STAKEHOLDER FORUM
ON
WHEELED MOBILITY

Proceedings from the Stakeholder Forum on Wheeled Mobility

held in Pittsburgh, Pa.

May 25 & 26, 1999

This is a publication of the Rehabilitation Engineering Research Center on Technology Transfer, which is funded by the National Institute on Disability and Rehabilitation Research of the Department of Education under grant number H133E980024. The opinions contained in this publication are those of the grantee and do not necessarily reflect those of the Department of Education.

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ACKNOWLEDGMENTS

"Coming together is a beginning, staying together is progress, and working together is success."   (Henry Ford)

On behalf of the Rehabilitation Engineering Research Center on Technology Transfer (T^2RERC) I would like to acknowledge and thank a number of people and organizations who are helping to make the Project on Wheeled Mobility a success.

First, I want to thank our sponsor, the National Institute on Disability and Rehabilitation Research of the U.S. Department of Education. Without their support, this valuable research would not have been possible.

I would like to thank the Federal Laboratory Consortium (FLC), Mid-Atlantic Region and its director, Rich Dimmick, for co-sponsoring this project. We hope that the Mid-Atlantic FLC will be an important source for technology solutions that address the needs and opportunities identified during the Stakeholder Forum. I would also like to thank Frank Koos of the FLC Locator Service for his help in recruiting some critical Forum attendees.

Special thanks to our partner and host RERC, the Rehabilitation Engineering Research Center on Wheeled Mobility at the University of Pittsburgh (also funded by NIDRR). In particular, Dr. Douglas Hobson deserves recognition for his guidance and input to this project, as well as the students from Pittsburgh's RERC and the Human Engineering Research Lab for their contributions to document preparation and logistical support at the Stakeholder Forum.

Of course without the many participation of consumers, clinicians, researchers, businesses and government, the Forum and overall Project could not be successful.   Thank you to everyone who participated in our initial telephone interviews, panels and the Forum itself.

I would like to thank our partners from the Research Triangle Institute, for providing valuable insights and assistance on technology transfer; AZtech Incorporated for developing the industry profile, and the Western New York Independent Living Center for bringing the consumer's perspective to this Project.

Finally, I would like to give my thanks to the staff at the T2-RERC whose hard work, team effort, patience and humor have sustained this Project from the very beginning.

Sincerely,
Dr. Stephen Bauer
Demand-Pull Project Director &
Co-Director of the T2RERC

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EXECUTIVE SUMMARY

In November 1998 the Rehabilitation Engineering Research Center on Technology Transfer (T^2RERC), partnered with the RERC on Wheeled Mobility to begin the *Demand-Pull Project on Wheeled Mobility*.

The goal of this Project is to identify unmet needs in the wheeled mobility industry segment (manual and power wheelchairs, and scooters) and to facilitate the transfer of technology solutions from Federal Labs, research institutions and other advanced technology developers to meet these needs.

The Project focused on four technology areas: manual wheelchair propulsion; motors and drive-trains; materials and components; and power, power management and monitoring. Technology needs identified within these four areas represent important and unmet customer concerns having a significant business potential for manufacturers. Further, technology solutions required to address these needs are likely to be beyond current industry capabilities or resources.

The Project depends upon the participation of a wide variety of disability specific stakeholders. In the case of the Wheeled Mobility Project these include product end-users (consumers), referral sources (clinicians), evaluators of existing or developing technologies (clinical researchers), producers of technology for commercial application (manufacturers), innovators of new technology (Federal Laboratory Consortium scientists), as well as representatives from various governmental agencies.

Full stakeholder participation helps to ensure that: unmet needs of consumers and manufacturers are clearly identified; the technological state-of-the-practice for current products is well characterized; and reasonable design and performance parameters are established for both short-term and long-term technology solutions. Particular benefits to stakeholders include that product customers help shape the design and performance characteristics of next generation products; scientists, engineers and clinicians become aware of research needs and opportunities and manufacturers are introduced to business opportunities and advanced technology solutions.

Further details on the steps and process of the Wheeled Mobility Project can be found in the Project Description of these Proceedings.

PROJECT DESCRIPTION

Introduction

The T2RERC's Demand Pull Project focuses on the transfer of emerging technologies, R&D capabilities, or design expertise from Federal Labs, advanced technology manufacturers, and researchers (referred to as "technology developers") to assistive technology manufacturers (referred to as "technology consumers").

The T2RERC Project utilizes a five-step process:

1) Select the Industry Segment

Each year, the T2RERC in partnership with a sister RERC begins a new demand-pull Technology Transfer Project that targets a distinct assistive technology industry segment. The partner RERC plays a key role in selecting the industry segment and in the identification of candidate technology needs.

2) Identify Technology Needs

Selection of specific technology needs relies upon the triangulation of information obtained from product end-users, technical and clinical experts and manufacturers. Consumer panels are utilized to obtain end-user information. Interviews are utilized to obtain information from technical experts, clinical experts and manufacturers. The T2RERC works with interviewees to protect intellectual property and business interests.

The T2RERC develops white papers and an industry specific profile to compliment and expand upon the information derived from the interviews and panels. A white paper is written for each distinct area of technology need. A white paper includes information on unmet customer needs; market information; business opportunities; and technology state-of-the-practice for products now in the market. The industry profile provides details about relevant manufacturers and products, it also identifies the overall market size, distribution channels, reimbursement issues, trade shows, and conferences for the targeted market segments. The partner RERC identifies reference materials, and reviews and validates the white papers and industry profiles.

3) Validate Technology Needs

A stakeholder forum is convened to provide additional focus and detail for the technology needs identified. Forum participants include: market, research and technical experts; advanced technology developers from related industry segments; product customers (e.g. end-users, clinicians, therapists, equipment vendors and service technicians); and private and public resource providers (e.g. representatives from federal agencies and national associations). Prior to the

Forum, all participants receive the industry overview and "white papers" that provide market and technical background on the technology areas to be discussed.

The purpose of the Forum is to:

1. Clarify and validate the existence of significant customer needs not addressed by current technology.

2. Validate that the unmet customer needs represent a significant business opportunity.

3. Validate that significant technical innovation is required to meet these customer needs.

4. Validate that the technical innovation cannot easily take place within the industry segment.
5. Establish design and performance targets for the technical innovation.

6. Identify barriers that might prevent the successful development or transfer of the technical innovation.

Stakeholder Forum outcomes and all prior work are used to generate problem statements that summarize customer needs, business opportunities, and technical needs and specifications.

4) Locate Technology Solutions

A web site is developed (located at the Research Triangle Institute) to disseminate problem statements and promote the technology transfer project to Federal Laboratories, advanced technology manufacturers, research institutions and other technology developers. Additional project promotion is accomplished through the T2RERC and partner RERC web sites; press releases; articles in journals, newsletters and trade publications; and presentations at trade shows and conferences. Technology developers are identified and contacted through phone, email and mail correspondence.

Technology developers submit [most] technology proposals through the project web site. Initially, all submitted solutions are non-proprietary. To confirm that technology proposals address customer needs, manufacturer needs and are also technically feasible the T2RERC and partner RERC review the technology proposals. External technical or industry experts may be utilized as part of this review. Proprietary information may be requested from the technology developer. In such cases, mechanisms to protect intellectual property are worked out between the technology developer and the T2RERC.

For promising technology proposals, disclosure agreements are negotiated between the T2RERC and these technology developers. These agreements allow the T2RERC to act as an agent of the technology developer when manufacturers.

5) Transfer the Technology Solution

The T2RERC, in partnership with AZtech (a marketing firm under sub-contract to the T2RERC), prepares a commercialization package. The commercialization package summarizes the end-user needs to be met, the business opportunity to be realized, the target technical specifications to be met, the technology proposal submitted to meet these specifications, and a business plan by which to achieve the transfer.

A marketing plan is developed that identifies target manufacturers and the strategy that will be employed to contact and present the commercialization package to these manufacturers.

The technology transfer is completed through mechanisms such as licensing the technology directly to a manufacturer; establishment of a research and development agreement between manufacturers; or a cooperative research and development agreement (CRADA) between a federal lab and a manufacturer.

Technology Transfer activities of the T2RERC are funded by a grant from the National Institute of Disability and Rehabilitation Research. The T2RERC receives no financial benefits from technologies transferred under this project.

Demand Pull Projects

Summary of Progress to Date

In September 1999, the "Demand-pull Project on Wheeled Mobility" was started in partnership with the RERC on Wheeled Mobility (Mobility-RERC). As of December 1999, the first three steps (Select Industry Segment, Identify Technology Needs, Validate Technology Needs) of the project have been completed. We are activity engaged in the completion of the fourth step (Locate Technology Solutions). To date, we have received approximately sixteen technology proposals. Dissemination of problem statements; and the solicitation and screening of proposals will continue until such time that appropriate technology solutions are identified.

In September 1999, a second project, the "Demand-pull Project on Hearing Technology" was started in partnership with the RERC on Hearing Enhancement and Assistive Technology (Hearing-RERC). As of March 1999, the first two steps (Select Industry Segment, Identify Technology Needs) will be complete. We are activity engaged in the completion of the third project step (Validate Technology Needs).

Timeline And Milestones: Demand-pull Project On Wheeled Mobility

October 1998: Project Inception

November 1998: Staff at AZtech and the T2RERC completed a comprehensive industry profile for the manual wheelchair, power wheelchair and scooter industries. This profile includes but is not limited to: manufacturers, product and contact information, and market share; market profiles; component suppliers; laws, regulations and reimbursement issues; trade organizations and journals; and shows and conferences.

February 1999: Consumer panels and interviews with researchers and industry representatives are completed and the gathered information tabulated. A joint meeting is held involving staff from the T2RERC, RERC on Wheeled Mobility and RTI. Four technology areas are selected on which focus the project:

White Paper 1: Manual wheelchair propulsion

White Paper 2: Motors and Drive-trains

White Paper 3: Materials and Components

White Paper 4: Power, Management and Monitoring

April 1999: Staff at the T2RERC and RTI completed "White Papers" for each of the four technology areas. Each White Paper includes the unmet manufacturer and customer needs; market potential and business opportunity to be realized if the need is met; the current state-of-the-practice for products and technology; and a short list of open issues. Students and staff at the Mobility-RERC reviewed the White Papers, for accuracy and completeness.

Approximately eighty persons including major manufacturers, leading researchers, Knowledgeable end-users, government officials, and other relevant stakeholders are identified and contacted. After determining their interest and availability, each of these persons is mailed a copy of the four White Papers, a project description, and logistical information pertaining to attendance at and participation in the upcoming Stakeholder Forum.

May 24th and 25th 1999: The "Stakeholder Forum on Wheeled Mobility" is held in Pittsburgh Pennsylvania. The event is hosted by the RERC on Wheeled Mobility while staff from the RERC on Technology Transfer managed the logistics, data gathering, breakout group moderation and related activities. Approximately sixty-five persons attended the Forum including manufacturers, researchers, clinicians, end-users, distributors, federal lab scientists and other stakeholders. Data gathered at the Forum added substantially to information developed through earlier consumer panels and expert interviews. Process quality is monitored for the purpose of improving future practices. All participants are asked to complete a survey at the Forum's closing. All staff and student assistants are asked to document their observations and suggestions.

June 1999: T2RERC and RTI staff completed six Problem Statements for the following sought-after technologies:

Problem Statement 1: Geared Hubs for Manual Wheelchairs
Problem Statement 2: Motors Problem
Problem Statement 3: Transmissions Problem
Problem Statement 4: Improved Tires Problem
Problem Statement 5: Battery Monitoring Technologies
Problem Statement 6: Battery Charger Technologies

The principal focuses of the Problem Statements are technical requirements and targets for the needed technology solutions and anticipated barriers to the realization of these solutions. Each Problem Statement also includes the unmet manufacturer and customer needs; market potential and business opportunities; and the current state-of-the-practice for products and technology.

A seventh Problem Statement for manual wheelchair power assists was drafted. This Problem Statement has not been widely disseminated because innovative power assist products were being introduced to the market at the time the Forum was being held. The draft is publicly available upon request from the T2RERC and has already been provided to a number of manufacturers.

Finally, Forum data suggests that the potential is developing for the transfer of advanced battery technology to the Wheeled Mobility industry. Forum participants suggested that the Mobility-RERC take the lead on a "battery consortium" whose purpose would be to monitor the emergence of advanced battery technologies and guide its application to the wheeled mobility industry. The T2RERC believes that it can make a useful and active contribution to the consortium's efforts if it is put in place.

September 1999: T2RERC and RTI staff completed a web-site for the dissemination of Problem Statements to federal laboratory scientists and other technology developers. Over three hundred representatives of the federal laboratory consortium were notified by mail.

