An Evaluation of Wheelchair Restraint Systems Used in the Transportation of Disabled Persons

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AN EVALUATION OF WHEELCHAIR RESTRAINT SYSTEMS USED IN THE TRANSPORTATION OF DISABLED PERSONS

BY

ROBIN LYNN DRESPEL
B.A., University of South Florida, 1984

RESEARCH REPORT

Submitted in partial fulfillment of the requirements for the degree of Master of Science in the Graduate Studies Program of the College of Engineering University of Central Florida Orlando, Florida

Fall Term
1985
ABSTRACT

There has been a significant effort to provide disabled persons with increased independence and mobility. The federal government requires that transportation facilities be made accessible to the disabled, and the number of handicapped persons using these facilities is expected to increase significantly in the future.

Restraint systems have been required for passenger cars since the 1960s, and considerable effort has been dedicated to increasing public awareness of the benefits of seat belt usage. Little effort has been devoted to the development of restraint systems for individuals who must use wheelchairs as vehicle seats.

A survey was conducted in the Central Florida area to determine what types of restraint systems are being used by agencies responsible for the transportation of the wheelchair passengers. A cost analysis was performed which shows that the implementation of effective restraint systems can often be justified on economic grounds.

Sled tests have shown that most of the restraint systems available on the market do not provide adequate protection for wheelchair passengers. This document provides a description of many securement products, test results, and recommendations for wheelchair restraint improvements.
With all my love, I dedicate this research report to my parents, who have supported and encouraged me, shared their love, and helped me to understand and grow.
ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and appreciation to Dr. Jose A. Sepulveda for all of his assistance and guidance on this project. I would also like to thank Dr. Gary E. Whitehouse and Dr. Chin Lee for their help and encouragement throughout my graduate program at the University of Central Florida. Special thanks to Mr. Daniel Fiscoff for his help in the preparation of this research report.

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Finally, I would like to extend my love and appreciation to three very special people. To my sister Shirley and brother Paul, my sincerest thanks for all the kind thoughts and encouragement given throughout my college career. I wish to express my deepest gratitude and love to my sister Barbara for the dedicated support, guidance, and strength that she has always given me.
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INTRODUCTION

All persons in our society require transportation facilities for work and leisure activities. Despite legislation mandating equal access, public transit systems have been mostly inaccessible to persons who are confined to wheelchairs. These individuals must rely on federal, state, and local agencies to provide transportation in specially modified buses or vans. While a significant effort has gone into providing transportation services for the disabled, little concern appears to have been given to the safety of the passengers.

This report is intended to provide an overview of the problems associated with the transportation of the disabled, and an evaluation of the restraint systems designed to secure wheelchairs and prevent injuries in the event of an accident. In Chapter I, statistics are provided on the incidence of disabilities requiring wheelchair confinement, as well as the problems associated with the transportation of the wheelchair occupants. Chapter II contains a description and evaluation of the securement devices available to make transportation safer. The results of a survey of transportation vendors, agencies, and nursing homes in the Central Florida area which use wheelchair restraint systems are provided in Chapter III. These
agencies were asked to describe the securement systems used in their vehicles. Chapter IV presents a decision tree analysis comparing the cost of accidents involving restrained versus unrestrained wheelchairs, and a sensitivity analysis of the decision based on variations in the cost of accidents. A discussion of the methods available for testing the effectiveness of wheelchair securement devices is examined in Appendix A, and conclusions and recommendations resulting from these analyses are discussed in Chapter V of this report.
CHAPTER I
TRANSPORTATION OF THE DISABLED

Disabled persons require transportation for employment, shopping, personal business, recreational activities, and medical reasons. The disabled often have difficulties using public transit systems such as subways, buses, and rail systems because they are usually designed for able-bodied persons. As part of an overall effort to enable handicapped persons to live more independent and productive lives, the United States government has been legislating mandatory access to transportation systems. The Urban Mass Transportation Act of 1964 defined transportation-handicapped individuals as

any individual who, by reason of illness, injury, age, congenital malfunction, or other permanent or temporary incapacity or disability, is unable without special facilities or special planning or design to utilize mass transportation facilities as effectively as persons who are not so affected (National Highway Traffic Safety Administration 1984).

The Urban Mass Transportation Act mandated that public transit systems be made more accessible to the handicapped. Despite this legislation, the two largest mass transit systems built in the United States since 1964 in San Francisco, California, and Washington, D. C., have been largely inaccessible to the disabled (Mark Battle Associates
1978). In order to increase compliance with the legislation, the Congress passed the Biaggi Amendment to the Urban Mass Transportation Act in 1970. This amendment made it national policy that disabled persons should have equal access to mass transit facilities (Kelvin 1979). The Federal-Aid Highway Act of 1973 stated that federally financed projects must be "planned and designed so that mass transportation facilities can be utilized by elderly and handicapped persons" (Mark Battle Associates 1978). Additional emphasis was placed on the transportation of the disabled with the passage of the Vocational Rehabilitation Act of 1973. This bill was enacted to

... evaluate existing approaches to architectural and transportation barriers confronting handicapped individuals, develop new such approaches, enforce statutory and regulatory standards and requirements regarding barrier-free construction of public facilities and study and develop solutions to existing architectural and transportation barriers impeding handicapped individuals. (Melvin, Harden, Schneider, and Cossairt 1983).

Despite these legislative efforts, most public mass transportation systems cannot be accessed by the disabled. In May, 1976, the Department of Transportation imposed a regulation which stated that "federally funded transportation agencies must provide a means of transportation for the elderly and handicapped if funds are to be continued" (Rider, McDermott, and Thompson 1976). In order to comply with the legislation and avoid loss of federal support, most major cities provide transportation to
the handicapped in the form of small buses or vans (Melvin, Harden, Schneider, and Cossairt 1983). These vehicles are usually standard or modified vans and body-on-chassis small buses which can accommodate between 7 and 15 passengers. The vehicles are operated by special agencies for the disabled, or public transit systems providing community-oriented transportation services (Urban Mass Transportation Administration 1984).

The elderly population in the United States is increasing rapidly due to a declining birthrate and increasing life expectancy. The United States population over 65 years of age was approximately 25 million in 1980, and the number will increase to more than 35 million by the year 2000, and to more than 64 million by the year 2030 (Schmid 1985). These statistics are shown in Table I.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>NUMBER OF PEOPLE</th>
<th>PERCENT OF POPULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>25,544,000</td>
<td>11.3</td>
</tr>
<tr>
<td>1983</td>
<td>27,400,000</td>
<td>11.7</td>
</tr>
<tr>
<td>2000</td>
<td>35,000,000</td>
<td>13.0</td>
</tr>
<tr>
<td>2030</td>
<td>64,000,000</td>
<td>21.0</td>
</tr>
</tbody>
</table>

(CENSUS BUREAU PROJECTIONS)

The Department of Transportation estimates that approximately one-third of all Americans over 65 are disabled in some manner. In addition, an estimated 5,000
persons become disabled through accidents involving injury to the spinal cord (Rider, McDermott, and Thompson 1976). The growing population of transportation-handicapped persons will greatly increase the need for facilities to transport the disabled in the future.

