TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

IDEA Innovations Deserving Exploratory Analysis Project

TRANSIT COOPERATIVE RESEARCH PROGRAM

A Public-Transit-Compatible Restraint System for Wheelchair Users

Steven Reger and Tom Adams
Cleveland Clinic Foundation

Report of Investigation

TRANSIT IDEA

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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.

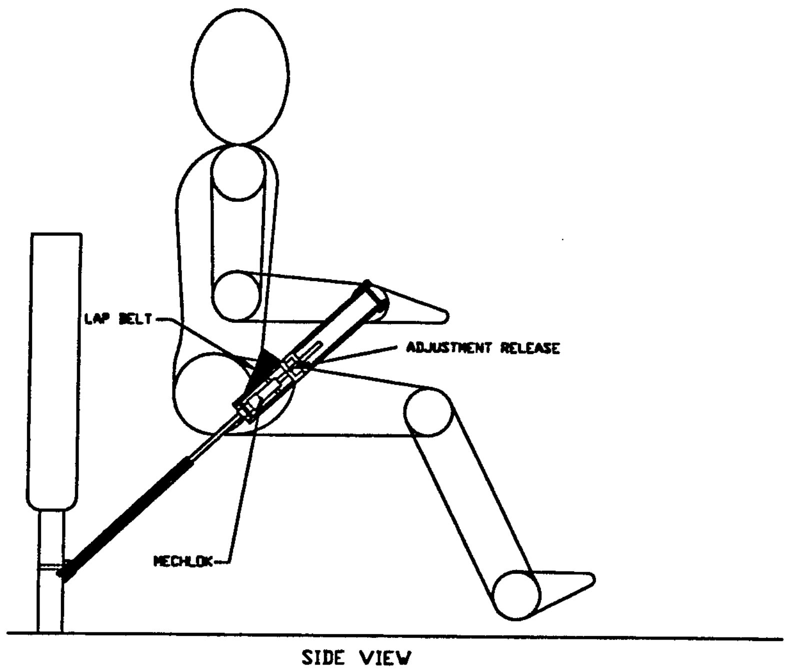


Figure 1. Design concept for restraint system

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 usually used with only 31% of fixed route drivers and 74% of paratransit drivers.
- All seven wheelchair users indicate that vehicle mounted lap belts are not 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 usually used 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.

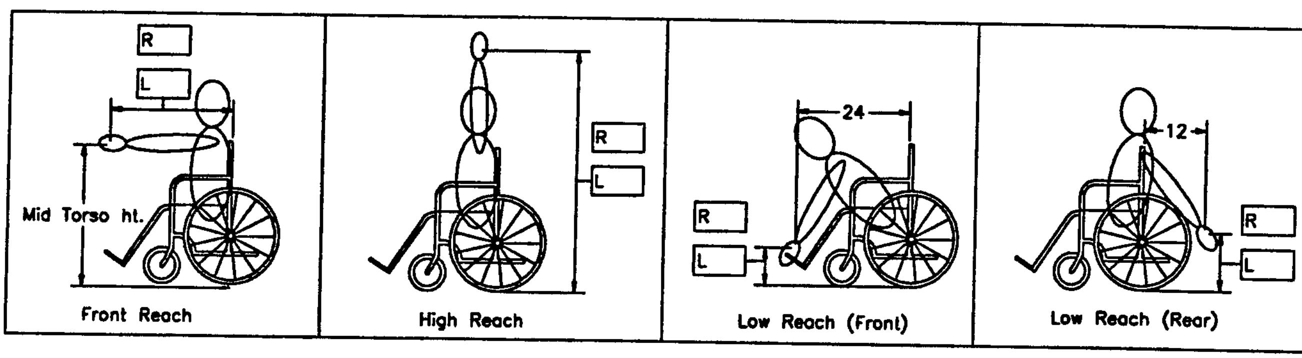


Figure 2. Anthropometric measurements
The results from this testing are shown in Table 3. This data provided general design guidelines for accessible components. Many wheelchair users can reach components located between 15 and 60 inches above the floor, from 12 inches behind them to 24 inches in front 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 ± stand. dev.)	English units (mean ± stand. dev.)
Seat height	51 ± 5 cm	20.1 ± 2.0 in
Seat to rear	30 ± 5 cm	11.8 ± 2.0 in
Low reach	38 ± 16 cm	15.0 ± 6.3 in
High reach	147 ± 20 cm	57.9 ± 7.9 in
Front reach	60 ± 12 cm	23.7 ± 4.6 in.
Grip Force	200 ± 150 N	45.5 ± 34.1 lb.
Pinch Force	50 ± 35 N	11.4 ± 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.

