

TASK: T-2 DEVELOPMENT OF WHEELCHAIR SECUREMENT INTERFACE CONCEPTS

Investigators: Gina Bertocci, Jules Legal, Douglas Hobson and Patricia Karg

Rationale

Wheelchairs, their securement devices, occupant restraints and transport vehicles all must function as a system, if individuals are to safely and independently use both public and personal vehicles while remaining seated in their wheelchairs. Currently, securement systems for wheelchairs are often inadequately applied, are time consuming to use, and require the involvement of a vehicle operator or an attendant. A universal solution is needed that provides independent, quick, and safe securement. Improving accessibility and safety relies upon standardized methods being developed and adopted for interconnecting the respective technologies. The successful development of new docking-type securement devices, that eliminate several of the disadvantages of commonly used belt-type devices, depends upon standardized ways of interconnecting the wheelchair with vehicle-mounted securement hardware. The adoption and promulgation of a universal interface device (UID) standard for docking

devices can ultimately mean that a person can access and have their wheelchair secured in any transport vehicle, in a manner offering equivalent safety to other riders seated on the vehicle.

Goals

The goal of this project was to facilitate the adoption of a universal interface device standard developed by a trans-industry effort. The approach chosen to reach this goal was as follows:

1. research, develop and evaluate design specifications for universal interface hardware designs that meet constituency-defined needs;
2. conceptualize universal interface device concepts that will foster compatibility between present and future technologies; and
3. foster acceptance and inclusion of concepts and design specifications in national and international standards development.

Universal Interface Concept

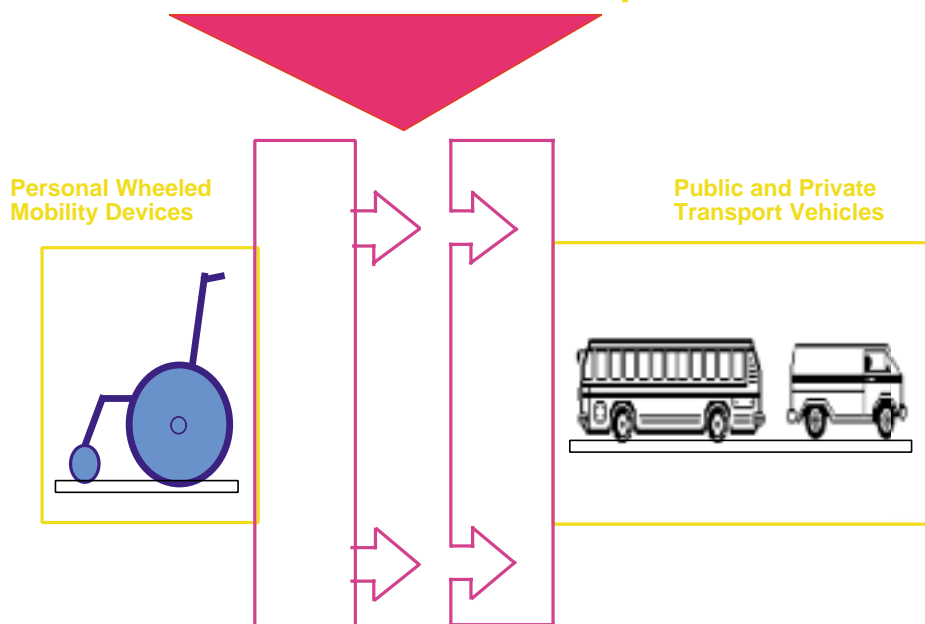


Figure 44 - Illustration of Universal Interface Docking concept

Standardization of the geometry and location of the docking hardware on wheeled mobility devices will allow industry to design and produce vehicle-mounted docking securement devices that are universally compatible.

Methods Summary

The first step in the process was to characterize wheelchair frames and determine the feasibility of adding a common universal attachment. A database of wheelchair frames was developed in this process. This work helped to identify the optimal location for placement of the hardware, as well as necessary clear zones surrounding the hardware. Another initial step was to gather information on the state of the technology in transport vehicles and securement design. In addition, consensus among the involved constituents on the need for a UID had to be established. Reaching agreement on a UID for docking devices between diverse interests such as wheelchair users, wheelchair manufacturers, tiedown manufacturers, vehicle manufacturers and transporters is a challenging undertaking. Focus group meetings, one involving wheelchair users and the other involving industry, were held to this end. Once it was established that there was a need for a UID standard, the two groups worked toward defining and prioritizing the design criteria.