**Transportation of Wheelchair-Bound Persons**

A significant percentage of disabled persons require the use of wheelchairs for mobility. There are approximately 430,000 wheelchair users in the United States. Table I contains the Urban Mass Transit Administration statistics on wheelchair usage.

<table>
<thead>
<tr>
<th>AGE</th>
<th>NUMBER USING WHEELCHAIRS PER 1000 POPULATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNDER 18</td>
<td>0.42</td>
</tr>
<tr>
<td>18 TO 64</td>
<td>1.44</td>
</tr>
<tr>
<td>65 AND OVER</td>
<td>11.54</td>
</tr>
<tr>
<td>ALL AGES</td>
<td>2.10</td>
</tr>
</tbody>
</table>

In order to make transportation more accessible to wheelchair users, devices such as lifts, ramps, servo controls, and vehicle modification kits have been developed (Schneider 1981). More concern seems to have been directed toward the problems of boarding and disembarking than to the issue of adequate securement and protection of the
wheelchair passengers from injury in the event of an accident (Orne, Barak, and Fisch 1976).

Collisions and Passenger Restraints

In a typical collision, a vehicle will come to a complete stop within one-tenth of a second. In many cases, the passenger compartment is undamaged because the crushing of the front end absorbs most of the force and serves as a cushion for the rest of the vehicle (Ontario Ministry of Transportation and Communication 1975).

The second and more important collision is known as the "human collision." One-fiftieth of a second after the vehicle stops, the occupant strikes into the dashboard, windshield, or other object in the interior of the vehicle. The forces generated by the second collision are equivalent to those exerted upon the human body as it hits the ground after falling from a three-story building (United States Department of Transportation 1976).

Restraint Systems for the Able-Bodied

Motor vehicle crashes are the leading cause of paraplegia, and the largest single killer of Americans under the age of 34. A significant number of studies have shown that the use of safety belts reduces the likelihood of injury or death in the event of an accident. Seat belts are effective because they spread the stopping force widely across the strong parts of the body and prevent the second
collision with fixed objects in the vehicle. It has been estimated that approximately 15,000 lives would be saved each year if all drivers and passengers in the United States wore their seat belts.

Front and rear seat lap belts have been installed in all U.S. built automobiles since 1966 as a result of legislation passed in many states. The federal government mandated that all 1968 model vehicles be equipped with both lap belts and shoulder harnesses (O'Neill 1985). The combination of lap and shoulder belts have been shown to be at least 57% effective in preventing injuries (Wilson 1981). Several states, such as New York and Illinois, have recently passed laws requiring seat belt use in automobiles.

The Need for Wheelchair Restraint Systems

Although a large number of studies have been directed toward restraint systems for automobiles, relatively little concern has been directed toward the safety of vehicles used in the transportation of the disabled. Those who use wheelchairs as vehicle seats are of particular concern because they are at high risk of injury in the event of a collision (Schneider 1981). A large percentage of wheelchair users suffer from musculoskeletal disorders which render them more susceptible to injuries due to such factors as bone embrittlement.
Disabled persons who are capable of transferring to a vehicle seat should use the manufacturer's three-point safety belt (combination of lap belt and shoulder harness). These devices have been proven effective in preventing injuries and death during the human collision. (Melvin and Harden 1983). For persons who must remain in the wheelchair, effective securement devices are required to reduce the probability of injury in the event of an accident. Many wheelchair securement devices in use today not only provide limited protection in the event of an accident, but violate crashworthiness design principles and as a result may put the occupant at greater risk than not using the system at all (Schneider 1981). The most primitive securement devices are simply ropes or chains, which are insufficient to prevent injury to the passengers (Kelvin 1979).

If a securement is not provided, the wheelchair's brakes are the only means from preventing the wheelchair from sliding about inside the vehicle. The frictional force between the wheelchair's tires and the vehicle floor is used to keep the wheelchair in place. Studies conducted at Texas A&M University showed that the coefficient of friction between the tires and floor is only 0.4. This frictional force is inadequate to restrain the wheelchair in the event of an accident, as only 0.4g vehicle acceleration force would cause the wheelchair to break loose (Rider, McDermott,
and Thompson 1976). An impact of 1.5g (1.5 times the force of gravity) will cause the wheels to bend out of shape. A force of 2.5g can cause the wheelchair to disintegrate, enabling the chair and the occupant to become projectiles in the vehicle (Kelvin 1979). In order to provide adequate passenger protection, securement devices must be able to withstand a force of 15g peak deceleration. Table III lists the forces required to provide this protection (Schneider 1981).

**TABLE III**

<table>
<thead>
<tr>
<th>OBJECT</th>
<th>MASS (Kg)</th>
<th>FORCE (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard wheelchair</td>
<td>23</td>
<td>3,400</td>
</tr>
<tr>
<td>Occupant</td>
<td>73</td>
<td>10,910</td>
</tr>
<tr>
<td>Power chair</td>
<td>50</td>
<td>7,500</td>
</tr>
<tr>
<td>Standard chair plus occupant</td>
<td>96</td>
<td>14,310</td>
</tr>
<tr>
<td>Power chair plus occupant</td>
<td>123</td>
<td>18,450</td>
</tr>
</tbody>
</table>

The mass of an average power wheelchair with an occupant is 123 kilograms. The force required to restrain this mass at 15g is 18,450 Newtons. Advanced wheelchair securement designs are required to withstand forces of this magnitude and protect occupants from injury in the event of an accident. Based on the results of testing at major
universities, design criteria have been established for wheelchair securement devices. Restraint systems designed using these criteria will do a better job of preventing serious injuries in the event of an accident. The design criteria and product evaluations are discussed in Chapter II, and the restraint system testing procedures are shown in Appendix A.
CHAPTER II
WHEELCHAIR SECUREMENT DEVICES

One of the major difficulties in the securement process is that most wheelchairs in use today were not developed with consideration for use as a motor vehicle seat. In many studies, the standard wheelchair has been found to be capable of withstanding impacts of 20g. However, the upholstery will not always provide the necessary resistance to forces generated by lap-belted occupants during frontal collisions, and the seat-back fabric may not be sufficiently strong to resist the body's rebound on rear impact (Melvin and Harden 1983).

Wheelchair Securement Device Design

Tests have shown that most of the securement systems are not adequate for occupant protection in most accidents. Many of the devices were developed and manufactured by small companies which are neither familiar with the basic principles of occupant protection, nor the magnitude of force generated in accidents (Schneider 1981).