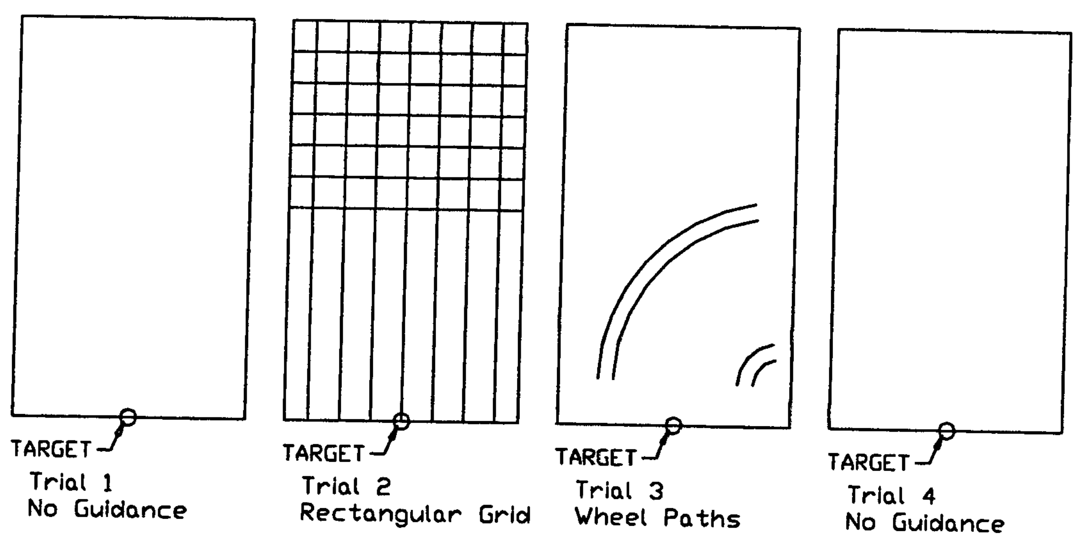


Figure 3. Floor patterns to assist with wheelchair positioning.

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)

Prototype Designs

During the project, the current occupant restraint design evolved through two earlier designs. Each of these three designs is described below to illustrate both the design process and the rationale leading to the final prototype design.

1. Stanchion –mount design

This concept, shown in Figure 4, was developed and tested under previous TCRP funding (Project C-1) and its potential benefits were the catalyst for this project.

