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Quality of Life Technology; The State of Personal Transportation

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Abstract

Motor vehicles are a technology that has been embedded in the built environment since the early 1900s. Personal transportation is important for the quality of life of individuals with disabilities because it gives a feeling of freedom and it enables individuals with mobility impairments to participate in the community. The process is described for evaluating individuals and their cognitive, sensory and physical abilities that are important for (safe) driving. A case is made for independent mobility for individuals with disabilities and the elderly by first giving an overview of the functional, cognitive and sensory abilities that are key for driving. Secondly we describe the types of vehicle modifications and state-of-the-art controls that are available and on the horizon and how these technologies are selected to meet driver needs. Next requirements for driver safety systems are discussed for those drivers that remain seated in their wheelchairs. Finally, emerging and innovative driving enhancement systems, such as obstacle avoidance and navigation, are discussed and so are their benefits to aid elderly drivers and drivers with disabilities in safe and independent driving.

Introduction

For the vast majority of the U.S. population, community participation and basic activities of daily living depend on access to personal vehicular transportation. This culture of "automobility" [1] is likely to continue and it appears that older persons will need to drive more in the future [2]. This trend is complicated by license loss among older drivers. The total drop in licenses among individuals between the ages of 60-84 in 2000, for reasons other than death, was 1.8 million [3, 4].

As with the aging population, there is a related trend in wheeled mobility use (i.e. wheelchairs, scooters, etc.). In the past 30 years, there has been a six-fold increase in the US population of wheeled mobility users and we can expect the total number to reach 4.3 million by 2010 [5]. Particularly relevant is that this "growth far exceeds the growth in the older population" (p. 15). Within this population, about a quarter of individuals drives and almost a third does not live in areas with public transit services. Lack of access to transportation is one of the most frequently cited problems for rural residents [6]. For individuals with mobility limitations that live in remote areas, or in areas that are not along the route of fixed route transit services, special arrangements need to be made with for example Paratransit services for which eligibility criteria exist.

For all individuals, including those with disabilities and the elderly, access to the community is important for employment, socialization, health services, and for the operation of households and businesses. A study done by Gray et al. [7, 8] indicates that one of the key barriers to community participation among individuals with disabilities is transportation. The infrastructure in the United States is built around the widespread use of motor vehicles and public transportation systems. These include commuter rail systems, metro, fixed and demand route transportation services that are commonly in place for those who cannot afford, are unable to drive or choose not to use a personal motor vehicle. There are currently projects underway to produce autonomous vehicle that can drive them-selves. Until these technologies are perfected, persons with disabilities choosing to drive themselves in a personal vehicle will have to rely on their own abilities to control a vehicle.

Equipment and modifications currently available make it possible to compensate for many physical limitations of vehicle drivers. Devices to assist a disabled driver have made steady improvements since the early times of President Roosevelt. As with all changes in technology, the ability to produce and profit from sales of devices is paramount. The driving mobility industry is unique in that the volume of sales is significantly low. This has resulted in small businesses being the major developing sector of the industry and product concepts that only addressed a particular functional disability. The device or product to support the device may have worked well, but a change in the way a disability is treated, new materials to lessen the weight of a product, the availability of colors or other technology changes may have made some company's product undesirable.

Practices To Promote Safe And Independent Driving

Clinical considerations in driving

The United States has approximately 11,000 individuals with new spinal cord injury (SCI) a year and a varying numbers of disabilities from stroke, muscular dystrophy, ataxia, spina bifida, amputations, reduced upper extremities (traumatic and congenital absence), amyotropic lateral sclerosis (ALS), multiple sclerosis, spinal muscular atrophy, polio, arthrogryposis, osteogenisis imperfecta, rheumatoid arthritis, and a variety of other illnesses [9, 10]. Each injury, ailment, disease or disorder has its unique set of motor, sensory and cognitive issues to be addressed in order to consider a person's suitability to be a safe and independent driver [11]. With each condition, there may be some expected limitation, but the degree of disability generally varies between individuals. For example, the difference in physical ability of a person with a spinal cord injury can vary significantly depending on the level and complexity of the injury. This can be further complicated in that, the event that caused the SCI might have created a secondary effect in a traumatic brain injury (TBI). This may not be noticed until the interactive cognitive skills of driving are required [12].

