

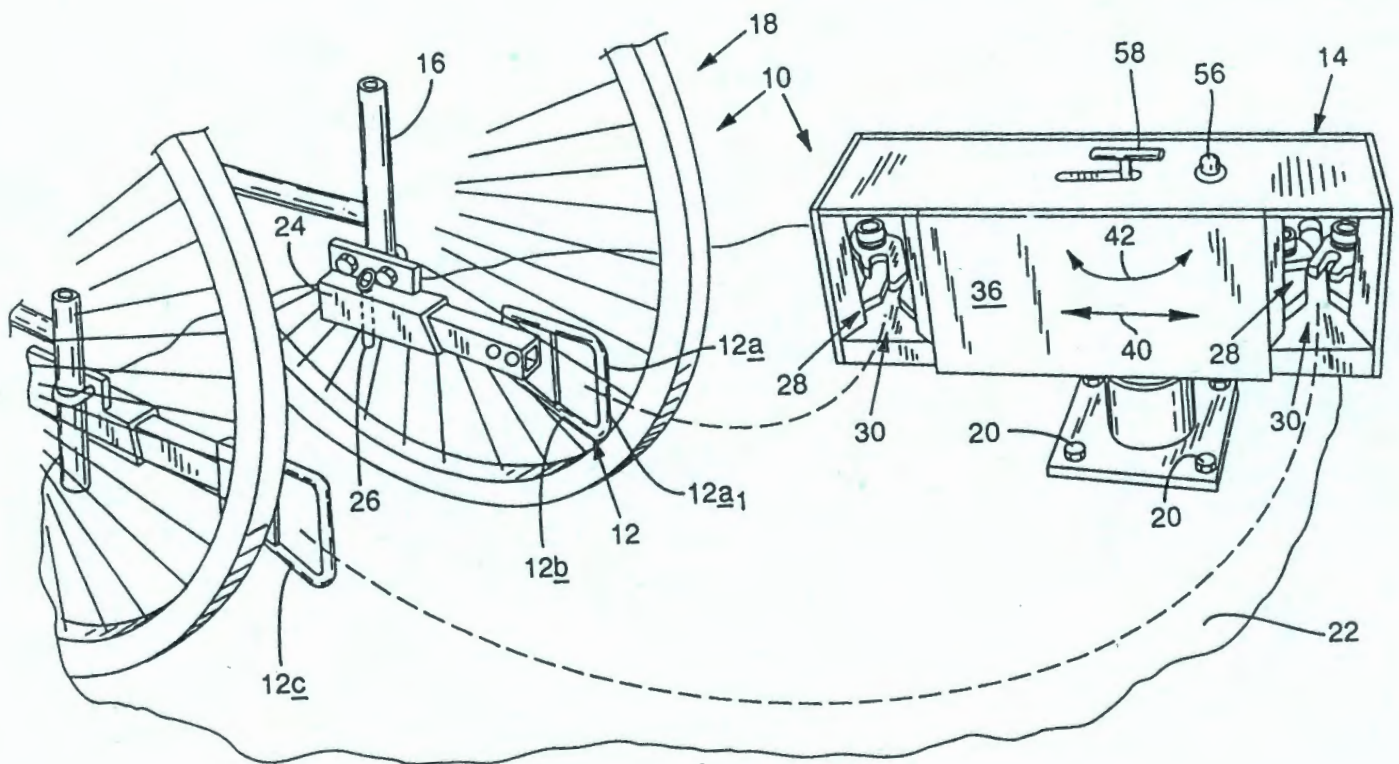


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PREPARATION OF THE OSU SECUREMENT SYSTEM FOR A DEMONSTRATION PROJECT

December 1995

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PREPARATION OF THE OSU SECUREMENT SYSTEM FOR A DEMONSTRATION PROJECT

Final Report

December 1995

Prepared by

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16. Abstract <p>The preparation of the OSU Securement System for a Demonstration Project has been a multifaceted and multi-year project. The project has involved the development and testing of an occupant restraint system and interface design concepts for a large number of "mobility aids in common use". The project has also involved technology transfer activities such as patent applications and license rights to the technology. The project design team has been involved in numerous standards organizations activities, the development of a production version of the securement system, and sled tests of the production version of the OSU securement system. The OSU Securement System is an "auto engaging" securement system that is also known as the "Independent Locking Securement" (ILS) system.</p> <p>The Quality Functional Deployment method was used for the design of the OSU Restraint System. The QFD approach included surveying present technology, establishing customer requirements, studying design loads, determining functional decomposition of the device requirements, establishing engineering requirements, bench marking present technology, generating new idea, selecting a final design, construction of several prototypes, conducting human-factor testing and undertaking both static and dynamic tests, and making a final recommendation of the design. An Advisory Committee consisting of persons with disabilities and representatives of a number of transit agencies assisted with the design and calibration of the QFD matrix. In addition to the restraint system, a number of mobility aid interfaces were designed to be used with the Independent Locking Securement System. The project report documents the many activities of the research and development project.</p>					
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ENGLISH TO METRIC

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 1 square foot (sq ft, ft²) = 0.09 square meter (m²)
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 1 quart (qt) = 0.96 liter (l)
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 1 cubic foot (cu ft, ft³) = 0.03 cubic meter (m³)
 1 cubic yard (cu yd, yd³) = 0.76 cubic meter (m³)

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1 millimeter (mm) = 0.04 inch (in)
 1 centimeter (cm) = 0.4 inch (in)
 1 meter (m) = 3.3 feet (ft)
 1 meter (m) = 1.1 yards (yd)
 1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm²) = 0.16 square inch (sq in, in²)
 1 square meter (m²) = 1.2 square yards (sq yd, yd²)
 1 square kilometer (km²) = 0.4 square mile (sq mi, mi²)
 1 hectare (he) = 10,000 square meters (m²) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
 1 kilogram (kg) = 2.2 pounds (lb)
 1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

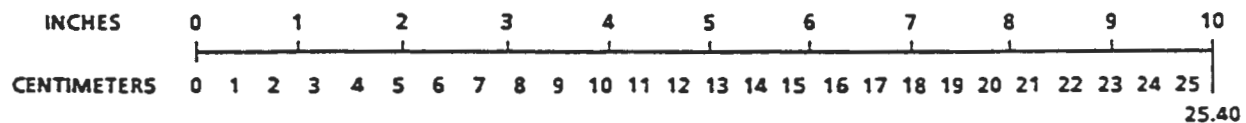
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1 milliliter (ml) = 0.03 fluid ounce (fl oz)
 1 liter (l) = 2.1 pints (pt)
 1 liter (l) = 1.06 quarts (qt)
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 1 cubic meter (m³) = 36 cubic feet (cu ft, ft³)
 1 cubic meter (m³) = 1.3 cubic yards (cu yd, yd³)

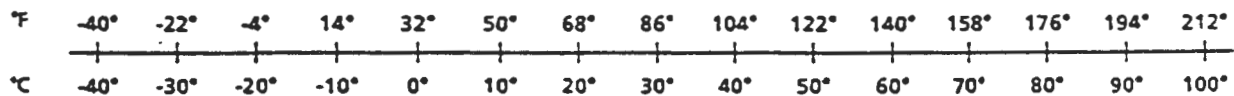
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EXECUTIVE SUMMARY

The preparation of the OSU Securement System for a Demonstration Project has been a multifaceted and multi-year project. The project has involved the development and testing of an occupant restraint system and interface design concepts for a large number of "mobility aids in common use". The project has also involved technology transfer activities such as patent applications and license rights to the technology. The project design team has been involved in numerous standards organizations activities, the development of a production version of the securement system, and sled tests of the production version of the OSU securement system. The OSU Securement System is an "auto engaging" securement system that is also known as the "Independent Locking Securement" (ILS) system.

The Quality Functional Deployment method was used for the design of the OSU Restraint System. The QFD approach included surveying present technology, establishing customer requirements, studying design loads, determining functional decomposition of the device requirements, establishing engineering requirements, bench marking present technology, generating new idea, selecting a final design, construction of several prototypes conducting human-factor testing and undertaking both static and dynamic tests, and making a final recommendation of the design. An Advisory Committee consisting of persons with disabilities and representatives of a number of transit agencies assisted with the design and calibration of the QFD matrix.

In addition to the restraint system, a number of mobility aid interfaces were designed to be used with the Independent Locking Securement System. Since there are no universal mobility aid designs there are no universal interface designs. Many mobility aids lack the structural integrity to support any securement system and these mobility aids will continue to cause problems for transit agencies and transit passengers. There are many new types of mobility aids and some very traditional mobility aids that are robust, durable and strong, and can support the loads imposed by securement systems under crash conditions. The time has come for the transit industry, securement system designers and manufacturers, and mobility aid manufacturers to come to agreement on the mechanical requirements of mobility aids that are used on public transportation vehicles. A start has been made by several groups concerned with the development of standards for belt style securement systems. The interfaces were designed for manual and powered mobility aids. Extensive interface development will be part of the demonstration project.

The technology transfer activities included the application and award of a U.S. Patent for the ILS securement system. A U.S. manufacturer was licensed to manufacture and market ILS systems, however the manufacturer did not meet the diligence clauses of the agreement and so the license agreement was terminated.

The OSU Securement System and OSU Restraint System have introduced new concepts in the design of wheeled mobility aid securement systems. Auto-Engaging Securement Systems is a new term that has been introduced to describe this technology. The initial reaction to this technology by transit agencies and transit passengers who use public transit has been exceedingly positive. It is anticipated that the demonstration project at Lane Transit District in Eugene will provide operational data that will answer a number of questions that the new concepts have raised. It is also anticipated that the demonstration project will document the operational advantages of the OSU securement system.

The OSU Securement and Restraint System project team is very optimistic that auto-engaging securement systems will become the industry standard in the next five to ten years.

ACKNOWLEDGEMENTS

The Preparation of the OSU Securement System for a Demonstration Project would not have been successful without the strong support of the Advisory Committee. The Advisory Committee was made up persons with disabilities who regularly ride public transportation as well as representatives of a number of transit agencies in the Pacific Northwest, and state and local government officials. Appendix A lists the members and addresses of the advisory committee. The project team consisting of Joseph Zaworski, Garrett Clarke David Ullman, Derald Herling, and K.M. Hunter-Zaworski, would like to thank a number of people who gave special support to the project. In particular, they thank George Izumi, Roger Tate, Elizabeth Solomon, and Marina Drancsak of the U.S. Department of Transportation, Federal Transit Administration, for their strong encouragement and support for the team members and project; and Mr. Dennis Cannon of the U.S. Architectural and Transportation Compliance Board (The Access Board)for his direction and guidance.

The project team is thankful for the support for the project given by Drs. Reistad and Huber, Chairmen of the Department of Mechanical Engineering and Civil Engineering, respectively, at Oregon State University.

The project team is very grateful for the strong support, mentoring, guidance and direction given by Mr. Bill Henderson, recently retired from the Snohomish Senior Services.

The project team would like to give a very special acknowledgement to Patricia Nielsen, Accessible Transit Planner with TRI-MET in Portland, Oregon, and the members of her Citizens Advisory Committee for Accessible Transit. We also thank Jan Campbell of the City of Portland for assistance in organizing advisory committee meetings. The project team would like to give a very special acknowledgement to Micki Kaplan, Accessible Transit Planner with Lane Transit District in Eugene, Oregon, and the members of her Citizens Advisory Committee for Accessible Transit. Their support and guidance was instrumental in the direction of the project.

The project team also thanks Dr. Larry Schneider and his staff of the University of Michigan Transportation Research Institute for their assistance in the sled tests of the prototypes.