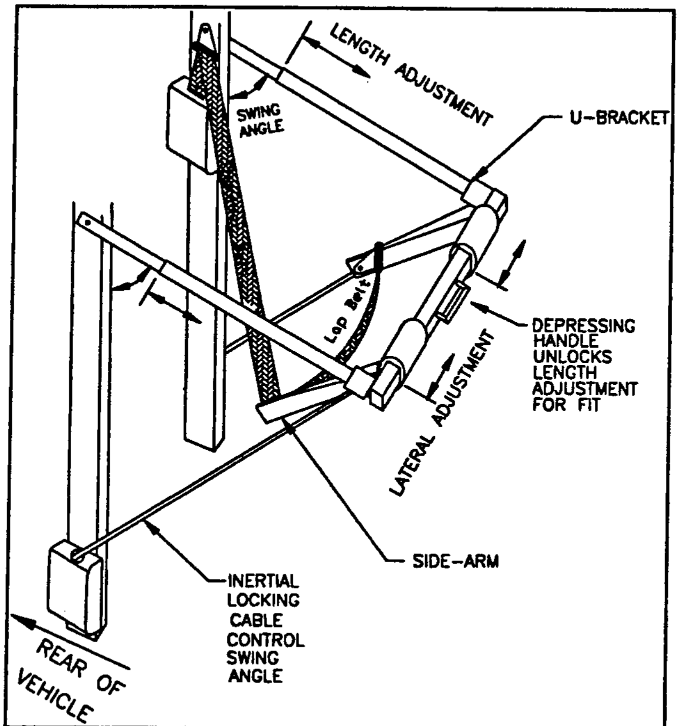


Figure 4. Stanchion Mounted Design

Design

Two vertical stanchions are mounted to the vehicle structure in the back of the wheelchair bay. A U-Bracket is mounted to the two stanchions, and pivots about a horizontal axis. The lap belt is anchored on two folding side-arms are attached to the base of the U-bracket. The side-arms have a limited amount of lateral motion, so that they can accommodate different size individuals and different wheelchair positions. The lateral resistance, however, is sufficient to limit the lateral motion of the wheelchair user. To assure the side-arms are correctly located for various seat heights and wheelchair positions, the length of the U-Bracket is adjustable. An internal locking mechanism is released by depressing a handle located on the front of the U-Bracket. When locked the mechanism will hold in excess of 5,000 lbs.

Another unique feature is that the shoulder belt is mounted to the structural stanchion, which is correctly located relative to the wheelchair seat. Nearly all other wheelchair occupant restraint systems rely on the vehicle side-wall for providing a structural member for mounting the shoulder belt, and these members are seldom in an appropriate location for optimal safety.

Operation

When a wheelchair user boards the bus and approaches the wheelchair bay, the vehicle operator will lift the U-Bracket and unfold the side-arms. The lap belt, anchored to the ends of the side-arms, will extend as the arms unfold. Once the wheelchair is in place, the U-Bracket is lowered, with each side arm sliding between the user's hips and the armrest of the wheelchair automatically positioning the lap belt against the user's pelvis and anchoring it near the hip joints for optimal protection. Once the lap belt has been correctly set, the stanchion-mounted shoulder belt can be attached to the lap belt similarly to many existing occupant restraint designs. During normal traveling, the U-Bracket may be lifted at any time, giving the feeling of freedom that is comparable to that provided by emergency locking retracting shoulder belts. During an impact or severe vehicle maneuver, however, the U-Bracket position is locked using a similar inertia responsive device.

When the system is not in use, the U-Bracket is stored in the down position, with the side-arms folded. In this position, the restraint system will not interfere with the use of the wheelchair bay for other seating.

Evaluation

This design demonstrated acceptable performance during 30 mph, 20-g sled impact testing based on performance criteria specified in recent ISO and SAE draft standards. It was also tested according to the test procedures for 5-g lateral impacts identified in the TRB *Guidelines for Wheelchair Securement and Occupant Restraint for Public Transit Applications.* Its performance during this test met the stated criteria, and appeared to be superior to that of traditional three-point restraint systems. The concept was presented to transit administrators, vehicle operators, and wheelchair users, through surveys, and the results suggested the need and desire for several changes to the original concept.

2. Wall- mount design

The feedback received through the surveys are reflected in a less obtrusive design which deploys from a frame mounted along the vehicle side wall as shown in Figure 5.