Establishment and priority ranking of the criteria and definition of the clear zones was only the first step. To be adopted universally and eventually promulgated through national and international industry standards, feasibility of the approach had to be demonstrated. Therefore, a series of potential interface hardware designs meeting the criteria were developed and tested. To ensure that the designs met the defined criteria, the RERC, as in other tasks, used the Quality Function Deployment (QFD) design process. The QFD is a design tool that involves a multidisciplinary design approach. It is a process for translating customer requirements into appropriate technical requirements at each stage of the product development process. This process allows for proactive quality control and focuses on planning and problem prevention, rather than problem solving down the road. The process is accomplished through

a series of matrices and charts that deploy customer requirements and related technical requirements through the product development phases. The first step of the QFD process involves developing the matrix known as the "House of Quality", which is a basic design tool. The defined and ranked design criteria and identified clear zones were used as inputs to the QFD design matrix.

Several conceptual hardware configurations were designed and fitted to test wheelchairs (Figure 44a&b). The initial concepts were evaluated through feedback from users and industry, strength testing and compatibility testing with production wheelchairs. The evaluations and feedback led to a final design that was further evaluated. The latter design was incorporated into a draft standard and submitted to an independent standard development group (ANSI/RESNA) for further development and creation of a standard. Details of the outcomes of this process are presented below.

Outcomes Summary

Design and Development

The concept of the universal interface was first presented in the 1995 RESNA Proceedings {Hobson, 1995}. Initial development activities were reported in the 1997 RESNA Proceedings {Karg, 1997}. The initial activities focused on an investigation of the array of wheelchair frames in an effort to categorize them and determine commonalities. A survey data form of 45 data points was developed to record relevant wheelchair characteristics, and a database was constructed to maintain and organize the information {Bertocci, 1996; Bertocci, 1997}. This survey provided important information such as the location of the center of gravity and the nature of the existing frame configurations with respect to the ease of adding a common universal attachment design for the purpose of docking securement on motor vehicles. This was used to identify the optimal location for placement of the hardware, as well as the necessary clear zones.

Additional efforts included gathering information on flip-up bus seats, current securement configurations and wheelchair compartment designs on vehicles. Current docking devices were also



obtained for evaluation. Visitations to leading securement companies were made, providing insight into the current state of the technology.

The next step was to organize and host industry meetings and consumer focus groups to identify the desire and need for a universal design standard, and to identify design specifications. Two industry meetings have been held that included wheelchair manufacturers, securement manufacturers, vehicle manufacturers, and transporters. A focus group comprising manual and power wheelchair users that use public and/or private transportation was held in the time between the two industry meetings.

There was overwhelming agreement on the need for a universal interface for docking devices and that a design standard should be pursued. To that end, the two groups then generated lists of design criteria for the universal interface; a list of 19 criteria resulted from the two groups. The eight criteria listed below were included in the top 6 ranked criteria of the consumer group and/or the industry group. The first two bullets were ranked first and second priority by both groups independently, and the third and fourth appeared on both lists. The remaining four appeared on only one of the ranked lists as indicated by either an "I" (industry) or a "C" (consumer) following the criterion. These criteria and their ranking provided a target for the ensuing research effort. These results have been disseminated to two standards development groups.

The partial listing of the design criteria for the universal interface, as referenced above, is as follows.

- Meet all applicable safety standards (I, C)
- Promote independent securement (I, C)
- Maintain original function of wheelchair (e.g., folding, feel, maneuverability) (I, C)
- Accommodate all wheelchair types and sizes that are used as motor vehicle seats (I, C)
- Compatible with all vehicle types that transport passengers seated in wheelchairs (driver docking and fold-down seats accommodated) (C)
- Promote quick securement time (less than 1 minute from being positioned at the securement station to securement) (C)

- Does not preclude use of existing tie-down and occupant restraint systems (I)
- Allow retrofit to existing wheelchairs (I)

The design criteria were used to implement the Quality Function Deployment (QFD) design process. This method was used to assure the needs and desires of all project stakeholders have been considered and are effectively incorporated into the design of the hardware. Finally, several hardware designs were developed and some fabricated for consideration and evaluation. Clear zone requirements with respect to the wheelchair to allow access to interface hardware were also established. Industry and consumer representatives indicated they would like the feasibility of the designs evaluated before the standard was created and subsequent work was performed to this end. The evaluation of the proposed hardware designs and status of these efforts were reported at the 1998 RESNA Conference {Karg, 1998}.

