IDEA PROJECT FINAL REPORT
Contract TRANSIT-16

IDEA Program
Transportation Research Board
National Research Council

September 1998

A Public-Transit-Compatible Restraint System for Wheelchair Users

Steven Reger and Tom Adams
Cleveland Clinic Foundation

INNOVATIONS DESERVING EXPLORATORY ANALYSIS (IDEA) PROGRAMS MANAGED BY THE TRANSPORTATION RESEARCH BOARD (TRB)

This investigation was completed as part of the TRANSIT-IDEA Project, which is one of four IDEA programs managed by the Transportation Research Board (TRB) to foster innovations in surface transportation. It focuses on products and results for transit practice in support of the Transit Cooperative Research Program (TCRP). The other three IDEA programs areas are: ITS-IDEA, which focuses on products and results for the development and deployment of intelligent transportation systems (ITS), in support of the U.S. Department of Transportation's national ITS program plan; NCHRP-IDEA, which focuses on products and results for highway construction, operation, and maintenance in support of the National Cooperative Highway Research Program (NCHRP); and HSR-IDEA, which focuses on products and results for high speed railroads in support of the Federal Railroad Administration. The four IDEA program areas are integrated to achieve the development and testing of nontraditional and innovative concepts, methods, and technologies, including conversion technologies from the defense, aerospace, computer, and communication sectors that are new to highway, transit, intelligent, and intermodal surface transportation systems.

Background

Current automotive restraint philosophies and regulations are increasingly moving toward passive restraints with the realization that many travelers will not make even small efforts to apply an occupant restraint system. It should not be surprising, therefore, that occupant restraints for wheelchair users that are difficult, awkward and time consuming to apply are seldom used. Although totally passive restraints for wheelchair users on public transit is not yet feasible, new designs need to focus on minimizing the efforts to operate the systems. This project is an attempt to move the industry in that direction.

Contributing to the complexity of occupant restraint systems is the ADA[1] and SAE[2] objective to offer the same level of crash protection to wheelchair users on transit vehicles as received by individuals using OEM seats in personal automobiles. This approach requires the restraint systems to be able to pass a 20 g 30 mph simulated impact test. Since the completion of the TRB *Guidelines for Wheelchair Securement and Personal Restraint for Public Transit Applications,*[3] discussion has resurfaced among standards groups concerning the design loads for securement and restraint systems that are used on large, public transit buses. [4,5] There is little or no data validating that these large buses, driven primarily on crowded city streets at low speeds, sustain crashes close to 20-g. Until these governing documents reduce their test requirements, however, restraint designs must be made robust enough to meet the demanding requirements. This strength is provided with a compromise in appearance, cost, and ease of use.

Protection of travelers during a vehicle impact is an essential objective of an occupant restraint design. This project recognizes that unless a restraint system meets nearly all the needs of the user and transit provider, it will not be used, or may be used incorrectly, and the intended crash protection will not be realized. Particular attention was therefore given to convenience and operation using the criteria identified from the surveys and interviews of wheelchair users, transit providers, and vehicle manufacturers.

The investigating team developed a conceptual model for a universal wheelchair occupant restraint system as part of an earlier Transportation Research Board (TRB) program – TCRP C-1. (6) Whereas most products and research work have tried to include wheelchair securement and occupant restraint in a single system, this project focused its resources on the occupant restraint part of the problem. The design is intended to be used in parallel with a wheelchair securement system. The prototype uses the proven concept of lap and shoulder belts for occupant protection, but uses an innovative design (Figure 1) to improve its operation with wheelchair seated passengers. The proposed system offers a significantly easier and faster operation that virtually eliminates the need for the vehicle operator to reach to the floor or contact the wheelchair user, and many wheelchair users will be able to position the restraint themselves. This overcomes a major barrier to the use of occupant restraints.

When the device is not in use, it is stored so that it does not interfere with passenger seating or ambulation. The lap belt is also stored on a small retracting spool so that the belting will remain clean when not in use.