Effective restraint systems must allow the wheelchair to be secured so that it does not break apart, collapse, or move significantly during a collision. In addition, the occupant must be provided with adequate restraints to
prevent the second collision with the vehicle interior. The restraint should place a minimum load on the delicate tissues and organs of the body (Melvin and Harden 1983).

Testing of wheelchair securement devices (discussed in Appendix A) has led to the development of specific crashworthiness design principles for the transportation of the disabled in wheelchairs.

Design Criteria

Hardware strength. Wheelchair securement hardware must be of adequate strength to withstand impacts of 15g.

Quality control. Manufacturers must maintain adequate quality control on all joints and welds (Rider, McDermott, and Thompson 1976).

Reinforcement. The strength of the wheelchair itself may have to be augmented with steel plates. The reinforcement parts should attach to the strongest points of the chair and extend the width of the chair in front and back in order to prevent the lateral collapse of the chair during a collision.

Positive engagement. The reinforcing hardware should engage easily and positively to eliminate the possibility of incomplete engagement (Humana Hospital Lucerne 1985).

Mounting requirements. Restraints should be attached to the floor of the vehicle with four bolts. Mounting securement
devices with two bolts is considered a design deficiency (Rider, McDermott, and Thompson 1976).

**Placement of the Wheelchair in the Vehicle**

Wheelchairs should not be placed in a side-facing orientation because the occupant is more vulnerable to injury in the event of a frontal collision. Wheelchairs are designed to fold for easy storage and handling. The impact of a frontal collision can cause a side-facing wheelchair to fold, increasing the probability of serious injury to the occupant. Side-facing wheelchair placement is used most frequently in the seating of disabled children in buses because this arrangement allows more wheelchairs per vehicle. These vehicles are usually not equipped with special seats to distribute loads over the sides of their bodies during front-end collisions (Seeger and Caudry 1983).

**Head Restraints**

Broad, padded head restraints should be used to prevent rapid backward head movements which can result in whiplash neck injuries (Seeger and Caudry 1983).

**Independent Restraint**

The wheelchair and its occupant should be restrained independently. A single lap belt anchored to the floor or wall of the vehicle would result in excessive loads exerted upon the passenger (Seeger and Caudry 1983).
Distribution of Load

Impact forces should be distributed over the skeletal structures as much as possible to reduce the injuries sustained in an accident. An upper torso restraint should be used in addition to a lap belt to prevent the passenger's head and chest from striking vehicle surfaces during the second collision (Seeger and Caudry 1983).

Point of Securement

The restraint system should hold the wheelchair by the frame. It is poor engineering practice to hold the wheelchair by its wheels because testing indicates that they are not able to withstand a side load in excess of 1.5g (Rider, McDermott, and Thompson 1976).

Texas A&M Evaluation of Wheelchair Restraint Systems

A major study of wheelchair securement devices was conducted at Texas A&M University's Industrial Engineering Department in 1976. The purpose of the study was to determine if the restraint systems incorporated effective design and fabrication practices. The systems evaluated were Atlantic Research Corporation's "Single Wheelchair Locking Station," Collins Industries' Models W-40, W-45, and W-49, Double D Industries' "DepenDa Lock," and Speedy Wagon Sales Corporation's "Tie Down" and "Sureloc" (Model VO-76). In addition, Texas A&M evaluated their own prototype system called "Clamp" (Rider, McDermott, and Thompson 1976).
Atlantic Research "Single Wheelchair Locking System"

Description. This system uses a locking assembly which is bolted to the floor of the vehicle. The assembly restricts the use of the device to passengers only and not for drivers. The wheelchair is first backed into the locking assembly. The rear wheels of the wheelchair are then secured to the assembly by placing a clevis pin through each of the two wheels. The safety belt is attached to the locking station. The belt is worn over the occupant's lap, and can be adjusted for proper fit. The cost of the system was $138.62.

Evaluation. The design of "Single Wheelchair Locking Station" requires that an attendant be present to secure and release the wheelchair. The chair is constructed using mild steel, and most of the welds were good. Excessive movement was exhibited under moderate loads, but the chair was evaluated as being capable of securing a wheelchair for vehicle travel subject to the correction of some minor drawbacks.

Collins Industries "SAF-T-LOCK," Model W-40

Description. This device is used to secure the wheelchair only. No information on passenger securement is provided. The wheelchair must be backed into two locking brackets, which constrains this device for passenger applications only. The wheelchair is secured with clevis pins through each of the two rear wheels. This violates one of the
principles of good wheelchair securement design. An attendant must be present to secure the wheelchair. The Collins Industries Model W-40 costs $57.50.

**Evaluation.** The restraint system is difficult to back into from the wheelchair occupant's point of view. The restraint system is made of mild steel. Some welds showed no heat penetration into the adjoining members, and five welds on one restraint broke when pulled with a 5g force. The use of only two bolts (one per side) to secure the restraint post to the floor is considered a design deficiency. Sharp corners are present on the restraining posts. This system was rated as "not capable of securing a wheelchair for vehicle travel at this time."

Collins Industries "SAF-T-LOCK," Models W-45 and W-49

**Description.** Both of these securement devices use automatic holding brackets, and are restricted to use for passengers only. The wheelchair is secured by a pivoting clamp which closes and locks as the rear wheels force the clamp when backing into the device. An attendant is not required for the use of these restraint systems. Model W-45 comes with an electric release which enables the occupant to release his or her wheelchair. The cost of Model W-45 is $112.50, while the Model W-49 sells for $84.50.

**Evaluation.** These systems are similar and were evaluated together. Both systems were considered difficult to back
into from the occupant's point of view. Occasionally, the restraint would not release properly due to spoke interference. The units are constructed from mild steel. Some of the welds showed inadequate heat penetration and exhibited surface cracks following the application of test loads. Both models use only two bolts instead of four to hold the restraint to the floor. The restraint attaches to the rear wheels of the wheelchair, which is a design deficiency. Both models were judged to be incapable of securing a wheelchair for vehicle travel due to deficiencies which are hazardous to the safety of the occupant.

Double D Industries "DepenDa-Locks," Model DD-1

Description. This restraint system secures only the wheelchair; no information on passenger restraint is provided. The DepenDa-Locks Model DD-1 can only be used for passenger restraint. The system is activated automatically by the rear wheels of the wheelchair as they enter the bracket forcing a pivoting clamp to close and lock. An attendant is not required to secure the wheelchair, but must be present for its release.

Evaluation. An unusually small clearance between the wheelchair and restraint resulted in some difficulty in backing the wheelchair into the restraint system. The unit is constructed with steel. The welds were considered to be good, but the basic design of the restraint is to clamp to
the rear wheels of the wheelchair, which is poor engineering practice. The wheelchair is not stable under moderate loads. This restraint system was evaluated as incapable for securing a wheelchair for vehicle travel, and is insufficient for loads as low as 1 g.