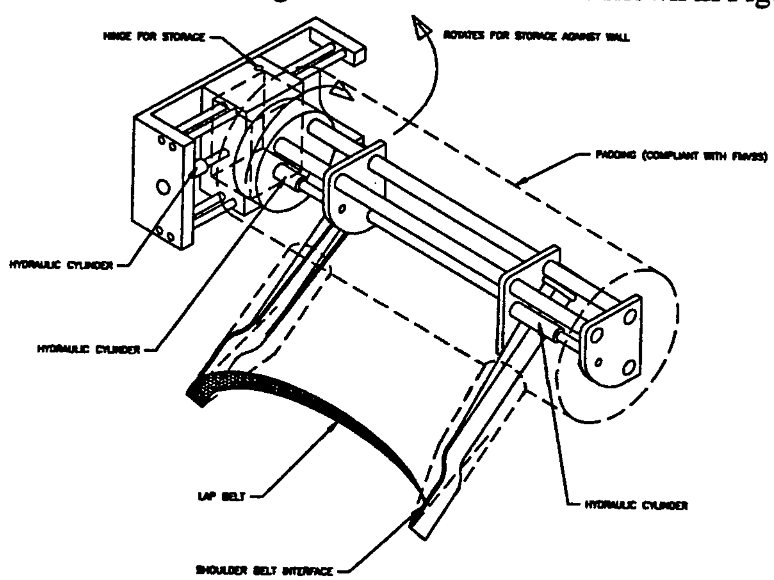


Figure 5. Wall-mounted restraint design

Design

The changes made from the stanchion-mount design, and the rationale for each is listed below.

1. The occupant restraint mounts to the vehicle wall rather than the floor.
   Rationale: All three surveys indicated a concern with the physical size and appearance of the original design. This new concept will eliminate any components near the aisle or in the foot space of passengers when not in use.
   The transit administrators indicated that they prefer a system that is integrated into the vehicle structure, thus allowing structural components to be built into the vehicle wall for supporting the occupant restraint.

2. The unit is stored by swinging it horizontally until it rests against the wall, just above any seats that may be in the area, and at the bottom of any windows on the wall.
   Rationale: *There was a significant amount of concern that the original design could allow the device to fall down from the overhead stored position and injure a passenger. The new design keeps the device against the wall and low.*

3. The occupant size adjustment will be forward/rearward, rather than rotating about a point near the occupant shoulder.
   Rationale: *A human factors review of individuals seated in wheelchairs, indicates that the range of pelvic heights is less than the range in the location of safe lap belt anchorages.*

4. Hydraulic dampers will restrict motion during an impact while allowing free adjustment. This replaces mechanical locks.
   Rationale: *Hydraulic dampers will prevent rapid motion, as during vehicle impacts, but will allow slow motions, such as those needed to position the restraint device. This concept allows the user to feel unrestricted, while maintaining a rigid system when needed without cumbersome locking mechanisms.*

5. The shoulder belt will be optional and anchored on a separate floor or wall mounted stanchion next to the vehicle wall.
   Rationale: *The ADA mandates that shoulder belts be available for wheelchair users, (although the surveys indicate that they are seldom used). Since the rear mounted stanchions are no longer part of the design, a separate component may be needed to properly locate the shoulder belt. This requires a single stanchion, however, that can be mounted next to the wall where it will be out of the way. Shoulder belts from other system could be used and mounted with the procedures currently used by transit systems, with an appropriate interface on the lap belt anchorage of the revised occupant restraint system.*

Operation

The individual in a wheelchair positions themselves facing forward in the wheelchair bay. They then reach forward, unlock the device, and swing it toward them until it latches (similar to a door latch needing no further action). The contoured lap belt arms are rotated down around the person's pelvis, automatically locating the lap belt correctly. The arms will fit between the person's pelvis and the sides or arm rests of the wheelchair.

When the device is not in use, the contoured arms that anchor the lap belt are rotated upward and are locked in place vertically. The entire arm is then rotated so that it rests above the seat backs at that bottom of the windows.

Evaluation

This design was presented to the resource panel and project collaborators. While it was widely agreed that this represented a major improvement and addressed the primary issue of appearance and safety, further revisions were suggested. The wall mount design was not feasible on the selected vehicle design due to the relative position of the window frame and the seat. To overcome the window to seat interference, the final panel-mount design was conceptualized with input from the transit vehicle designer, Mr. Lance Watt, formerly of Flxible Corp.

3. Panel Mount design

Design:

Although a one-piece unit is desirable to minimize the amount of adjustments, the demands of a low profile identified during the evaluation of the stanchion mounted prototype, and the vehicle structure identified during the evaluation of the wall-mounted prototype, required a two-piece solution. This design, schematically shown in Figure 6 uses two independent rails that are mounted to the panel behind the wheelchair. This panel matches the geometry of the wheelchair barrier that is currently used on buses.

