Chapter 7: Conclusion

Research and design efforts on a new wheelchair PAU invention have successfully produced an inexpensive, highly-portable product which can quickly convert a manual wheelchair into a power-operated wheelchair. Two generations of working prototypes have been developed and fabricated over the three-year duration of the project. Evaluations conducted with the second prototype have demonstrated the effectiveness of the new PAU and defined performance and user interaction characteristics. Results of the evaluations were combined and interpreted to produce a list of identified problems and recommended design changes. It is suggested that this list serve as a basis for the design process during the next product iteration. Summaries of the findings are presented here with a statement concerning the future of the project.

Expert Information Interview Evaluation

Interviews conducted with eight experts in the field of wheelchair operation and rehabilitation sciences identified user interaction and performance concerns. The experts also provided suggestions which were incorporated into the subsequent evaluations and avenues to improve possible design deficiencies. No significant problems were identified, and therefore no major changes were made to the prototype prior to the performance and usability evaluations.

Performance Evaluation

Performance tests with the PAU in power mode produced the following results with a 165-pound user load:

- -- The PAU is capable of traversing a one inch high vertical obstacle.
- -- The maximum speed produced by the PAU is 2.25 miles per hour.
- -- The PAU is capable of operating for over four miles on flat ground with one charge of a nine pound battery (the unit will operate with larger batteries as well).
- -- The PAU can ascend a smooth ramp with an angle of six degrees. With a rough surface, the PAU can ascend a ramp with an angle over ten degrees (new building codes limit ramp angles to approximately five degrees).
- -- The evaluation team was unable to create a maneuvering scenario on flat ground which caused any wheel of the wheelchair to leave the floor (thus the device affords good dynamic stability).
- -- Additional tests found that the PAU can be reliably operated on carpet, wet surfaces, over common obstacles (short curbs, thresholds, etc.), and on rough surfaces such as gravel and cement pocked with holes.

Usability Evaluation

The PAU was successfully evaluated in a usability study with wheelchair operators to demonstrate usability, identify and prioritize design deficiencies, and determine avenues for improvements. Testing conducted with seven potential consumers of the PAU found the device to be quite usable. On the scale of one to seven, where one is "Easy" and seven is "Difficult," the average "ease of operation" rating provided by the participants was 2.3. All of the participants with normal upper body capabilities were able to independently attach and detach the PAU and battery, transfer in and out of the wheelchair with the PAU attached, and maneuver the unit in power mode. Results

also determined that the time required to perform these evaluated tasks was far less than the time the subjects estimated they would be willing to spend on the tasks as consumers. Four of the seven participants said that the product would be useful to them. Two of the seven explained that they are too active in this stage of their lives to use such a product, and the last participant simply stated that it "does not fit my needs."

Design Recommendations

The results from the usability evaluation were compared to findings from the expert information interview and PAU performance evaluations. These combined outcomes were reviewed for trends indicating aspects of the PAU design which may be decreasing performance effectiveness or user satisfaction. The findings have been interpreted and combined with design team input to produce a suggested list of design features which need to be changed with the next PAU prototype iteration. The following design deficiencies outline the major areas identified.

- -- Safety issues included identification of a pinch point at the top of the column unit and loss of wheelchair control resulting when the drive wheels lose ground contact or friction.
- -- Components which require a stronger design include the securing crossbars, the handle, and contact surface areas of aluminum parts.
- -- Maneuvering in reverse is difficult due to the trailing drive wheel assembly.
- -- Attachment and detachment procedures are designed for two dexterous hands. One-handed procedures were identified as a design priority.
- -- Excessive resistance to motion can exist between the upper crossbar and securing blocks which must articulate.
- -- Some component locations and accessibility features provide unnecessary obstacles to operator procedures. Identified components include the battery sling, upper crossbar release mechanism, column in transfer mode, external wires, and column unit plug.
- -- The handle arm design, oriented toward the user, precludes use of the PAU by large operators.
- -- The finger trigger requires finger strength and dexterity to operate.

Product Development Process

The next step in the product development process is to address design areas where changes will be necessary (where testing has identified safety issues). A simultaneous cost/benefit analysis can be performed on the recommended design changes which are not mandatory. Project managers may wish to base this analysis on refined target consumer population characteristics and other production and maintenance factors. The next generation prototype development team should also include a manufacturing specialist to develop mass production strategies for component fabrication and assembly.