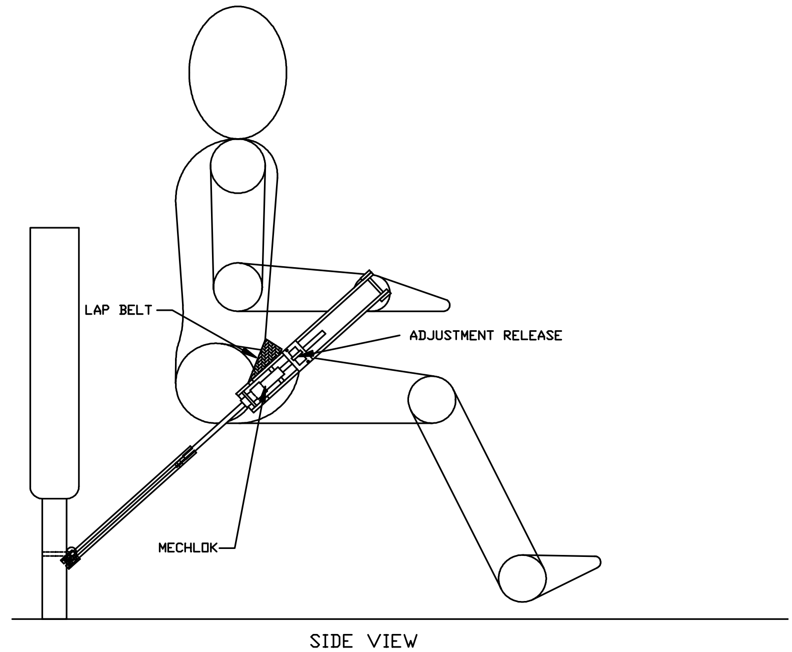


Figure 1. Design concept for restraint system

The occupant restraint has been developed with attention to the needs of transit service and wheelchair travelers. The restraint system was designed to be compatible with cost effective manufacturing processes, vehicle design, operating procedures, human factors, and occupant protection practices.

The final prototype design was developed through three iterations, each one incorporating further improvements that enhanced the performance of the previous design. To minimize costs and develop a prototype that will encourage commercialization, significant effort was devoted toward establishing a simple, but functional design. Off the shelf components were selected, and machined parts were designed with large tolerances whenever possible. The components were assembled to verify that the geometry and operation were satisfactory. An important aspect of this concept is integration into the vehicle designs currently used on most transit buses.

Establishing Design Criteria

The formation of the design criteria was based on multiple inputs from a resource panel, the existing TRB Guidelines, user and transit administrator surveys, human factors testing of wheelchair using travelers and an experienced public transit vehicle designer. These inputs are summarized below.

Resource Panel

To assure objectivity and a practical design, a diverse and highly qualified resource panel was established to oversee the project progress. This panel was an essential component of this project and provided balanced and objective input to the project staff. The composition of the panel emphasized the commitment to meet the joint needs of the transit industry and its consumers. The panel members have been active participants in the field of wheelchair transportation on public transit, and their qualifications are listed below in Table 1.

Table 1. Resource Panel Membership

Member	Affiliation	Experience
Barry Barker	Transit Authority of River City	Executive Director
Norm Santos	Chicago Transit Authority	Project Engineer
Alan Smith	Akron Metro RTA	Director of SCAT (Paratransit service)
Frank Polivka	LAKETRAN	General Manager
Frank Anderson	Paralyzed Veterans of America	Executive Director, Uses a manual wheelchair
Jesse Anderson	Consumer	Board of Directors of GCRTA Uses power-wheelchair
Joe Kiren	Paralyzed Veterans of America	Executive Director, Uses a manual wheelchair
Margaret Meyer	Services for Independent Living	Project Director, Uses a power wheelchair
John Feathers	AARP Andrus Foundation	President, Advocate for the elderly
Gil Haury	Invacare, Inc.	Director of wheelchair testing SAE/ISO committees wheelchair transportation

TRB Guidelines

The TRB publication *Guidelines for Wheelchair Securement and Personal Restraint for Public Transit Applications* identified initial objectives for occupant restraint systems and provided quantitative design criteria for public transit use. The guidelines give specific test conditions and recommended results for evaluating occupant restraints. The guidelines generally state that the operation of restraint systems must be simple, convenient and rapid and include human factors issues and operation times. Systems not meeting these criteria were previously unacceptable. Additionally, they specify that occupant restraint systems must control the occupant motion during specific test conditions simulating a frontal or lateral vehicle impact.