**Speedy Wagon Sales Corporation "Wheelchair Tie Down"**

**Description.** This device secures the wheelchair and the occupant, and may be used by passengers or drivers. The device may be entered from the front or rear. An attendant is required to secure the wheelchair by fastening the two security clamps at the front of the wheelchair frame. The system costs $50.00.

**Evaluation.** The "Wheelchair Tie Down" is easy to secure and release. The restraint is constructed from steel, and a safety belt is included to secure the occupant to the vehicle. The restraint system allowed excessive motion during moderate loads, and was judged to be incapable of securing a wheelchair and occupant for vehicle travel.

**Speedy Wagon Sales "Sureloc Wheelchair Lock," Model VO-76**

**Description.** This system requires a vacuum line for operation, but is not included with the device. The Sureloc Wheelchair Lock can be used by passengers and drivers. The restraint is activated by moving the wheelchair forward into the holding bracket. A restraining pin, activated by
vacuum, secures the wheelchair to the bracket. The system sells for $195.00.

**Evaluation.** The Sureloc securement device is relatively easy to secure and release. The operation of the system is dependable. No sharp corners are present in the restraint, which is constructed with steel. The welds were of high quality. Texas A&M personnel judged this system to be capable of securing a wheelchair with slight modifications.

Texas A&M University, "CLAMP"

**Description.** "CLAMP" was designed to secure only the wheelchair, not the occupant. Electric power is required to operate the restraint system, so only electric wheelchairs can be restrained. The restraint is activated by driving over a holding bar which is clamped after the bar passes between the caster wheels of the wheelchair. A 12 volt DC current is applied to an electric motor in response to the activation of a switch by the occupant. This system is completely operated by the occupant; no attendant is required. The CLAMP prototype cost is estimated at $200.00.

**Evaluation.** This restraining device is constructed with Aluminum. The base plate is made of steel and adjoining pieces are welded. The electrical equipment consists of standard items from General Motors. The clamping action secures the wheelchair frame, not the rear wheels. The
device was judged to be capable of restraining a wheelchair for vehicle travel.

**Wayne State University Design**

A wheelchair restraint system was designed for use in buses used to transport the disabled at Wayne State University. The design criteria were made general enough to meet the safety requirements of wheelchair-confined passengers traveling in most buses, trains, and other vehicles which provide access to wheelchairs (Orne, Barack, and Fisch 1976).

The wheelchair restraint system contains a rearward facing vertical restraint couch designed to protect the passenger and the wheelchair from front-end collisions. A three-point safety belt system which attaches to the frame of the securement device provides restraint in rear-end collisions and protection from the human collision in front-end accidents. A cable system secures the wheelchair to the base of the framework of the restraint couch (Orne, Barack, and Fisch 1976).

Tests of the Wayne State University wheelchair restraint system indicate that complete passenger protection is provided for collisions at speeds approaching 30 mph. The restraint system was custom-built for use at Wayne State University, and no cost data are available.
**Collins Saf-T-Lock and Saf-T-Straint**

A study of restraint systems for handicapped children was sponsored by the Bureau of Crippled Children in Madison, Wisconsin, and performed by the Highway Safety Research Institute at the University of Michigan in Ann Arbor, Michigan. The Collins Saf-T-Lock was used to secure the wheelchair, and the Collins Saf-T-Straint padded safety belt system was used for passenger securement (Schneider and Melvin 1978). The research project also evaluated restraint systems used in the transportation of disabled children seated in school bus seats. A discussion of the results of those tests is beyond the scope of this document.

**Results**

The Collins Saf-T-Straint was determined to be inadequate for protecting wheelchair occupants. The belt load is applied up on the abdomen rather than on the pelvic bone. This can result in internal injuries in the event of a collision.

The Collins Saf-T-Lock restraint system was effective in holding the wheelchair, but did not provide adequate protection against forward pitch of the wheelchair. This product provides inadequate protection for the side-facing applications which are commonly used in the transportation of disabled children in school buses.
"Q-Straint" Tie-Down and Occupant Restraint System

The Q-Straint (A. Girardin, Inc.) wheelchair and occupant restraint system for transportation of the physically disabled was tested in 1984 by the University of Michigan Transportation Research Institute (UMTRI). Q-Straint is a four-point belt tie-down system, and comes equipped with anchoring hardware. This restraint device can be used with or without special steel brackets which attach to the wheelchair. The testing at UMTRI was performed without the use of the chair brackets (University of Michigan Transportation Research Institute 1984). The Q-Straint retails for approximately $400.00.

Results

The results of the testing indicate that the wheelchair and dummy passenger were restrained extremely effectively by the Q-Straint system. There was no obvious damage to any of the restraint hardware, and the wheelchair showed little damage after the impact. The tie-down belts were easy to install and use.

Q-Straint has also been tested and approved by the Department of Transport in Ottawa, Canada, and received their approval as being adequate for the restraint of wheelchairs.
Summary

Most of the wheelchair restraint systems evaluated by major universities and testing facilities have been shown to provide inadequate passenger protection in the event of an accident. Some of the more recent restraint designs, such as Q-Straint, have incorporated many of the design criteria discussed in this chapter, and have proven to be more effective in providing occupant protection.

A survey was performed in the Central Florida area to determine if wheelchair restraint systems are being used by agencies responsible for the transportation of the disabled. The survey procedures and results are discussed in Chapter III.
A survey was conducted in the Orlando, Florida, area to determine which securement devices are installed in vehicles used to transport wheelchair-bound individuals. Four vehicle vendors, five transportation agencies, and ten nursing homes were contacted during the course of the survey. The names and addresses of the vendors and transportation agencies are listed in Appendix C.

**Vendor Survey**

The vendors contacted were facilities which convert vans for use by wheelchair-bound passengers and drivers. Each vendor was asked the following questions:

1. Do you use restraint systems? What type?
2. What is the cost of these systems?
3. How many wheelchairs can be accommodated by your vehicles?
4. How are the passengers seated (forward, sideways, etc.)?
5. How many vehicles are converted per year?
6. Do you lease or sell the vehicles?
7. Who is responsible for upgrading the equipment?
8. What testing is performed on the securement devices?
Action Mobility Products Services, Incorporated
This vendor uses the Aeroquip restraint system. Aeroquip is a four-point wheelchair securement device which fits all wheelchair designs, including motorized chairs. The cost of the device is $175.00, including seat belts. No head restraints are used in the vehicles.

Action Mobility converts approximately 75 vans per year. These vehicles can accommodate 4-6 wheelchair passengers, and forward seating arrangements are recommended by the company.

Vehicles can be rented at a cost of $53.00/day, $0.15 per mile, plus a $10.00 insurance charge. The cost on a weekly basis is $285.00, $0.12 per mile, and $70.00 for insurance. Leasing a vehicle for one month costs $970.00, and $0.09 per mile, plus a $300.00 insurance charge. Testing of the restraint systems is performed by the manufacturers. Action Mobility Services is in charge of upgrading their own wheelchair restraint systems.