November 1999: T2RERC staff complete (write, edit, format and compile) the "Proceedings for the Stakeholder Forum on Wheeled Mobility." These Proceedings were mailed to Stakeholder Forum participants and other interested parties. The Proceedings include a summary of the Industry Profile; White Papers; data gathered from forum participants; Problem Statements; data gathered through evaluation efforts; partner descriptions; and participant contact information.

In addition to the activities listed above, staff at the T2RERC and RTI is contacting federal laboratory scientists and advanced technology manufacturers to further promote the Project and Problem Statements. The Project has been written up in Rehab Report (November 1999), RESNA News (November-December 1999), Paraplegia News (July 1999, page 22), in addition to the NEWSLINK article mentioned above. Editors at NASA Tech Briefs have been contacted to determine whether the Problem Statement Abstracts can be disseminated through this publication.

Four web-sites (the RERC on Technology Transfer, the Federal Laboratory Consortium, AZtech, and the RERC on Wheeled Mobility) currently reference the RTI web-site. These links serve to “funnel” potential technology developers.

February 2000: To date approximately twenty technology proposals have been received. Additional proposals are in negotiation. Staff from the T2RERC, the Mobility-RERC, RTI and AZtech have identified seven technology proposals with good potential for transfer. Commercialization packages and marketing plans are being developed for each of the seven proposals. Disclosure agreements are being negotiated with technology developers. Manufacturers identified in the marketing plan will be contacted once disclosure agreements are in place.

STAKEHOLDER FORUM PROTOCOLS

The Stakeholder Forum discussions were based upon the information contained in four White Papers disseminated to participants prior to the meeting. Each of the White Papers was developed into a topic area for group discussion. Participants were organized into two sets of four groups based on their expertise or area of interest.

On the first day everyone was divided into their assigned groups and participated in focus group discussions on one of the four topic areas. The following morning each person participated in a second topic area. This method allowed everyone to be involved in two of the four topic areas, which increased the number of people involved in creating the problem statements used to identify opportunities between technology suppliers (researchers) and technology consumers (manufacturers).

Participants in the discussions represented all of the stakeholder groups identified in the project outline. A heterogeneous group brings a greater variety of perspectives to the discussion. This method has proven to be extremely useful when evaluating the reality of products in the market and how they interact with the user and their environment. It is also helpful when evaluating issues that are important to product design, development, manufacture and distribution.

Four moderators lead the four sessions, each responsible for their topic area on both days of the Forum. Moderators led each group with a script developed from the White Papers as well as additional information gathered during the earlier interview phase of the project. A team of technical support personnel who had been involved in the initial research of material for the White Papers was also available to clarify key issues within the group's discussion. As well, T2RERC staff acted as transcribers to document relevant issues from each session. To ensure accuracy of the documentation, each group reviewed the transcript before the session was completed.

Participants were informed of the process that would be followed during each of the three-hour discussion groups. Each moderator followed a common protocol outline but they were given an element of flexibility to adapt their interview techniques to suit their personal style, and more importantly to adapt to the dynamics of the group itself. This is in keeping with the focus group philosophy of creating an open environment for discussion with the freedom to react to what the group has experienced rather than responding to questions identified by researchers. The moderator’s role was to ensure that the discussions remain relevant to the topic area with the ultimate goal of identifying technical barriers to the development of "next generation" wheelchair or scooter technology.

The protocols developed for group discussion included six steps:

1. Establish a common knowledge base of each participant from his or her perspective as the various stakeholders. Issues discussed included the environmental affects on wheeled mobility products, service or technical experiences, safety issues, and other product related experiences.

2. Identify current technologies that pertain to the topic area and discuss their limitations and advantages. For example, "What types of wheeled mobility products are on the market?", and identify their benefits and/or limitations as they relate to the experiences in the discussion section above.

3. Converge on top technologies meeting important end-user needs and addressing current industry limitations.

4. Identify specific design or consumer requirements to achieve the "ideal" product. Each participant was encouraged to develop criteria or design specifications of the perfect product (ideal) without limitation of current technologies used in the industry.

5. Identify and define the technical barriers that currently constrain developing the ideal device.

6. Review notes from discussion to ensure participants agreed with conclusions.

On the final afternoon representatives from each discussion group presented the results of their group to the full delegation of Forum attendees. Attendees were given the opportunity to contribute to the report if they had additional information or comments that needed to be included.

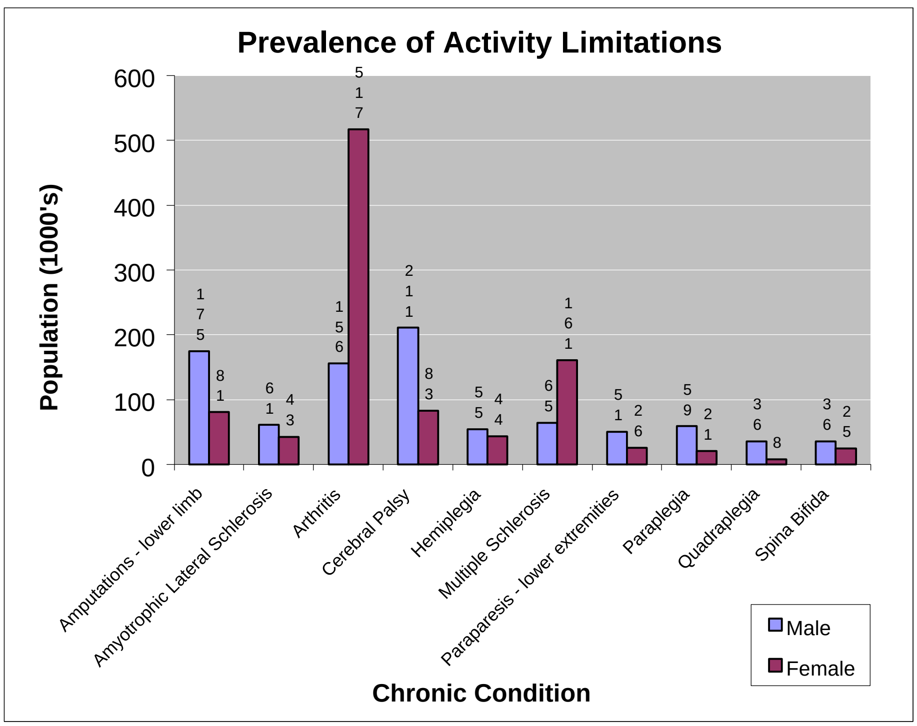
The reports from each topic area were collected by the T2 RERC and were used as the basis for writing the problem statements found within this publication.

INDUSTRY PROFILE

The following is a brief summary of the wheelchair and scooter market in the United States. It is intended to provide the reader with a basic understanding of the market's size based on potential users of these devices. This section also presents information on the wheelchair/scooter market in relation to the home medical market, including reimbursement issues that may affect the overall sale of the product(s) within the industry.

Users of wheelchairs and scooters include people who are unable to walk, or who have difficulty walking due to neurological dysfunction or muscular weakness. Individuals who might be likely users include those with spinal cord injuries (SCI), hemiplegia, and other types of paralysis, multiple sclerosis (MS), cerebral palsy (CP), amyotrophic lateral sclerosis (ALS), spina bifida, arthritis, and lower limb amputees (Figure 1).

Figure 1



Disability in the United States: Prevalence and Causes, 1992 (LaPlante, 1995)[i]

Jones & Sanford[ii] (1996) reported that there were 1,363,026 manual wheelchair users in the United States. In addition, there were 93,467 power wheelchair users. This totals 1,459,493 wheelchair users in the USA alone, which is the equivalent of 38% (Figure 2) of equipment purchases for the entire home medical market.

Figure 2

Approximate Home Medical Equipment Market by Major Product Category

Wheelchairs	38%
Home Care Beds	27%
Bathroom Safety Supplies	15%
Ambulatory Aids	10%
Miscellaneous Patient Aids	10%

Market share of the home medical market by major category.

Source: Find/SVP Inc., New York, 1998[iii]

The scooter market is smaller than wheelchairs. According to Jones & Sanford[iv] (1996), there are 63,636 scooter users in the United States. Typical users of power scooters include individuals in need of mobility assistance outside of the home, in particular for travelling long distances. This condition can be temporary, permanent and stable, or permanent and progressive.

Product Classifications

Medicare, Medicaid, Department of Veterans Affairs and insurance companies consider wheelchairs and scooters as Durable Medical Equipment (DME). Reimbursement is provided depending upon whether it is a manual wheelchair base, a power wheelchair base, or wheelchair options and accessories.

Durable Medical Equipment consists of items - usually "hardware" - that is used at home (Duff, 1997[v]). It must be able to stand up to repeat use, used in the home environment, and be medically useful (that is, its first use must be medical, something a healthy person wouldn't ordinarily need).

Medicare and other health care insurance companies classify scooters for reimbursement as a power operated vehicle (P.O.V.).

A) Manual Wheelchairs

The key functional ability needed to use a manual wheelchair is the use of at least one arm.

According to reports from Medicare (Health Care Financing Administration, Office of Information Services)[vi], the major reimbursement party for both manual and power wheelchairs, manual wheelchairs are one of the top 20 reimbursed products in the USA. Medicare expenditures over a three-year period for a manual wheelchair grew at a steady rate from $95 million in 1995, to $97 million in 1996, to $103 million in 1997.

B) Power Wheelchairs

The key functional ability that is required to use a powered wheelchair is voluntary control over some body function that can be utilized to control switch technology when maneuvering the chair.

Medicare[vii] sources showed a three-year growth rate starting at $24 million in 1995, $64 million in 1996, and $140 million by 1997.

C) Wheelchair Options & Accessories

Wheelchair accessories and options are considered any modifications or additions made to an existing wheelchair due to medical necessity or recreational purposes and are not sold as part of the original chair. Options and accessories can include the following items: arm, back, foot and legrests; specialty seats; handrims; rear wheels and wheel locks; batteries/chargers and parts for motorized/powered chairs; misc. accessories, such as cup holders, tote bags, and umbrellas. While all are optional, reimbursement for coverage will depend on the item as well as the individual's needs.

D) Scooters

Scooter operation requires the use of at least one arm (for steering and controlling the speed), trunk control for sitting and balance, and the ability to transfer into/out of it.

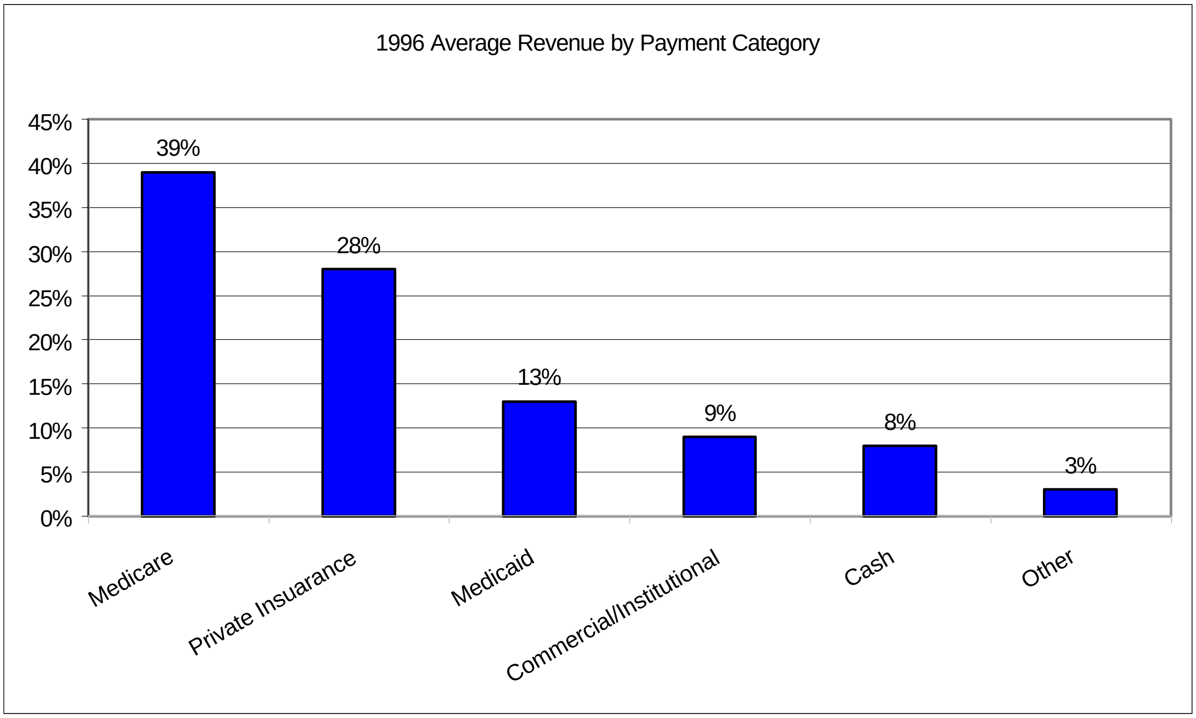
"The USA scooter market is expected to grow from $129.6 million in 1997 to $154.4 million in 2001 according to analysts Frost & Sullivan."[viii].