Surveys

To evaluate the compatibility with transit needs and attitudes, a survey was developed and disseminated to high level administrators with input to the purchasing decisions at 12 transit authorities throughout the country, representing large and mid-sized organizations. A small number of authorities were targeted, to achieve a 100% return rate. This technique prevented biased data from selectively returned surveys not representative of the entire population. Transit systems included in the survey were:

BART (Bay Area Rapid Transit District, Oakland, CA)
CTA (Chicago Transit Authority, Chicago, IL)
GCRTA (Greater Cleveland Regional Transit Authority, Cleveland, OH)
LACMTA (Los Angeles County Metropolitan Transportation Authority, Los Angeles, CA)
METRO RTA (Akron, OH)
METRO (Metropolitan Transit Authority, Houston, TX)
METRO-Dade Transit Agency (Miami, FL)
NJ Transit (Newark, NJ)
RTD (Regional Transit District, Denver, CO)
SEPTA (Southeastern Pennsylvania Transit Authority, Philadelphia, PA)
TARC (Transit Authority of River City, Louisville, KY)
WMATA (Washington Metropolitan Area Transit Authority, Washington, DC)

The restraint concept was also presented to vehicle operators who must address the day-to-day issues involved with transportation of wheelchair users. Theses surveys were developed and disseminated by the Greater Cleveland RTA and the Cleveland Clinic. Nineteen forms were completed by paratransit operators, and thirteen forms were completed by fixed-route operators. Survey forms were also distributed to wheelchair users who travel on GCRTA vehicles and from these, seven were completed and returned.

The most significant finding from the survey data, is that although crash safety is consistently reported as being the highest priority, vehicle mounted lap and shoulder belts are seldom used. The following data illustrates this conflict:

- All three surveys confirm that crash safety of the wheelchair user is considered the single most important aspect of occupant restraint (92 % of administrators, 85% of fixed route drivers, 100% of paratransit drivers).
- Lap belts are <u>usually used</u> with only 31% of fixed route drivers and 74% of paratransit drivers.
- All seven wheelchair users indicate that vehicle mounted lap belts are <u>not</u> needed because they can balance themselves or have a wheelchair anchored lap belt.
- All seven wheelchair users indicate that shoulder belts are not used.
- Shoulder belts are <u>usually used</u> with only 15% of fixed route drivers and 6% of paratransit drivers.
- The administrators felt that the current occupant restraint systems are acceptable for crash safety (92%).

This conflicting data reinforces the **critical need for a nationwide educational effort** to inform those involved in transporting individuals seated in wheelchairs that crash safety can only be obtained when vehicle anchored lap and shoulder belts (or other restraint devices) are properly positioned on all trips.

The second priority in occupant restraints depended on the type of service. Fastening time was most important for fixed route drivers (77% vs. 28% of paratransit drivers) while user comfort was more important for paratransit drivers (74% vs., 28% of fixed route drivers). Interestingly, none of the transit systems had quantitative data related to the cost of using the current occupant restraint system.

The survey also showed strong interest from the transit administrators (75%) in pursuing an alternate occupant restraint design, while about half of the vehicle operators were willing to use the illustrated proposed design on the vehicles they drive. The ease of use was considered the most significant advantage for using the proposed design, while the large size of the supporting structure was viewed negatively. The transit administrators strongly favored (87%) a restraint system that which was integrated into the vehicle structure rather than a modular after market component.

Overall, the survey results indicated a need for restraint systems that can be used independently and rapidly by many wheelchair users. The full benefit of improved designs will be realized only when individuals seated in wheelchairs are able to reach and operate the controls. Although in practice some individuals will require assistance with any design, appropriate designs can minimize the amount of assistance needed. Consequently, the reduced driver involvement will allows for less stop dwell time, as the operator can be seated and preparing to drive as the wheelchair users secure their wheelchairs and fasten the occupant restraint.