The question that needs to be answered for any potential driver (teen/adult/mature) during a clinical evaluation: Is this driver processing pertinent, environmental traffic information in a timely manner, and executing appropriate and timely responses based on the perceptions of situations encountered? The best person to answer this question is a trained and Certified Driver Rehabilitation Specialist (CDRS). A CDRS is knowledgeable in the selection, use and application of the devices and methods for drivers with disabilities. An unbiased perspective about what type of equipment will work best for a driver can have a huge impact on driver safety, the longevity of their driving career, the cost of the modifications and the ability to maintain the equipment.

Often a team approach is used to best understand all the details involved in determining the appropriate equipment and training for a safe and independent driver. An Occupational Therapist (OT) will establish the physical and cognitive baseline of a potential driver and a Driving Instructor (DI) will safely guide the driver through basic vehicle functions and an on-the-road evaluation. A Rehabilitation Engineer (RE) will provide equipment and methods for the driver to compensate for any physical limitations. All team members may participate in each portion of the evaluation and in the selection of appropriate assistive driving devices and in some cases the roles of OT, DI and RE are performed by one and the same individual.

Most clinicians that are involved with driving assessments, equipment selection and driver evaluations are members of the Association for Driver Rehabilitation Specialists (ADED) [13]. In 2008 there were about 576 ADED members of which 229 are CRDSs [13]. This number is small compared to the increased need for services to enable driving by older adults and individuals with disabilities. As part of the Quality of Life Technology Engineering Research Center Safe Driving Project, the University of South Florida and University of Pittsburgh are currently evaluating the use of a driving simulator to train individuals with disabilities in the use of adaptive driving equipment in a simulated driving environment. The use of driving simulators has potential to assist in driving assessments due to their relatively low cost, ability to track driver learning and ability to make instrumentation adjustments on the fly. Obviously, actual road driving remains a key component in the assessment process and when learning safe driving in the community [13].

Functional Abilities

A battery of tests and assessments are administered to create a baseline from which the CDRS-team can appraise safe driving potential. These tests do not necessarily conclude the client's driving potential: they establish which functional abilities the person has and the limitations that could pose a problem when driving. The client's ability to compensate for any deficit while behind the wheel is the true test of a driver's potential [14]. The standardized and non-standardized tests and assessments to determine safe driving potential address the following factors [15]:

- Vision & perception: The client is administered standardized test to determine visual acuity as well as visual fields, color vision, depth perception, contrast sensitivity, processing time, visual tracking, and the ability to multitask. These test help determine how well the client sees what they see and if it is where they see it.

- Strength & range of motion: Physical characteristics of the client are measured. For each limb, strength and active range of motion are determined for the ability to operate the primary controls of the vehicle. Head rotation for scanning traffic is observed and documented. Other areas assessed are: joint restrictions in neck and limbs, motor control, dexterity and balance.
- Reaction time to determine eye – limb coordination: Several tests are given to the client to gather information on the potential driver's ability to process visual information and react to it properly. Characteristics about the client's disability are noted to consider such things as the progressive nature of the disability and if this will impact the choice of driving equipment.
- Cognitive issues and confidence: Other tests will provide information from the potential driver's on understanding road signs, engage in more complex driving situations and determine their ability to multitask. Observations are made in: memory, visual processing, visual perception, visual special skills, selective and divided attention, and executive skills.
- Driving assessment process: Once the clinical details of the driver have been established, the evaluation progresses to the vehicle assessment. Considerations for access to the vehicle are investigated, progressing from whether the driver is able to transfer from the outside of the vehicle to the driver seat, to the driver sitting in their wheelchair at the

driver station. Numerous arrangements and adjustments in between these extremes dictate the final scenario for access. Once access has been established, and safety systems are in place (shoulder/lap belt) the driving controls are considered. The dominant hand is usually chosen for steering, but this may deviate if other factors and/ or equipment are presented.