Braun Corporation
Braun Corporation manufactures its own wheelchair restraint systems for the vans which it converts for use by the disabled. The Braun restraint system consists of a rear-wheel tie-down device, which retails for approximately $250.00, and an optional front-wheel anchor which costs an additional $50.00. The devices hold the wheels in place
through the use of two half-inch diameter steel pins. Two-inch wide seat belts are provided with the securement devices.

This organization converts approximately 50 vans per year for use in the transportation of disabled persons. Each vehicle can accommodate four passengers. The wheelchairs can be transported in a both side-facing and forward-facing orientation.

The vehicles converted by Braun Corporation sell for $15,000 to $17,000. The organization does not lease vehicles. Since Braun manufactures their own restraint systems, they test their own securement devices and are responsible for any equipment upgrades.

Florida Handicap Supply, Incorporated

This vendor uses a rear-wheel tie-down system. The front wheels of the chair are not secured. The use of seat belts is optional. The wheelchair restraints cost $125.00 per chair. Four passengers can be seated in the vehicles, and the wheelchairs face forward. The company prepares approximately 45 vans per year.

The vans converted by Florida Handicapped Supply can be purchased for approximately $18,000. This vendor does not lease vehicles. Restraint system testing is performed by the manufacturer, and the agency upgrades their own restraint systems.
World of Independence

Creative Controls, Incorporated (CCI) wheelchair restraint systems are used by this organization. CCI uses rectangular plates which attach to the wheelchair sideframes. Two steel bars connect between these plates at the front and back. A pair of hooks lock inside the tie-down platform locking the rear bar into a retainer bracket (Melvin and Harden 1983). The cost of the CCI restraint is $165.00, which includes seat belts.

World of Independence converts approximately 48 vans per year. Each vehicle can accommodate 4-6 passengers in a forward seating arrangement. The company sells the vans for $18,000 to $30,000 depending on the size and equipment desired. The vehicles can be leased for $56.00 per day and $0.12 per mile.

This organization does not perform any testing of the securement devices, and relies on the results provided by the manufacturers. The director of the driver education program is in charge of upgrading the restraint system.

Transportation Agency Survey

The agencies contacted provide transportation services for wheelchair passengers. Each agency was asked the following questions:

1. Do you use restraint systems? What type?
2. How many wheelchairs can be accommodated by your vehicles?
3. How are the passengers seated (forward, sideways, etc.)?
4. How many vehicles do you operate?
5. What is the cost to lease the vehicles?
6. Who is responsible for upgrading the equipment?
7. What testing is performed on the securement devices?

Center for Independent Living

This agency uses the Braun restraint system discussed in the vendor survey section. Three buses are used to transport passengers, and the wheelchairs are secured in a side-facing orientation.

The cost of transportation in this agency's vehicles is $20.00 per one-way trip. Passengers are required to wear seat belts on all trips. The Center for Independent Living is responsible for upgrading their own equipment. All restraint system testing is performed by the manufacturer.

Federation of Senior Citizens

This agency uses a rear-wheel wheelchair securement system which includes seat belts. Two vehicles are operated: a 14-seat model and an eight-passenger model. Both vans use side-facing seating arrangements. Head restraints are not used in the Federation vehicles.
Federation provides transportation services at no cost to the disabled passenger. The agency receives funding from government grants, the United Way, and Seminole County. Restraint system upgrades are made through trial and error, and by consultation with experts in the field. Securement device testing is performed by the manufacturer. Federation is monitored twice per year by the Agency on Aging, an organization that oversees the operation of many agencies which serve the needs of the elderly.

Florida Rural/Metro Transportation

This agency uses a double-ring wheelchair securement device which locks the frame of the chair to the floor of the vehicle. The agency operates six vans and one bus. The bus seats 11 wheelchair passengers, and the vans seat 2-5. The occupants of both vehicles face forward. The use of seat belts is mandatory.

The cost of transportation is $15.00 each way plus $1.00 per mile. The agency provides wheelchair securement upgrades, and the testing of the restraint systems is performed by the manufacturer.

Orange County Board of Education

The Orange County Board of Education operates 50-60 buses equipped for the transportation of students with wheelchairs. The Aeroquip four-point restraint system is used as the securement device (see vendor survey). The
buses can accommodate 2-10 wheelchairs mounted sideways. Passengers are required to wear seat belts.

Transportation services are provided by Orange County at no cost to the disabled students. The agency upgrades the securement systems based on the opinions of experts, actual experience, and the availability of funding. The wheelchair restraints are tested by the manufacturers.

Yellow Cab Company

Yellow Cab Company provides transportation services to the disabled through a contract with Tri-County Transit (Orange, Osceola, and Seminole Counties). The agency operates two buses and three vans. Each vehicle uses a two-wheel locking restraint system which attaches to the rear wheels of the chair. Seat belts are used which strap around the passenger and are secured to the floor of the vehicle. A total of five wheelchair passengers can be accommodated in the vehicle. The occupants sit in a side-facing position.

Rides can be obtained for disabled persons at a cost of $0.90 per mile for passengers without wheelchairs, and $1.20 per mile for passengers with wheelchairs. Upgrading of the wheelchair securement devices is performed by Yellow Cab Company. Testing of the equipment is performed by the manufacturer.
Nursing Home Survey

A large percentage of wheelchair users are elderly (Chapter I). Ten nursing homes in the Orlando, Florida, area were contacted to determine if they provide transportation services for their wheelchair-bound residents.

Personnel at the nursing facilities were asked the following questions:

1. Do you have residents who are confined to wheelchairs?
2. Do you provide transportation for these residents? What type?
3. What agencies are used to transport your residents?

Of the ten nursing homes surveyed, one did not have any mobile residents who use wheelchairs. Six out of the ten nursing homes transfer residents from wheelchairs to regular seats in automobiles, vans, or buses. The remaining three nursing homes use transportation agencies, such as Yellow Cab Company and Federation Transportation Company (see transportation agency survey).

Summary

The majority of the wheelchair securement devices consisted of rear-wheel locking mechanisms. The level of performance for this type of device is generally inadequate
for wheelchair securement based on the results of the sled testing methods discussed in Chapter II and Appendix A.

Another deficiency uncovered in the survey was the lack of support on the part of these agencies to stress the importance of seat belt use. Many companies are not including safety belts and harnesses with their restraint systems. The combination of wheelchair and occupant restraint is required for complete passenger protection.

Side-facing seating arrangements were used by some of the agencies contacted. This method increases the probability of severe injury in the event of a front-end or rear-end collision.

None of the companies contacted use head restraints in conjunction with wheelchair securement devices. Head restraints should be used to prevent neck injuries.