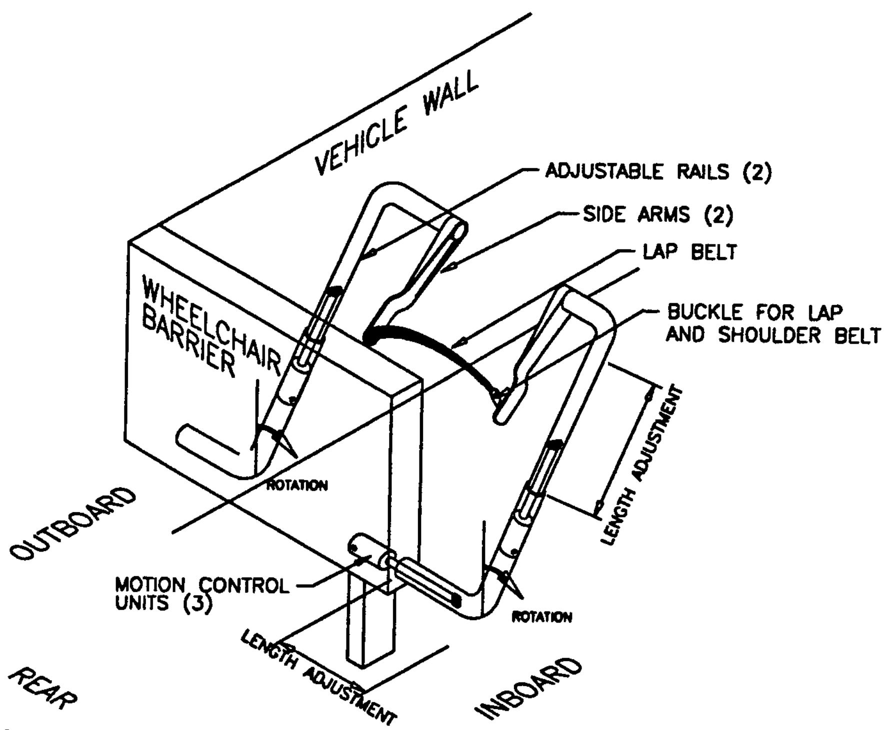


Figure 6. Panel Mounted Design

Mechlok devices (P.L. Porter, Inc.) with a 12-inch stroke were found to meet the design requirements and were selected to control the length adjustments and horizontal position. These are sliding mechanisms that are normally locked, but can be temporarily released using reliable Bowden (Bicycle brake) cable systems The locking mechanisms can withstand in excess of 2200 lb. each, and two can be controlled simultaneously with a single lever supplied by the manufacturer. Rotational control of the rails are controlled by two retracting belts (not shown) mounted on the panel and fastened to center of each rail.

To facilitate easy assembly, adjustment, and access, a preliminary prototype with an open rectangular frame was developed rather than the more aesthetic round frame shown in the concept picture. This model demonstrated that the range of adjustments was adequate and a final design incorporating enclosed tubes was constructed through a sub-contract with Cleveland State University.

Operation

Since the wall side rail is not width adjustable, the wheelchair user must position the wheelchair so that the side-arm will fit between their hip and the arm-rest of the wheelchair. The human factors data has demonstrated that many wheelchair users can achieve this, while others will need assistance. Once the wheelchair is positioned, each rail is raised from its vertical stored orientation (Figure 7a), and positioned with the lap belt anchorage next to the user's hip. When the release lever is squeezed on the underside of the rail (Figure 7b), all adjustments are unlocked for easy positioning. Once the lever is released, all adjustments are locked and the lap belt anchorages will remain in place. (Figure 7c).

Evaluation

The prototype was mounted on a GCRTA bus in place of the usual wheelchair barrier. Measurements were made regarding geometric fit within the bus interior. Three individuals then used the system while seated in a manual wheelchair. The following observations were made during the evaluation of the prototype on-board the vehicle.

1. The centerline of the panel is approximately 1 inch to the rear of the centerline of the current wheelchair barrier. This is caused by a uniform panel width whereas the current wheelchair barrier is contoured to better match the geometry of the side-mounted seat in the wheelchair bay.
2. Knee clearance behind the panel was 10-1/2 inches compared to 11-1/2 inches for other seats on the bus.
3. Able-bodied individuals seated in a wheelchair were able to operate the restraint without needing assistance.
4. The lap belt anchorages were placed correctly relative to the users' hips.
5. Operation of the retracting lap belt was confusing for a user who was not familiar with its design
6. The lower portion of the rails needs to be stiffened.