The UID standard will provide the basis by which all involved industries can design and produce compatible wheelchair securement products. Design of the docking devices will be limited only in that the wheelchair hardware (i.e., the universal interface) geometry, location in space, and surrounding clearance will be defined. The industry meetings centered around the debate of two configurations of a UID located on the lower rear portion of the wheelchair. One configuration, that was favored after the second industry meeting, is two vertically oriented structures (Figure 44a), aligned side by side {Karg, 1997}. However, the discussions in the third meeting (June 1997) tended to return to the appealing approach of having a horizontal bar across the rear, similar to the grab bars offered on several scooters (Figure 44b). Evaluations of these two configurations revealed several pros and cons of each (detailed below). The horizontal bar proved better for ease of retrofit to existing wheelchairs however, did not provide a reaction point to prevent rear or end wheelchair rotation during a crash. Thus, two horizontal bars may be necessary. The vertical configuration would allow for the needed stability, however appeared to be more difficult to retrofit and integrate into existing wheelchair designs.

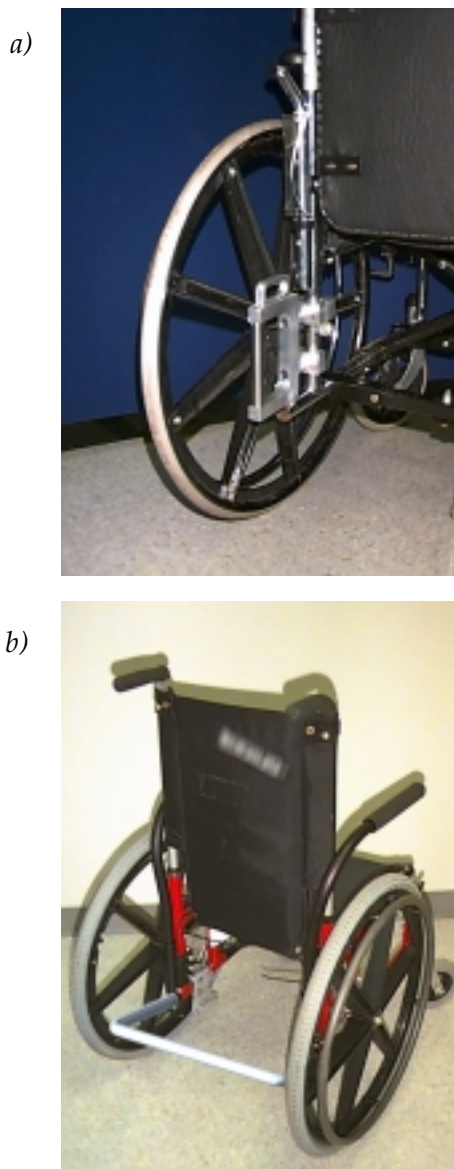


Figure 44 – Conceptual designs: (a) vertical concept (b) horizontal concept

Evaluation

Compatibility testing: Field tests were performed to evaluate the compatibility of the vertical and horizontal design configurations with existing production wheelchairs to assess the ease of retrofit, as well as the ease of incorporation in future designs. Approximately a dozen wheelchairs representing the different classes, including pediatric wheelchairs, were evaluated. In general, the wheelchairs surveyed more readily accommodated the horizontal interface. However, in some cases, overall wheelchair length was increased, which is undesirable. The problems generally found with the vertical configuration were

battery box interference in placement, and inadequate distance between the battery box and wheel for access of the interface. In addition, the various wheelchair widths dictated various spacing of the vertical interface components, placing more demands on the docking system design.

Dynamic testing: The vertical interface design was dynamically tested for strength using a drop test jig to simulate dynamic conditions for a 20 g crash with a 200-220 lb wheelchair and a 50% male occupant. The load was applied perpendicular to the 3/4" solid aluminum tubing making up the vertical interface component. With successive testing at these loads only slight deformation occurred.

Reaction point analysis: Since the primary concern with using a rear-only securement was wheelchair rotation, crash simulations were performed to analyze various interface configurations. The simulations use a surrogate wheelchair used in sled testing of belt-type securement systems. The surrogate was designed to represent a standard power wheelchair occupied by a 50% male wearing an integrated restraint. The simulations were not validated with sled testing, but could be used for comparative purposes. Front wheel excursions at time of 250 msec during the rebound phase of a frontal crash were used to characterize the crash response of the wheelchair. Initially a 1" diameter horizontal bar was placed 11" above the floor (at the center of gravity of the wheelchair) and had an excursion of 6.9". Then two horizontal circular bars were tested separated by 5" and 2" and had excursions of 3.5" and 3.9", respectively. The analysis emphasized the need for a second reaction point to prevent excessive wheelchair rotation when securing the wheelchair at the rear only. The results showed that a double horizontal bar would provide the desired second reaction point.

Based on the information and research to date, the group at the June 1997 industry meeting discussed the relative merits of the vertical versus the horizontal interface configurations. The vertical configuration had been chosen as the most promising in previous meetings. In light of new data, the group decided the horizontal configuration looked promising as well and that it should be further researched by the RERC

team, especially with respect to stability and wheelchair rotation.