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CHAPTER 1 – INTRODUCTION

The preparation of the OSU Securement System for a Demonstration project has been a multi-year and multifaceted project that has ranged from the development of an occupant restraint system to the technology transfer, patenting and licensing of the original OSU securement system. The project has come to completion with the start of a full scale demonstration project of the OSU securement system in Eugene, Oregon. This is sponsored by Project ACTION and will be completed in June 1996. The OSU Securement System problem analysis and design are described in detail in two volumes of the final project report for the design of a "Universal" Securement System [8,9]. This report will document the many activities that have brought the technology from the university laboratory into full scale implementation. This report will also discuss the evolution of the restraint system design, and the progress on the development of mobility aid interfaces.

A sub task of the Preparation for Demonstration project was the OSU Restraint System Project (OSU Restraint Project). The project included the passenger restraint problem analysis, design and construction of a restraint system prototype, and extensive testing of both the operational and engineering aspects of the restraint system. The primary objective of the OSU Restraint Project was to design, build, and test a mobility aid passenger restraint system that would operate with the OSU Securement System as well as other securement systems, on both fixed route and paratransit vehicles. The major requirements for the system were to maximize mobility aid user independence, minimize transit vehicle operator involvement, minimize attachment and release time, and satisfy all the proposed restraint standards and guidelines.

The development of interfaces between the mobility aid and the OSU Securement System has been an ongoing effort involving a number of undergraduate engineering students, and other independent manufactures. Several of the concepts for a "universal" interface for some classes of mobility aids are discussed.

Technology transfer activities have involved a significant amount of effort on the part of Mr. Bill Hostetler of the Technology Transfer Office at Oregon State University, the patent and trademark lawyers and executives at Mobile Tech.

In addition the project team has been involved in numerous presentations, and standards committee meetings, and responses to public inquiries.

Organization of the Report

The final report discusses the various activities associated with the project. Part 1 discusses the development of the OSU Restraint System. Part 2 includes a discussion of the development of various interface concepts. Part 3 provides an overview of the Patent and Licensing Process.

Part 1 of the final report details one part of an effort to design an easy-to-use, effective restraint system for mobility aids users on transit vehicles. Specifically, this part focuses on the Quality Functional Deployment (QFD) technique used to understand this problem which has proved challenging both technically and politically. The technical difficulty of restraining mobility aid users on both fixed route transit vehicles (buses) and demand response vehicles (generally vans) is evidenced by the dissatisfaction of the user communities with what is currently available. Political difficulty is evidenced by the number of diverse committees that are concerned with the problem and the number of standards organizations producing requirements for such systems. The main political issues for mobility aid users, is the regulation that a passenger restraint system must be provided, but the mobility aid users are not required to use the restraint system on fixed route buses. The complexities of the problem will become clear in this report.

Chapter 2 of this report discusses the background of the restraint project, problem statement, research goals, design objectives, and introduces the Project Advisory Committee. Chapter 3 introduces the Quality Functional Deployment Method with minor reference to how it was applied to the OSU Restraint System Project. Chapter 4 provides a brief literature review and summarizes a survey of present technology. Chapters 5 and 6 discuss details of the QFD application to the restraint system problem. Chapter 5 details the engineering requirements of a restraint system for mobility aids. Chapter 6 discusses the benchmarking of existing restraint technology. Chapter 7 describes the design of the OSU restraint system. Chapter 8 discusses the operational and engineering tests of the passenger restraint system.

Part 2 discusses the development of the mobility aid interfaces. Chapter 9 provides an overview of the interface development process that has involved a number interested parties.

Part 3 and Chapter 10 discusses the technology transfer activities surrounding the OSU Securement System. Chapter 11 provides a brief summary of project recommendations. Chapter 12 includes a list of references used in the report.

PART I

CHAPTER 2 – OSU RESTRAINT SYSTEM

Background

Providing access on public transit vehicles for persons with disabilities is a well established goal of all public transit agencies. People with disabilities use a variety of mobility aids and other assistive devices and rely on public transportation for their personal mobility. However, the diversity and styles of wheeled mobility aids create significant problems for public transit agencies when it comes to securing them on transit vehicles. This problem was identified by Project ACTION's Reconnaissance Survey as well as by a large number of transit agencies [10]. Before going further into the problem, it is important to have a well defined vocabulary. Some of the key words and phrases used in this report are as follows.

Vocabulary

A Person with a Disability: A person with a disability is defined in part by the U.S. Department of Transportation 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 and services as effectively as persons who are not so affected."

Mobility Aid: Mobility aid refers to a chair mounted on wheels to facilitate the mobility of persons with disabilities in a seated position. Some common wheeled mobility aids are three wheeled scooters, power base wheelchair, powered wheelchairs, light weight sport style wheelchairs, and manual wheelchairs.

Securement System: The securement system refers to the apparatus installed on transit vehicles for the purpose of limiting motion of an occupied wheeled mobility aid in a specific location in the vehicle.

Restraint System: The purpose of the restraint system is to hold a passenger in a seated position during transportation by transit vehicles. (Note the distinction: a securement system is for a mobility aid and a restraint system is for a person.)

Problem Statement

The problem of restraining mobility aid users stems from two sources. First is the need to adequately restrain mobility aids users when travelling in transit vehicles. Currently a number of different types of systems are available to accomplish this, most making use of two or three belts that attach to the side wall and the floor of the vehicle. These systems were derived from hardware developed for the securement of cargo on aircraft or passenger car seat belt systems. Most require the driver or an attendant to attach the personal restraint system.

The second source for the problem of restraining mobility aid users is the American with Disabilities Act (ADA) requirement that all transit vehicles must be equipped with a three point passenger restraint system. The ADA regulations do not specify that the restraint must be used. This report will describe implicitly some of the problems with the existing restraint systems.

Research Goals

The project undertaken at Oregon State University had two primary goals: to fully understand the problem and to design, build and test a prototype system based on this understanding. These two requirements needed an organized and unbiased party to develop the information needed to design new systems and develop new ideas. Additionally, an organized method, such as the Quality Functional Deployment Method (QFD) allows others to critique it, build on it and modify it as the problem matures and evolves in time. Additionally, the (QFD) method described in this report is organized, repeatable and modifiable by other researchers. Finally, and most importantly, the method resulted in the generation and organization of information that formed the foundation for development of concepts and a prototype restraint system. The QFD method had been used successfully by the design team in the development of the OSU Independent Locking Securement System, and is documented in [8,9].

Design Objectives

The major design objectives of the OSU Restraint System were as follows:

1. Accommodate a large variety of mobility devices, such as sports style manual wheelchairs and "scooter" style electric wheelchairs, using the OSU Independent Locking Securement System as well as other securement systems,

2. Safely provide restraint for the passenger,
3. Satisfy the USDOT/FTA American with Disabilities Act (ADA) regulations and guidelines, as well as the proposed Canadian Standards Association (CSA) regulations for Mobility Aids Securement and Occupant Restraint (MASOR)[3].
4. Reduce securement time and operator involvement, and provide as much independent operation by wheeled mobility aid users as possible,
5. Reduce time for release of mobility aid user from the restraint system, to reduce cycle time, and permit rapid evacuation if necessary,
6. Be applicable to both fixed route and demand responsive transit vehicles, and satisfy the technical requirements of the different vehicles operating in urban, suburban and rural settings,
7. Operate in all climatic conditions,
8. Maximize occupant protection,
9. Not require extensive operator training for correct use,
10. Operate as a continuum between the transportation vehicle-mobility aid and occupant.

Project Advisory Committee

An advisory committee, which was formed to assist with the securement system project, was retained for the development of the passenger restraint system. An Advisory Committee had been formed in 1987 for the Human Factors in Public Transportation Safety Project undertaken by OSU/TRI for the USDOT/FTA. Both the new and previous advisory committees had many of the same members. The project advisory committee was made up of persons with disabilities who regularly use transit, and many also represent organizations associated with disabilities. Other members of the advisory committee included: accessible transit planners, transit vehicle operators, maintenance personnel, transit managers, and state government representatives. The advisory committee had representatives from Lane Transit District (LTD) in Eugene, Oregon, TRI-MET in Portland, Oregon, METRO in Seattle, Washington, and B.C. Transit in Vancouver, B.C. Appendix A includes a list of members of the Advisory Committee.

CHAPTER 3 – THE QUALITY FUNCTION DEPLOYMENT METHOD FOR UNDERSTANDING ILL-DEFINED PROBLEMS.

Quality Function Deployment (QFD)

The QFD method, was developed in Japan in the mid-1970s and introduced in the United States in the late 1980s. Using this method, Toyota was able to reduce the costs of bringing a new car model to market by over 60 percent and to decrease the time required for its development by one-third. They achieved results while improving the quality of the product. Many U.S. companies now use the QFD method regularly. As described below, the method involves a time commitment, but it assumes the problem is understood and saves much time later. Its effectiveness thus dictates that it be followed from the beginning of all design projects. For more details on this method see references 1 or 2 or Volume 1 of the final report for the OSU Securement System.[8]

The QFD Technique: OSU Restraint System Application

The QFD technique serves to insure that the problem is well understood. It is useful on all types of design problems and results in a clear set of customer requirements and associated engineering measures and targets. It may appear to slow the design process but, in actuality, it doesn't. Time spent developing information in the Problem Understanding Form is returned in time saved later in the design process.

In the early stages of the QFD technique, we had the assistance of an advisory committee. The makeup of this committee was based on our identification of the "customer" for the restraint system product. The list of customer types evolved as literature was studied and the methodology followed. The types of customers identified were:

- Mobility Aid Passenger
- Other Passengers
- Transit System Operator (driver)
- Transit System Maintenance Personnel
- Transit System Manager
- Transit Vehicle Manufacturer
- Mobility Aid Manufacturer
- Securement/Restraint System Manufacturer
- Standards Groups/Other Organizations

The advisory committee, consisting of representatives from most of these groups, met to assist in developing the customers requirements and weighing their importance. The list of customer requirements that evolved through these meetings and review of the literature are listed in a QFD matrix, which is too large to publish. It is not possible to discuss all the considerations that went into the QFD matrix. However, the basic factors in the matrix followed directly from the project proposal and earlier work undertaken by Hunter-Zaworski [6,7]. One of the most useful aspects of the QFD method is the effort required to translate the customer requirements into engineering requirements. The need to convert the usually abstract customer requirements into measurable variables requires extensive effort to understand the basic elements of the problem and their interactions. Thus, in Chapter Five, each engineering requirement that comes from the customer requirements will be discussed in detail. First, in Chapter 4, the literature reviewed for background is discussed.

Customer Requirements

A Quality Functional Deployment (QFD) matrix of customer and engineering requirements similar to the matrix for the Oregon State University Securement System project was developed.

Customer Requirements Questionnaire

The following list of 41 statements was the basis of the questionnaire that was sent out to the customers.

1. The mobility-aid passenger will need minimal training.
2. The transit operator will need minimal training.
3. If the restraint system requires connection (attachment), it can be connected in only one obvious way.
4. If the restraint system requires connection (attachment) or disconnection, the passenger's 'personal space' is not invaded too much by "others" that must connect/disconnect it.
5. The restraint system will not effect the use of the mobility aid securement system.
6. If the restraint system must be connected, it will be easy to connect.

7. If the restraint system must be disconnected, it will be easy to disconnect.
8. The restraint system must be able to be connected quickly.
9. The restraint system must be able to be disconnected quickly.
10. The restraint system can be used with any commonly used mobility-aid.
11. The restraint system shall be easy and neat to stow.
12. The restraint system shall be easy and neat to retrieve.
13. The restraint system will allow easy adjustment for passengers of different sizes.
14. The restraint system will allow for misalignment of the mobility-aid in the securement system.
15. If a passive (non-contacting) restraint system is used it shall be activated only under an accident condition.
16. The restraint system should be connected or attached by the transit operator.
17. The restraint system should be connected or attached by the mobility aid passenger.
18. The restraint system should be connected or attached by other passengers.
19. For disembarking, the restraint system shall be released or disconnected by the transit operator.
20. For disembarking, the restraint system shall be released or disconnected by the mobility aid passenger.
21. For disembarking the restraint system shall be released or disconnected by other passengers.
22. The restraint system will operate as designed in hot, wet, cold, salty, or snowy conditions.
23. The restraint system will physically restrict/restrain movement of mobility-aid passenger outside of a 'wobble room' zone during all normal starts/ stops and cornering.