Reimbursement

When purchasing Durable Medical Equipment, such as manual and power wheelchairs, there are several avenues for reimbursement consumers can consider, both public and private. These options include Medicare, the major reimbursement source (Figure 3), as well as, Medicaid, the Veterans Administration, private insurance, workers' compensation, and community service groups (for example, Lions, Kiwanis, and so on).

It should be noted that, private insurance normally takes precedence over any government sponsored programs. In these situations the secondary payer, for example, Medicare, will pay the remaining balance if the primary payer does not cover the full amount, or, if the claim is refused by the primary payer: providing the claimant qualifies for Medicare coverage in the first place[ix].

Figure 3



Expenditures in the wheelchair market according to methods of payment:

Source: NAMES Industry Survey, 1997, & HIDA Home Care Financial Performance Survey, 1997[x]

According to the US Census Bureau[xi], 162 million Americans were covered by private insurance related to employment of self or by family members.

During the same study period (results gathered from 1987 to 1995), the number of people on Medicaid coverage was 34 million, and those with Medicaid coverage was 32 million. There were approximately 41 million people reporting no health coverage of any type.

Since scooter users may have some ability to walk scooters are often deemed leisure or recreational items and not medical necessities, and are therefore not reimbursable by some insurance companies or programs. However, the difference in acceptance may be as simple as the doctor stating that the scooter is required for use indoors and outdoors -- thereby justifying a medical necessity.

A summary of the major funding sources, including information on the legal basis, eligibility requirements, and payment policy can be found in Figure 4. Specific reimbursement rates are not included in this report due to the individual requirements of each wheelchair prescribed, in particular wheelchair prices and coverage of powered chairs. Most reimbursement agencies responded the coverage was heavily dependent upon the ability to prove "medical necessity".

According to Medicare[xii], it requires a physician's prescription for DME. Also required is supporting documentation, called a certificate of medical necessity that identifies the client's diagnosis, prognosis, the reason that the equipment is required and an estimate from the doctor on the duration that the equipment will be used.

Figure 4 – Overview of Key Funding Sources for Wheelchairs & Scooters

Funding Source	**Legislative/Legal Basis**	**Eligibility**	**Payment Policies**
Medicare, Part B	Title XVIII of the Social Security Act	Persons who are 65 years or older and persons who are under 65, but disabled enough to qualify for Social Security Disability Insurance (SSDI) for at least 25 months.	Durable Medical Equipment (DME) is equipment which can withstand repeated use, is primarily and customarily used to serve a medical purpose, generally is not useful to a person in the absence of an illness or injury, and is appropriate for use in the home. If considered to be DME, a device is covered, whether purchased or furnished on a rental basis.
Medicaid	Title XIX of the Social Security Act	Categorically needy persons who are eligible for AFDC or Supplemental Security Income programs. Some states cover medically needy whose income, after medical expenses, fall below income threshold.	Varies from state to state, but generally follows Medicare policies. Medical necessity is critical factor for payment
TEFRA	Tax Equity and Fiscal Responsibility Act of 1982 Birth through 6	Provides coverage for children diagnostically eligible (as established by SSI definition), but would be financially ineligible for SSI due to parent income. Children must meet medically necessity requirements for institutional care	The intent is to provide the necessary services, including equipment for the child, to remain in the home versus institution.
Private	Insurance Contract	Persons recognized as	Depends upon the terms of the

Insurance: Health, Disability Liability, and Self-Insured Employers' Insurance		beneficiaries/dependents under particular insurance policy	contract. In some cases, equipment is specifically excluded, however, often is not explicitly specified in the contract. Payment then depends upon insurers' legal obligations, and the role of the desired equipment in meeting those obligations.
Federal/State Rehab: Title I: VR Services; Title VI: Supported Employment; Title VII: Independent Living; Title VIIC: Independent Living (Elderly Blind)	Rehabilitation Act of 1973 and Amendments (Title I)	Working age persons who are disabled and have some potential to benefit. Emphasis is on persons with severe disabilities. Other Titles of Rehab. Act stress Independent Living/Support Employment, where vocational potential is not the determining factor.	Equipment that is justified as expediting goal of vocational placement. Usually purchases reserved for clients who are at least job ready (Title I). In many states, rehab. Agency retains ownership to equipment.

Veterans Administration	Title 38 of the U.S. Code	Veteran's service/financial status -Category A: Service connected veterans or non-service connected, but with income below $15, 000 (single); $18,000 (with dependent). Category B: Veterans not in Category A, but with annual income below $20,000 (single); $25,000 (with dependent). Category C: all other veterans.	Equipment is paid for when deemed part of overall medical or rehabilitation intervention, which is dependent upon eligibility status. VA pays for equipment, such as mobility and transportation aids, when deemed necessary. Benefits provided to Category B vets on an as-available basis and to Category C vets as available, with some co-payment required.
Workers' Compensation	Individual state Workers' Compensation Laws	Workers covered under employer's workers' compensation policy, as mandated by state law.	Many states require physical and vocational rehabilitation benefits as means of helping return injured workers to the workplace. Equipment is often purchased as part of the rehabilitative process when deemed cost-effective
Credit Financing	Federal Reserve Regulations including anti-discrimination law (Reg. B), and Truth in Lending Law (Reg. Z)	Based upon applicant's credit history, collateral, and other assurance of the likelihood the loan will be repaid	Some equipment that would be difficult for bank to resell in event of default may need to be secured in other ways, however, borrower basically determines what is to be financed

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[1] U.S. Census Bureau of the Census; "Health Insurance Coverage: 1995 - Table B;" September, 1996
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2. Forum Proceedings

A. Introduction to Technologies

B. Manual Wheelchair Propulsion

C. Power Management and Monitoring

D. Motors and Drive Trains

E. Material and Components

A. Introduction

Introduction

The Technologies section of these Proceedings summarizes information related to each of four technology areas:

- Manual Wheelchair Propulsion
- Power, Power Management and Monitoring
- Motors and Drive-trains
- Materials and Components

Each technology area has four sub-sections. These sub-sections are: the "White Paper;" Forum Data; and one or more Problem Statements. A description of each sub-section follows.

White Paper

A White Paper was written for each of the four technology areas. A White Paper includes information on unmet customer needs; market information; business opportunities; technology state-of-the-practice for products now in the market. The White Papers compliments the information provided by the Industry Profile.

The Industry Profile provides an overview or relevant manufacturers and products; identifies the overall market size; distribution channels; reimbursement issues; trade shows; and conferences for the targeted market segments. The Industry Profile can be found in Section [-----] of these Proceedings.

The White Papers and Industry Profile were provided to all persons participating in the Stakeholder Forum to establish a common knowledge base.

Forum Data

The Stakeholder Forum was held May 25th and May 26th ,1998 at the Wyndham Garden Hotel, in Pittsburgh, Pennsylvania. The Forum had a number of purposes that include:

- Identify or provide detail on significant customer needs not addressed by products currently available.
- Confirm that unmet customer needs represent a significant business opportunity.
- Establish that significant technical innovation is probably required in order to meet these customer needs.
- Confirm that the required technical innovation is likely to be beyond the means or capabilities of manufacturers within the industry segment.
- Establish design and performance targets for the sought after innovation.
- Identify barriers that might prevent the successful development or transfer of this innovation.

Two groups were run for each of the four technology areas. Information obtained from these groups falls in four major categories:

1. Priority Customer Needs - unmet customer and manufacturer needs.
2. State of Existing Technologies - technological “state-of-the-practice” for products currently in the marketplace.
3. Ideal Technology Requirements - design and functional specifications and parameters for the desired technology.
4. Barriers to Realization of Ideal Technology - market, technical, regulatory and other barriers that might prevent the transfer or development of the desired technology.

All forum data was derived from transcriptions of group participant comments. These comments were then paraphrased so as to avoid distorting information while attempting to communicate this information as clearly and unambiguously as possible to readers.

Group processes allow for some variation. For this reason, some groups have additional paraphrased comments such as additional “Suggestions,” “Recommendations” or “Other Technology Needs.”

A more complete description of Forum Protocols can be found in Section [-----] of these Proceedings.

Problem Statements

Outcomes from the Stakeholder Forum and all prior work are used to generate Problem Statements. Problem Statements outline the need for technology; technology state-of-the-practice for products currently in the market; specifications and parameters for the “ideal technology solution;” and barriers/impediments that must be overcome to achieve this ideal technology.

Our partner, the Research Triangle Institute (RTI) has many years of experience transferring technology from the Federal Labs to private sector manufacturers. RTI disseminates the problem statements to Federal Laboratories, advanced technology manufacturers, research institutions and other technology developers. Proposed technology solutions are submitted to RTI in hard copy or through the RTI web-site. Initially, all submitted technology solutions are non-proprietary.

Proposed technology solutions are reviewed by technical and industry experts to confirm that these solutions address the problem and are technically feasible. All proposed technology solutions are available to the T2-RERC and the partner RERC. Following the initial review, proprietary information may be requested from the technology developer. In such cases, the protection of intellectual property is worked out between the technology developer and the T2-RERC.

B. Manual Wheelchair Propulsion

- **White Papers**
- **Forum Data**
- **Problem Statement 1: Geared Hub Technologies**

White Paper: Manual Wheelchair Propulsion

Technology Area

Consumers, experts, industry contacts and researchers interviewed, identified **manual wheelchair propulsion** as an area in need of technological advancement. This technology area includes methods of wheelchair propulsion other than manual wheel turning, as well as wheelchair component design changes to facilitate efficient propulsion. There are over 1.4 million wheelchair users and about 75% of them use manual wheelchairs. There has been little change in the design of the manual wheelchairs over the last decade. Manual wheelchairs are complex systems and wheelchair design can limit propulsion, independence and accessibility. The investigation of manual wheelchair propulsion has become increasingly important because the population of individuals using wheelchairs is growing and requires efficient mobility to maintain a quality of life equivalent to the general population. Several attempts have been made at improving manual wheelchair propulsion, such as changes in the wheels and tires, adding gears and designing alternative propulsion systems. Still, experts and consumers generally agree that innovation in propulsion is still needed.

The need

There are 3 main reasons that improvements in manual wheelchair propulsion technology are important.

Users Achieve Greater Independence

Individuals who use manual wheelchairs need to be as active as the population at large in order to seek and maintain gainful employment, pursue recreational activities and past times, and achieve greater independence in daily activities. Everyday obstacles such as ramps, door thresholds, uneven terrain, soft carpet, and travel distances often require more strength and endurance than is available to some individuals. Improved propulsion technologies will reduce physical fatigue and effort required for wheelchair propulsion, and improves wheelchair maneuverability. Such technology would especially benefit the elderly who generally have less strength, and decrease stress on the upper body and joints for the average user.

Users Benefit Physically

Pain and upper extremity injury is common among manual wheelchair users. Shoulder related injuries have been shown to be present in up to 51% of manual wheelchair users. In addition, the prevalence of elbow, wrist and hand pain has been reported to be 16%, 13%, and 11% respectively (Koontz, et.al., 1998). The incidence of carpal tunnel syndrome and rotator cuff tendonitis, for example, is greater than 50% for people who regularly use manual wheelchairs as compared to 3% for the general population (Snowbeck, 1998). During wheelchair propulsion, users must exert large forces in order to propel the chair forward. In addition, the component of force that is directed in towards the hub does not contribute to forward motion but is necessary in order to provide friction between the hand and the pushrim (Koontz, 1998).

The User Population is Significant

Individuals who use manual wheelchairs generally have lower extremity weakness, paralysis, or amputation making walking unsafe or difficult at best. They may include individuals with spinal cord injuries, hemiplegia and other types of paralysis, multiple sclerosis, cerebral palsy, spina bifida, arthritis, and lower limb amputations. The majority of these individuals could benefit from improved wheelchair propelling efficiency at various times in their day. Jones & Sanford (1996) reported an estimated 1,363,026 manual wheelchair users in the United States alone. This market is expected to continue growing at a rate of about 10% per year into the year 2002. Medicare expenditures over a three-year period for a manual wheelchair averaged $98,000,000 annually from 1995-1997 (HCFA, 1997).

Basis for Discussion

Factors affecting propulsion include power assists, gears, steering methods, hand rim configuration, wheel diameter, wheel camber, tire hardness, user's center of gravity and caster design and alignment. This paper will review the three areas of technology affecting wheelchair propulsion that experts mentioned could benefit from improved technology. They include 1) power assisted technology, 2) geared technologies, and 3) one-arm drive technology.