- Driver evaluation: The potential driver is progressively given control of the vehicle. Depending on the situation, the CDRS or DI may start with the client steering in a safe environment, like a parking lot. Eventually, the evaluation will progress to also operating the gas/brake controls and will move out onto the streets and then to even greater traffic interaction. The potential driver will be exposed to turns, controlled intersections, light and heavy traffic and confusing situations to test their ability to respond appropriately.
- Flexibility to test suspected capabilities: At times the CDRS or DI may observe a characteristic of the potential driver that is an indicator of a lack of driving skill or a cognitive limitation. This may be the result of the client being a new driver with little experience on the road. It could also be an indicator of a larger issue that will require substantial understanding of the client's disability and the mobility equipment used to compensate for the disability.
- Endurance issues: Persons with certain disabilities frequently have limitations caused by fatigue (for example, those with muscular dystrophy, multiple sclerosis, or post polio syndrome). A CDRS and DI with an understanding of a persons' disability can observe if the driver is showing signs of tiredness or lack of concentration from fatigue or extreme temperature changes. Startle responses can also impact the client's safe driving and are to

be evaluated as well by traversing for example rumble strips and speed bumps.

Vehicle selection and modification

Vehicle modifications should preferably be done by vehicle modifiers who follow guidelines established by the National Mobility Equipment Dealers Association (NMEDA) [11]. This organization is dedicated to broadening the opportunities for people with disabilities to drive or be transported in vehicles modified with mobility equipment [11]. There are a large variety of vehicles available to drivers with disabilities, and the array of types and sizes of cars and vans is almost unlimited. When minivans and full size vans are modified with a lowered floor, the accessibility to vehicles for a wheelchair user has an even greater application. Although the main purpose of lowering the minivan floor is to position the eyes of a driver in a wheelchair at the correct height relative to the windshield, another benefit is that an access ramp can be at a lesser slope for ease of ingress.

Dependent on whether or not the driver uses a wheelchair and the type of vehicle (sedan or SUV, truck, van or mini-van) there are several ways and assistive technologies available to help individuals with disabilities enter and exit the vehicle. For individuals that have minor limitations a simple grab bar may be adequate. A swivel seat can be used for individuals that are unable to maintain balance while stepping into the vehicle. When an individual is unable to independently and safely transfer from a wheelchair into a motor vehicle seat, a ramp and/or lift needs to be installed for boarding and exiting assistance so the driver can position their wheelchair in the driver station. Ramp systems are becoming increasingly popular and are made to fold out from the doorway as well as slide out from under the floor. Wheelchair lifts have been in use for over thirty years and have caused a major change in the mobility of the individuals with disabilities. As a result of this type of product, a wheelchair user is now able to be independent and mobile. The impact of mobility on a person's well-being, including the ability to get out and about, to interact with the community, to obtain gainful employment are some of the major desires of a complete life and should not be underestimated. "Without what you do…I wouldn't have a life" (comments from a wheelchair lift customer in 1979). There have recently been major changes in the national standards applied to the manufacturing and installation of wheelchair lifts for individual usage. These changes address safety concerns by adding warning devices and vehicle interlocks to prevent the lift from improper and unsafe use [16, 17]. Wheelchair users may encounter space constraints in their vehicle. A transfer seat base can be used to position the OEM seat at a desired location to best facilitate a transfer. The transfer seat base typically mounts to the floor in the driver location and the OEM seat is bolted to a top plate. The device allows for the seat to move forward and backward, up and down and rotate to the right through the use of control switches. A driver with disabilities would dock their wheelchair behind the seat and transfer. After the transfer is complete, the user would operate the switches to position the seat for driving. Some makers of transfer seat bases have successfully crash tested their product, so the OEM seat belts can be attached to the seat (B&D Independence Inc. Mt. Carmel, IL). Technology developed by Freedom Sciences (Freedom Sciences LLC, Philadelphia, PA) allows a wheelchair-seated driver to pull up to the side of their vehicle and transfer into a power seat that extends from the vehicle so that it is level with the driver's wheelchair seat. After the individual has transferred into the power seat, the wheelchair is (remotely) parked in a docking system at the back of the vehicle [18]. This system can be useful for individuals using powered mobility devices and having the ability to perform independent side-to-side transfers.

Driving Controls

Primary Controls

Primary controls refer to the steering, accelerator and brake controls of the vehicle. For a disabled driver, the wheel and pedals may need to be modified to allow for less strength or range of motion. Relocation of the control inputs to a position where they can be reached may be needed. Various interfaces are used to allow a driver to have a secure connection with the vehicle. These control interfaces range from a simple spinner knob, to a yoke and T-shape device for a driver with grip strength, and tri-pin arrangements to allow for a secure hold when a driver has minimal grip strength.