Many agencies are involved in providing transportation services to the disabled. However, the wheelchair restraint systems used by the majority of these agencies do not provide an adequate level of protection for the passengers. The securement devices violate many of the optimal design criteria discussed in Chapter II of this report. Due to the high cost of accidents involving wheelchair passengers, and the pain and suffering of the victims, the implementation of improved wheelchair securement systems can often be justified on both economic and humanitarian grounds. A cost analysis of restraint systems is presented in Chapter IV.
CHAPTER IV

COSTS AND BENEFITS OF WHEELCHAIR RESTRAINT SYSTEMS

The United States Department of Transportation estimates that a total of 3,650,000 injuries occur per year in the United States as a result of vehicular accidents. The total cost associated with these accidents is estimated to be $25 billion annually (National Highway Traffic Safety Administration 1983).

A total of 3,400,000 people were involved in vehicle accidents in the United States in 1983. With a total population of 230,000,000, the probability of being involved in an accident is 1.5% (National Highway Traffic Safety Administration 1984). If the assumption is made that wheelchair-bound persons are involved in a proportional amount of accidents as able-bodied persons, then the total number of accidents involving wheelchair occupants is approximately 7,700 annually. The cost of an individual accident involving a wheelchair passenger can be significantly higher than those for able-bodied individuals because the disabled often have weakened skeletal conditions.

The medical costs associated with an accident are as follows:
1. Curative medical expenses (hospital room and board, treating physician's fees, and surgeon's fees)

2. Physical and occupational therapy

3. Miscellaneous expenses (x-rays, medications, ambulance, etc).

In addition to medical expenses, the other costs associated with accidents are:

1. Loss of income (any wages lost due to a hospital stay or recovery period are considered by evaluating life expectancy, past wages, predicted wages, etc.)

2. Permanent injury

3. Pain and suffering (encompasses the time spent in the hospital, the time to full medical recovery, and the probability of future complications or surgery).

Experts at Humana Hospital Lucerne Spinal Injury Center estimate that the cost of an accident involving an unrestrained wheelchair passenger range from $10,000 to $40,000. If an effective wheelchair restraint system is used, the injuries sustained in accidents are significantly less severe. The costs associated with accidents involving restrained wheelchairs range from $500 to $2,500. These cost figures include all medical and miscellaneous costs listed above.

The cost of the restraint systems evaluated as being acceptable in this document range from $138.62 (Atlantic Research Single Wheelchair Locking System) to $400 (Q-
Strait Tie-Down). The cost of these devices is low in comparison with the potentially large medical bills, loss of income, and the pain and suffering associated with accidents involving non-restrained wheelchairs. The average cost of the effective restraint systems examined in this document is approximately $200.00.

Decision Tree Analysis

In order to evaluate the decision to implement wheelchair restraint systems, a decision tree analysis was performed. Two alternatives are available:

1. Use a wheelchair securement device.
2. Do not use a securement device.

In a decision tree, the two alternative decisions are evaluated at all potential states of nature. In this analysis, there are two possible outcomes:

1. An accident will occur (probability = 0.015).
2. An accident will not occur (probability = 0.985).

The costs associated with all possible outcomes are shown in Table IV.

TABLE IV
WHEELCHAIR ACCIDENT COSTS

<table>
<thead>
<tr>
<th>WHEELCHAIR SECUREMENT</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ACCIDENT</td>
</tr>
<tr>
<td>NO</td>
<td>$25,000</td>
</tr>
<tr>
<td>YES</td>
<td>$1,700</td>
</tr>
</tbody>
</table>
If a wheelchair securement device is not used and an accident does not occur, then no cost is incurred. If a collision occurs, then the cost associated with the accident is estimated by the midpoint of the expected range provided by Humana Hospital Lucerne ($25,000).

If a wheelchair securement device is used, a $200 cost is incurred for the purchase of the system. If an accident occurs, then the total cost of the accident is the sum of the cost of the securement device ($200) plus the cost of the accident. The cost using securement systems was also estimated by the midpoint of the expected range ($1,500). Therefore, the total cost of an accident using a restraint system is $1,700. If no accident occurs, then the total cost is simply the cost of the wheelchair restraint ($200).

The decision tree for this model is shown in Figure I. The expected cost of a potential accident is $223 using a wheelchair restraint system, and $375 without a securement device. Based on this analysis, the investment in wheelchair restraints can be justified economically as well as on the basis of the prevention of pain and suffering.

Sensitivity Analysis

Because of the wide range of costs associated with accidents involving wheelchairs, a sensitivity analysis was performed in order to determine the effect of changes in accident costs on the decision. The cost associated with
collisions involving unrestrained wheelchairs was allowed to vary from $10,000 to $40,000, and the accident cost of restrained wheelchairs was analyzed in the range of $700 to $2,700. The sensitivity analysis values and results are shown in Table V.

FIGURE I
DECISION TREE FOR WHEELCHAIR SECUREMENT SYSTEMS

<table>
<thead>
<tr>
<th>DECISION</th>
<th>PROBABILITY</th>
<th>EVENT</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>USE SECUREMENT DEVICE</td>
<td>0.015</td>
<td>Accident Occurs</td>
<td>$1,700</td>
</tr>
<tr>
<td>(Expected Cost: $223)</td>
<td></td>
<td>No Accident Occurs</td>
<td>$200</td>
</tr>
<tr>
<td>DO NOT USE SECUREMENT DEVICE</td>
<td>0.015</td>
<td>Accident Occurs</td>
<td>$25,000</td>
</tr>
<tr>
<td>(Expected Cost: $375)</td>
<td></td>
<td>No Accident Occurs</td>
<td>$0</td>
</tr>
<tr>
<td></td>
<td>0.985</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

FIGURE I
DECISION TREE FOR WHEELCHAIR SECUREMENT SYSTEMS
TABLE V

SENSITIVITY ANALYSIS

<table>
<thead>
<tr>
<th>CASE</th>
<th>COST OF ACCIDENT RESTRAINT</th>
<th>NO RESTRAINT</th>
<th>EXPECTED COST RESTRAINT</th>
<th>NO RESTRAINT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$1,700</td>
<td>$25,000</td>
<td>$223</td>
<td>$375</td>
</tr>
<tr>
<td>2</td>
<td>$1,700</td>
<td>$10,000</td>
<td>$223</td>
<td>$150</td>
</tr>
<tr>
<td>3</td>
<td>$1,700</td>
<td>$40,000</td>
<td>$223</td>
<td>$600</td>
</tr>
<tr>
<td>4</td>
<td>$700</td>
<td>$25,000</td>
<td>$208</td>
<td>$375</td>
</tr>
<tr>
<td>5</td>
<td>$2,700</td>
<td>$25,000</td>
<td>$238</td>
<td>$375</td>
</tr>
</tbody>
</table>

The sensitivity analysis examines the entire range of expected accident costs with and without restraint systems. The results show that the total cost of accidents is lower using the wheelchair restraint system in four out of five cases. Holding the accident cost using secured wheelchairs constant at $1700, the break-even point for costs associated with unsecured wheelchair accidents was determined to be $14,833. This was calculated using the equation

\[
C(N) = \frac{(W \times P(N) + C(S) \times P(A))}{P(A)}
\]

where
- \(C(N)\) = the break-even cost associated with accidents involving unrestrained wheelchairs,
- \(W\) = the cost of the wheelchair restraint system ($200),
- \(P(N)\) = the probability of an accident not occurring (0.985),
- \(C(S)\) = the cost associated with accidents involving restrained wheelchairs ($1700), and
- \(P(A)\) = the probability of an accident (0.015).