Power Assisted propulsion Technology

Statement of the Problem

Experts and industry contacts mentioned power assisted add on units for manual wheelchairs as an area for further technology development and improvement. There are various units currently available and the weight of the attachment, how it is mounted, how it is controlled and the amount of power it provides vary. A national consumer focus group evaluation conducted by the RERC/TET in 1998 revealed that power assist devices in general were selected by the participants as an area that needed improvement. Experts and researchers participating in this project identified the problems as the following:

- Adding a power assist unit to a manual wheelchair will increase the weight of the wheelchair and may offset the distribution of mass or balance and center of gravity possibly making it more difficult for the user to propel when the power assist is disengaged (Brubaker. 1990).

- Heavy power assist units can stress the wheelchair frame if the wheelchair is not specifically designed to accommodate the unit.

- Some of the units are cumbersome to attach and detach requiring the assistance of a second person.

- Some power assist devices incorporate friction rollers that push against the tires to propel the chair. They can produce excessive tire wear.

- Some power assist devices do not work on cambered wheels.

- Most power assist devices utilize a rechargeable battery and include a battery charger as an accessory that requires access to an electrical outlet.

- Power assist devices cost between $2100 to $7000 depending upon the design and model.

Current Solutions

The objective of a power assist device for manual wheelchairs is to provide an inexpensive, portable unit which can temporarily convert a manual wheelchair into a power operated chair. This is usually accomplished by attaching a battery operated drive system to the wheelchair. Power assist components typically include batteries and a charger, a motor, a mechanical interface between the motor and drive wheels, mounting hardware, and a driving interface for user control.

Current product literature on power assist devices was reviewed. These products and components currently weigh anywhere between 46 and 85 pounds. Batteries account for 20–22 pounds. Power assist units achieve variable ranges of speeds of 4 to 4.7 mph, can drive up 15% grade and can cover up to 10 miles per battery charge on flat surfaces. They can operate over distances of 10 to 20 miles on a single charge of the battery.

Power assist devices are attached on the back of the chair, can be incorporated into the wheels, be attached underneath the chair, and can have various steering mechanisms such as joysticks or steering columns. One unit includes a 12-volt charging cable that works from the cigarette lighter socket of the car, and functions as a generator each time the driver brakes or changes direction.

Issues to Consider

- Under what conditions would users of power assists be eligible for third party reimbursement?

- Is there a way to decrease unit size and weight?

- Can the products work across a wide range of wheelchairs?

- Can the unit be easily engaged and disengaged as a function of power demand?

- Can the products be less cumbersome to attach and detach?
- Can distance traveled on one charge be increased?
- Could the evolving technology used for electric bicycles and other electric vehicles be transferred to the manual wheelchair industry?

GEARED TECHNOLOGIES

Statement of the Problem

Actuation of gears is typically achieved through cables. Cables tend to get caught on parts of the chair. Users do not like the look of the cables. They also require an additional lever for operation. Another approach to multi-gear control is by using multiple rims but this increases the width of the chair and may impede access through narrow spaces. There are increased safety hazards associated with increasing speeds and propulsion such as the greater risk for tipping.

Current Solutions

Manually operated single geared hubs are the state of the practice. Like the power assist add-ons, they could be particularly advantageous to the elderly or those with limited endurance to increase their independence and maneuverability. They are especially helpful when traveling indoors and outdoors, over varied terrain, up inclines, and over long distances. They add extra weight to the wheelchair but can reduce the amount of force needed to propel the chair.

Geared hubs act as an interface between the push rim and drive wheel of the wheelchair. A low gear ratio provides mechanical advantage at decreased operating speed, while higher gear ratios provide high operating speed at lower mechanical advantage. A low gear ratio is useful for going up inclines or over soft surface areas. A higher gear ratio is useful for fast travel over hard, level ground or declines. Without gearing there is a 1 to 1 ratio - between the rotation of the handrim and the rotation of the wheel. With a 2 to 1 ratio, a complete rotation of the hand rim results in one half rotation of the wheel.

When considering hub redesign, experts have also mentioned a need for improved hub brakes. Manual wheelchair brakes are designed as dynamic or parking. A dynamic brake allows the user to apply force on the wheels while the chair is in motion. These can be hub brakes or caliper brakes (similar to bicycle brakes). Parking "brakes" are wheel locks that are sold as accessories to most manual wheelchairs (Thacker, 1994). These brakes are usually cam lever, toggle lock, or push-to-lock wheel locks, although pull-to-lock locks are also available. Users of wheelchairs brake using several methods. They use their hands to pull back on wheel handrims. This is very hard on hands and can cause hand injury. Others chose to pull back on wheel locks to stop which causes excess wear and damage to tires.

Issues to Consider

- What are the market issues for geared hub and brake technologies?
- What are the system requirements for geared hub and brake technologies?
- What technologies exist in parallel industries which might be successfully transferred, perhaps providing economies of scale?
- Which user populations would most benefit from improved geared hub and brake technologies? In what ways would they benefit?
- What impact would geared hub and brake technologies have on user's safety, performance, access to environments, independence and so forth?

ONE ARM DRIVE AND LEVER TECHNOLOGY

Statement of the Problem

One armed drive technology may be confusing for some to learn as it is not necessarily intuitive, and the users generally require good upper body strength. Alternative steering methods designs must be intuitive and reasonably functional especially for the elderly population. Despite the potential benefits of lever drive propulsion; few lever drive wheelchairs are commercially manufactured or widely used. These wheelchairs tend to be larger, heavier and more difficult to fold and transport.

Current Solutions

The one-arm drive wheelchair is a manual wheelchair with both handrims mounted on one side. One arm drive wheelchairs have been available for some time, and a few lever type drive systems have also been available. These are generally designed for one-handed use. They are not add on units and must be purchased as a complete wheelchair. One arm drive wheelchairs are manufactured by some of the larger wheelchair manufacturers. They consist of a wheel with two hand rims and the wheels are basically tied together so that they can be controlled by one hand. Lever driven or ratchet arm systems have been explored. They consist of a lever-operated drive attached to the hub of each wheel. Applying a push/pull motion to the top end of the levers propels the wheelchair. The user moves the lever forward and backward to propel the chair and turns it left and right to turn the chair. A number of studies have shown that lever propulsion is more efficient than handrim propulsion for paraplegics as well as quadriplegics.

Issues to Consider

- What are the technical problems of the ratchet/lever arm systems and how can they be overcome?

- Could one arm drive and lever chairs be designed to be more intuitive?
- What is needed to make it easier to propel a one-arm drive?
- What are the system requirements for ratchet/lever arm systems?
- What technologies exist in parallel industries which might be successfully transferred, perhaps providing economies of scale?
- Which user populations would most benefit from improved ratchet/lever arm systems?
- What impact would ratchet/lever arm systems have on user's safety, performance, access to environments, independence and so forth?

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Forum Data: Manual Wheelchair Propulsion

1. Problems with current propulsion systems

Manual wheelchair propulsion has a major impact on social life of the user as it determines to a great extent the range of environments in which the user can move in. At the same time many hygienic, safety and security issues are related to manual wheelchair propulsion. There are several problems associated with the current propulsion system. These are highlighted below. Most of these problems apply to all types of propulsion systems being used today, though some of them may be specific to some propulsion system.

A. Common environments that cause difficulty in propelling a manual wheelchair:

- Soft services, (gravel, sand, grass)
- Carpeting.
- Side walks that are uneven,
- Wintry and wet conditions
- Hills

Note: These environments are especially difficult for persons having the use of one upper limb.

B. Problems that people experience when propelling a manual wheelchair:

- Backaches
- Hand and finger blisters
- Exhaustion.
- Shoulder, wrist, elbow pain,
- Rotator cuff disease,
- Carpal tunnel syndrome.
- Burning of the hands on the rims
- Dirty clothes,
- Calluses on the hands
- Dirty hands
- Perspiration
- Over heating

C. Safety issues when propelling a manual wheelchair:

- Difficulty in controlling the chair when the user’s hands slip
- Small sharp objects pack into the wheelchair's tires and can cut the user's hands when they are propelling the wheelchair
- The wheelchair tends to unbalance rear-ward when propelled
- The wheelchair is difficult to maintain balance when the casters get caught in drains and potholes
- User’s hands can be injured when braking with the wheelchair's wheel-lock

- User's hands can be injured when braking or stopping the wheelchair
- A wheelchair user's foot could drag on the ground without user knowing it and get injured
- Controlling the manual wheelchair's speed up and down inclines or rapid speed changes on level surfaces is a safety issue.
- Faulty brakes/wheel-locks can cause the wheelchair to roll unexpectedly.

Other Comments:
- If footrests become loose they can drag or catch against objects.
- The lack of push handles can contribute to head injury or whiplash if user tips or falls backwards.
- Lack of wheelchair visibility to motorists is a safety concern.
- When personal items are hung from the back of the chair, they are difficult to reach, out of sight and subject to theft.
- Disassembly and lifting of the manual wheelchair into the auto can be a difficult.

GEARED SYSTEMS

1. State of Technology

A gearing system gives the user a mechanical advantage enabling persons with limited strength (e.g. elderly) to independently propel themselves. Some gearing systems can accommodate standard hand rims. The ability to self-propel improves the cardiovascular strength of the user.

Limitations for Current Gear Systems:
- Have few gear ratios
- Gear switching mechanisms are sometimes sloppy
- Some designs add to chair width
- May not provide adequate feedback (force / travel distance per stroke) as the user gets from standard push rim. For example, when the user pushes the rim ¼ cycle, the wheel rotates through ¼ cycle. With gearing, the user must somehow understand the force and distance associated with a ¼ cycle push.
- Adds weight to the wheelchair
- User may be mechanically disadvantaged when traveling long distances due to mechanical loss in the gearing system and added weight.
- May require better hand and upper limb dexterity than standard push rim.
- Users may not understand the benefits (e.g. improved independence, health, …) of geared systems
- Wheelchair users have not generally accepted available geared hub systems. (Likely for some of the reasons listed above.)

1. The Ideal Technology

The ideal geared technology should:

- Be retrofit-able to a wide range of manual wheelchairs.
- Be able to utilize a lever interface (in addition to or as an alternative to a "standard" push-rim) .
- Weigh 5-7 pounds or less, especially if built into the wheels
- Should not bump up ultra-light chair weight to the standard chair weight category
- Have fail safe mechanism that will restore 1:1 gearing ratio and allow operation as a "standard" manual chair
- The user should be able to "lock out" the gearing mechanism to allow operation as a standard manual wheelchair
- Not add to the rotational weight of the wheel
- Not make noise, but provide audio feedback (similar to mountain bikes) when shifting gears
- Gear change might be accomplished with pressure pads (possible mechanism)
- Gear change mechanism should have variety of mounting options
- Gear change mechanism should require low dexterity
- Changing gears should occur simultaneously for both wheels
- Gear system should not hinder independent movement of wheels
- Have a reverse gearing ratio similar to low gear forward, with adjustments
- Be ruggedly designed to allow hill climbing and access to rugged terrain
- Be almost invisible (in other words should perfectly blend with wheelchair aesthetic)
- Be an accessory and not built into the chair
- Switch easily from low gear to high gear
- System should have linear geared system (continuous progressive gearing) [most ideal case]
- System should have four gears with gear ratios starting at between 1:2 to 2:1 [acceptable but less ideal case]
- User should be able to shift gears during the propulsion stroke.
- User should not have to stop propelling the wheelchair in order to change gears
- Sense your need and automatically change gears while in motion [most ideal case]
- Have a shifting mechanism (e.g. lever) to change gears [acceptable but less ideal case]
- User should be able to change gears while in motion [less ideal case]
- Gear change should be manual (user selectable) rather than automatic
- Give the user more distance per stroke than a standard manual wheelchair (useful for active users wanting to cover distance more rapidly)
- Should accommodate those with lesser energy levels as well as the highly active population
- Requires less (hand) dexterity and ability (grip and upper body strength) than current manual wheelchair propulsion systems

- Not affect free wheeling
- Be integrated into the push rim and hub
- Accommodate high end (active, full strength) and low end (inactive, minimal strength) users (gearing system should be universal in this respect)
- Have a stop feature
- Have automatic braking system
- Sense and slow the chair, assisting in stopping the chair once the user applies resistance (or different pressures) to the rims (braking system)
- Provide no more hazard to the hand than current propulsion methods
- "Be in" standard wheel with quick release
- Work similar to the gearing system in a bicycle
- Be financed with HCFA

3. Barriers and Roadblocks

The gearing system:

- Should not affect quick release wheels
- Not affect folding of the wheelchair
- Should not increase the width of the chair

POWER ASSISTS

1. State of Technology

Power assist systems are perceived to turn a manual wheelchair into a power wheelchair. It gives the user a choice of using a manual or power chair without transferring between the chairs. At the same time it is much cheaper than power chair. It reduces the physical strain on the user and extends the range of environments in which the user can move (e.g. uphill, rougher terrain etc.). Power assists chairs also help in stopping the wheelchair without grabbing onto wheels or wheel locks.