If a driver has sufficient upper extremity range of motion and strength, they may be able to use mechanical devices to operate the vehicle gas/ brake controls. Rods and levers can be positioned so the driver's hand can operate the pedals. Controls that use a motor to move the pedals are referred to as powered controls. The driver would operate a lever that would cause a motor to move the OEM pedals. Another example of powered controls can be found in reduced effort steering. The strength required to turn the steering wheel is generally reduced by 50% or 75%, which can help a driver who lacks strength in steering. In the event of an engine failure (such as a fan belt coming off) the steering pump would stop providing power steering and the driver would require substantial strength to turn the steering wheel. A separate pump used for backup would turn on when it senses low hydraulic pressure in the steering system. This pump would allow steering to remain operational at reduced effort long enough for the driver to pull over to a safe location. A steering backup system is also advisable for standard power steering systems when a driver has enough strength for the OEM power steering, but not enough to turn the steering wheel when the engine is off. Most devices that reduce the force needed to operate primary controls incorporate a backup system that would allow for continued reduced effort on vehicle controls when the vehicle engine fails to operate.

New advances in vehicle controls have allowed for electronic or computer interfaces to control the steering, gas and brake. This can be accomplished with a two-handed system or at the most extreme level a joystick input. At this "drive-by-wire" stage, there is no direct mechanical linkage between the operator and the vehicle. This method incurs some degree of risk due to the possibility of electrical system failure. If designed correctly, this is not as big of a concern as one might think. In fact, many commercial jets are "fly-by-wire" and have performed quite well over the years. Drive-by-wire provides an opportunity to select from a wide array of control choices including joysticks, levers, and small diameter rotary inputs, thus permitting custom control designs appropriate for a driver's specific needs.

This drive-by-wire technology has not been fully optimized for use in mainstream vehicles yet and there remain inherent control issues with electronic interfaces and computer controls. The main areas are the lag or delay in response time and the absence of sensory feedback from the road due to the lack of a closed-loop system. Because of these limitations, the driver must possess above average cognitive skills and the training requirements to use drive-by-wire are extensive.

Secondary Controls

The primary controls are used to "drive" the vehicle. The secondary controls are used to "manage" the vehicle and interact with the elements and other drivers on the road. Operating the turn signals or shifting the transmission are some of the necessities when driving, and are examples of secondary control functions. Secondary controls are different in their own way and are classified into three modes. Where turn signals, the horn, hi-beam and wash/wipe functions fall into the "mode A" control category that is used when the vehicle is moving, the "mode B" category of secondary controls can be operated when the vehicle is stopped and under driver control. Examples of "mode B" controls include shifting the transmission, ignition and vehicle startup. The third group of controls, "mode C", is for when the vehicle is stopped and includes the door locks, radio, hazard flashers, heater/vent/air conditioner (HVAC), light controls; mirrors; parking brake, power seats, rear accessories (defogger), and child safety window locks. There are many devices available to accommodate the disabled driver and controls can be located to be operated by the elbow, a free finger, a mouth stick or through voice input.

Early vehicle conversions used existing OEM switches and attached levers and extensions to permit the driver to reach the secondary controls. These adaptations can still be used reliably today, but the design of the newer vehicles precludes some previously used applications. Today we have individuals with higher levels of disabilities on the road, requiring a more sophisticated system to allow independent control of secondary vehicle functions. Operating a single switch with the touch of a finger or bump of the elbow can trigger a micro-computer to signal the driver to select a function and a second action of the switch will operate the selected function. The system needs to match the driver's ability and comfort level so it can be used reliably [19].

Wheelchairs Used as Seats in Motor Vehicles

Drivers using OEM seating

If a person's disability has resulted in a minimal loss of strength and range of motion in only one or two limbs, many relatively simple methods of vehicle controls can be employed. In this case the driver can often use the existing (OEM) vehicle seat. The seat may be accessed from the driver door or from the inside area of a van or minivan. If a mobility device is used, such as a wheelchair, scooter, crutch or walker, the driver will need to stow and secure the aid in a safe location. Driving from the OEM seat is a preferred method because the seat is designed and tested to meet Federal Motor Vehicle Safety Standards (FMVSS) [20]. The seat also provides a stable platform to drive from and it is designed to work with the vehicle mounted safety systems such as the head and backrest, seat belt system and airbag system designed to protect drivers in the event of a motor vehicle accident.