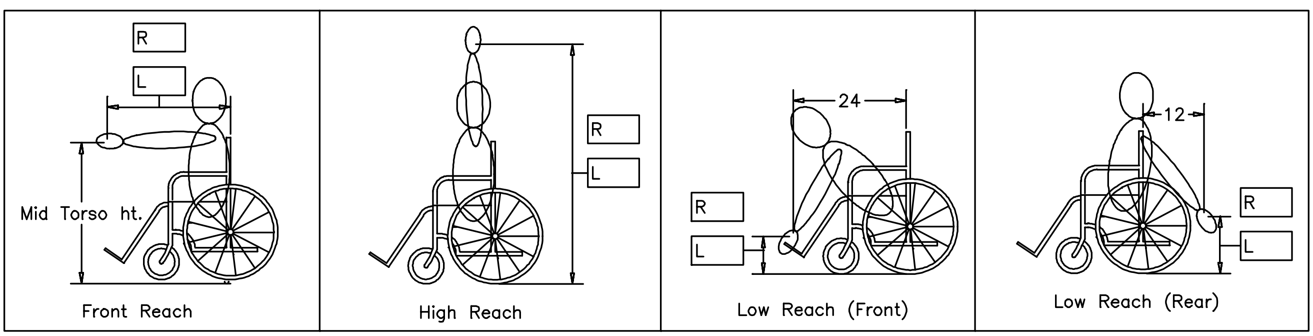
Human Factors Testing

The difference in functional abilities among wheelchair users and the lack of available data demanded human factors testing of typical wheelchair travelers. Characteristics needed for user operable restraint systems were identified through anthropometric and functional abilities testing as described below:

Anthropometry	**Functional Abilities**
Strength	Wheelchair location
Range of motion	Wheelchair orientation
Dexterity	Positioning time
Anthropometry	
Body position	

Anthropometry

The sample population consisted of 6 female and 10 male wheelchair users with an average age of 37 ± 8 years. They used 10 manual wheelchairs, 4 power wheelchairs and 2 scooters. Hand strength was measured according to standard occupational therapy practice using a Jamar™ dynamometer and pinch meter. Dexterity was measured using various types of karabiner and open hooks that required different levels of coordination of the fingers and thumb to attach and remove each from a closed tubular form. Range of motion data was obtained by measuring from the intersection of the wheelchair seat and back to the furthest point where a test subject could grasp an object. Measurements were made in several directions as shown on the data collection



form in Figure 2.

Figure 2. Anthropometric measurements

The results from this testing are shown in Table 3. This data provided general design guidelines for accessible components. Many wheelchair users can reach components located between 15 and 60 inches above the floor, from 12 inches behind them to 24 inches in front of them, and they can apply a grip strength of 40 lbs., and a pinch strength of 10 lbs. Many of them, however, had difficulty performing tasks that required fingertip control.

Functional Abilities

To simplify the operation and design of the occupant restraint, the number of adjustments were minimized. The data below showed that seat position was relatively constant (± 2 in.) relative to the wheelchair position. Additional information was needed that identified how accurately wheelchair users could position their wheelchairs. To obtain this data, testing was performed with wheelchair users at three different locations.

Fifteen wheelchair users (9 females and 6 males, using 11 power wheelchairs, 3 scooter, and 1 manual wheelchair) volunteered for testing. Testing was performed indoors, with orange cones defining the edges of the aisle and wheelchair bay in the simulated vehicle interior. A 12-inch high target was positioned on the floor at the rear of the wheelchair bay to represent the target. A bracket was attached to each wheelchair so that it rolled along the floor behind the wheelchair. Each wheelchair user was asked to maneuver their wheelchair into the simulated wheelchair bay and then back up to position the bracket as close as possible to a target.

Table 3. Anthropometric data

Anthropometric characteristic	SI units (mean $\pm$ stand. dev.)	English units (mean $\pm$ stand. dev.)
Seat height	51 $\pm$ 5 cm	20.1 $\pm$ 2.0 in
Seat to rear	30 $\pm$ 5 cm	11.8 $\pm$ 2.0 in
Low reach	38 $\pm$ 16 cm	15.0 $\pm$ 6.3 in
High reach	147 $\pm$ 20 cm	57.9 $\pm$ 7.9 in
Front reach	60 $\pm$ 12 cm	23.7 $\pm$ 4.6 in.
Grip Force	200 $\pm$ 150 N	45.5 $\pm$ 34.1 lb.
Pinch Force	50 $\pm$ 35 N	11.4 $\pm$ 8.0 lb.