Future plans

Minor modifications will be made based on the observations described above. Once these have been implemented, the system will be mounted onto the GCRTA bus. The bus will travel to various locations where transit operators and wheelchair users will evaluate the system in a hands-on trial. The ease of operation, compatibility with various wheelchair styles and positions, and the simplicity of operation will be evaluated. Another area of particular interest will be the reaction to the size of the device. To resist the high loads from a 20-g, 30-mph impact, 2-1/2 by 1-1/2 inch steel tubing (1/8 wall thickness) is necessary. Recognition of lower impact levels will allow for a significantly more streamlined and aesthetically acceptable system.

The final evaluation for the system will be a static pull-test to determine compliance with the Federal Motor Vehicle Safety Standard for Seat Belt Anchorages (FMVSS 209). This test was to be performed using equipment at Flxible Corp. that is no longer available. Alternative solutions are being discussed with Cleveland State University and NASA Lewis Research Center.

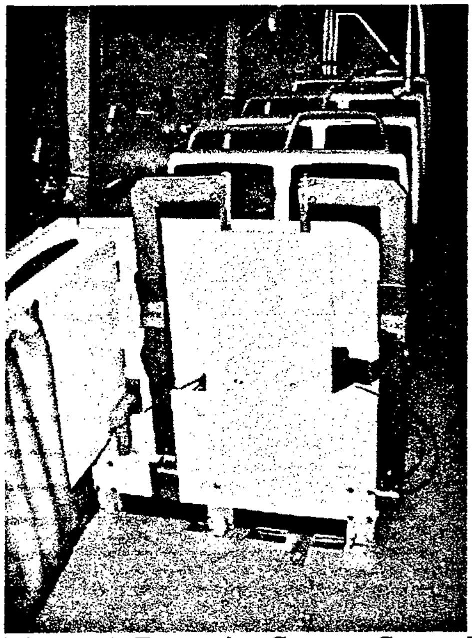


Figure 1. Restraint System Stowed

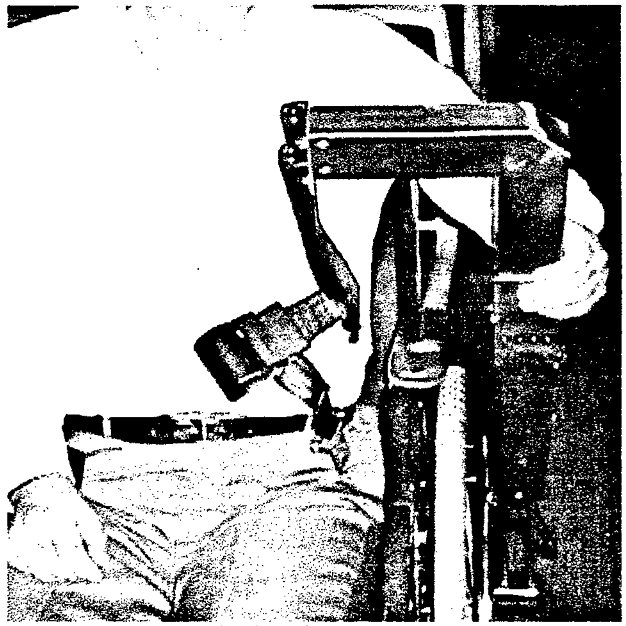


Figure 2. User Adjusting the Restraint

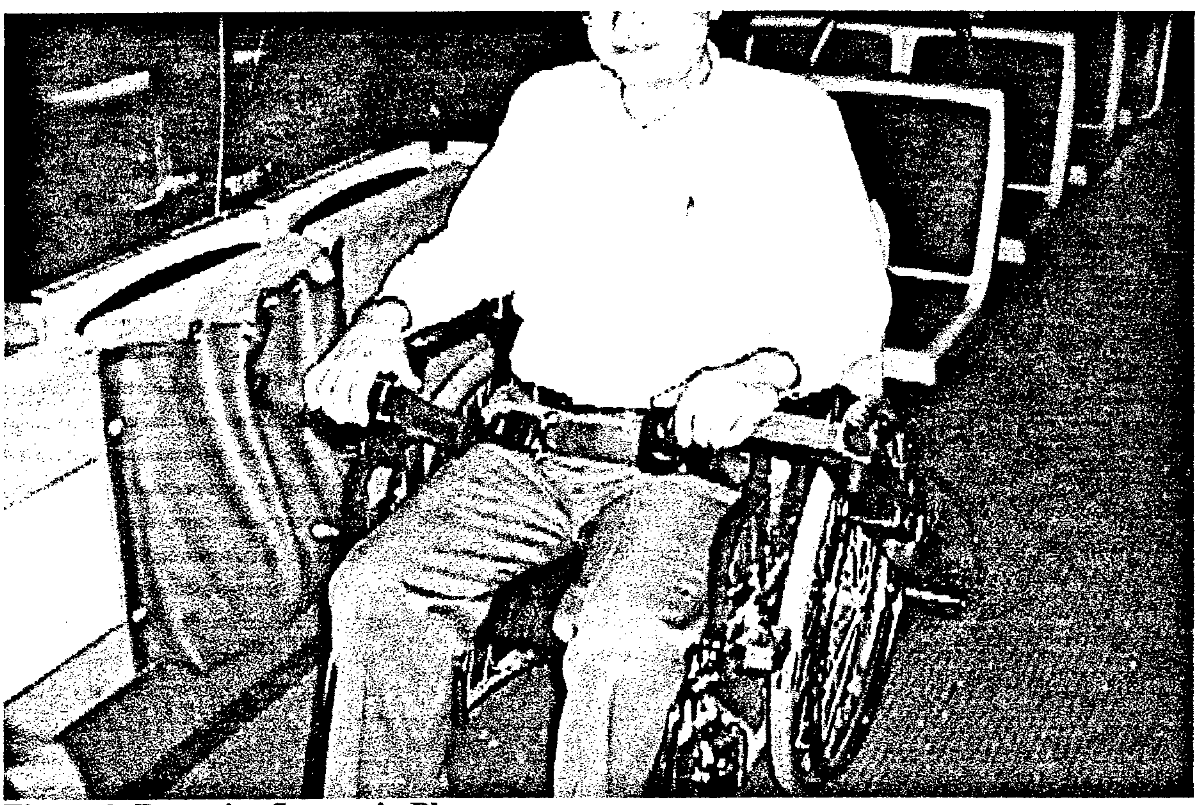
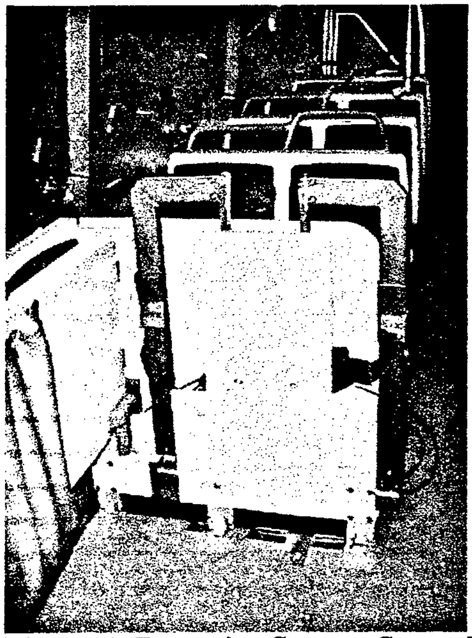