Drivers Seated in Wheelchairs

Individuals that stay seated in their wheelchairs during driving can often not use the OEM seats due to their postural needs or inability to independently transfer in a safe and timely manner from their wheelchair seat onto the OEM vehicle seat surface. Because OEM seats are designed to withstand crash-level loading and are positioned to function optimally with airbag system and the 3-point safety restraint (seatbelt), individuals that stay seated in their wheelchairs are disadvantaged in several ways. First, their wheelchair may not be designed to function as a seat in a motor vehicle. Second, the occupant restraint system or seat belt system does not always optimally fit around the driver's pelvis and upper torso due to interference of belts with the wheelchair frame and armrests. Thirdly, the airbag may be disconnected due to the selection and placement of primary vehicle controls [21, 22]. Furthermore a wheelchair needs to have sufficient rigidity to provide a stable driving platform and have a means for tight securement in the driving position during normal driving conditions but also during a vehicle impact. Individuals who use a power wheelchair with tilt-in-space features may encounter additional issues when using their tilt system in the tight driver station or while driving. Depending on the level of disability, a wheelchair-seated driver's primary control system may range from a highly sensitized to a simple mechanical lever. In a highly sensitized system, even a small movement of the secured wheelchair or seating system may translate into significant alterations in driving control positioning, causing difficulty in maintaining lane position.

When selecting a wheelchair for use as a seat in a motor vehicle, it is recommended to choose one that complies with ANSI/RESNA Volume 1,Section 19: Wheelchairs for Use as Seats in Motor Vehicles [23]. So-called "WC19" compliant wheelchairs feature appropriate wheelchair battery retention during vehicle impact (powered wheelchairs only), a crashworthy seat surface, four easy identifiable anchor points to secure the wheelchair with a 4-point tiedown system and an attachment point on the wheelchair frame to anchor a crash safe wheelchair mounted pelvic belt [24]. Awareness of WC19 compliant wheelchairs among CDRS is important in providing wheelchair-seated drivers with optimal (transit-safe) wheelchair seating while driving in a motor vehicles [22].

Although a 4-point belt-type tiedown system is the standard system to secure wheelchairs in motor vehicles [25], these systems are primarily designed for use by an assistant. Wheelchair users are typically unable to independently secure their wheelchair with a 4-point tiedown system. Therefore, wheelchairs used by drivers in private vehicles are commonly secured with an automated lock-down system that allows for independent and automatic docking of the wheelchair to the vehicle floor. This docking type securement secures the wheelchair in a specific position and prevents the wheelchair from moving more that a nominal distance in and around three axes. There are several wheelchair tiedown and occupant restraint (WTORS) manufacturers (EZ-Lock, Permobil, Q'Straint and Sure-Lock) that have developed docking systems and matching brackets that attach to the bottom of a wheelchair. To ensure safe driving, it is important that docking-type securement systems are dynamically tested to meet performance criteria said forth in SAE J2249 and ISO-10542 standards [25, 26].

To minimize excessive rider movement and to limit a wheelchair-seated driver from impacting driving controls, the windshield or other interior structures, it is essential that a driver can use the safety belt system (shoulder and lap belt) independently. For this system to be effective, belts should fit snugly across the pelvis, chest and shoulder [27-29]. The van modifier and CDRS need to communicate to make sure that the safety belt system is placed in such a way that the wheelchair-seated driver can easily and independently enter the driver station and that belts fit snugly across the pelvis and upper torso. Q'Straint in collaboration with the Rehabilitation Engineering Research Center at the University of Michigan and Pittsburgh, is currently developing a system that provides wheelchair seated drivers with independent and easier access to the seat belt system. And for those individuals whose armrests interfere with proper belt routing, the belt can be disengaged and positioned through the armrest for a more optimal fit. Easy belt positioning and proper fit are best achieved if the wheelchair chosen has an "open-style" armrest that allows the pelvic belt to lie close to the body and provide optimal positioning and fit. A closed or "T-shape" armrest prevents an optimal pelvic belt fit and forces the belt over or against the armrests structure [22], allowing the driver's pelvis to move forward (submarine) during a frontal impact [30, 31].

If the muscles supporting the lower and/or upper torso are not adequate to maintain proper body position during severe driving maneuvers, additional (lateral) supports should be used, such as a chest harness, lateral stabilizers, pelvic supports or shoulder pads. These postural supports should be used in addition to the seat belt system and not in lieu of because most wheelchair-mounted belts have *not* been crash tested and some are even designed to break away from the wheelchair during a vehicle crash.