24. The restraint system will feel comfortable to the user inside the "wobble room" zone during normal starts/stops and cornering.
25. If a passive restraint system is used, the restraint system will not contact the mobility aid passenger except when required to during an accident.
26. If the restraint is a "contacting" type system, the restraint system shall not be able to be over-tightened.
27. The restraint system will not be capable of causing harm or injury to other passengers during normal use or as a result of an accident condition.
28. When not being used, the restraint system shall be reasonably protected from vandalism.
29. The restraint system shall have minimal volume.
30. The restraint system will not visually interfere with other passengers.
31. The restraint system will not physically interfere with other passengers.
32. The restraint system shall not interfere with other passengers when stowed.
33. The vehicle floor space modification for the restraint system will be minimal.
34. The cost per mobility-aid station will be less than \$500.
35. The cost per mobility-aid passenger will be zero.
36. The restraint system useful life will equal the vehicle useful life.
37. The restraint system will appear sturdy.
38. The restraint system will not accidentally release under any conditions.
39. The restraint system will require minimal maintenance
40. The restraint system can be installed in all types of buses and vans.

41. The restraint system shall be easy to clean.

This chapter briefly introduced the quality functional deployment (QFD) method and discussed the background materials and information that assisted with the development of the quality functional deployment matrix.

CHAPTER 4 – LITERATURE SEARCH

Literature Search

An extensive literature search was conducted of commercial securement/restraint systems, vendor material for mobility aids, past tests of securement systems, relevant conference materials, and design reports for the development of the OSU Independent Locking Securement System project. The literature review and annotated bibliography was documented in Volume 1 of the final report for that project [8]. This chapter discusses the literature review that was done specifically for the development of a passenger restraint system. The goal of the literature search was to understand the design problem, define all potential customers, understand what customers wanted in a restraint system, understand the scope of application of the restraint system, become familiar with the many types of mobility aids and securement/restraint systems, and study previous testing of restraint devices.

Patent Search

Numerous subject areas related to restraints were searched yielding 13 patents that represents the present spectrum of devices. No new concepts were discovered that are not in some form described below in the present technology section. There was only one concept that was somewhat unique from the above present technologies and that was a frontal cushion device. It modeled in concept the roller coaster ride device.

A search of the US Patent Office Gazette yielded a number of patents that were of interest. Table 4.1 lists the most recent securement/restraint system patents.

Present Technology Survey

The survey of present technology was undertaken by surveying transit agencies [23], collecting technical information on commercial and prototype restraint systems. Three general categories cover the present technology for restraint systems: devices that have been designed and built and are commercially marketed by vendors; devices that are put together by local transit agencies from component parts commercially available; and devices that are the result of specific projects, or ideas that have been generated but have not gone past the prototype stage.

TABLE 4.1. Recent Securement/Restraint Patents

Issue Year	Patent Number	Title
1974	3811701	Restraining Device for a Vehicle Passenger
1982	4354696	Device for Passive Actuation of a Safety Belt
1983	4396228	Integrated Shoulder Harness and Lap Belt Restraint Apparatus
1984	4427210 4432119 4488691	Wheelchair and Occupant Restraint System Electrically Released Seat Belt Torso Restraint System
1985	4508294 4541425 4552381	Air Bag Restraint System Head and Torso Restraint Passenger Restraint Safety System
1988	4738413 4779700	Harness Restraint System Passive Seat Belt Arrangement for a Vehicle
1989	4796917	Passive Seat Belt System
1991	4997204	Passive Safety Harness

A summary of commercially available systems are outlined below.

TIE TECH Inc. – A four point belt restraint system. This system was developed primarily for the school bus market. A roll bar with padded head rest is also part of the restraint system. The belts are anchored to the floor using a cargo aircraft track. The belt system must be tightened by each passenger or attendant for correct restraint. The system is completely active (as opposed to a passive or no action required by the user/attendant) and has been crash tested.

AMERICAN SAFETY Inc. – Two types, a four and three point belt restraint system. This system was developed for the airline industry for use by the flight attendance crew in their special takeoff and landing seat. Belt retractors are also available. The belts are tightened by the flight attendant. Retractors are automatic. The system is active.

PYROTECT Inc. and SIMPSON RACE Products – Both of these systems are a five point belt restraint. These are intended for automotive racing applications. One special feature of this belt system is the fifth belt that prevents 'submaning' of the person. All belts are tightened manually. The system is active.

MINE SAFETY APPLIANCE International(MSA) – A number of specialty belts and safety harnesses are part of their product line. None of these would work conveniently with mobility aid passengers.

AEROQUIP Corp. – Load binder tie downs for trucks and air cargo. None of these would work with mobility aid passengers even though they show a manual wheelchair example. This system could be used in a para transit van application.

Automotive Passive three point belt system – This restraint system is a passive seat/shoulder belt system found on late model passenger cars. As the car door shuts, the belt system wraps around the passenger. The system is passive or automatic.

Air bag systems – This technology is found in late model passenger cars and is meant to be used in conjunction with a two point seat belt restraint. The air bag is inflated automatically upon crash sensing.

Two point seat belt – This restraint system is the application of a standard automotive seat belt for use in a bus. Some systems have seat belt retractors. All of these systems have the belt bracket bolted to vertical stanchions or to the floor. The system is completely manual.

Seat belt on Mobility Aid – A simple automotive type seat belt is installed on the frame or seat of the mobility aid (all types).

Roller coaster seat bar – A couple of amusement park/fair ride manufactures were contacted to inquire about the technology that they use for their rides. Their restraint system primarily relies on centrifugal forces to keep the passenger in the seat but also have a padded bar that pushes against the thighs and abdomen when locked in place.

Restraint Standards

Standards that apply to restraint systems include the USDOT ADA requirements [4] and the Federal Motor Vehicle Safety Standards (FMVSS) Part 571 Subpart B for Seat belt assemblies for Occupant crash protection #571.208 and Seat belt assemblies #571.209 [5]

Much of the material collected for the Oregon State University Securement System project was used for establishing customer requirements for the personal restraint system. Additionally, literature in the area of newer passive restraint systems was collected. It appears that the present standards and all the past literature considers only a belt style restraint system. Thus all quantitative material refers to a belt configuration and geometry.

In the areas of quantitative valued safety standards, such as Head Injury Criteria (HIC), all requirements reference a person without disabilities. Specifically, Federal Motor Vehicle Safety Standards require femur loading below 2250 pounds (ref. 571.208 S6.1.4) which for a mobility aid passenger may not be a safety requirement. Additionally, HIC and thorax accelerations values may not be appropriate for persons with disabilities.

CHAPTER 5 – ENGINEERING REQUIREMENTS

Engineering requirements were developed for each customer requirement on the QFD matrix. These engineering requirements are discussed in this chapter. The engineering requirements are divided up into several groups. The divisions of the engineering requirements are: performance requirements (1-29), spatial requirements (30-33), cost requirements (34-36), appearance requirements (37), safety requirements (38-39), and maintenance requirements(40-42). In the list of engineering requirements, the target value refers to the quantitative design goal and the engineering unit refers to the way the goal is measured. For example, mobility aid passenger training time has a target value of 2 and engineering units of minutes. This means that the design goal of the restraint system is that mobility aid passenger training time should not exceed 2 minutes.

Performance Requirements

1. Percent of Mobility Aid Passenger that can remain in mobility aid when using the Restraint System.
Target value = 100, Engineering units = %
2. Number of 'other' securement systems that can be used with this Restraint System.
Target value = 100, Engineering units = %
3. Ways Restraint System can be improperly used.
Target value = 0, Engineering units = ways
4. Mobility Aid Passenger training time.
Target value = 2, Engineering units = minutes
5. Transit Operator training time.
Target value = 5, Engineering units = minutes
6. Number of comments from Mobility Aid Passenger that 'personal space' was invaded when using Restraint System.
Target value = 0, Engineering units = comments
7. Increase in Mobility Aid securement connection time because of Restraint System.
Target value = 0, Engineering units = minutes

8. Increase in Mobility Aid securement disconnection time because of Restraint System.
Target value = 0, Engineering units = minutes
9. Adjustments required to be made from one Mobility Aid to the next Mobility Aid before Restraint System can be used.
Target value = 0, Engineering units = steps
10. Steps required to stow Restraint System.
Target value = 0, Engineering units = steps
11. Time required to stow Restraint System.
Target value = 0, Engineering units = minutes
12. Steps required to retrieve Restraint System.
Target value = 0, Engineering units = steps
13. Time required to retrieve Restraint System.
Target value = 0, Engineering units = minutes
14. Increase in total 'bus stop' time due to Restraint System connection.
Target value = 0, Engineering units = minutes
15. Steps required for Restraint System connection.
Target value = 0, Engineering units = steps
16. Increase in total 'bus stop' time due to Restraint System disconnection.
Target value = 0, Engineering units = minutes
17. Steps required for Restraint System disconnection.
Target value = 0, Engineering units = steps
18. Increase in 'restraint connection time' due to wet, cold, salty, or snowy conditions.
Target value = 0, Engineering units = minutes
19. Increase in the number of required Transit Operator interactions with Mobility Aid Passenger because of Restraint System.
Target value = 0, Engineering units = steps

20. Number of parts added to Mobility Aid because of Restraint System.
Target value = 0, Engineering units = parts
21. Mobility Aid Passengers surveyed will report Restraint System is 'comfortable' during all normal usage.
Target value = 100, Engineering units = %
22. Federal Motor Vehicle Safety Standards #571.208 are met.
Target value = yes, Engineering units = y/n
23. Will have device(s) that reduce energy to Mobility Aid Passenger.
Target value = yes, Engineering units = y/n
24. All hardware that is connected by Mobility Aid Passenger will be positive latch type.
Target value = yes, Engineering units = y/n
25. Restraint System material performance in areas of staining cloths, soiling, tearing, cutting of hands will equal present automotive seat belt standards.
Target value = pass, Engineering units = p/np
26. Ways Restraint System can be overtightened.
Target value = 0, Engineering units = ways
27. Restraint System edges and corners will have radius.
Target value = 1/16", Engineering units = inches
28. Corrosion performance of Restraint System will equal that of automotive seat belt.
Target value = yes, Engineering units = y/n
29. Number of times per year Restraint System will become inoperable due to vandalism.
Target value = 0, Engineering units = occurrences

Spatial Requirements

30. When in use, Restraint System volume will be less than.
Target value = xx, Engineering units = cubic inches

31. When in use, reports from 'other passengers' that the Restraint System is visually obstructive.
Target value = 0, Engineering units = reports
32. When in use, reports from 'other passengers' that the Restraint System is physically obstructive.
Target value = 0, Engineering units = reports
33. When stowed, reports from 'other passengers' that the Restraint System is physically or visually obstructive.
Target value = 0, Engineering units = reports

Cost Requirements

34. Restraint System cost.
Target value = 500, Engineering units = \$
35. Mobility Aid cost.
Target value = 0, Engineering units = \$
36. Useful life of Restraint System.
Target value = 10, Engineering units = years

Appearance Requirements

37. In a survey the Restraint System will be rated as being 'sturdy'.
Target value = 80, Engineering units = %

Safety Requirements

38. Emergency release will be identifiable.
Target value = yes, Engineering units = y/n
39. Ways the Restraint System can become inoperable.
Target value = 0, Engineering units = ways

Maintenance Requirements

- 40. Maintenance time per year per unit.
Target value = 2, Engineering units = hours

- 41. Number of vehicles that can be retrofitted with Restraint System.
Target value = 100, Engineering units = %

- 42. Increase in vehicle cleaning time per timed cleaned with Restraint System installed.
Target value = 2, Engineering units = minutes

This chapter discussed the engineering requirements for the development of a passenger restraint system. The engineering requirements reflect the translation of the customer requirements into quantitative design goals.