Hybrid interface design and evaluation

The hybrid interface (Figures 45 and 46) appears to provide the advantages of both the horizontal and vertical design concepts, along with providing the critical anti-rotational reaction points. This approach has an advantage over the double horizontal bar approach by reducing the level of complexity of docking system-to-interface engagement. Additionally, the hybrid interface promotes docking system centering on the wheelchair. The proposed dimensions are intended to be wheelchair compatible, and are based upon the previous surveys and data analysis across varying wheelchair types.

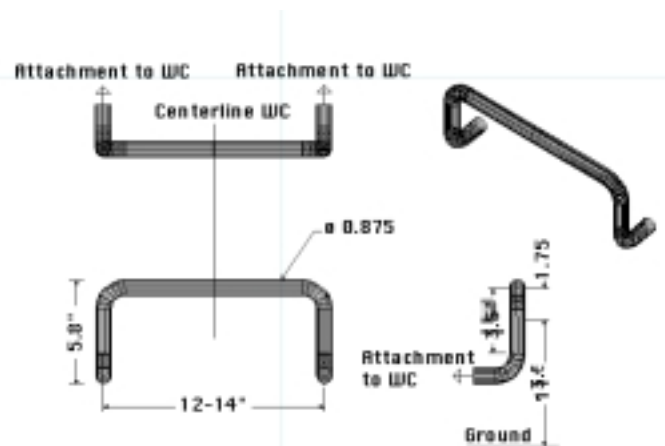


Figure 45 - Hybrid UID concept and design specification

We conducted preliminary simulations using a 2-D Working Model analysis. The model was not validated, but was used to obtain a general evaluation of the crash dynamics and response of the wheelchair with the hybrid interface. The wheelchair exhibited a controlled response in these simulations. The next step was to perform static testing on the hybrid design. The testing showed that the UID maintained up to a 10,400-lb load. When failure occurred, it was at the point where the UID interfaced with the test jig, which in this case was a press fit into the UID tubing, resulting in an area of stress concentration. The final evaluation was a dynamic test that used the hybrid design to interface an SAE surrogate wheelchair with a docking system that had been designed, in part, to prove the feasibility that a docking system could be designed that would

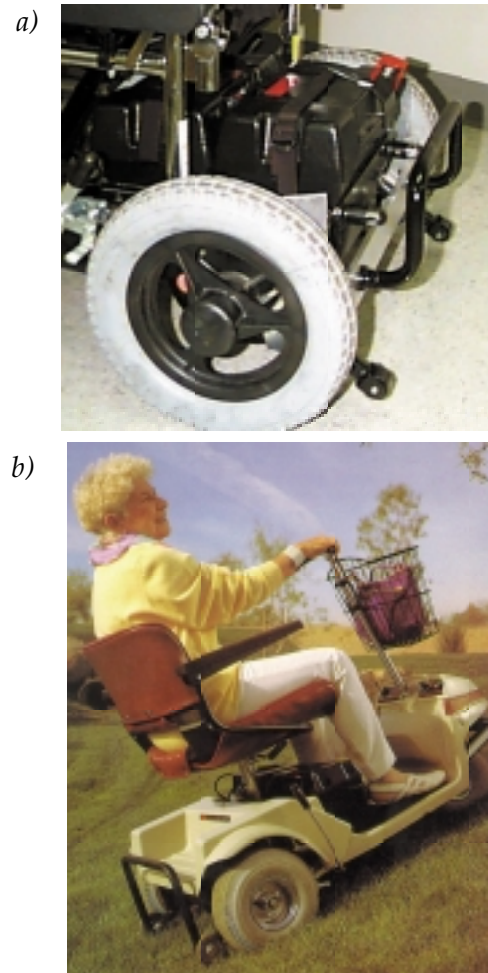


Figure 46 - Hybrid UID concept, example of integration into (a) a powered wheelchair and (b) a scooter

successfully mate with the hybrid interface design. The sled test was performed according to the SAE J2249 specification [SAE, 1996]. The test met J2249 requirements for wheelchair and occupant response and proved the feasibility of the hybrid UID concept.

Recommended Future Developments

The final step as the RERC funding period came to a close was to formalize the standard development process with an independent standard agency. In Spring 1998, a formal request and draft standard was submitted to ANSI/RESNA Technical Guidelines Committee to initiate a new work item on the UID Standard. The new work item has been approved and work will begin in Spring 1999. The draft standard must now continue through the standard development process in the hands of the ANSI/RESNA working group for the transport wheelchair (SOWHAT).

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