Research has further indicated that wheelchair-seated drivers are often positioned in close proximity to the steering wheel in order to reach the vehicle's adaptive equipment [21, 22]. In cases of vehicle accidents where the air bag deploys, severe injuries can occur, especially if the driver is not using a properly positioned seat belt system. The National Highway Traffic Safety Administration, which sets standards for motor vehicles, allows certain exemptions and alterations to air bags for vehicles used by disabled drivers. Air bags may be disconnected depending on the make and model of the vehicle. However, when disconnecting or removing an airbag, the driver should use a well-fitted and well-positioned safety belt as a means for occupant protection.

Finally, OEM vehicle seats are equipped with a headrest to reduce the risk of neck injury during frontal and rear impact, by limiting head movement [32-34]. Guidelines for the use of postural support devices by wheelchair users during motor vehicle travel state that excessive rearward head and neck movement can be reduced by the use of a wheelchair-mounted headrest. Although headrests may not be designed to withstand crash level loading [35-37] they can provide partial protection (against whiplash) if positioned close to the back of the head [38].

Safety and Information Systems

Directly minimizing risk of occupant injury can be done through the use of safety and informational system onboard a vehicle. There are several technologies on the market and on the horizon that can aid individuals with disabilities and the elderly in safe driving.

Navigation

For drivers who do not have difficulty with divided attention, the value of in-vehicle navigation may indeed be an important feature due to reductions in confidence and/or ability to navigate in unfamiliar territory. If drivers acknowledge this difficulty, they only drive on very familiar routes. Thus, in-vehicle navigation systems are becoming very attractive to drivers as a means to compensate for poor or impaired way finding abilities. This includes non-disabled drivers in a new or confusing area who are "impaired" by the unfamiliarity of the environment.

Collision Warning Systems (CWS)

This functionality warns for potential collisions and has obvious benefit in the form of early warnings for drivers who have difficulty perceiving the road scene and/or have slow response times. The desire to reduce rear-end crashes is the motivation for these systems since approximately 30% of all crashes, injuries and property damage are of this type [39]. Collision warning systems (CWS) and blind spot detectors have been on the market but have mostly been installed on commercial vehicles such as tractor-trailers. Blind spot detectors can benefit those individuals that have limited head/neck range of motion. Most sensors only watch ahead of the car, but some include side looking presence sensors to help with lane change maneuvers. Research systems capable of more complex side warning have been tested [40], but these are far from getting to market due to the difficulty of tracking vehicles in two dimensions. In all of these cases, a user interface indicates to the driver when a collision is imminent, thus prompting corrective action by the driver.

Adaptive Cruise Control (ACC)

When CWS is tied to the automobile's cruise control, the vehicle can automatically respond to front obstacles by releasing the accelerator, shifting to a lower gear, and/or activating the brakes. This system is referred to as adaptive cruise control. This feature has the potential to help drivers who have a tendency to stop too late or who have trouble maintaining an appropriate following distance. Currently, ACC is an option on some luxury cars and is available in some modern commercial trucks. Most of these systems are designed for highway speeds but there are also systems that operate all the way down to stop-and-go traffic. While CWS and ACC will likely improve safety for the general public, there are certain design concerns regarding ease of use and legal liability. As such, most consumers in the United States will encounter ACC before CWS.

Proximity Sensors and Obstacle Avoidance

One technology that is particularly attractive to drivers who have limited neck motion is the parking aid. Parking aids include rear proximity sensors and other parking collision avoidance systems [41]. These systems typically utilize audible alerts or iconic displays on the dashboard to indicate that the driver is about to back into an object. There is also anecdotal evidence that such systems reduce the use of mirrors and direct visual inspection in the general public. This is complicated by the rather poor performance of some of these systems [42]. Nevertheless, rear camera systems are becoming increasingly common. More recently, automated parallel parking and docking alongside curbs [43] is becoming a market reality – drivers can now purchase a semi-autonomous parallel parking option for certain vehicles.

