions. However, these differences are tending to narrow over time and are insignificant compared to the key requirements and test methods in which harmonization has been achieved. The following is an itemized summary of the key features contained in the standards now in effect or in the final stage of completion.

**WHEELCHAIR TIEDOWN AND OCCUPANT RESTRAINTS (J2249, ISO 10542, Parts 1/2)**

**Scope:**
- Adult passengers or drivers (US-J2249 includes children)
- Public and private vehicles
- Applicable to all wheelchairs, including scooters
- Forward-facing orientation only
- Requires the use of pelvic and shoulder belt restraints
- Requires dynamic testing of the WTORS
- Requires labeling and user instructions
- Requires disclosure of presale test information

**Design Requirements:**
Conforming WTORS must be designed to:
- be used with only one wheelchair and one occupant at a time,
- include a belt-type occupant restraint
- not require components of wheelchair tiedowns and occupant restraints to pass through the wheels of a wheelchair,
- not require removal of wheelchair frame material, drilling into the wheelchair frame, deformation of the wheelchair, welding, or use of an adhesive process during installation,
• once installed, be operable without tools,
• incorporate features to prevent unintentional loosening of all fasteners,
• have all small manually detachable hardware and fittings tethered to WTORS subassemblies, and
• include a manual override in case of power failure for any power-operated tiedown or restraint.

Conforming tiedowns must:
• not release if any wheelchair component deforms, or if one or more tires deflate during a vehicle impact,
• include a means to minimize vehicle-induced movement of the wheelchair that does not require the use of tools,
• have end fittings that comply with a specified geometry,
• not depend on the wheelchair brakes, and
• not utilize the occupant restraint to secure any portion of the wheelchair.

Conforming occupant restraints must:
• have both pelvic and upper torso belts designed to apply forces to the occupant's skeletal regions,
• function independent of the wheelchair, such that the restraint belts anchor to either the vehicle or wheelchair tiedown components so that occupant-restraint loads are not transmitted through the wheelchair,
• have belt restraints that can be adjusted in length without the use of tools,
• provide for a range of adjustment of the pelvic restraint,
• provide for a range of adjustment in the upper-torso restraint,
• have the junction of the shoulder and pelvic belts of three-point belt restraints located not less than 150 mm from the ATD centerline, and
• located at least 1,100 mm above the wheelchair ground plane, and
• not depend on an air bag in order to conform with the performance requirements of the standard.

Dynamic Strength:  
When subjected to a 20 g, 30 mph (48 kph) crash pulse:
• the ATD must be retained in the seat of the surrogate wheelchair (SWC),
• the SWC shall be in an upright position on the impact sled,
• no WTORS anchorage components or securement end fittings shall be detached or separated,
• release of the SWC from the wheelchair tiedown shall not require the use of tools,
• release of the ATD from the occupant restraint shall not require the use of tools,
• no part of the WTORS shall exhibit visible signs of tearing, fragmentation, fracture, or complete failure of any load-bearing part, unless such parts are intended to fail in a manner that limits the forces on the occupant,
• the WTORS shall exhibit no dangerous roughness, sharp edges, or protrusions likely to increase the risk of injury to the occupant, and
• the force required to open the buckle of any tiedown or occupant restraint components shall not exceed 60 N.

Identification, labeling, instruction and warning requirements:
• WTORS and replacement parts must be permanently and legibly marked with specific labeling information,
• Manufacturers must provide written instructions for the installer and the use and maintenance of the WTORS,
• Manufacturers must provide specific warnings about potential hazards in using the WTORS.
Editorial: Wheelchair Transport Safety—Evolving Solutions, Douglas A. Hobson, PhD

WHEELCHAIRS FOR USE IN MOTOR VEHICLES (ANSI/RESNA WC-19, ISO 7176-19)

Scope:
- Manual wheelchairs, powered wheelchairs, scooters, tilt-in-space wheelchairs,
- Forward-facing wheelchair-seated adult occupant (children included in WC-19),
- Wheelchairs for use in both public and private vehicles,
- Wheelchairs secured by a variety of tiedown devices,
- Occupant restrained by pelvic and upper torso belts.