Social Benefits and Future Applications

The new PAU invention has been designed to provide independence to disabled persons which has not previously been available. Transportable, powered mobility means that wheelchair users can easily move their wheelchairs from one location to another in a personal vehicle, and then travel longer distances when arriving at the new location. People who previously required an attendant to push the wheelchair up grades, will be able to power up slopes independently. The features of the new

design and expected low cost will make this independence available to a much broader pool of consumers than the more expensive products with safety and operational deficiencies.

Future applications of the product may also include providing inexpensive powered mobility to countries without the financial resources to provide more elaborate assistance. The product may be useful to organizations with limited funds that must offer customers powered mobility as required by law. The increased independence of wheelchair users may alleviate some of the strain on local governments required to provide transportation to wheelchair users. This may be accomplished by permitting larger numbers of wheelchair operators to utilize personal vehicles, thereby decreasing the load on accessible public vehicles. It is also anticipated that as a leased item, the new invention will offer transportable powered mobility to the temporarily disabled who are not equipped to handle the special transportation needs of bulky electric wheelchairs.

References

Avakian, E. A., and Masi, J. V. (1993). Method of and Apparatus for Motorizing Manually Powered Vehicles (United States Patent Number 5,186,269).

Axelson, P., and McLaurin, C. A. (1990). Wheelchair Standards: An Overview. In Journal of Rehabilitation Research and Design Clinical Supplement No. 2: Choosing A Wheelchair System (pp.100-103). Baltimore, MD: Department of Veterans Affairs.

Berger, E. H., Ward, W. D., Morrill, J. C., and Royster, L. H. (Eds.) (1986). Noise and Hearing Conservation Manual, Fourth Edition. Fairfax, VA: American Industrial Hygiene Association.

Bowe, F. G. (1995). The Political and Economic Issues That Drive and Derail Assistive Technology Development. Generations, XIX, 37-40.

Broadhead, D. G., and Hobson, B. M. (1991). Power Assist Device for a Wheelchair (United States Patent Number 5,222,567).

Butler, C. (1995). Mal Bonding. In Sales and Marketing Management, 147, 66-72.

Casali, J. G. (1994). Universal-Fit, Quick-Connect Power Drive/Steer Attachment for a Wheelchair (United States Patent Number 5,651,422).

Coker, T. R. (1983). Detachable Electric Drive Unit for Wheelchair (United States Patent Number 4,386,672).

Coker, T. R. (1991). Detachable Electric Drive Unit for Collapsible Wheelchair (United States Patent Number 5,016,720).

COMSIS, Corporation. (1988). Product Safety and the Older Consumer. Washington D.C.: U.S. Consumer Product Safety Commission.

Cooper, J. B., Long, C. D., Newbower, R. S., and Philip, J. H. (1982). Critical Incidents Associated with Intraoperative Exchanges of Anesthesia Personnel. In Anesthesiology, 56, 456-461.

Del Galdo, E. M. (1986). Development and Evaluation of Critical Incidents as an Interface Design Tool. Unpublished thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Del Galdo, E. M., Williges, R. C., Williges, B. H., and Wixon, D. R. (1986). An Evaluation of Critical Incidents for Software Documentation Design. In Proceedings of the Human Factors Society 30th Annual Meeting (pp. 19-23). Santa Monica, CA: Human Factors Society.

Duke, S. (1950). Motor Attachment for Wheelchairs (United States Patent Number 2,495,573).

Fitts, P. M., and Jones, R. E. (1947). Psychological Aspects of Instrument Display. 1: -Analysis of 270 "Pilot-Error" Experiences in Reading and Interpreting Aircraft Instruments. In H. W. Sinaiko (Ed.), Selected Papers on Human Factors in the Design and Use of Control Systems (pp. 1-38). New York, NY: Dover Publications.

Flanagan, J. C. (1954) The Critical Incident Technique. In Psychological Bulletin, 51, 327-358.

Gaal, R. P., and Johnson, D. O. (1993). Phase 1 Initial Evaluation of Power Add-On Units for Lightweight Wheelchairs (Technical Report). San Francisco: San Francisco State University, Wheeled Mobility Center.

Garin, P. V., and Lusk, D. E. (1993). Foldable Wheelchair With Optional Power or Manual Drive (United States Patent Number 5,197,559).

Gitlin, L. N. (1995). Why Older People Accept or Reject Assistive Technology. Generations, XIX, 41-46.

Goldenfeld, I. V., Mautner, Y., and Mastov, E. (1988). Wheelchair Drive (United States Patent Number 4,759,418).

Hall, Z. W., Kupfer, C., and Leshner, A. I. (1996). Reauthorization of the National Institutes of Health Hearing. U. S. Senate. Committee on Labor and Human Resources. Washington, D. C.: GPO.