CHAPTER 6 – IDEA GENERATION FOR THE DEVELOPMENT OF THE PASSENGER RESTRAINT SYSTEM

Idea Generation

The following ideas were generated and used with a Pugh's method of selection. Pugh's method is also called decision-matrix method. It is a very effective method for comparing concepts, scoring them, and finding which concept has the highest possibility for meeting the customer requirements set. Table 6.1 is a description of the candidate restraint systems. The reference letter refers to letters that were assigned by the project team to a number of different designs and concepts. The description of the design includes the commercial name or describes the concept of restraint. The attachment points refer to where the restraint system is attached to the vehicle. There are two options for the rear of the mobility aid and this includes either the floor of the transit vehicles or onto the securement system itself. Some restraint systems attach to the side or the front of the transit vehicle. Often restraint systems that use shoulder straps or harnesses attach to the top or roof structure of the transit vehicle. There are some lap belt type restraint systems that attach to the mobility aid itself. The passenger interface consists of four main classes of restraint. These include belts, air bags, cushions, or a combination of the three. The belts systems include lap belts only which is referred to as a two point system, a lap belt and shoulder strap which is a three point system, a lap belt and shoulder harness which is called a four point system, and finally a lap belt with a tee strap to prevent submarining and shoulder harness which is called a five point system and is often used by race car drivers. Air bags are usually torso fitting or torso and knee fitting. There are three types of activation and these include automatic deployment, passenger activation and external activation.

Final Ideas and Selection

Evaluation Using the Decision Matrix Method

This section will describe a process that has proven very effective for comparing concepts that are not refined enough for comparison to the engineering requirements. This method is fairly simple and is called the **decision matrix** method or, **Pugh's method**. The essence of this method is to score each concept relative to another in it's ability to meet the requirements. Comparison of the scores developed will give insight to the best alternatives and give good information for making decisions. In actuality, this technique is very flexible and can be easily used in other, non-design situations (e.g., which job offer to accept or which car to buy). It is especially useful in forcing careful consideration of the comparison criteria.

Table 6.1 Description of Candidate Restraint Systems

REF	DESCRIPTION	ATTACHMENT POINT	PERSONNEL INTERFACE	ACTIVATION BY
A	Tie Tech	floor	4 point belt	para++
B	Racing harness	rear floor	5 point belt	para++
C	Auto seat belt	shoulder floor	3 point belt	para++
D	Tie Tech + Retractor (inertial)	floor	4 point belt	para++
E	Auto seat belt + retractor (inertial)	floor	3 point belt	para++
F	Auto seat belt	floor	2 point belt	para++
G	Auto seat belt + retractor	floor	2 point belt	para++
H	Simple seat belt	Mobility Aid	2 point belt	home
I	Passive 3 point car design		3 point passive	
J	Passive 2 point car design		2 point passive	
K	Air bag on Mobility Aid	Mobility Aid	air bag	passive
L	Air bag on front wall		front/ceiling air bag	passive
M	Air bag on swing arm		side air bag	passive
N	Air bag on front wall + 2 point belt		belt + bag	para++pass
O	Air bag on swing arm + 2 point belt		belt + bag	para++pass
P	Swing arm from side		side cushion	passive
Q	Swing arm form front/ceiling		front cushion	passive
R	Swing arm from back/overhead		top cushion	passive
S	Seat belt on Mobility Aid + air bag		Mobility Aid + front 2 point belt + bag	home + passive
T	Seat belt on Mobility Aid + cushion		Mobility Aid + front 2 point belt + cushion	home + passive

This is an iterative evaluation method which: will test the completeness and understanding of requirements; will rapidly identify the strongest concepts; and will help foster new concepts if warranted. This method is most effective if each member of the design team performs it independently and the individual results are compared. The results of the comparison lead to a second repetition of the technique, with this iteration continuing until the team is satisfied with the results. There are four steps to this method.

Step 1: Choose Criteria for Comparison

First it is necessary to know the basis on which the concepts are to be compared to each other. In the application of the QFD an effort was made to develop a full set of customer's requirements for the design. These were used to generate a set of engineering requirements and targets that are used to insure that the resulting product will meet the customer's requirements. However, the roughly sketched concepts that were developed, were not refined enough to compare to the engineering targets for evaluation (a mismatch in level of abstraction). The use of the targets must wait until the concept is refined to the point that actual measures can be made on the product designs. Thus, the basis for comparing the design concepts must be the customer's requirements. These, like the concepts, are abstract and thus suitable as a basis for comparison.

Part of understanding the design problem is establishing the importance of each of the customer's requirements. There are two groups of criteria; "musts" (noted by an "**") and "wants" that were weighted relative to each other. Concepts that could not meet the "must" requirements were filtered out in the go/no-go comparison. Comparison between concepts at this point are always made relative to the "wants" requirements. "Must" requirements may also be included if the engineer feels they will help in differentiating between the concepts.

If the customer's requirements had not been developed, this evaluation technique could still be used. However, developing the comparison criteria would require significantly more work than discussed here.

Step 2: Select the Items to be Compared

The items to be compared are the different concepts developed during concept generation. It is important that all the items to be compared are developed to the same level of abstraction and in the same language.

Step 3: Generate Scores

By this time in the design process, every designer has a favorite concept, one that he/she thinks is the best of the concepts that have been developed. Using this concept as a datum all the other designs will be compared to it relative to each of the requirements. If the problem is the redesign of an existing product, then this product, abstracted to the same level as the concepts, can be used as the datum.

For each comparison with the datum, the concept being evaluated is judged to be either better than, about the same as, or worse than the datum. If better than the datum, then the concept is given a "+" score. If it is judged to be about the same as the datum or it is not clear which is best then an "S" is used, where S=same. If the concept does not meet the criteria as well as the datum then it is given a "-".

Note that if a comparison to a design requirement is impossible to make then more information needs to be developed. This may require more analysis, further experimentation or just better visualization. It may even be necessary to refine the design through the methods described earlier and then return to make the comparison.

Step 4: The Total Score

After a concept is compared to the datum for each criteria then four total scores are generated: the number of plus scores, the number of minus scores, the overall total and the weighted total. The overall total is the difference between the number of plus scores and the number of minus scores. The weighted total is the sum of each score multiplied by the importance weighting. An "S" counts as zero, a "+" as +1 and a "-" as -1.

The scores must not be treated as absolute measures of the concept's value rather they are for guidance only. Ways to interpret these scores are as follows.

- If a concept or group of similar concepts have a good overall score or a high "+" score, it is important to notice what strengths they exhibit (Which criteria they meet better than the datum). Likewise, groupings of "-" scores will show see which requirements are especially hard to meet.
- If most concepts get the same score on a certain criterion then examine that criterion closely. It may be necessary to develop more knowledge in the area of the criterion in order to generate concepts that are better than the rest relative to it. It may be that the criterion is ambiguous, and interpreted differently by different members of the team or unevenly interpreted from concept to concept. If the criterion has a low importance weighting, then don't spend much time on clarifying it. However, if it is an important criterion then effort is needed to generate better concepts or clarify the criterion.
- To learn even more from this method re-do it with the highest scoring concept as the new datum. This iteration should be redone until a clear "best" concept(s) emerges.

After each team member has iterated on this procedure, then the entire team should compare their individual results. The results can vary widely because both the concepts and requirements are not well

refined. Discussion amongst the members of the group should result in a few concepts to refine. If not then the group needs to clarify the criteria or generate more concepts for evaluation.

There are two variations that may be of use in situations where enough information is available. The first is to make use of the weighted total score. This often gives a little more insight as the most important criteria are treated as such. The second variation requires the use of a finer scoring system than the three level system. This can be done in terms of a seven level scale where:

- +3 criteria met very superior relative to datum
- +2 criteria met much better than the datum
- +1 criteria met better than the datum
- 0 criteria met as well as datum
- 1 criteria met not as well as the datum
- 2 criteria met much worse than the datum
- 3 criteria met far worse than datum

Assumptions for Analysis:

- 1) Restraint system must meet Federal Motor Vehicle Safety Standards (FMVSS)208 which is HIC and chest acceleration only, since femur loading is not relevant for Mobility Aid Passengers, and it must also meet FMVSS 209 which applies to belt hardware strength.
- 2) Restraint system should equal Oregon State University securement ease of use.
- 3) Score high on Pugh's matrix for customer requirements.

In Table 6.2 the following acronyms are used:

MA	Mobility Aid	A	Tie Tech
SS	Securement Systems	H	Lap Belt
IU	Interface Unit	M	Air Bag
BM	Bench Mark	N	Air Bag and Lap Belt

Table 6.2. Pugh's Method for the OSU Restraint System

Pugh's Method for Oregon State Restraint System Date July 1995		BM	A	H	M	N
PERFORMANCE	Mate MA to SS					
	Hold MA normal					
	Hold MA crash					
	Move SS into position					
	Be light		-			-
	No movement of MA: norm					
	Not be damaged by SS					
	Not damage other items					
	One IU fits all MA		+	+	+	+
	Will be Rigid after 3 years			-		
SPATIAL	Have mim. volume		-	-	-	-
	Be removalable		-	-		
	Not problem to MA		-			
	Mate with SS slot					
MATERIAL	Last 5 years					
	No degradation					
MANUFACTURING	Be producible		-		-	
	Can be Mass Produced		+	+	+	+
COST	Have min. cost		-	+	-	-
APPEARANCE	Be athetical		-	-	-	-
SAFETY	Meet Government standards					
MAINTENANCE	Require no maintenance			-		

INSTALLATION	Be quick to install		-	-	-	-
	Be easy to install		-	-	-	-
	Have min. extra parts		-	-	-	-
RECYCLE	Be recyclable					
	Sum of '+'		2	3	2	2
	Sum of '-'		10	8	7	7
	TOTAL		-8	-5	-5	-5
BM is Bench Mark device						
A is Tie Tech Style device						
H is a simple lap belt device						
M is an air bag and mechanical swing arm						
N is an air bag and lap belt device						

Results from Pugh's Matrix:

1. Tie-Tech will meet Federal Motor Vehicle Safety Standards 208/209 but not Oregon State University ease of use.
2. A lap belt that is connected at home on the user of the Mobility Aid , and is attached to the Interface Unit on Mobility Aid, meets the Oregon State University but not the Federal Motor Vehicle Safety Standards .
3. An air bag on a mechanical swing arm coming up from the seat bottom/side could meet both Federal Motor Vehicle Safety Standards and Oregon State University ease of use. This device is superior to Tie-Tech in 16 other ways and is only inferior in that it alone will not provide support for the Mobility Aid Passenger during normal vehicle motion.
4. An air bag plus a lap belt on the Mobility Aid is superior without drawbacks.

This system concept (#4) has tremendous flexibility. It provides for a simple addition of a belt to the Mobility Aid, through the Interface Unit on Mobility Aid, that will give some level of passenger protection during an accident. If the passenger chooses not to have a belt installed or use it, then he has reduced the transit agencies liability. If an air bag is provided with a disable button, that can be activated to disable the system, then again the passenger has reduced the transit agencies liability.

From Pugh's matrix one can deduce design directions such as the following:

Compared with the bench mark unit.

- a) Under Performance category, a superior design system will maximize pluses (+) from the line Mobility Aid User requires minimum training down to fast disconnection of the restraint system; transit operator interaction with the mobility aid user is minimized; no modification to the mobility aid is required; wiggle room forward, and wiggle room side.
- b) Under Performance category, a superior design system will minimize negatives (-) from the line Without injury-normal acceleration down to Without injury-accident rearward.