Holding the cost of accidents without wheelchair securement constant at $25,000, the net accident cost using restraint systems is lower for the entire range of accident costs associated with secured wheelchairs ($700-$2,700).
A break-even analysis was also performed with respect to the probability of accidents. The analysis assumed a fixed accident cost of $25,000 without a restraint system, and $1700 with a securement device. The probability at which the expected net cost of an accident with a securement device equals the net cost without a securement device was determined using the equation

\[ P(A) \times C(S) + W \times (1 - P(A)) = C(N) \times P(A) \]

where 
- \( P(A) \) = the break-even probability of an accident such that the net cost of restrained and unrestrained accidents are equal,
- \( C(S) \) = the cost associated with accidents involving restrained wheelchairs ($1700),
- \( W \) = the cost of the wheelchair restraint system ($200), and
- \( C(N) \) = the net cost of accidents in which restraint systems are not used ($25,000).

The break-even probability was determined to be 0.85%, which is approximately half of the probability estimated by the National Highway Traffic Safety Administration. This analysis shows that the accident rate would have to drop significantly for the net cost of unsecured wheelchair accidents to be equal to the cost of collisions using restrained systems.

**Summary**

The use of wheelchair restraint systems can be justified based on the reduction in pain and suffering of the accident victims. The decision tree analysis presented in this chapter shows that restraint systems can also be
justified on the basis of reduced total cost. A sensitivity analysis indicates that the cost savings associated with restrained wheelchairs are valid for a wide range of accident costs. Conclusions and recommendations based on the research and analyses performed for this report are contained in Chapter V.
A considerable effort has been placed on making motor vehicle transportation accessible to wheelchair users, particularly in the form of small buses and vans. Wheelchair restraint systems currently in use are generally inferior to those available for the general population. This situation is made more critical because the disabled are more susceptible to injury in an accident.

Most wheelchair restraint products on the market today have been developed by small companies which are inexperienced in the design of occupant protection devices. Some of the systems contain sharp corners and other design deficiencies which may make them more dangerous in the event of an accident than using no restraint system at all.

The basic principles of crashworthiness design applied in the design of restraint systems for the able-bodied should be applied in wheelchair restraint systems. The structure of the restraint system should be strong enough to withstand deceleration forces of 15g or more. The restraint should be mounted to the floor with four bolts to prevent the device from breaking loose. Wheelchairs should not be placed in a side-facing position in the vehicle because more serious injuries can result in a collision. The wheelchair
and the occupant should be restrained independently in order to avoid placing excessive load upon the passenger in an accident. The passenger restraint should be designed to distribute the load evenly over the occupant, and head restraints should be used to prevent whiplash.

A survey of vendors, transportation agencies, and nursing homes in the Central Florida area revealed that most agencies do not provide adequate wheelchair securement devices in their vehicles. A cost analysis of restraint systems has shown that the implementation of effective wheelchair securement can be justified on the basis of a reduction in total accident cost. Effective restraints can also result in a significant reduction in pain and suffering which cannot be measured in dollars and cents.

A number of wheelchair securement devices have been tested at Texas A&M University, Wayne State University, and the University of Michigan Transportation Research Institute. The tests confirm the inadequacy of most of the current products for restraining wheelchairs and their passengers (Schneider 1981). Significant improvements can be made if the manufacturers incorporate the results of the sled tests into future designs. The Q-Straint system is an example of an effective wheelchair securement device which was designed by a Queen's University team from Mechanical Engineering and Surgery. There is a need for a more dedicated effort on the part of the government, foundations,
research institutions, and manufacturing organizations to provide effective wheelchair restraint system designs. Regulations should be established to ensure that these systems are implemented in the vehicles which transport the disabled.
APPENDIX A

WHEELCHAIR RESTRAINT TESTING METHODS
Texas A&M University Test Plan

A test plan was developed at Texas A&M University to evaluate the capability of commercially available wheelchair restraint systems to hold the wheelchair and occupant in position during vehicle motion and collision. The following areas were examined (Rider, McDermott, and Thompson 1976):

1. Does the restraint system accomplish its stated purpose?
2. Are good design and fabrication practices used?
3. What actions or decisions are required by the occupant or attendant?
4. What are the possible occupant and attendant errors?
5. What is the movement of the wheelchair for inertial forces from \( 0g \) to \( 1g \) (the range of forces normally encountered during driving)?
6. What movements, permanent deformations, and failures are noted for inertia forces greater than \( 1g \)?

A test plan was developed to aid the researchers. The test plan is for static testing only so that the inertia effects due to applying the forces are negligible. The authors recommend that those devices which perform adequately in the static test should be evaluated using dynamic testing techniques (Rider, McDermott, and Thompson 1976). A copy of the test plan is provided in Appendix A.
Test Equipment

Each wheelchair restraint system was evaluated using static testing techniques. A strong structure was developed between the restraint system and the puller in order to generate forces greater than 100 pounds. A test sled was developed for this purpose. The frame of the test sled is constructed of double 2" x 6" boards reinforced with iron. The restraint systems are bolted to a one-eighth inch plate, which simulates the van or bus floor. An anthropomorphic dummy was used to simulate an occupant in the wheelchair.

An A-frame and hydraulic cylinder provide the means of pulling on the wheelchair and occupant with forces up to 4000 pounds. The test sled moves approximately 5" during the testing process, so a "come-along" unit was added to take up the movement. Two pointers were used as a reference to measure the motion of the wheelchair during testing: one pointer at the original position, and another at the final location of the wheelchair.

After completion of the sled test, a test plan form was filled in for each wheelchair restraint device. The results of the product testing are discussed in Chapter II.

Wayne State University Test Plan

The Wayne State University wheelchair restraint system was evaluated dynamically using sled deceleration tests conducted on the Wayne Horizontal Acceleration Mechanism-III
A fiftieth percentile anthropomorphic dummy (5 feet 8 inches, 162 pounds) was used as a surrogate for the disabled passenger (Orne, Barak, and Fisch 1976). A manual wheelchair with a three-point belt system was used in the tests. The wheelchair securement cable was engaged in a spring-loaded lever mechanism at the base of the restraint couch and the pedestal was clamped to the sled. A collision was simulated by bringing the sled up to the desired impact velocity, and then decelerating rapidly.