Limitations:

- Puts greater limits on manual wheelchair by adding weight and complexity to the manual wheelchair, and increasing the cost
- The power assist increases overall maintenance
- Power assists are not perceived to be reliable and are perceived to add to the overall likelihood of malfunction
- The user may become "stuck" when venturing into environments that he or she would normally not access with a "standard" manual wheelchair
- Issues related to batteries, power source (size, weight, charging etc) comes into picture
- Power assists tend to be noisy and heavy
- Current power assists don't fit across a wide range of chair models
- Wheelchairs utilizing a power assist are hard to fold which impedes the portability of the chair

2. Development of the Ideal Technology

The ideal power assist should:

- Weigh a maximum of five pounds
- Run for a dollar a day
- Should cost $1000 or less
- Have speeds, which ranges from walking to a running speed of up to 7 mph
- Be safe. It should include power on/off switches that will enable/disable the system
- Have variable mounting capabilities.
- If device fails, it should operate like a MWC
- Have smart controls that would automatically change speeds/gears
- Could be integral (hub/axle design, inner-tube, frame) or removable from the chair. If removable it should be done easily by the end user (not requiring special tools)
- Be quiet
- Not be damaged by rapid changes in torque demands
- Not be damaged by impact shocks occurring at different speeds of use
- Allow the user to set the "degree (gain) of" the power assist
- Benefit people with motor weakness, motor in-coordination, respiratory compromise, fragility, paraplegia, shoulder problems, elderly
- Work in all environments, bad weather, good, indoors and out, on motor vehicles
- Work over ramps and on uneven terrain
- Have simple engineering design
- Be durable
- Need low maintenance, easily cleaned
- Assist in stopping
- Be unobtrusive and small in size, not adding to width of chair
- Be portable, easily installed or removed from the chair
- Be lightweight (be lifted easily by a person using one arm)
- Should not interfere with storing or transporting the manual wheelchair
- Have a backup power source that should be readily available (utilizes "off the shelf" battery)
- Be able to run the chair eight hours continuously
- Utilize rechargeable, portable batteries
- Battery should recharge while it is being used (e.g. going downhill)
- Power assist should engage when needed (change of slope or surface), perhaps utilize some "smart technology" to accomplish this
- While power assist is operating, it should sense the force applied to the push rim and assist accordingly.
- Have a manual override
- Manual engagement and disengagement is "easy"
- Must be fail safe and not interfere with regular manual wheelchair operation.
- Must be retrofit-able to all/many manual wheelchair models
- Use requires same cognitive and motor skills as standard manual
- Control interface needs to be easily reached by user

- Chair should be steered by force to the rims (same as they are steered now)
- System should have variable speed control so that speed can be adjusted to conditions
- Reliable, cost efficient to use, readily available for purchase and affordable for people to buy
- System should be capable of being financed by same funding sources that currently purchase manual wheelchairs
- System should be cosmetically pleasing
- Should meet all ISO and ANSI standards and consumer acceptance testing

3. Barriers and Roadblocks

- Size should not interfere with functions of the manual wheelchair -can't extend beyond the overall width and length of chair
- Five year life of power source
- Device should accommodate “conventional” batteries

Appendix A

This appendix lists out the pros and cons of various systems that are used to propel the manual wheelchair. These systems were not selected by group participants as the top two needs and subsequently have not been explored as fully as “geared systems” and “power assists.”

PUSH RIMS

Limitations:
- Requires good hand grip
- Pushing the rim creates hygiene issues for the user
- Pushing rims have some safety issues
- Requires use of both upper extremities
- May not be the most bio-mechanically efficient propulsion mechanism
- Can cause over-use of muscles
- Larger wheels get in the way of user transfers
- Limits wheel size choice
- Material of the rim becomes cold in the winter, which increase numbness and affects arthritis
- Shape and size of rim is not optimal for gripping and propelling
- Some surface coatings on the push rim affects the user's grip
- Push rim materials break down over time

Advantages
- Lightweight
- Compact

- Directly responsive to user force on push rims and provide most precise feedback
- Provides propulsion options for users: push the tire, the rim, tire & rim, or one arm drive technology
- Easily understood and adaptable
- Mechanically simple
- Wide acceptance from users
- Least expensive
- Rim can have several different types of coating (changes look and feel)

LEVER SYSTEMS

Limitations:

- Low acceptance by users
- Adds weight to the wheelchair
- Limits the wheelchairs ability to be folded
- Limit access to environments by making the chair higher and wider
- Makes side transfers more difficult for the user
- Requires full arm use in a push/pull effort
- Aesthetically obtrusive
- Awkward to use relative to standard push rim (for most users)
- Not aesthetically pleasing
- Hard to control the direction i.e. changing from forward to backward motion I(and vice versa) is difficult
- Significantly increases the cost of the chair

Advantages:

- Provides the user a mechanical advantage (through gearing or equivalent)
- Provides less tiresome way of propelling
- The user can go faster and farther (in outdoor use)
- Levers are ergonomically better for the user (less body stress induced by propulsion forces then for push rim)
- The user stays cleaner when using a lever system
- Steering (for some individuals) can be easier
- Steering can be adapted to one arm drive
- The system is not limited just to large wheels
- Levers can have unlimited configurations (e.g. lever height, angle, shape, …)

ONE ARM DRIVE SYSTEMS

Limitations

- Adds weight to the wheelchair
- Gives the wheelchair a wide turning radius
- Past attempts to sell showed no market (one manufacturer reported sales of five units a year)
- Adds significant weight to wheelchair
- The user has difficulty initiating movement

- The user needs to make adjustments to change directions from backward motion to forward motion and vice versa
- One lever drives do not provide smooth, continuous movement
- Braking the chair while using the drive is difficult
- Body posture suffers from use of one arm, (more toned in one place)
- The user needs the use of a foot for steering
- Chair tracking (steering) is difficult

Advantages:
- Requires only one arm to push chair
- The user can control everything through the lever. This may helpful for some people.

AUTOMATIC HILL HOLDER (CLIMBER SYSTEM) OR GRADE AID

Limitations:
- Can injure fingers
- It only works on rubber based tires (doesn't work on good polyurethane tires)
- Disengagement can be difficult as they are fitted very low on the chair

Advantages:
- Simple
- Cheap
- Small

AXLE PLATE ADJUSTMENT

Limitations:
- Only on high end expensive wheelchair (K5 chairs)
- Chair can go over backwards if positioned too far forward (change center of gravity)

Advantages:
- Puts axle in better position to relative to shoulder height for ergonomic propulsion
- Less possibility of overuse injuries because chair is fit to individual dimensions
- Lowers rolling resistance
- Inexpensive to manufacture

CAMBER

Limitations:
- Decreases backward stability
- Makes chair wider
- Wears tires down
- Adjusting the camber require taking chair apart and getting out of chair

Advantages:

- User's strokes are up and down, improved bio-mechanically
- Adds side to side stability
- Rolling resistance doesn't change

Problem Statement 1: Geared Hub Technologies

We seek innovative geared hubs for manual wheelchairs.

Description of the Problem

There are more than 1.4 million wheelchair users, and about 75% of them (about 1.05 million) use manual wheelchairs. The population of individuals using wheelchairs is estimated to be growing at a rate of 10% per year into the year 2002. Manual wheelchair users generally have lower-extremity weakness, paralysis, or amputation, making walking unsafe or difficult at best. They may include individuals with spinal cord injuries, emiplegia and other types of paralysis, multiple sclerosis, cerebral palsy, spina bifida, arthritis, and lower-limb amputations.

A user's independence, access to environments, health, and safety are all affected by their ability to propel the wheelchair. There has been little change in the basic design of manual wheelchairs over the past decade. The user typically propels, steers, and brakes the motion of the wheelchair by pushing against or grasping the pushrim. The user must apply large forces to accomplish these actions. The force directed inward toward the wheel hub does not contribute to propulsion or braking but is necessary in order to generate friction between the user's hands and wheelchair pushrims.

Injury is common among manual wheelchair users. Shoulder-related injuries have been shown to be present in up to 51% of manual wheelchair users. In addition, the prevalence of elbow, wrist, and hand pain has been reported to be 16%, 13%, and 11%, respectively. The incidence of carpal tunnel syndrome and rotator cuff tendonitis, for example, is greater than 50% for people who regularly use manual wheelchairs as compared to 3% for the general population.

Manual wheelchair users generally brake or slow their wheelchairs by producing a frictional force, opposing wheel motion between their hands and the pushrims. Both propelling and braking the wheelchair can produce blisters and calluses on the user's hands.

Environmental factors can increase the force required to propel a manual wheelchair. These factors include soft rolling surfaces (e.g., sand, gravel, dirt, mud, thick carpeting); rough, broken, or uneven surfaces (e.g., potholes, sidewalk cracks); inclined surfaces (e.g., hillsides, curbs, ramps), and weather-affected surfaces such as snow and ice.

Environmental and human factors can reduce a user's ability to produce and apply the forces necessary to propel and brake a manual wheelchair. Rain, sleet, snow, and perspiration can reduce the friction between the user's hand and the pushrim. Cold can reduce the user's ability to grasp the pushrim. Fatigue reduces the user's ability to generate the force for propulsion or braking. Heat can accelerate the onset of perspiration and fatigue.

Propulsion of manual wheelchairs improves a user's cardiovascular fitness and upper body strength. As one would expect, a user's strength and stamina typically diminish over time. Of necessity, these users must transition to a power wheelchair or be pushed about in a manual wheelchair by a caregiver. Frail elderly and persons in the later stages of progressive disabilities typify such users. Extending the period during which these user's can self-propel would provide important health and independence benefits.

Current State of Technology

The forces needed to propel, brake, or steer a manual wheelchair depend on pushrim and wheel diameters, pushrim design, tire and surface properties, surface contour, and propulsion biomechanics, which vary from user to user. Geared hubs allow a user to select the level of propulsive force appropriate to their physical abilities, personal preferences, and environmental conditions. The mechanical advantage provided by a geared hub is characterized by its "gear ratio." For a standard hub without gearing, there is a 1-to-1 ratio between the rotation of the hand rim and the rotation of the wheel. For a geared hub having a 2-to-1 gear ratio, a complete rotation of the hand rim results in a one-half rotation of the wheel.

A low gear ratio allows a user to propel with decreased force albeit at low speeds. In general a low gear ratio would be useful when the user is going up inclines or over soft surfaces, is fatigued, or has decreased strength and stamina. A high gear ratio requires a user to generate more force in order to propel, steer, or brake but allows the user to propel at higher speeds. In general, a high gear ratio would be useful for fast travel over hard, level ground or declines or for active or athletic wheelchair users.

Geared hubs can have a number of discrete gear ratios from which to select or a continuously variable gear ratio that allows the user to select any gear ratio between some lower and upper bound.

The mechanism by which the user selects a gear ratio is an important design consideration. A common mechanism is a system of levers and cables (similar to road bikes). However, levers and cables tend to get caught on clothing and environmental obstacles, can impede the user's movements, and are considered, by users, to be unsightly. Using this method to change gear ratios, the user must interrupt the continuity of propulsion by moving their hand from the pushrim to the gear-selection lever. Multi-rim geared hubs have been designed whereby each rim drives a different gear ratio. The user selects a gear ratio by selecting and pushing against a matched set of rims. Multiple sets of rims must necessarily be offset vertically or horizontally. Horizontal rim offset increases wheelchair width and decreases the user's access to confined environments. Rims that are vertically or horizontally offset are more difficult for the user to reach and change propulsion biomechanics. A multi-rim approach is not likely to be compatible with continuously variable gearing.