The first prototype selection was based upon the ADA requirements for having a 3 point belt restraint system rather than developing any of the above concepts. The use of available present technology that could be used in an unmodified form directed us towards the system developed.

CHAPTER 7 – DESCRIPTION OF THE OSU RESTRAINT SYSTEM

Description of System

The Restraint System was designed for forward facing installation in public buses but is easily adapted to any vehicle type that has a floor structure that can carry the required design loads. It was also designed to be integrated into existing seating arrangements and styles with no reduction in vehicle seating capacity, and was also designed for installations on either side of the vehicle. The Restraint System was designed to be used by mobility aid passengers who use all 'common' types of mobility aids.

The Restraint System is co-located with the securement system, and it was designed to compliment the Oregon State University or ILS Securement System but is easily integrated with any other independent mobility aid securement system that is forward facing for the mobility aid and its passenger. It is intended to be an independent restraint system and does not require any connected device(s) to the securement system. No part of this restraint system depends on any other device for its proper operation, save the vehicle itself. The system uses two standard automotive type seat belts, a lap and a torso unit, that can be used independently or together. It is an active, rather than a passive, restraint system.

The mobility aid passenger, in this bus configuration, backs down the aisle, being forward facing, and docks in the mobility aid securement area. The user, after securing themselves into the mobility aid securement system, can then choose which, if any, portion(s) of the restraint system they desire to use. The mobility aid passenger, or if unable, another passenger or operator, must manually pull or extract the belt(s) from their housings and latch the buckle connections. The lap belt is intended to extend across the lap. The torso belt extend across the upper body area. These two belts make up a three point restraint system. The lap belt system will be either color coded or have a different sized buckle to distinguish it from the torso belt. Release from the belts and the restraint system, is accomplished by pushing the center release button of the buckle(s) as is commonly done with automotive seat belts. The belts will automatically retract back into their housings. The retractors provide nearly unlimited 'wobble' room for the torso area of the passenger by the use of inertial retractor reels for this belt and the lap belt has standard 'snuggness' from the use of standard locking retractors. No 'anti-submarine' strap is included in the system.

The belts and retractors are located inside either a structural member or a housing that is intended to protect the belts and retractors from dirt and damage as well as safely transfer the design loads to the vehicle. The structural members have a three piece configuration which allows triangulation of the design loads to the vehicle and will be padded for normal safety considerations. The present design shows the two main structural members as being free standing and only attached to the vehicle floor. In an early

prototype, the third member of the triangulation, attaches to the bus wall track, the same track that also serves to anchor the passenger seats to the wall. The attachment point of this third member is not restricted to the prototype design's seat wall track but can be attached to the vehicle floor or wheel well area as desired. All of these three structural members can be easily integrated into the vehicle seating and wall structure if so desired.

During normal vehicle operation, when no mobility aid passenger is using the mobility aid securement system, the restraint system will be retracted in a 'stowed away' condition free from vandalism and contamination.

Design Loads

The restraint system was designed to the limiting loads of the breaking strength of the belts and buckles used. The torso belt design load is 900 N or 4000 pounds of force and the lap belt at 1350 N or 6000 pounds.

Passenger Movement

The upper body or torso has nearly unlimited 'wiggle' room when the torso belt is used and the lap movement is equivalent to the snugness of a passenger car lap belt (25-50 mm or 1-2 inches).

Belt and Retractor Details

The belts and retractors were fabricated for this project by a United States manufacture who presently supplies these items to the transportation industry. They were manufactured to meet the FMVSS 209/210 standards.

The torso belt retractor is a web sensitive inertia reel "that has an independent functioning, sensing and locking mechanism. The reel provides freedom of movement until a predetermined G-force occurs at which time it locks positively. When tension is removed from the belt, the original free movement is reinstated." (quote from the manufactures technical literature). The lap belt retractor is a standard locking type.

Since the aisle side of the system has one belt with two buckles the belts can be color coded, one for the lap and one for the torso and the buckles so matched for ease of matching or different sizes of buckles could be used.

Spatial and Floor Envelopes

Spatial requirements were those imposed by the standard seating on a public transportation bus with the requirement that no reduction in seating capacity occur with the restraint system installed.

CHAPTER 8 – ENGINEERING TESTS OF THE OSU RESTRAINT SYSTEM

Introduction

The goal of performance testing is to demonstrate the validity of a design concept and to provide insight which may result in significant design improvements. In the case of the OSU restraint system, the specific goals were to demonstrate both its strength and its effectiveness in protecting a mobility-aid occupant. This was accomplished by using a sled test facility to accelerate a dummy-occupied mobility-aid to test speed and then decelerate rapidly to simulate a high-G crash. The results clearly demonstrated the strength and effectiveness of the restraint system and the value of using the OSU securement system when restraint is belt-based. The protection of the occupant (dummy) was very acceptable for the standard test conditions used. General conclusions about the restraint effectiveness are more difficult to draw. This is because there is a high degree of variability in the possible seating configurations and occupant postures when considering the entire community of mobility-aid users.

In the pages that follow, the goals of the tests are outlined in detail, the facilities and qualifications of the personnel involved are described, the test procedures are outlined, and then the results and conclusions drawn from the testing are presented.

Test Goals

There were two goals for the testing of the OSU restraint system:

1. Demonstrate the inherent strength of the restraint system
2. Demonstrate adequacy of occupant restraint during a vehicle crash.

The OSU restraint system is fairly conventional from the occupant's point of view, but since it must be retrofit onto vehicles without benefit of other structural members, it must have an inherent strength which is adequate to withstand design crash loads. In the case of a post-based restraint system such as this, the primary structural load is due to the force of the shoulder belt acting at the top of the post. The stresses in the post are due to a combination of a compressive component and a bending component with the bending component being by far the largest contributor to overall stress (see Figure 8.1). With an understanding of the nature of expected stresses, the goal of demonstrating inherent strength could be achieved

Figure 8.1. A 2-D Representation of Stress Distribution

quantitatively by using strain gages to determine actual stresses in the restraint system structure. In addition, a qualitative determination of structural strength can be made through observation of any permanent deformation in the restraint system as a result of a crash test. Thus, the first of the goals for testing of the restraint system could be explicitly stated as follows:

Demonstrate the inherent strength of the OSU restraint system by subjecting it to simulated crash conditions. Evaluate the structural integrity of the restraint system by (a) installing strain gages at key locations and monitoring them throughout the test run and (b) examining the restraint system after the test run for any signs of plastic deformation.

The second goal, demonstrating adequacy of occupant restraint, involves some quantitative measures but conclusions are necessarily limited to the specific combination of mobility aid, anthropomorphic dummy, and initial seating position that was used. In more explicit terms, this goal could be stated as:

Demonstrate the adequacy of the restraint system for occupant protection by using a test dummy and subjecting it to simulated crash conditions. The dummy should be an instrumented, 50th percentile male anthropomorphic dummy and should be seated in a normal position on a common mobility-aid at the start of the test.

Although not a specific goal, some consideration was given during design of the test to documenting the effectiveness of the OSU securement system when used with the restraint system. To this end, the common mobility-aid specified for the second goal was modified to be a heavy mobility-aid (such as a power base) to demonstrate the value of good securement.

Facilities and Personnel

The restraint system testing was done at the National Institute for Aviation Research at Wichita State University. This is a new facility and has been used primarily for the evaluation of aircraft seat crashworthiness. The test sled at this facility is accelerated pneumatically, has a short free run, and is then decelerated by deformation of metal bars. The shape of the deceleration curve is determined by the thickness of the bar(s) being deformed. A standard shape for this curve in aircraft industry tests is a triangular deceleration pulse. For our purposes, the personnel at this facility developed a square pulse to correspond with the pulse shape used in testing the OSU securement system.

Involved in this testing of the OSU restraint system were personnel from Wichita State University, Oregon State University, and the University of Michigan Transportation Research Institute (UMTRI). From Wichita

State, the facility director and test supervisor was Joseph A. Mitchell. Mr. Mitchell's experience in sled testing is quite extensive in the arena of aircraft crashworthiness. He was assisted by several graduate students whose responsibilities included calibration of the pulse envelope, preparation of instrumentation and data collection, and operation of the high-speed video camera used to record crash results.

The representative from Oregon State University was Dr. Joseph R. Zaworski. His area of expertise is that of instrumentation and testing. He directed the original testing of the OSU securement system including its static testing, in-vehicle testing, sled testing, and quasi-dynamic testing of the latch mechanism. His responsibilities for testing of the restraint system were to insure that OSU's goals for the tests would be met.

The third key person involved with restraint testing was Dr. Larry Schneider of UMTRI. Dr. Schneider is a nationally recognized expert on the testing of restraint and securement systems and his role was to offer advice on test procedures, comments on the quality of the tests, and some informal interpretation of the results.

Procedures

The actual test procedures were straightforward and follow a typical protocol for using general purpose test devices such as a decelerator sled, anthropomorphic test dummy, acceleration and load transducers, and transient signal recording and processing equipment:

1. Review pre-test calibration of all instrumentation and certification of test dummy to assure compliance with good measurement practice.
2. Calibrate the deceleration curve for the test sled. Since the use of a nominal square pulse for deceleration (i.e., deceleration which jumps immediately to 20G, stays there until zero velocity is reached, and then immediately drops to 0G) was new to the Wichita test facility, several pre-test calibration runs were completed prior to the tests to demonstrate to Drs. Zaworski and Schneider that the test pulse would be acceptable. These tests were done with weights on the test sled to simulate the weight of the actual combined load of a mobility-aid, securement system, anthropomorphic dummy, and restraint system.
3. Mount and test strain gages on the restraint system column.
4. Install the securement system and restraint system on the sled.

5. Secure the mobility-aid being tested (a Fortress 655 power base weighing approximately 200 pounds). Position the test dummy on the mobility-aid and install the belts of the restraint system.
6. Run the automated test sequence: Check all instrumentation signals for appropriate "zero-G" levels; charge the acceleration system; initiate countdown; start the data acquisition equipment and high speed video camera; release the sled; impact; stop all automated data acquisition.
7. Take post-crash still photographs and collect qualitative information on final position of test dummy, condition of the restraint system, and condition of the mobility-aid.

Subsequent to completion of the testing, a written report was compiled which included the test calibration data, plots of the data that were recorded, and a VHS copy of the high speed video footage that was taken during the impact period of the test.

Results

A copy of the quantitative results are included in the final report prepared by the National Institute for Aviation Research at Wichita State University[12]. A summary of the test results for the OSU restraint system follows:

Test conditions: 20 mph, 15G deceleration
Peak Shoulder Belt Load: 800 lb.
Left Side Peak Lap Belt Load: 300 lb.
Right Side Peak Lap Belt Load: 800 lb.
Peak Column Strain: 600 microstrain (corresponds to 18ksi stress)
HIC (Head Injury Criteria) for Dummy: 249

There were no unusual or surprising findings. The deceleration curve was a good approximation of a square wave which began at a speed of 20 mph and then decelerated at a constant 20G to 0 mph. The stress levels reached in the restraint system were very nearly those that were predicted (approximately 18,000 psi) thus confirming the design factor of safety of 3. There was movement by the dummy due to stretching of the restraint system belts. Also, a small amount of submarining of the dummy under the lap belt was seen. There was essentially no movement of the mobility-aid during the test and therefore no additional load imposed on the dummy.