Figure 3. Restraint System in Place



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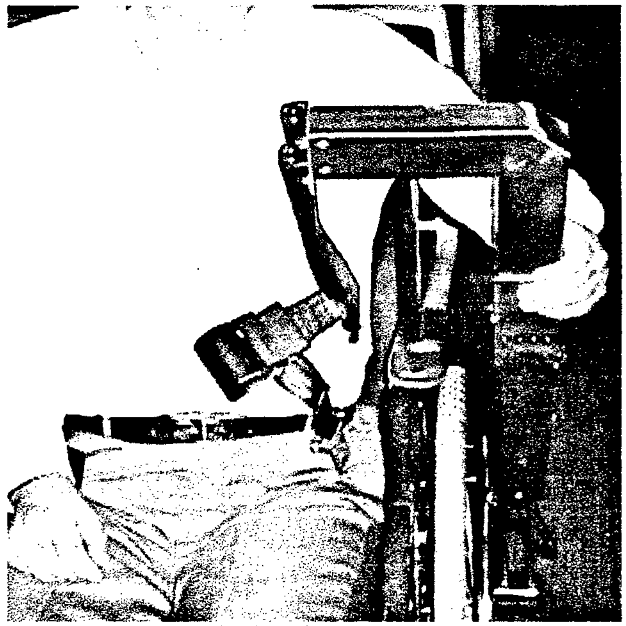

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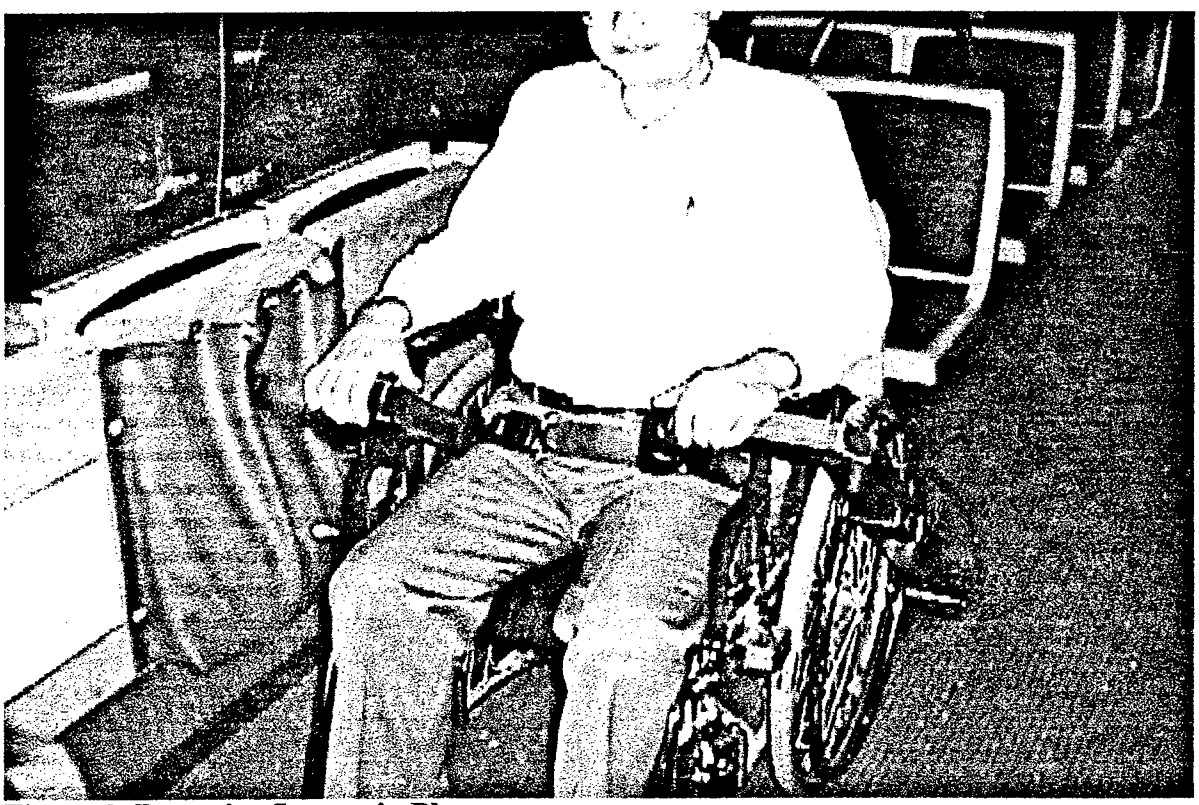

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