Technology Needs and Barriers

Information gathered from users, manufacturers, clinicians, and other stakeholders has identified characteristics of an ideal geared hub system. Minimum requirements are identified as items that "must" be addressed to make a design acceptable; other attributes that will benefit the design are identified as items that "should" be addressed. Specifically, a geared hub system…

1. Must be part of a drive wheel that replaces a standard drive wheel rather than being a retrofit or add-on to a standard drive wheel.
2. Must retain a single, "standard" pushrim as part of its design. This pushrim should resemble a standard pushrim in both its form and function.
3. Should have continuously variable (linear) gearing. If continuous variable gearing is not practical, then the geared hub system should have (at least) four discrete gear ratios in the (approximate) range of 1-to-2 through 2-to-1. Note: It may be appropriate to have a few geared hub systems whose gear ratios reflect the needs of distinct user populations (e.g., frail elderly versus active, athletic). Consumer or clinical trials could better define the optimal range of gear ratios and specific gear ratios.
4. Must provide "reverse gearing" for propelling backward. Note: Group participants suggested that a single reverse gear ratio equal to the lowest forward gear ratio would be optimal. Consumer or clinical trials could better define the optimal reverse gear ratio.
5. Should offer manual selection of gear ratios rather than an "automatic" gear ratio selection—gear ratio automatically changes in response to applied torque. Gear ratio selection must have the following characteristics:
   - a single user interface—as opposed to separate interfaces for the left and right wheels—to shift both wheel hubs simultaneously.
   - shift smoothly through all (the entire range of) gear ratios.
   - shift smoothly while the chair is in motion—i.e., being propelled.
6. Must offer a user interface for gear ratio selection with the following characteristics:
   - minimal user dexterity required to operate
   - minimal user force required to operate
   - simple, intuitive actions required to operate
   - no interruption of propelling required to operate o no obtrusive levers, cables, or similar hardware
   - easily mountable in many locations on the wheelchair
   - easily mountable or configured in a range of orientations Note: Manual wheelchair users suggest that an interface similar to pressure pads (like big button switches) may be the optimal user interface. They suggest that the geared hub system should also be able to utilize other user interfaces (pressure pad, lever, etc.) in order to accommodate diverse user abilities.
7. Should "feel about the same" as a standard manual wheelchair from the perspective of a person pushing either wheelchair. must have the following physical characteristics:

- weigh 7 pounds or less
- not increase the width of the manual wheelchair
- not change the look of the wheelchair—i.e., unobtrusive appearance
- not change any other wheelchair functions—e.g., portability, disassembly,folding

8. Should generally be quiet during use. When the user shifts gears, the geared hub system should provide an auditory “click” (similar to mountain bikes) confirming the gear ratio change.
9. Must have a safety mechanism that allows the user to independently revert to a 1-to-1 gear ratio.
10. Must not add significantly to the rotational inertia of the drive wheel—i.e., flywheel effect.

C. Power Management and Monitoring

- **White Papers**
- **Forum Data**
- **Problem Statement 1: Battery Monitoring Technologies**
- **Problem Statement 2: Battery Charger Technologies**

White Paper: Power Management and Monitoring

TECHNOLOGY AREA

Power, Monitoring and Management (PM&M) is one area that consumers, clinicians, researchers and manufacturers identified as requiring significant technological improvements. Power Monitoring means the ability to routinely and accurately determine the amount of power expended and remaining within a wheelchair battery. Power Management means the ability to correctly, safely, and efficiently discharge and recharge a wheelchair battery while maximizing cycle life.

THE NEED

Power wheelchairs are used predominantly by people with both lower and upper extremity impairments, such as those resulting from cerebral palsy, high-level spinal cord injury, or muscular dystrophy. There are over 93,000 power wheelchair users in the U.S. alone (Team Rehab, 1997). The "standard power wheelchair" accounted for $166 million in Medicare expenditures in 1997. We include power scooters in the discussion due to the overlap in power monitoring and management issues. Scooters are used by people of all ages but are particularly popular among older people (64,000 users) who acquire mobility impairments as they age.

The "power" in power wheelchairs is considered to be a limiting factor in performance. Some stakeholders desire an increase in the device's range of travel (i.e., charge capacity). Others may be satisfied with range but desire either reductions in size/weight of the power source, or better procedures for charging and monitoring battery power. Power management and monitoring must include attention to three primary components: (1) the battery, (2) the charger, and (3) the monitor or gauge of remaining battery capacity or range. Improvements are sought in each of these areas; however, this project recognizes the there are great difficulties inherent in the transfer of battery technology.

A common issue across all technology areas is that of cost and reimbursement pressures. While wheelchairs enjoy wide reimbursement coverage, problems remain for power wheelchairs. Payments remain low, barely or perhaps not covering the cost of more specialized, service-intensive wheelchairs. Current reimbursement policies have four key features to be aware of:

- Medically necessary (i.e., not a convenience item)
- Emphasis on cost rather then product attributes
- Service costs not well recognized
- Oriented toward short-term needs rather than long-term capabilities.

All opportunities for new technology development and insertion into this market must take these issues into consideration, recognizing that cost sensitivity is real and that payers are reluctant to trade-off increased up-front costs for possible long term benefits.

Many industries and federally-sponsored programs use and rely on battery power for equipment and subsystems in products for the consumer market, information technology, defense and aerospace. It seems likely that either appropriate technologies are already available to improve the monitoring and management functions important to wheelchair and scooter users, or that these other stakeholders would be willing to collaborate on developing improved power management and monitoring to serve their own needs as well – the dual-use rationale for technology transfer.

BASIS FOR DISCUSSION

Consumers would benefit from components that could:

- accurately track and calculate charge/recharge requirements,
- determine the actual state-of-charge at any time,
- calculate remaining time/distance available based on prior use,
- track the battery's performance degradation over time.

Given the mobility and dexterity limitations of many users of power wheelchairs and scooters, the power monitoring and management capabilities should be integrated or paired with the controller system, which is typically positioned for optimum access by the consumer.

The goal of the Forum is to select a high-priority problem and develop a problem statement that specifies requirements for a commercially viable solution. The following points are provided to help Forum attendees prepare their opinions and input on these important topics.

BATTERIES Statement of the Problem

Stakeholders desire improvements in three important features of batteries: 1) energy density, 2) cost, and 3) cycle life. Energy density determines how much power can be stored in a given size and weight battery, with range (capacity) resulting from the battery's tradeoff between size and weight. Cost is determined by a combination of the raw materials, manufacturing requirements, and economies of scale. Cycle life is the number of charge/discharge cycles the battery can withstand before its performance degrades to a point of inoperability.

Current Solutions

Power wheelchairs presently are powered by deep discharge lead-acid (mostly gel-cell) batteries, with 24 volts the most common configuration. Typical battery life is 9-14 months or 365 cycles annually. Replacement may occur more often when 3rd party reimbursement permits it. Typical cost is $200 per battery. Lead-acid batteries are:

- Heavy (9-14 Kgs) - making replacement difficult for the user and limiting portability of spare batteries.
- Large - impacting wheelchair design due to the space required under the seat.
- Limited in current output - resulting in poorer performance in high torque situations.

A 1996 national survey of power wheelchair users indicated that batteries and tires were among the items most frequently needing repair or replacement (Lane, Usiak & Moffat, 1996).

Much battery research has gone into nickel metal hydride (NIMH) and lithium (Li) technologies. Alternative energy storage methods, such as flywheel energy storage, have been considered but remain merely an R&D interest at present. Battery technologies presently being developed for electric vehicles, currently being developed by the USABC (United States Advanced Battery Consortium), have a great potential for applications in electrically powered wheelchairs is actively pursuing this.

Virtually every commercial wheelchair uses lead-acid batteries as they have been the most reliable, cost effective and practical battery on the market for decades. Newer battery technologies include NIMH which is a maintenance free battery with energy densities 2-3 times the lead-acid battery and Zn/Ni (Nickel –Zinc) batteries which have the highest energy density and lowest cost of any of the Ni-based battery. Li/FeS2 provides power densities 6-7 times that of lead acid & are maintenance free. Lithium Ion batteries have high energy densities and are used in notebook computers. Lithium metal polymer technologies offer high energy density and extended run time. (Ni-Cd) Nickel Cadmium batteries have been used with wheelchairs primarily because of their long cycle life under high depths of discharge, but they cost about six times that of deep discharge lead-acid batteries (Bayles, et.al., 1994).

Issues to Consider

What is the relative importance of capacity (range), recharge time, cycle life, size, weight, and cost? How do these trade-offs vary among different types of wheeled mobility products and different populations of users?

- In what ways could wheelchair designs be improved by significant reductions in either battery size or weight or by alternative physical configurations of batteries?
- What are the prospects for transferring battery technology from other industry sectors? Would the industry consider a consortium approach to wheelchair battery development?
- What factors would payers evaluate in considering trade-offs, for example, a battery which is more expensive but offers a longer cycle life?
- Is there flexibility in reimbursement for better but more expensive battery technologies?

POWER MONITORS Statement of the Problem

The state of charge of the battery in an electric wheelchair [or scooter] is of vital importance to the user. Despite the long-standing presence of multiple power monitoring gauges and battery charging systems, the existing systems are recognized as inadequate by wheelchair manufacturers, researchers, clinicians, consumers and care providers. A gauge that routinely and accurately tracks power discharge and remaining power, and then translates this into a measure of remaining capacity, would substantially improve the consumer's independence (Thacker, J.G., 1988). The Power monitoring should also track the state of battery's integrity so that the battery can be replaced before a critical failure.

Current Solutions

Current power indicators for lead acid batteries are based on simple voltmeters. Given the power discharge curve for lead acid batteries, voltmeter monitors are at best inaccurate, and at worst misleading, indicators of remaining battery capacity. These are commonly used because they are inexpensive and compact, and at least provide a general indicator of power.

The voltage levels being monitored can vary greatly with changes in the load placed on the battery, even thought the battery's actual state-of-charge is not changing greatly. When a battery is placed under a heavy load (e.g., while the wheelchair/scooter is being driven up an incline, through deep pile carpeting, or loose soil/gravel), the terminal voltage drops substantially until the load is removed. While under a heavy load and for some time afterward, the voltage monitor, will indicate a lower state-of-charge than actually exists. As a result, the voltage monitors produce variations in state-of-charge readings, due to the wide range of loads placed on the battery during typical daily use. Further, there is no means to translate remaining power into estimates of remaining range, so the user is forced to estimate the remaining range through trial and error (Thacker, J.G., 1988).

There may be more accurate options available. For example, the computer industry uses an SM Bus for monitoring the battery's status. Both the power monitoring and charging systems are paired with the battery technology. The power monitor tracks the flow of current in to and out from the battery. The battery's full charge level is also tracked, so that the power monitor can assess battery degradation over time. This monitoring/charging system has the additional feature of being programmable, so that key parameters can be entered and the charging system can be accurately matched to battery performance specifications.

Regardless of the type of power monitor used, integrating the power monitoring device within the controller would reduce the number of components the user has to monitor and manage. It will improve reliability, make it more accessible, improve component sourcing for manufacturers, and reduce size.

Issues to Consider

- How would one specify the requirements for a technology that can accurately monitor the remaining power and more accurately measure the remaining range for lead-acid batteries?
- What diagnostic or self-testing capabilities can and/or should be incorporated for power monitoring of lead-acid batteries? How can microprocessors be used more effectively for this function?
- How is power and range information best conveyed to the user?
- How can we specify the technical requirements for power monitoring technology that is most appropriate for power wheelchairs and scooters?
- What capabilities would permit power monitoring devices to be compatible with changes in battery technologies?
- What are the barriers to integrating power monitoring into controllers?

CHARGING Statement of the Problem

Improper charging of a battery reduces battery life, while more frequent replacements increase the total cost to the user or third-party payer. There is a need for a charger with built-in intelligence to determine battery status and optimum charge schedule. This would reduce a substantial problem identified by power wheelchair manufacturers and end users. Also, having the charger permanently on-board the wheelchair or scooter would eliminate many of the problems reported by users, provided care is being taken to avoid accidental shocks and other safety hazards. Most chargers are too large to incorporate into the chair/scooter, and the available smaller chargers are reportedly less reliable. Consumers prefer on-board charging systems but major providers such as the Department of Veterans Affairs do not support on board charging systems. User safety and provider liability are the concerns regarding on-board chargers, although manufacturers who provide on-board charger report negligible to non-existent hazard problems.

Current Solutions

When considering performance in general, if the charger does not recharge the battery completely, the recharge capability will degrade over time. That is, the number of remaining charge/discharge cycles remaining before failure will diminish. Failure is typically defined as an inability to maintain voltage, capacity and safety margins under the expected set of usage conditions. Five hundred (500) cycles is a realistic figure for battery life.

Research has determined that current chargers are inefficient and that these inefficiencies may damage the battery being charged. There is a disparity in charger performance, with some simply undercharging during an eight hour cycle, while others may actually damage the battery (Seeger, 1989). Research has also established a high degree of consumer dissatisfaction with existing battery chargers (Bauer, et al, 1998).

There are no onboard battery charging systems for powered wheelchairs, although they do exist for scooters. These onboard chargers have to be UL approved.

Previous discharge history is important when the battery is allowed to stand idle for long periods of time, or discharged at rates and capacities considerably different from normal use. A wheelchair battery does not usually become over-discharged since protective circuits in the wheelchair controller prevent this action. However, if the battery is left discharged after use it will spontaneously continue to discharge, especially at high temperature. In a week or so the battery may become so over-discharged that it will no longer be rechargeable (Kauzlarich, et.al, 1994).