Some pictures from the high speed video taken during the test are shown in Figure 8.2. The movement of the dummy can be seen to include forward movement during the initial deceleration (due to belt stretching),

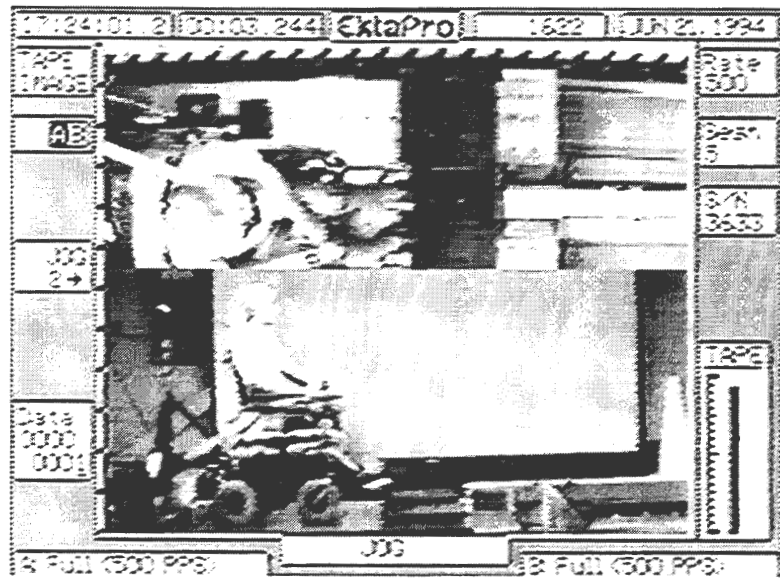


Figure 8.2.a. Side and Top View Prior to Impact

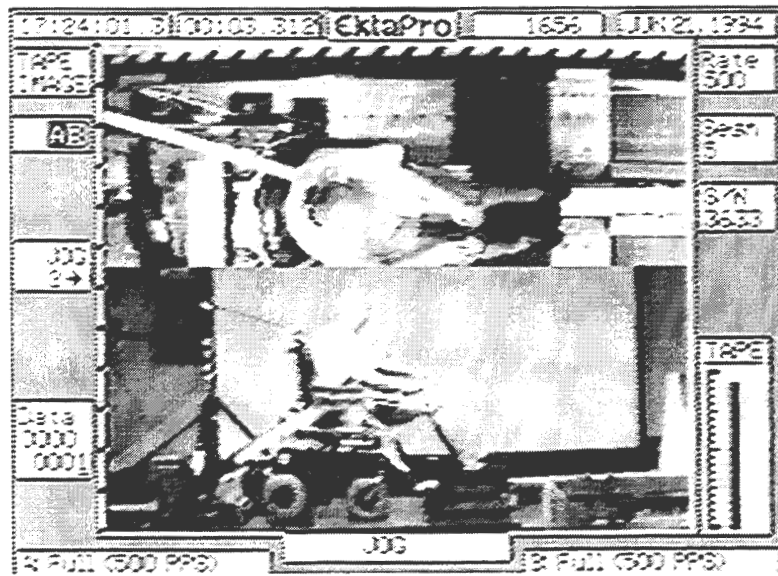


Figure 8.2.b. Initial Forward Movement of the Dummy During Impact

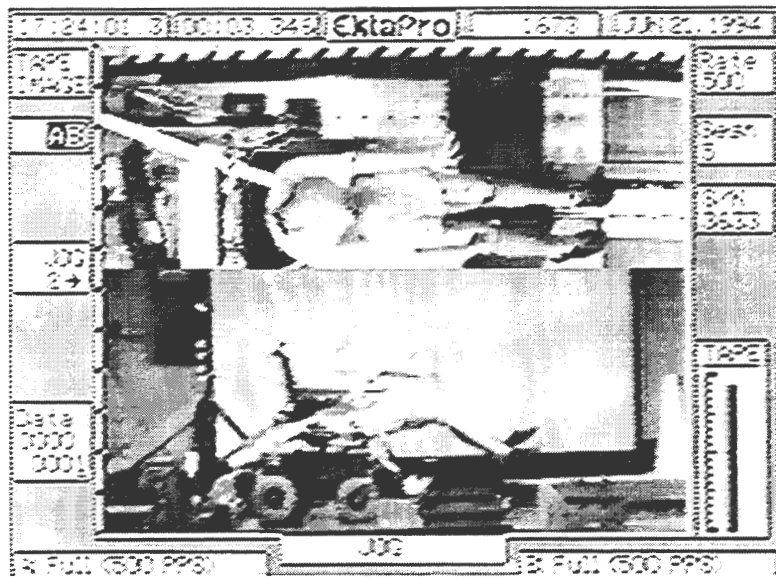


Figure 8.2.c. The Mobility Aid Has Not Moved, but There is Slight Submarining of the Dummy Under the Lap Belt

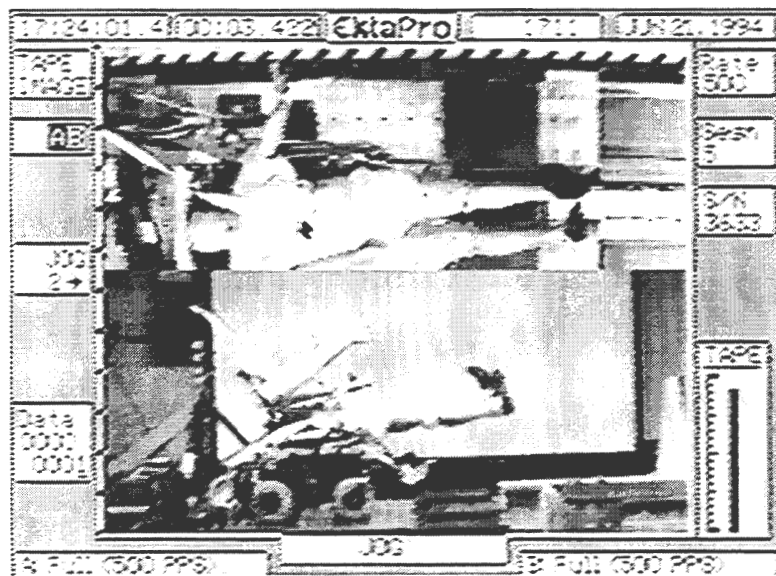


Figure 8.2.d. The Dummy is in Full Rebound Position Due to the Snapping of the Restraint Belts

some submarining under the lap belt during the very final portion of the deceleration, and then rebound as the belts shrink back to nearly their original length. Also worth noting is the lack of movement of the mobility aid in this sequence of pictures.

Conclusions

All goals of the testing phase were met and the key conclusions that resulted are as follows:

1. The OSU restraint system performs as designed when tested under crash conditions. There is substantial deflection in the belt portion of the restraint system and very little deflection in the restraint structure itself. All goals for testing the inherent strength of the restraint system were met and adequacy of the design was appropriately demonstrated.
2. The sled tests also demonstrated that occupant restraint characteristics of this system are acceptable. Motion of the dummy was limited and the imposed loads on the dummy were maintained at an acceptable level. The HIC calculated for this crash was well below what is normally seen in airworthiness crash tests and was comparable to what is typically seen in tests on high quality automotive restraint systems.
3. The importance of good mobility-aid securement was clearly demonstrated. The loads imposed on the restraint system were clearly due to only the mass of the test dummy. If the securement system had allowed forward motion of the mobility-aid during deceleration, the seat and seat-back of the mobility aid would have pressed the dummy from behind and increased the total load on both the dummy and the restraint system.

PART 2

CHAPTER 9 – MOBILITY AID INTERFACES

Introduction

The development of interfaces between mobility aids and the OSU Securement System was undertaken in part during the initial design phase of the securement system. Further development was done at Mobile Tech, and recently undergraduate students at OSU worked on several designs. Extensive development of interfaces is being done as part of the Easter Seals Project ACTION Demonstration project. This chapter summarizes the design efforts that have been completed prior to the Project ACTION activities.

The OSU securement system was designed to accommodate any mobility aid in "common use", and this includes four major classes of mobility aids: manual wheelchairs, power wheelchairs, scooters and power bases. It is obvious that given the variety of styles, types and sizes of mobility aids that there is no single "universal" interface, but there are certain interface concepts that accommodate specific classes of mobility aids.

Interface Design Philosophy

The design team that developed the OSU securement system made a decision early in the design process that established certain key aspects of the interface design. In particular, it was decided that the interface attachment to the mobility aid must be permanent. The rationale for this decision was based on the fact that the interface must be capable of safely transmitting the high loads encountered in a 20g crash. As a result the interface must be attached to the strongest part of the mobility aid frame. The design team also felt that it was very important that the transit vehicle operator should not be involved in applying the interfaces since that would add to the time required for securement. Vehicle operators should not have the additional responsibility of determining where the safe attachment points are for the wide variety of mobility aids. The design team proposed that the interfaces be mounted on the mobility aids by people familiar with mobility aids such as mobility aid dealers or transit staff that have been specifically trained to mount interfaces.

A semi-universal interface was developed for manual wheelchairs. This system is based on a bracket that is permanently mounted to the hub area of the wheelchair frame. This is usually the strongest part of the wheelchair frame. Removable D-ring assemblies slide into the bracket and are secured with small bolts.

This design combination of a bracket and removable D-ring assembly permits simple adaptation to a large number of manual wheelchairs, allows wheelchairs to be collapsed, and does not add any significant additional weight to the mobility aid.

The designs for powered mobility aids, which include scooters, power wheelchairs and power bases are more specific for each device. Some of the power wheelchairs can be fitted with brackets and removable D-ring assemblies, but the majority of interfaces tend to include more permanent bracket and D-ring assemblies.

Design Methodology

The Quality Functional Deployment (QFD) method was used for all the interface design projects. This methodology has been extensively discussed earlier and in the other reports documenting the development of the OSU securement system [8,9]. The OSU securement system established a number of fixed parameters and these include the D-ring geometry and placement, the D-ring material, and a requirement that no permanent modifications be made to the mobility aids. The D-ring geometry and placement in space has been established by the dimensions of the capture mechanism, and these were determined as a result of extensive engineering analysis. Also, the D-ring material was established as a result of extensive engineering analysis. The D-rings are designed to deform in the event of a severe crash approximately 20g's. The rationale for this is that the D-ring will absorb some of the crash energy which will reduce the amount of energy transmitted to the mobility aid user. The requirement that no permanent modifications be made to the mobility aids has been relaxed for certain mobility aids. The initial design constraint implied that no holes could be drilled into the frame of the mobility aid. For most manual wheelchairs this design constraint still holds, since drilling holes into the wheelchair frame would weaken its structural integrity. For manual wheelchair interfaces the brackets mount around the frame members or use pre-existing holes.

Design Options

Several design options are presented, however these should not be taken as definitive designs. Copies of the design concepts are included in Appendix B.

SCOOTER (Amigo Rear Wheel Drive)

This design includes a one piece interface with three supports and quick release capabilities. The entire interface may be taken off the mobility aid with the removal of three pins.

MANUAL WHEELCHAIR (Quickie P100)

The Quickie P100 wheelchair that this interface was designed for had "wheelie bars" which obstructed the path of the securement system. A solution to this problem is the removal of the "wheelie bars". This removes the obstruction to the interface and provides an excellent mount for the D-ring Assembly. The user of this particular mobility aid did not want the "wheelie bars" on the mobility aid at all. This modification was not considered permanent since the "wheelie bars" are easily reinstalled. The interface is two assemblies with one being a mirror image about a mobility aid centerline of the other. The separate D-ring assemblies are supported by existing bolts which previously held the wheelie bars. The assembly is made of medium carbon steel.

MANUAL WHEELCHAIR (Everest and Jennings Premier)

The E&J premier has accessible frame tube on the rear of the mobility aid near the required position for the D-rings. This mobility aid has a collapsible frame with the upholstery slung between the vertical back members and horizontal seat members. The width of the wheelchair is determined in part by the width and condition of the fabric. As the fabric stretches over time the width of the wheelchair increases. Since this wheelchair also collapses it is important that the interface not take up any additional space. Approximately two inches total is allowed between frame tubes for interface assemblies. The final design consists of two separate assemblies mirrored on each side of the rear of the mobility aid. Assembling the interface involves sliding the end cap off the frame tube, sliding on a piece in a horizontal position, rotating it to vertical, and pulling it back so that the hooked front engages a vertical frame tube. A bolt closing the hook is attached to secure the unit in place. A second piece is assembled with the first piece using a clip, requiring no tools. This piece holds the D-ring and may be flipped or assembled on the other side of the piece to accommodate, with adjustments, up to one inch increase in distance between rings. The width adjustment does not require tools making assembly easier as well as allowing adjustments away from home.