Driving Behavior and Feedback

There are also opportunities to observe driver behavior and provide feedback. This is already done in fleet vehicles [44] and is starting to be used by the regular public. Such monitoring and coaching must walk a fine line; drivers may perceive the loss of privacy to outweigh the benefits. Systems with poor user interaction models run the risk of being perceived a nuisance. Work in drowsy driver monitoring [45] suggests that driver coaching systems that employ a "trusted advisor" interaction model can provide effective information in a manner that drivers will accept. Research on this front specific to drivers with disabilities is underway [46].

The Future in Personal Transportation

Paradigm Shift

There are two major technological paradigm shifts in the foreseeable future. First, the automotive industry is starting to see market penetration by Intelligent Transportation Systems (ITS). A decade ago it was believed that it would be possible to move directly from vehicles operated by humans to fully automated vehicles. After initial successes [47, 48] it was found that the technical, institutional, and societal barriers are too difficult to overcome all at once. Instead, an incremental approach became the new paradigm and the incorporation of new vehicle capability is occurring at the component level. ITS has steadily evolved from research prototypes to successful commercial products. Examples include automatic crash notification, collision warning and avoidance, lane keeping assistance, vision enhancement systems, driver monitoring, and in-vehicle navigation systems. The DARPA Urban Grand Challenge [49] demonstrated that automated driving in non-highway settings is considerably closer to reality, thus prompting renewed calls for more rapid progress towards fully automated cars [50]. This, of course, would provide significant value to drivers with significant disabilities.

Second, the aging of the population is leading to greater awareness within the automotive industry that improvements must be made in a variety of areas [51]. The industry is also interested in quicker production cycles and reusable components. A component designed to support the needs of older drivers in one model line may also be used in a model line targeted at younger drivers. These factors combine to present incentives to embrace universal design. This is supported by a recent "wish list" of research initiatives, applications, and system changes put forward by the American Medical Association which includes a call for improvements in vehicle design on this function: "Age-related changes in vision, cognition, and motor ability may affect an individual's ability to enter/egress a motor vehicle with ease … We encourage vehicle manufacturers to explore and implement enhancements in vehicle design that address and compensate for these physiological changes" [52] p. 189.

ITS and the trend towards reusable components are fundamentally changing the way cars work. Multi-function displays on the dashboard are now common and factory installed drive-by-wire is on the horizon. There are already vehicles on the market with no mechanical link between the accelerator and the engine. These trends provide key opportunities to reduce the cost of vehicle modification through standardized communication protocols [53-55]. Interestingly, the research community has already started merging adaptive driving with ITS. For example, drive-by-wire products designed for the vehicle modification market were used by competitors in DARPA's recent automated vehicle competitions [56].

Finally, the cost of modified vans and equipment range between $200 and $90,000 for a fully equipped vehicle. These adaptation costs are normally absorbed by a third party payers such as insurance or State offices of Vocational Rehabilitation. In addition there are alternative funding sources (for individuals that do not work) to get driving systems paid for. Universal Design, as mentioned above is an important way to minimize cost of conversion vans. There are van companies coming to the market with vans that feature low floors in their base models. This low floor design allows for easy conversion for someone who uses a wheelchair and needs a lift or ramp.

Summary

To ride safely in a vehicle, disabled drivers must use adaptive equipment and technology that is specific to his or her functional abilities. Furthermore, to minimize passenger and driver injury and damage from driving controls in the case of an accident, it is essential to wear a well-positioned shoulder and lap belt that can be independently secured by the driver. For those individuals that ride while seated in their wheelchair and for unoccupied wheelchairs, the wheelchair needs to be safely secured to the vehicle floor during transportation to maintain a safe distance to driving controls during the ride and to ensure the wheelchair does not move during vehicle maneuvers.

There are several aspects of driving and preparing for driving during which a disabled driver can experience discomfort or experience unsafe conditions. These instances include difficulty boarding and/or exiting the vehicle, maneuvering inside the vehicle into the driver area, securing the wheelchair in the docking system, positioning, securing and/or releasing the seat belt, discomfort when wearing the seat belt, reaching and/or using the primary and secondary controls and experience a loss of balance while making a turn. A CDRS and a NMEDA equipment dealer need to be consulted for their assistance by adjusting controls, replacing components and selecting alternative devices that meet the user's needs. Although personal vehicles may soon be standard equipped with drive-by-wire controls and safety information systems to enhance safe driving for all, communication between drivers and passengers with disabilities, a CDRS evaluator and a NMEDA equipment dealer remain key in assuring the safety of individuals with disabilities riding motor vehicles.

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