The wheelchair bay used for testing was 30 inches wide and 56 inches long, matching the dimensions of the Flxible buses used by Cleveland RTA. Different visual guidance patterns were used on the floor of the simulated wheelchair bay to evaluate their effectiveness in helping position the wheelchair. Each test subject completed the maneuver 4 times, using the floor patterns shown below. The performance difference between the first and last runs demonstrated the benefit of training.

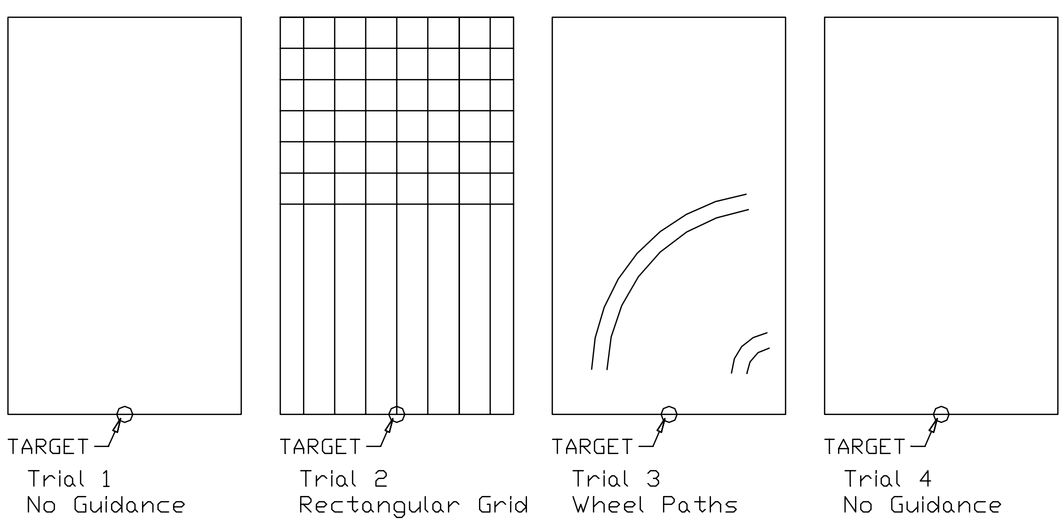


Figure 3. Floor patterns to assist with wheelchair positioning.

The tests were videotaped by two cameras, providing an overhead and rear view of the bracket as it approached the target. Global Lab software was used to analyze the videotapes, and record the distance between the center of the bracket and the target, the angle between the bracket and the centerline of the wheelchair bay, and the overall time to position the wheelchair.

While there was significant variation among users in overall performance and the effectiveness of visual guidance, the users generally improved in accuracy, orientation, and time with each run, as shown in Table 4. The results indicated a consistent ability to reach the target in the wheelchair bay, and the motivation to travel and improve their accuracy with training. Thus, an occupant restraint requiring center positioning of the wheelchair or scooter in the bay is a reasonable and attainable objective for the design.

Table 4. Wheelchair Positioning Data

	No Guidance	Rectangular Grid	Entry Path	No Guidance
Final distance from the target (in.)	1.0 ± 1.0	0.7± 0.7	0.6± 0.6	0.5± 0.4
Final wheelchair angle (degrees)	11± 8	9± 8	11± 12	7± 7
Positioning time (sec.)	75± 50	70± 40	60± 35	50± 30

Design Criteria

Collectively, the input from the survey, human factors evaluations, and resource panel finalized the design criteria for developing the occupant restraint system, focusing on the needs of all the users involved. The summary of the design criteria is given below in Table 5.

Table 5. Design Criteria for Restraint Prototypes

Criteria	**Specifications**
Attach / release time	1 minute
User independence	80 %
Tamper resistant	Cannot be made inoperable without tools
Durability	400 lb. vertical load Seals around opening
Components in passenger area	Permanently attached to vehicle structure Cannot block windows, normal seating, or aisles Store out of normal seating area
Components that touch person	Maintained off floor
Accessible components	15 - 60 inches above floor 36 inches from rear of w/c bay
Mechanisms	Operable with whole hand function Operable with less than 40 lb. of grip Operable with less than 10 lb. force
Adjustments	Fit 5th to 95th %tile Compatible with a 5 wheelchair styles
Crash safety	Support sustained 5,000 lbs. forward load (FMVSS 209) Allow less than 375 mm of forward motion at the lap belt Support 1320 lb. lateral (5 g. lateral impact)