Analysis of Designs

Standard values of mobility aid mass of 300 lbm and deceleration of 20G were used to find common maximum force of 6,000 lbf to apply to each analysis. Consequently, the assumptions are very conservative and the corresponding factors of safety are also very conservative. Strength analyses were conducted at six different points for the Amigo Rear Wheel Drive. The first of these points was the interface between the mobility aid and the quick release bracket mount. The interface had the lowest safety factor for this mobility aid, but it was still acceptable at a value of 1.6. The other points of interest included the seat post quick release pin, the quick release sheath (both shear and tensile failure), and the quick release bar (also in shear and tensile failure). The safety factors of these other points ranged from a low

of 2.6 to a high of 6.7. One important point which these other points ranged from a low of 2.6 to a high of 6.7. One important point which was not directly analyzed was the joint between the seat post support bar and the transverse bar. The analysis involved at this point is quite complex. Previous testing with a very similar configuration showed that the joint does indeed perform adequately in crash conditions.

Stress analysis of the Quickie P100 included three points of interest. The interface design was such that failure would most likely occur in tension, compression or shear. The point that appears most critical is in the support tube the slides into the frame tubes of the mobility aid. The factor of safety in design for this point was only 1.3. Analysis for tearing at the bolt holes and shear of the bolts gave factors of safety around 2 to 2.5. These values all suggest adequate performance of the interface under impact conditions.

Points of concern for the strength of the interface for the E&J Premier were in tensile fracture of the plate, tearing of bolt holes, shear of bolts, and bending of the curved piece. The tube and plate sizes used in this interface unit provided as much or more material area as in the Quickie P100. Therefore, factors of safety should be as high or higher. Analysis showed that failure in tension of the plate is not likely with a factor of safety of 2.6. The shear of bolts as well as the tear out of the holes gave low but acceptable factors of safety of 1.5. The weakest link could be in bending of the curved piece. Here the factor of safety equalled only 1.1 during the worst conditions. These conditions included the assumption of 6000 lbf and the case where the major portion of the load in contacting the curved piece at the outside one inch from the flat plate. If the load contacts in the center of the curve half an inch from the flat plate, then the factor of safety doubles to around 2.

Ergonomic issues were also considered to some degree in the analysis. The strength analysis indicated that the factor of safety for each of the quick release pins on the lower brackets was about 5.2. The reason that this pin size was used has nothing to do with the strength requirements. A pin of this size is much easier for the user to handle. It is less likely to be dropped or lost, and the added weight is negligible in comparison to the practical benefits.

PART 3

CHAPTER 10 – TECHNOLOGY TRANSFER

The Technology Transfer aspects of the OSU Securement System Project involved the application and award of a U.S. Patent, and the licensing of a U.S. company to manufacture and market the product. This chapter will summarize those activities. The Office of Technology Transfer and Trademark and License at Oregon State University was involved in all aspects of the Technology Transfer process for the OSU Securement System technology.

The first phase of the technology transfer involved the preparation of an application for U.S. and Canadian Patents. This process involved the whole design team, the OSU Director of the Technology Transfer Office, and a firm of Patent Attorney's in Portland, Oregon. The development of the patent process involved creating drawings and written descriptions of the design that were appropriate for the patent process. The patent application did involve both the capture mechanism and the interface concept. This initial patent application was filed on July 22, 1993 under application number 96,056 and was awarded on September 6, 1994 as Patent Number 5,344,265. A copy of the front of the patent is included in Figure 10.1.

The second phase of the technology transfer process involved licensing the technology for manufacture and marketing. This process was very lengthy and was begun at the same time that the patent application was being prepared. A number of securement system manufacturers in the U.S. and Canada were invited to prepare bids for license rights to the technology. Initially, the design team had wanted to prepare non exclusive license agreements so that the technology could get out and be used. It was thought that market forces would drive acceptance of the technology. Potential manufactures informed us that they were not interested in a non-exclusive license because the market was too small to justify the development expense. After several months, two companies came forward with bids for license rights to the technology. One company is a U.S. subsidiary of a Canadian Manufacturer who was interested in marketing the technology but did not have the manufacturing capabilities. Mobile Tech of Hutchinson, Kansas, indicated that they could both manufacture and market the technology, and OSU awarded the license rights to Mobile Tech. Mobile Tech is a subsidiary of Collins Industries, and initially indicated that they were strong enough to take on a new technology, but they were also just starting to manufacture and market the under vehicle lift as well. Two new technologies proved to be too much for the small company. There were massive changes in the human resources of the company from the time the negotiations began to one year after the agreement had been signed. Mobile Tech was not able to meet the diligence clause specifications of

[54] SECUREMENT SYSTEM FOR A ROLLABLE MOBILITY AID

[75] Inventors: David G. Ullman; Katharine M. Hunter-Zaworski; Joseph R. Zaworski; Derald E. Herling, all of Corvallis; Garrett E. Clark, Salem, all of Oreg.

[73] Assignee: State of Oregon, acting by and through the state Board of Higher Education on behalf of OSU, Eugene, Oreg.

[21] Appl. No.: 96,056

[22] Filed: Jul. 22, 1993

Related U.S. Application Data

[63] Continuation of Ser. No. 930,194, Aug. 11, 1992, abandoned.

[51] Int. Cl.⁵ B60P 7/00

[52] U.S. Cl. 410/3

[58] Field of Search 410/3, 4, 7; 296/35.1, 296/35.2, 35.3, 35.4, 36, 65.1; 188/32, 5; 248/503.1; 280/250.1, 304.1; 297/DIG. 4

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 Brochure—by Creative Controls, Inc.
 (List continued on next page.)

Primary Examiner—Mark T. Le
 Attorney, Agent, or Firm—Kolisch Hartwell Dickinson McCormack & Heuser

[57] ABSTRACT

A securement system is provided for a rollable mobility aid with a frame and rollers, which aid is located adjacent surrounding structure such as the interior of a vehicle. The system includes protruding structure attached to such frame, with a substantially rigid, operative section that includes a broad engaging expanse. Also included is upright receiver (or capture) structure fixedly attached to such vehicle in a receiving position, and including a receiving section that is correspondingly broad with respect to the engaging expanse. The receiving section further includes a selectively actuatable securement/release mechanism for securing the operative section to the vehicle. The protruding structure is shown as plural spaced members, with the receiver structure being constructed with receiving sections to receive each member. The receiver structure is shown as capable of selective rotation about its vertical axis and selective translation with respect to its receiving position. The system is also shown with indicator structure operatively connected to the securement/release mechanism and structured to provide an indication of whether a securement condition exists. Plural types of actuators for the securement/release mechanism are also provided.

27 Claims, 6 Drawing Sheets

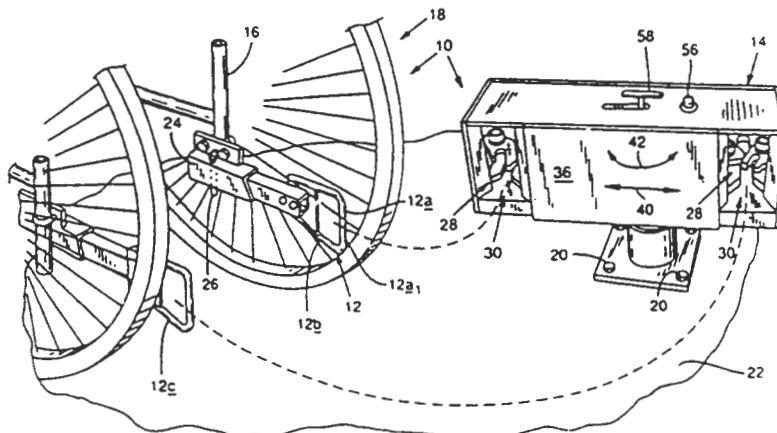


Figure 10.1. Copy of the Front of the Patent

the license agreement and as a result the license was terminated in the Fall of 1994. The technology is once again the responsibility of OSU. The door is open to companies interested in license rights to the technology, but no effort will be made until after the initial stages of the demonstration project are completed.

The preliminary steps have been taken to develop a patent application for the configuration of the OSU Restraint System. The design team is not optimistic that a patent will be possible for the restraint system. It is proposed that the new license agreement will include both the OSU Restraint System and OSU Securement System to form a complete package.

CHAPTER 11 – CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The OSU Securement System and OSU Restraint System have introduced new concepts in the design of wheeled mobility aid securement systems. Auto-Engaging Securement Systems is a new term that has been introduced to describe this technology. The initial reaction to this technology by transit agencies and transit passengers who use public transit has been exceedingly positive. It is anticipated that the demonstration project at Lane Transit District in Eugene will provide operational data that will answer a number of questions that the new concepts have raised. It is also anticipated that the demonstration project will document the operational advantages of the OSU securement system.

The major problem with this technology is the interface to mobility aids. Since there are no universal mobility aid designs there are no universal interface designs. Many mobility aids lack the structural integrity to support any securement system and these mobility aids will continue to cause problems for transit agencies and transit passengers. There are many new types of mobility aids and some very traditional mobility aids that are robust, durable and strong, and can support the loads imposed by securement systems under crash conditions. The time has come for the transit industry, securement system designers and manufacturers, and mobility aid manufacturers to come to agreement on the mechanical requirements of mobility aids that are used on public transportation vehicles. A start has been made by several groups concerned with the development of standards for belt style securement systems.

The OSU Securement and Restraint System project team is very optimistic that auto-engaging securement systems will become the industry standard in the next five to ten years.

Recommendations

1. Stronger support is needed to support the transfer of new concepts in transit technology from the research environment to industry.
2. Stronger support is needed to provide incentives for wheeled mobility aid manufacturers to work together with the transit industry to develop mobility aids that are safe for transport on public transport.

CHAPTER 12 – REFERENCES

An extensive resource library was developed to support the research necessary for the QFD method. The resource materials were organized into a reference base, and a brief summary of each item was incorporated into the reference base. The reference base is included in the final reports for the OSU Securement System Project [8,9]. The references listed below pertain directly to the preparation of this report.