Securement Points:
- Four securement points for strap-type tiedowns must be provided and clearly marked,
- Securement point design must comply with specified standard geometry.

Pelvic Restraint:
- Allow independent pelvic restraint to cross pelvis to anchor points within 30–75° range (sagittal plane angle),
- If integrated, provide a pelvic restraint angle within the 30–75° range (sagittal plane angle),
- Provide a clear path for anchorage of pelvic restraint to vehicle (independent restraint),
- In U.S., integrated lap belt required by 2002.

Postural Supports:
- Postural supports intended for use as occupant restraints must comply with J2249 or ISO 10542 WTORS,
- Postural supports not intended for use as occupant restraints must be labeled accordingly.

Dynamic Strength:
When subjected to a 20 g, 30 mph (48 kph) crash pulse:
- ATD must remain seated in the test wheelchair,
- must be no obvious component failure,
- Wheelchair and ATD do not exceed specified excursion limits,
- no wheelchair loading of occupant,
- detachable seat inserts remain attached,
- no part over 100 g breaks free of the wheelchair,
- batteries, if any, restrained with no leakage.

Identification, labeling, user instructions and warnings:
- Product identification and labeling that wheelchair meets the standard,
- Each securement point clearly identified with required symbol,
- User manual provided with specified written instructions and warnings,
- Labeling of those postural supports unsuitable for use as occupant restraints.

Future Work
Voluntary industry standards, once the most difficult first version has been successfully adopted and implemented, tend to take on a dynamic life of their own. Most national standards organizations, as well as the ISO, require a review and re-approval or revision of a standard every five years. This brings a new set of people to the table armed with the shortcomings discovered in having used the previous version and therefore anxious to implement changes warranted by practical experiences. It also allows for revisions that can include new innovations, technologies, and changes in clinical realities.

Much still remains to be done in the transport safety arena in terms of new standards development and related research. The following is only a brief overview of several of the key items that should lead to transport safety innovations in the near future.

As previously indicated, all add-on accessories, such as seating components, headrests, thoracic supports, knee blocks, trays, and anterior chest supports, have safety implications when used on a motor vehicle. Work in this area has just begun under the auspices of ISO 16840, led by Dr. Gina Bertocci.
Development of a docking securement standard is currently underway within the SAE and ISO working groups, led by Douglas Hobson. An early draft standard exists; however, agreement remains to be reached on the design of the UID. Parallel work is also taking place on a standard for clamping securement devices within ISO, led by Juan Dols of Spain.

In wheelchairs, the initial efforts have been focused exclusively on testing for a frontal impact on a forward-facing occupied wheelchair. Impacts, however, often occur from other directions, such as side and rear. Rollovers can also be the consequence of a vehicle collision. Standards development work, supported by ongoing laboratory research, needs to address these remaining impact directions, as is currently taking place in the vehicle industry. In the U.S., this new work will be organized within the ANSI/RESNA SOWHAT sub-committee, led by Larry Schneider. Dr. Schneider is also leading the preparation of the application guideline document on the recent ANSI/RESNA WC-19 standard.

The early work on totally integrated wheelchair occupant restraints offers many advantages, especially for school-age children and adults with limited upper body function. Currently, standards allow for the testing of such systems. Research and prototype development needs to demonstrate the design practicalities. As indicated by the article in this issue, the early stages of work are currently underway at the RERC on Wheeled Mobility, led by Dr. Gina Bertocci.

In conclusion, all standards development, to be successful, must be accompanied by an active dissemination and education program. Personnel from the RERC on Wheeled Mobility and others have actively hosted workshops and seminars on transport safety issues for consumers and clinicians for several years and will continue to do so. The RERC hosts a website on standards development that, in addition to posting the latest working group documents, also posts applications guidelines and slide presentations for downloading and use by others; see <http://www.rerc.upmc.edu/>.

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Standards:

Resources:

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