Some batteries exhibit a memory effect that causes them to lose capacity for several subsequent discharge/charge cycles, if partially discharged on previous occasions. In these instances, several complete charge/discharge cycles are needed to restore the capacity of the battery. Nickel-zinc and nickel-cadmium batteries have a strong memory effect, whereas the leading lead-acid batteries show little memory effect.

Conversely, to maximize the life of deep discharge lead-acid batteries, the battery should not be over-charged or over-discharged. If the deep discharge battery is not fully discharged during use, its charge/discharge life will be extended. For example, the battery’s life if doubled if the depth of discharge is reduced from 100% to 60%. Even though most batteries provide at least 90% of their full charged capacity after only 8 hours of charging, it is recommended that they always be charged fully by a charger that shuts off automatically when the battery is charged. Once a battery is fully charged, continued charging, even with a low current, can diminish service life(Thacker, 1994).

The previously cited problems with power monitoring make power management more difficult, because the consumer is almost never sure of the battery’s state-of-charge. Even with an accurate state-of-charge measure, the consumer may lack sufficient information on the battery’s capacity (which changes over time and through use), to choose the correct recharging point for optimum battery function and life(Panel Discussions, 1988) . Further, if the available charger does not recharge the battery to the correct level, the battery’s service life will be degraded.

Issues to Consider

- What diagnostic or self-testing capabilities can and/or should be incorporated into battery chargers?
- What battery charging functions should be the responsibility of the technology and what functions should be the responsibility of the user?
- If intelligent battery chargers could extend battery life, how much of an improvement would be necessary to justify third party reimbursement for an intelligent charger?
- Is it desirable to integrate battery monitoring and battery charging capabilities? If so, how?

- Do on-board chargers make sense from both the user and manufacturer perspectives? The user and the manufacturer need to be protected (the first from shock and the second from liability).
- Do smaller battery chargers and/or battery-chargers matched to batteries, represent significant needs in the powered wheelchair scooter market?

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Forum Data: Power Monitoring & Management (PM&M)

1. Batteries

A. Priority Customer Needs:

- Increased battery capacity per charge cycle - Existing battery capabilities are insufficient for some users, particularly those who attach multiple accessories or use their power chair/scooter as a one-passenger vehicle.
- Decreased battery size and weight - Users would like to be able to collapse power chairs/scooters for travel, but the battery box cannot be collapsed and weight is a barrier for portability. Size & weight sometimes precludes the prescription of a power chair because of access issues, or because the user needs to load/unload and transport the chair.
- Alternative battery configurations – Current battery configurations reduce the ability to design wheelchairs that meet mass transportation requirements.
- Sharing power and control between the wheelchair and accessories is not easily accomplished. .
- Battery life is related to battery quality, which in turn is related to cost. There is need for better quality batteries at low cost.
- Reimbursement for new battery technologies - Batteries with increased longevity will not be developed for the w/c market unless third part reimbursement agencies are willing to pay a premium for the increased capabilities

B. State of Existing Technologies:

- Currently, power management and monitoring systems must deliver excessive battery power to compensate for limitations in motor technology and drive-trains.
- Advanced battery technology is appearing in other industries. For example, lithium-polymer batteries yield 100 watts per kilogram (twice the power/weight ratio of lead acid). They are also more robust - providing longer cycle life. Computer, toy and power tool industries are driving the development of these batteries, with carts and electric vehicles being emerging markets. One problem to overcome for lithium-polymer battery technology is a low surge current tolerance relative to lead-acid batteries.
- Advanced battery technology is utilized in military applications (e.g., Military special forces require small, lightweight batteries with sufficient power to propel landing craft through water and on to land), but this technology has not yet been applied to w/c industry.
- Lead-acid batteries with higher energy densities and longer cycle lives are available in other markets.
- Lithium batteries have better monitoring capabilities (e.g., straight-forward correlation of battery voltage to remaining charge).
- Lithium ion batteries have three-times the energy density of lead-acid batteries.

- Integrated Controls - the CAN bus has been adapted by TIDE programs in Europe (Multi-Master, Multi-Slave Control), to provide integration of multiple devices all within the same bus.
- Accessory outlets - Some DMEs install accessory outlets as after-market items, however, many existing batteries lack sufficient energy density to power the chair and an array of accessory devices.
- Battery longevity - Some manufacturers reported battery life extending beyond that reported in the white paper (e.g., gel batteries should last 2 – 5 years). However, service providers find that batteries are actually lasting only 1 – 2 years. The difference may result from battery degradation due to sub-optimal power management (recharge practices) by users.
- Safety – batteries utilizing ether based electrolyte are fairly benign and have shown resistance to abuse.

C. Ideal Technology:

- Batteries should be lighter and smaller.
- Batteries should come in a variety of sizes, shapes and weights. Such options would support the flexible design of the power base. Designers must avoid batteries with sizes, shapes or weights that cannot be readily procured in the marketplace.
- Batteries with higher energy densities are needed that can serve as a power source for additional electrical devices. For example, it would be very helpful to power augmentative and alternative communication and other essential/peripheral devices through chair's power system.
- Batteries are needed with higher charge capacity that would allow the user to travel greater distances. This is very important to consumers.
- Batteries should have a low leakage current and be "user swappable" (the user can change the battery themselves). User swappable batteries will require some standardization (e.g. size, performance, connection, safety, …).
- Modular power cells (analogous to power tool power-packs), if small and light enough, would permit the user to swap out batteries from a charging station on daily basis – if user have sufficient dexterity and range of motion.
- Battery should be compatible with airline stowage requirements and the Air Carriers Act. Not all gel-cell batteries are currently approved.
- Batteries with reduced size and weight are needed that still retain their current power capacity. Such batteries would reduce the charging capacity requirements for on-board chargers.
- Batteries with smaller size and weight would reduce the overall weight of the chair. This would help with air travel and transportation needs generally.
- Smaller batteries would make power monitors more accurate.
- Matching an intelligent battery monitor to the battery technology would allow tracking of battery status and extend battery life.
- Batteries require significantly improved cycle life (increased number of charge and discharge cycles).
- Batteries need to be user safe for all normal or likely uses (e.g. charging, discharging under load, leakage discharge, …), environments (e.g.

temperature extremes, humidity extremes, …) and when damaged (punctures, over-charged…).

Other Suggestions:

- Pair the specification and development of lithium battery technology for wheeled mobility products with that of electric bicycles and scooters. The electric bike and scooter market is potentially huge. Successfully pairing would provide the economies of scale needed to make advanced batteries affordable.
- The niche market issue has traditionally been a barrier but now Lithium polymer battery manufacturers are hungry for new application markets – including niche markets.
- Track advances in battery technology for electric cars/bicycles. Leverage this industry's advances and investments in battery technology.
- A wheelchair consortium could provide lithium battery developers with specifications for wheelchairs and scooters. This would help to ensure that batteries developed for electric cars/bicycles are suitable for wheeled mobility products. Consortium could help shape guidelines for battery specifications (standard size, capacity, …).
- Explore hybrid power systems. For example, augmenting batteries with capacitors that store a reserve charge. Stored charge provides additional power under heavy load conditions. Another example would be an energy regeneration system analogous to that used in automobiles.
- Explore alternative (to battery) power technologies. For example fuel cells or solar power. Need economies of scale in order to make alternative power technologies for wheelchairs and scooters – (e.g., fuel cells, solar, …) affordable.
- Manufacturers should provide an outlets (connection ports) on the chair (controller/bus) to plug in other devices (analogous to a cigarette lighter socket in automobiles).
- Need to have a back-up power source for users, as an option to acquire and add when power is lost unexpectedly.
- Push beyond existing solutions and incremental improvements. For example, a power chair (or scooter) that charges itself at night, in the consumer's bedroom without the user having to take any specific action. Power chair (or scooter) should "always be charged," and alert the user to problems that can be remedied by the user. Such a power chair (or scooter) should also be available at an affordable cost.

D. Barriers to Realizing the Ideal Technology:

- At present, reimbursement policies are constraining battery development, and are actually pushing the technology backward, due to reduction in reimbursement (e.g., installation is often not covered by reimbursement).
- Wheelchair and scooter market is a niche market. "Last attempt" to link wheelchair companies to advanced battery manufacturers fell flat (e.g., advanced batteries had higher cost and were not widely available).

- There is a need to develop a wheelchair industry consortium, which can lay down the specifications and requirements for the wheelchair battery. These can serve as guidelines for advanced battery manufacturers to direct their research.
- The wheelchair industry has repeatedly invested in advanced battery development with no concrete outcomes. (This suggests that such a direct approach to is not likely to be fruitful.)
- Need to convince third-party providers of the long-term benefits of better batteries and chargers (e.g., increased battery life, decreased amortized costs), in exchange for possibly increased purchase cost.
- Some (but not all) lithium battery technologies have a potential for explosion. Battery technologies must address regulatory issues of safety and environmental disposal.

E . Priority Problems & Recommendations

Battery Problem 1: New batteries are being developed without input from wheelchair stakeholders (industry, clinicians, consumers, researchers, reimbursement sources) concerning today and tomorrow's requirements for battery capacities, performance and size/shape/weight dimensions. If the wheelchair stakeholders communicate their needs to the advanced battery developers while the battery parameters are being specified, the advanced batteries can be designed more appropriately.

Recommendation for Problem 1: Initiate a wheelchair stakeholder consortium (W/C Consortium), preferably led by the RERC on Wheeled Mobility. The W/C Consortium's purpose is to develop a set of battery specifications that reflect current and future power requirements. Once developed the W/C Consortium should disseminate these specifications to emerging battery technology developers and manufacturers, as well as to leading industries with similar battery requirements (e.g., golf carts, electric bicycles). The specifications should convey the short-term needs for current wheelchairs, and the ideal requirements for advanced battery technologies to power future mobility systems. This information will permit battery developers to incorporate wheelchair power requirements into their designs prior to full-scale production.

Battery Problem 2: Wheelchair users want to tap into the wheelchair's power source to power electronic accessories (e.g., augmentative communication devices, laptop computers, cellular telephones). Tapping into the wheelchair's power source is more convenient for the user than each device having its own batteries. Currently, the wheelchair's power source is not designed for this purpose. It lacks an appropriate interface for conveniently connecting powered devices, and the power capacity was not designed to supply accessory devices. DME dealers report that adding an accessory adapter plug such as a twelve-volt cigarette lighter is a common after-market practice. Many accessory devices are already compatible with this plug. Accessory plugs are becoming more a necessity than a convenience, as consumers have increasing requirements to maintain electronic links for information processing or telecommunications.

Recommendation for Problem 2: The RERC on Wheeled Mobility should work with consumers, clinicians and DME dealers, to define the requirements for a universal accessory power interface. They should then approach manufacturers to integrate this accessory plug interface into the power system. The accessory plug(s) should accommodate a wide range of electronic products. The accessory plug should be within reach of the user, such as at the controller box.

Battery Problem 3: Users lack a full understanding of the power monitoring and management practices needed to maximize battery life. For example, experienced power wheelchair users did not charge their battery on a daily basis, and did not appreciate the importance of doing so. However, battery manufactures assume these standard practices are followed when they establish the battery's expected life. Some DME dealers report absorbing the cost of battery replacements because the reimbursement systems are unwilling to pay for more frequent battery replacements. Consequently, many users do not realize the battery's full capabilities, the manufacturer's product does not perform up to expectations, and all stakeholders pay a premium for accelerated battery replacement.

Recommendation for Problem 3: The RERC on Wheeled Mobility's information dissemination program should develop a summary of power monitoring and management requirements, written for consumers. This summary should be disseminated to wheelchair users through DME dealers, State Tech Act programs, Independent Living Centers, UCP agencies and other appropriate sources. Where possible, organize consumers and DME dealers to collaborate on demonstrating the cost effectiveness of consumer education programs, by extending battery life and thereby reducing replacement costs.

Battery Problem 4: Battery power gradually diminishes through use, until the user either recharges the battery or drains the battery to the point where it can no longer power the wheelchair. Existing battery power systems have no reserve or auxiliary power source, which can provide supplemental power for the wheelchair (and other powered devices), in emergency situations. Consumers are not willing to reduce their existing battery capacity, to create a power reserve. They want it to add to their existing capacity.