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APPENDIX

- A -

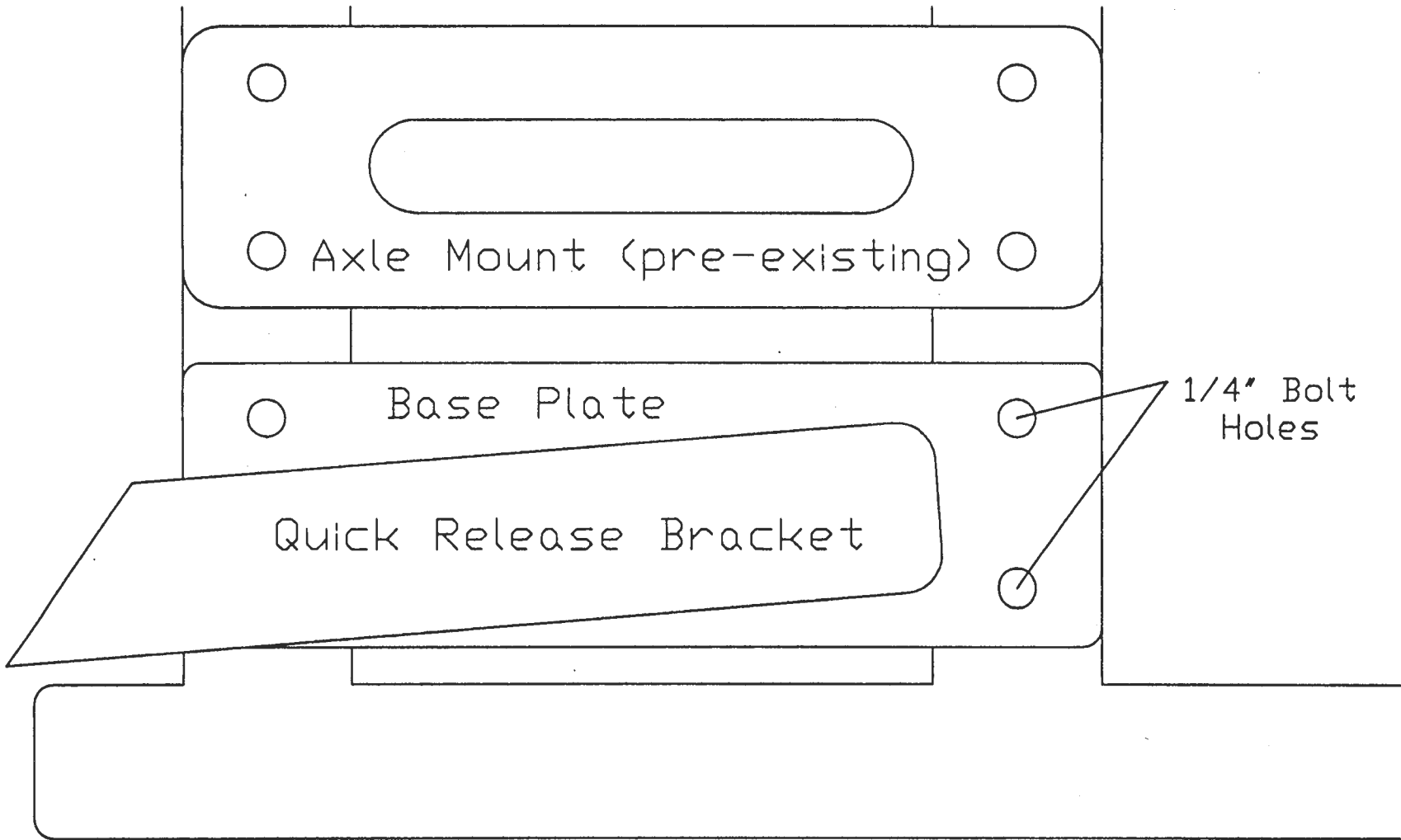
ADVISORY COMMITTEE MEMBERS

The OSU Securement system project design was based on the needs of persons with disabilities and transit operators. The Transportation Research Institute at Oregon State University, (TRI/OSU) has been working with an advisory committee made up of persons with disabilities and transit agency personnel since 1986 when TRI/OSU undertook the Human Factors in Public Transportation Study. Since that time TRI/OSU has had a number of projects related to transit accessibility and has worked with the advisory committee. The committee membership has changed over the years, but there are still a number of the original members. Several members of the advisory committee have had to withdraw due to illness and, consequently, new members were added. The advisory committee has been essential for the direction and guidance for all phases of the OSU Securement and Restraint projects.


Members of the Advisory Committee

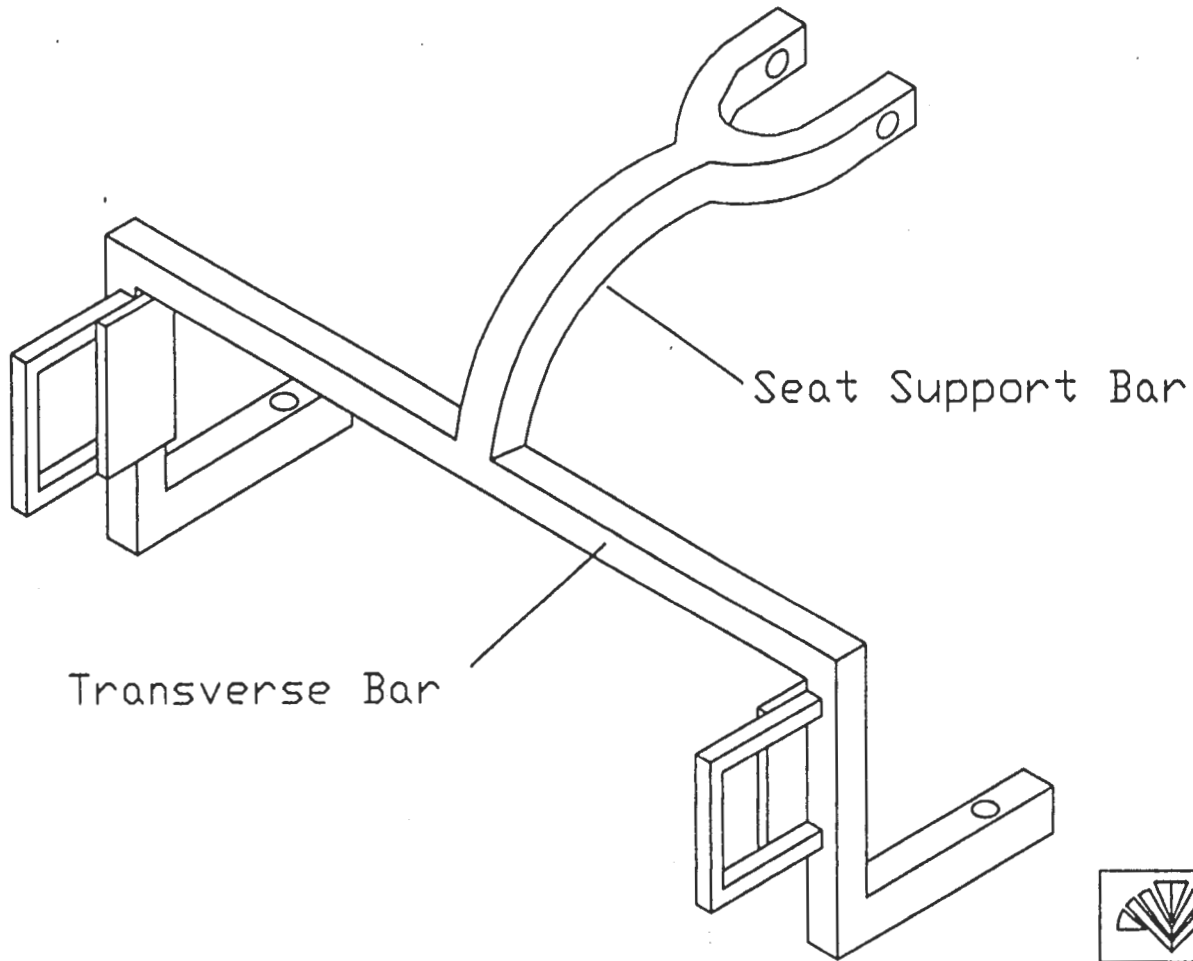
<p><u>Transit Agencies:</u> Lane Transit District (LTD) Eugene, Oregon TRI-MET, Portland, Oregon METRO, Seattle, WA B.C. Transit, Vancouver, B.C.</p>	
<p><u>Accessible Service Managers:</u> Micki Kaplan, LTD Patricia Neilsen, TRI-MET Park Woodworth, TRI-MET Cathryn Rice, METRO, Seattle Robert Carroll, METRO, Seattle Sue Stewart, METRO, Seattle Bruce Chown, B.C. Transit Debbie Krantz, B.C. Transit</p>	<p><u>Vehicle Operators:</u> LTD TRI-MET METRO B.C. TRANSIT</p>
<p><u>Accessible Transportation Committee Members:</u> LTD TRI-MET METRO B.C. Transit</p>	<p><u>Maintenance Personnel:</u> LTD TRI-MET METRO B.C. TRANSIT</p>


APPENDIX
- B -
INTERFACE DESIGN CONCEPTS

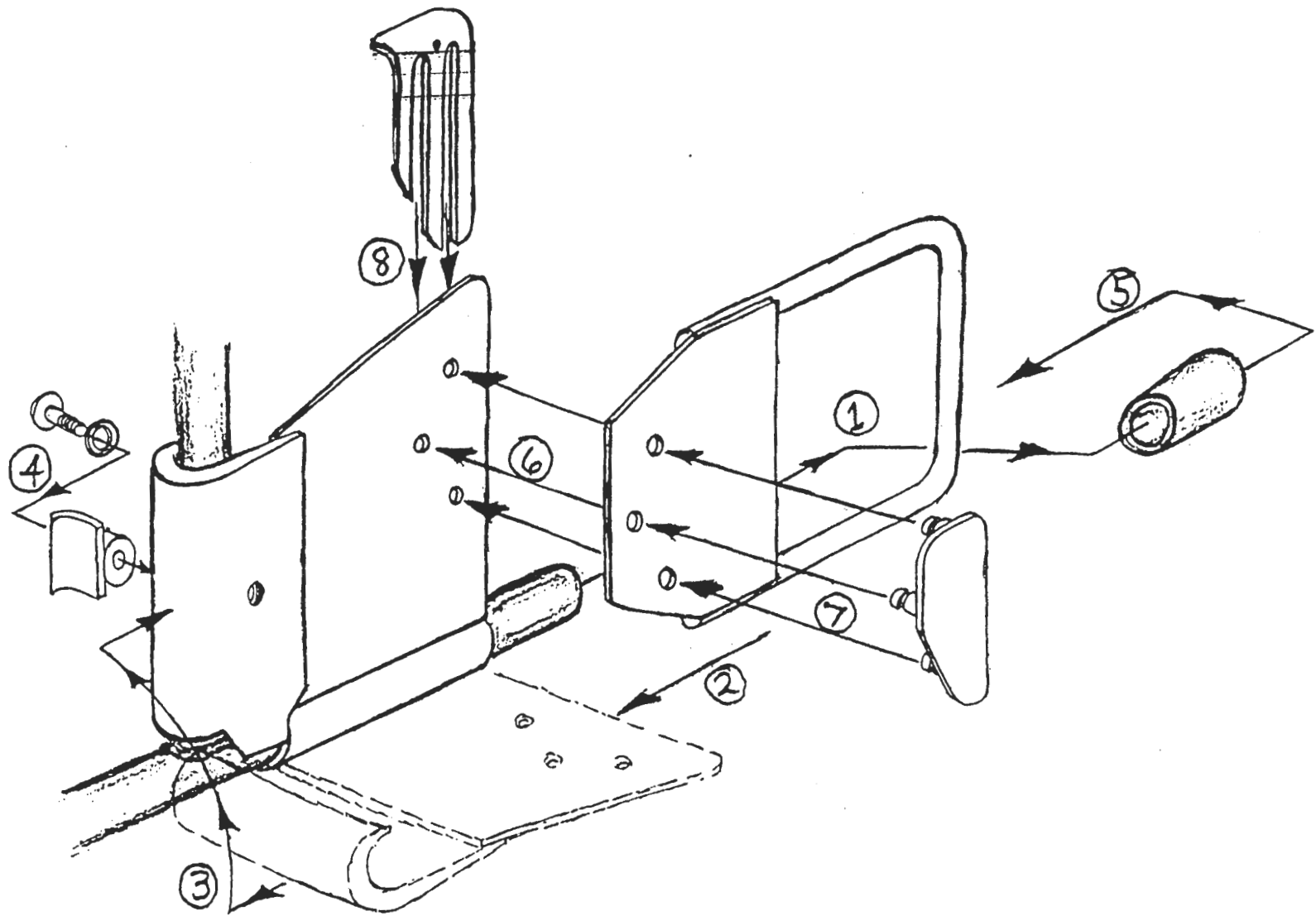


Side View

 Mobil-Aid Inc.	
Drawing Name: Q2 Plate	Scale: 1:1
Project Name: Securement Interface	
Drawn by: T. Johnson	Date: 12/6/94



 Mobil-Aid Inc.	
Drawing Name: Amigo Bracket	Scale: none
Project Name: Securement Interface	
Drawn by: T. Johnson	Date: 12/7/94



Everest & Jennings Premier Assembly Drawing.