Harris, G. F., and Smith, P. A. (Eds.) (1996). Human Motion Analysis. New York, NY: Institute of Electronical and Electronics Engineers.

Henderson, A. B. (1995). The Wheelchair Turns Hip as New Generation of User Demands Style. In Wall Street Journal, Sept. 28, A1.

Hix, D. and Hartson, H. R. (1993). Developing User Interfaces: Ensuring Usability Through Product and Process. New York, NY: Wiley.

Hobson, D. A. (1990). Seating and Mobility for the Severly Disabled. In Rehabilitation Engineering. Boston, MA: CRC Press.

Hotchkiss, R. D. (1993). Groundswell on Wheels. The Sciences, 33(4), 14-18.

IDHP (1991). The Illustrated Directory of Handicapped Products 1991-1992. Lawrence, KS.

Jones, G. C. (1990). Kit for Converting a Hand-Powered Wheelchair to an Electric Motor-Power Wheelchair (United States Patent Number 4,961,473).

Kaiho, Y., and Hirota, T. (1975). Electrically Drivable Wheelchair (United States Patent Number 3,905,437).

Kamenetz, H. L. (1969). The Wheelchair Book. Springfield, IL: Charles C. Thomas.

Karat, J. (1988). Software Evaluation Methodologies. In Handbook of Human-Computer Interaction (pp. 891-903). North-Holland: Elsevier Science Publishers.

Karchak, A., and Allen, J. R. (1975). Wheelchair Drive Package (United States Patent Number 3,893,529).

Karlsen, K. A. (1971). Battery Driven Wheelchair (Norwegen Patent Number 2,061,543).

Kleinwolterink, H. (1991). Power Attachment for Wheelchair (United States Patent Number 5,050,695).

Kropf, W. K. (1992). Power Unit for Driving Manually-Operated Wheelchair (United States Patent Number 5,135,063).

Lefkowicz, A. T. (1993). The Validation of a Perspective-View Micro-Computer Based Wheelchair Simulator. Unpublished thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Mastov, E., Mautner, Y., Gilad-Smolinsky, Z., and Levy, M. (1992). Electric Drive Attachment for a Wheelchair (United States Patent Number 5,113,959).

McFarland, S. R., and Wilson, A. B. (1986). Wheelchairs: A Prescription Guide. Charlottesville, VA: Rehabilitation Press.

McLaurin, C. A. (1990). Current Directions in Wheelchair Research. In Journal of Rehabilitation Research and Design Clinical Supplement No. 2: Choosing A Wheelchair System (pp. 88-99). Baltimore, MD: Department of Veterans Affairs.

Meeker, G. L. (1994). Apparatus and Method for Attaching a Motorized Wheel to a Wheelchair (United States Patent Number 5,494,126).

Meister, D. (1986). Human Factors Testing and Evaluation. New York, NY: Elsevier.

Nicosia, A., and Phillips, L. (1990). An Overview...with Reflections Past and Present of a Consumer. In Journal of Rehabilitation Research and Design Clinical Supplement No. 2: Choosing A Wheelchair System (pp. 1-7). Baltimore, MD: Department of Veterans Affairs.

Palmeri, C. (1993). Wheel-to-Wheel Combat. Forbes , 151(4), 62-64.

Porter, A. L., Roper, A. T., Mason, T. W., Rossini, F. A., and Banks, J. (1991). Forecasting and Management of Technology. New York, NY: Wiley and Sons.

Rabjohn, R. R. (1968). Power Operated Wheelchair (United States Patent Number 3,387,681).

Rosenthal, H. (1963). Electric Driving Apparatus for a Wheel Chair (United States Patent Number 3,100,547).

Stolov, W. C., and Clowers, M. R. (Eds.) (1981). Handbook of Severe Disability. Washington D. C.: U. S. Government Printing Office .

Treu, S. (1994). User Interface Evaluation: A Structured Approach. New York, NY: Plenum Press.

Warren, C. G. (1990). Powered Mobility and Its Implications. In Journal of Rehabilitation Research and Design Clinical Supplement No. 2: Choosing A Wheelchair System (pp. 74-85). Baltimore, MD: Department of Veterans Affairs.

Whiteside, J., Bennett, J., and Holtzblatt, K. (1988). Usability Engineering: Our Experience and Evolution. In Handbook of Human-Computer Interaction (pp. 791-817). North-Holland: Elsevier Science Publishers.

Zimmer, Z., and Chappell, N. L. (1994). Mobility Restriction and the Use of Devices Among Seniors. Journal of Aging and Health, 6, 185-208.