The peak deceleration force, in g's, is determined by the formula

\[ g = \frac{0.629 \times (\Delta V)^2}{s} \]

where \( \Delta V \) is the velocity in miles per hour and \( s \) is the sled stopping distance in inches. For example, a velocity of 15 mph and a stopping distance of 15 inches produces a peak deceleration of 9.44g (Orne, Barak, and Fisch 1976). Frontal impact tests of the wheelchair restraint systems were conducted at 9.82g and 15.10g, and rear-end collisions were simulated at 8g.

After each sled test was performed, the wheelchair was examined for damage. In order to determine the severity of the injuries that an occupant in the wheelchair would have received, acceleration measurements were taken at the head and chest of the anthropomorphic dummy. As discussed in Chapter II, the Wayne State University design performed well
in the sled tests, with little damage to the wheelchair and acceptable protection for the occupant.

Testing the Collins Saf-T-Lock and Saf-T-Straint

The effectiveness of the Collins Saf-T-Straint and Saf-T-Lock restraint systems were evaluated at the Highway Safety Research Institute sled facility at the University of Michigan. A sled impact pulse of 20 miles per hour, and 16g were used in the tests. The restraint systems were tested in forward, rearward, and side-facing applications.

The facility consists of an impact sled that moves on a 45-foot track into a pneumatic decelerator which is capable of simulating crashes up to 75 miles per hour and 75g. The sled is driven by a ram powered by compressed gas (Schneider and Melvin 1978). The sled operates on the principle of rebound, stopping and reversing direction abruptly. The results of the wheelchair restraint system tests are discussed in Chapter II.

Testing of the Q-Straint Tie-Down

The Q-Straint restraint system was evaluated at The University of Michigan Transportation Research Institute. A velocity of 30 miles per hour, and an average deceleration of 20g were used in the testing process.

The test was performed on the UMTRI impact sled, which develops the desired acceleration values by reversing its direction of travel during the impact event (University of
Michigan Transportation Research Institute 1984). Two seat belt load cells were used to measure the webbing tensions in the lap and shoulder belts of the anthropomorphic dummy. Data generated during the test are recorded and analyzed using a NOVA/4 computer. Two high-speed motion picture cameras were used to record the collision event.

The tests were set up with the dummy facing forward on the sled platform. The front Q-Straint belts were hooked to the front posts of the wheelchair by means of large steel hooks, and the rear straps were hooked to the rear vertical posts. The lap belt of the Q-Straint was attached to the rear tie-down straps, and the shoulder belt was attached to the right side of the lap belt. The Q-Straint performed very well in these simulated collisions. The results are discussed in Chapter II.

**Summary**

Testing of wheelchair restraint systems is accomplished by the use of sled tests. The sled is accelerated to a desired velocity and then abruptly stopped. Anthropomorphic dummies are used to simulate human occupants in the wheelchair. Acceleration forces are measured at the point where the restraint touches the dummy in order to determine if internal injuries would result in the event of an accident. The damage to the wheelchair and restraint system are also evaluated in the testing process.
APPENDIX B

TEXAS A&M UNIVERSITY RESTRAINT TEST PLAN
Test Plan

1. Can the wheelchair restraint as received be installed in a vehicle and used to secure a wheelchair? If not, why not?

2. Good design/fabrication practices
   a. Cables
   b. Fasteners
   c. Linkage, connections, grooves
   d. Welds
   e. Stress concentrations
   f. Material
   g. Tolerances
   h. Parts interference
   i. Adjustability (including van installation)
   j. Neatness and compactness
   k. Sharp edges
   l. Mounting of restraint (Permanent or portable?)

3. Required occupant/attendant actions/decisions
   a. Manipulates w/c into restraint system.
   c. Total time involved (Secure?, Release?).
   d. Watch for clearance.
   e. Move into restraint system, forward or backward.
   f. Learn operating procedures.

4. Possible occupant/attendant errors.
   a. Alignment of w/c.
   b. Failure to secure completely.
   c. Interference of parts.
   d. Wrong wheelchair.
   e. Move controls during vehicle operation.
   f. Failure to perform required maintenance.
5. Movement of w/c for forces from 0g to 1g (range of forces normally encountered during driving).
   a. Motion of w/c by pushing and pulling on it (Rolling?, Sliding?).
   b. Motion of w/c with .5g force.
   c. Motion of w/c with lg force.
   d. Yielding of members of the w/c and/or restraint.
   e. Spreading of joints in the w/c and/or restraint.
   f. Motion of the occupant (dummy) during tests.

6. Movement, permanent deformations, and failures for loads greater than 1g (range of collision forces). Deflection tests will be discontinued if failure of the system occurs. Permanent deformation measured after load released.
   a. Longitudinal loads (both directions)
      1. 2.5g force
      2. 5g force
      3. 7.5g force
      4. 10g force
      5. 12g force
      6. 15g force
   
   b. Lateral loads
      1. 2.5g force
      2. 5g force
      3. 7.5g force
      4. 10g force
      5. 12g force
      6. 15g force
APPENDIX C

SURVEY DATA
The name, address, and phone number of each vendor and transportation agencies contacted during the course of the survey are listed in this appendix. The name of the contact at each facility is also provided.

Vendor Survey

Action Mobility Products Services, Incorporated
500 West Lantana Avenue
Lantana, Florida 33462
Phone: (800) 432-1459
Contact: Donna Baatelean

Braun Corporation
5072 113th Avenue North
Clearwater, Florida 33250
Phone: (813) 576-2737
Contact: Karl Beck

Florida Handicap Supply, Incorporated
Highway 427, Unit 895-D
Longwood, Florida 32750
Phone: (305) 323-8710
Contact: Al Corridi

World of Independence
1800 South Division Street
Orlando, Florida 32805
Phone: (305) 422-1069
Contact: Terri Spears
Transportation Agencies

Center for Independent Living
130 West Central Boulevard
Orlando, Florida 32803
Phone: (305) 628-2253
Contact: Al Woodruff

Federation of Senior Citizens
P.O. Box 1332
Altamonte Springs, Florida 32715-1332
Phone: (305) 831-1631
Contact: Marie Goodwin

Florida Rural/Metro Transportation
4728 Old Winter Garden Road
Orlando, Florida 32805
Phone: (305) 298-6700
Contact: George Laberee

Orange County Board of Education
5140 North Pine Hills Road
Orlando, Florida 32808
Phone: (305) 291-7101
Contact: Catherine Odell

Yellow Cab Company
324 West Gore Street
Orlando, Florida 32803
Phone: (305) 422-4455
Contact: Dan Dease
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Kelvin, Allan E. "Human Factors in Rehabilitation and Health Care--Transportation for the Handicapped." 1979. (Typewritten.)


Nicholson, Robert M. "Where Have We Been--Where Are We Going?" Human Factors Engineering, Transportation Systems Congress and Exposition, (March 1979) 1-16.


University of Michigan Transportation Research Institute. "'Q-Straint' Tie-Down and Occupant Restraint System (Without Brackets)." October 19, 1984. (Typewritten.)