Recommendation for Problem 4: Emergency Auxiliary Power System - The W/C Consortium should define the requirements for a reserve power unit, for use in emergency situations. Requirements for such a system include the following:

- Power capacity - approximately 10% of a typical battery under high load conditions.
- Size - must be small enough to be integrated within the wheelchair, specifically within the configuration of the battery-box. This may be difficult because the battery box is already full, but it is a critical issue, because a new battery box mold would cost about $250,000 per manufacturer.
- Activation - should have a manual rather than an automatic switch operation, so the user is aware of the power situation and is prompted to take immediate remedial action.
- Charging - auxiliary power unit must be recharged with main power unit, to prevent charge degradation over time. However, the auxiliary power unit

should recharge more rapidly than the main power unit (e.g., less than one hour), so it can be readily available even after use.

- Cost - need to justify cost of auxiliary power unit to third party payers, for manufactures to view this as a business opportunity in the short-term. Private payment from the aging baby boom cohort will eventually create a market opportunity outside of the third-party system.

2. Battery Chargers

A. Priority Customer Needs:

- Dealers should be careful to match the right charger to the battery. Consumers want chargers that perfectly match with the battery technology so as to avoid any damage to the charger or battery.
- Chargers should be easy to use, compact or light weight.
- Two and four prong power plugs needs to be more durable as they degrade quickly, particularly with regular charging.
- Charger handles should be sturdy enough to handle constant use.
- The location of the charging unit connector should be accessible to users.
- Chargers should be very safe. Some consumers have strong concerns about the possibility of severe shock.
- Chargers should meet the ANSI/RESNA standard of 80% charge in 8 hours.

B. State of Existing Technology:

- In older chargers, amp-meters (rather than volt-meters) help the user determine the state of the batteries recharge cycle. Cost considerations are reducing their use.
- Modern chargers provide a constant charging current, so an amp-meter would not be a helpful.
- Electromagnetic Interference (EMI) may reduce monitor accuracy, but appropriate shielding can eliminate EMI.
- Medicare does provide reimbursement for on-board chargers because it is not an up-charge.
- “Smart chargers” exist. They monitor charge capacity over time so that the user can determine when recharge capacity has diminished to 50% - 60% of original capacity. Smart chargers would also permit the collection of data concerning battery life across multiple users over time. Some smart chargers can adjust to battery chemistry and shut down when full charge is achieved.
- Data acquisition systems can collect data that can be downloaded to a personal computer for analysis.
- “Pulse chargers” have been shown to increase battery life from 100 cycles up to 2000 cycles – but this depends on how “cycle” is defined. (In federal lab work “depth of discharge” was defined as being down 5-10% of capacity for some applications and down 75-80% of capacity for vehicles).
- SBM (System Bus Management) provides an intelligent read of battery status (for various battery types) in the computer industry (a board level product costs in the $15 range).

- Battery cell robustness (e.g. number of charge-discharge cycles, ability to tolerate rapid charging, ability to utilize “simple” charging protocols, …) varies with the type of battery.
- The excessive size and weight of existing battery chargers results from the use of transformer-based charging technologies.
- Scooters have on-board chargers that can be plugged straight into the wall, but wheelchairs don’t have that capability.
- Existing on-board chargers have limited charging capacity.
- Users with on-board chargers typically do not place heavy demands on their power supply. This is probably the reason that charging capacity problems have not arisen.
- Chargers with sufficient charging capacity (for power wheelchairs) are currently too heavy to include as an on-board charger. Some chargers are larger/lighter while others are smaller/heavier.
- There are serious safety and regulatory issues with onboard chargers for wheelchairs. Wheelchairs lack a common ground. In contrast, scooters are better grounded.
- Existing chargers do not provide users with any information concerning the batteries current charge level; recharge requirements; or the battery’s overall state of operation. Without this information, users have to estimate the power system’s needs through trial and error.
- Meeting Standards - dual-mode chargers (wet cell and gel) are available but it took a long time to get them developed and approved, so the market contains a large number of chargers that are currently considered obsolete. Many of these chargers don’t meet the ANSI/RESNA standard of 80% charge in 8 hours.
- Electric vehicles (automobiles and buses) face the problem of getting recharged on the road. A solution in process is induction charging. There are safety issues for this approach. An air gap of several inches means the power field is strong enough to cross that space. This presents a risk of either electromagnetic interference for pacemakers and wheelchair controllers, or electromagnetic radiation for the user and others. There is an access issue as well. The wheelchair user will need sufficient space in order to access the charging dock within the home or elsewhere, particularly if shielding is required to address safety issues.

C. Ideal Technology:

- Charger should be smaller and lighter with sufficient capacity for Group 24 batteries.
- Charger should be on-board or very portable, depending on the user's needs. Whether the charger is on-board or not, users want it to be light and accessible.
- It is critical that the process of charging the battery should be simple and easy for users because charging must be done on a daily basis.
- A charger that can accelerate the charging cycle significantly beyond current ANSI/RESNA standard (e.g., 80% in 8 hours). The benefit/cost must be assessed by individual if accelerated charging cycle adds to cost.

- Chargers should utilize standard connectors, which have adequate durability. (e.g. A barrel-type, three-prong connector with a metal casing would have increased durability.)
- The charger's power cord should be long enough (and retractable) to accommodate the expected distance between the chair and wall plugs -- such as those in hotel rooms behind beds or desks.
- The charger's connector should be within easy reach of the user – which varies with the user's range of motion. Industry should be given a range of locations that are highly accessible to the widest range of users, so they can build these requirements into PM&M system design.
- Chargers that utilize auto-docking would have significant value for people with severely limited range of motion (high level injuries). Attendants are not always available to assist these users with recharging.
- Chargers should be "intelligent." Intelligent chargers should monitor battery status; work to maintain battery integrity; adapt to different voltage levels; perform diagnostics; and provide warning of battery degradation.
- Intelligent chargers should help the user to monitor and manage their power system and extend battery life to the optimum designed for by the manufacturer.
- An equipment provider should be able to download battery usage information collected by a "smart" battery monitor. This will assist preventive maintenance efforts.
- A "smart" charger installed onboard the wheelchair/scooter, would continuously collect data on usage. On-board charger can greatly simplify monitoring & management process. For example, a "smart" charger could monitor usage patterns, but the monitoring data would be sporadic if the user was interchanging multiple chargers.
- The ideal charger would have a linear charging curve, work under surge current conditions, and recharge the battery rapidly under all load conditions.
- On-board chargers would be welcomed by industry if they had sufficient charging capacity (echoed by industry representatives). Industry would welcome any technology that would make on-board chargers feasible because it would simplify charger use by customers, and reduce costs (by reducing connections).

Other Suggestions:

- Some chargers help preserve battery integrity while others degrade it. In practice, there is no scheduled maintenance program for power chairs, but if there was, it would permit assessment of data collected in power system. Assessment of battery integrity is possible with existing systems, but would be better if the information could be downloaded from a smart power management and monitoring system.
- The connector should be within easy reach of the user – which varies with the user's range of motion. Industry needs to be given a range of locations that are highly accessible to the widest range of users, as a guideline for design.

- It is important to collect the history of battery charge/discharge cycles. Continuity may be lost if user has multiple chargers – the data collection unit may need to reside with the battery or with the power monitor.
- Experimental charging systems should be evaluated to determine their applicability to wheelchairs. For example, pulse charging techniques might increase battery life by anywhere from 100 to 2400 cycles. As a second example, inductive chargers would eliminate the need to physically connect the battery to the power source (being in close proximity to the charging unit would be sufficient).

D. Barriers to Realizing the Ideal Technology:

- Need to explore safety issues for on-board chargers and establish parameters for their safe use.
- The electromagnetic field generated by an inductive charging system could raise safety/health issues for the user and their equipment attached to the power wheelchair.
- Some consumers continue to use battery chargers that were considered to be obsolete by the manufacturers.

E. Priority Problems & Recommendations:

Battery Charger Problem 1: Existing chargers cause problems in power management and monitoring and compromise battery performance and integrity. Battery chargers do exist that have some of the capabilities of the ideal charger listed below.

Battery Charger Recommendation 1: Requirements for new on-board or very portable chargers compatible with popular wheelchair batteries:

- Charger should be designed to be sufficiently small and lightweight to be incorporated on-board the chair, or available as a very portable accessory – depending on consumer's preference.
- Charger should have sufficient intelligence to monitor and manage battery status, provide optimal charge to extend battery life to maximum possible. Should not work on pre-determined program (e.g., trickle charge), but instead sense the battery's condition and current status in the battery charge/discharge cycle.
- Charger should monitor the condition of the battery – The most critical aspect of monitoring is to know when it is time to get a new battery.
- Battery charger should monitor charging history (upside and downside for consumers) – currently part of SM Bus capability.
- Charge both sealed and open batteries.
- Smaller size (approximately 6"x4"x2")
- Reduced weight for on-board integration
- Sufficient charging capacity for Group 24 batteries.
- Standardized connectors.

- "Redundant display" would allow the charge status to be displayed during a power outage.
- Charger lifecycle beyond 3 years.
- Efficient for fast charging (meet/exceed current ANSI/RESNA standards (Part 14)– 80% of full charge in 8 hours).
- Adjustable for operation on different voltages (e.g., 115, 220, 230)
- Safety mechanisms to protect operator and manufacturer (e.g., GFI, rain test), to permit individual to remain in chair while recharging.
- Address ergonomic issues for user interface (e.g., formable plugs, retractable cord, easy access to the plug/connector by user, …).
- Silent operation (particularly for overnight charging in same room with consumer).
- Meet all applicable standards and regulations (e.g., ANSI/RESNA, VA, UL) for all parameters covered (e.g., storage and operating temperature range, vibration, drop)
- Retrofitting should be option for existing chairs.
- Business Issues
  1. Cost to manufacture/wholesale/retail levels - (Currently $50 - $70 retail price depending on charger capacity).
  2. Medical necessity – justification may be required for reimbursement, particularly for retrofitting existing chairs.
- Government R&D Issue - hit budget cycles or experience year delay.
- Advanced battery technologies may permit development of alternative chargers (e.g., inductive, SM/Communication Bus) to match new batteries.

3. Power Monitors

A. Priority Customer Needs:

- More accurate power monitors are needed. Volt-meter based monitors are simply not accurate, particularly for lead-acid batteries under varying load conditions. Users have to develop a "ballpark" understanding of the battery's remaining capacity through trial and error. Consumers learn to work with this process but it is not optimal.
- Monitors are needed which can provide user with sufficient detail about battery status, condition, remaining travel distance etc. Existing monitors have insufficient indicator detail (e.g., single green/red light that flashes when you are nearly out of power, while digital monitors have a row of bars which are more useful but still lack sufficient accuracy for distance or time remaining on charge. They require the user to estimate "remaining time" through trial and error (user is forced to become the battery monitor!).
- Improved monitors are especially important for users placing heavy demands on their power systems.

B. State of Existing Technology:

- Monitors are not part of a "systems" solution, where the system includes the monitor, charger and battery.

- Monitors are not matched or attuned to the performance characteristics of lead-acid battery technology.
- Power indicators do not accurately measure power remaining.
- Power indicators do not accurately show the power remaining.
- Advanced monitors of power status and battery condition might be available in the federal labs.
- Appropriate technology exists in other industries (e.g., SM Bus), but the challenge is applying them to lead-acid cells.
- The CAN Bus could provide multiple functions for wheelchair management and other functions (e.g., heads-up display, AAC interface).

C. Ideal Technology:

- Monitor should provide "range" information to the user. Range (e.g. remaining travel distance), as estimated from residual battery charge, will be highly dependent upon user behavior, electronic accessories and travel (load) conditions.
- Monitor should provide user-specific information about status of charge, distance remaining, and indicator of requirement for charge.
- Monitor should support a range of display interfaces.
- Monitor should be an integral part of a "power management and monitoring system." Battery range and condition could be determined from information stored in/available from this system.
- Monitor should estimate the time/distance remaining on the battery's useful charge. (This can probably be accomplished by analyzing the recent (e.g., past three hours) usage pattern.)
- A scheduled maintenance program would permit DME's to extract critical data on power management and monitoring (e.g., load testing, battery condition).

D. Barriers to Realizing the Ideal Technology:

- Consumer acceptance of more complex monitors will depend on the reliability and accuracy of the new monitors.
- Any range indicator will be highly dependent on user behavior, number of accessories and travel (load) conditions.
- Financial considerations have limited the charger options developed by manufacturers. These manufacturers are aware of more reliable monitors in parallel industries that could be modified to meet the needs of the wheelchair industry. However, if these monitors increase the chair's cost, they won't be covered by third party reimbursement.

E. Priority Problems & Recommendations:

Power Monitor Problem 1: Current monitoring systems do not fully support all the needs of different users for information to conduct appropriate power management and monitoring. Some consumers rated improved monitors as high priority and other rated it lower.

Power Monitor Recommendation 1: Develop improved monitoring process/output that provides required discharge/recharge information to user (daily) and service provider (history). An accurate indicator of Power Monitoring and Management parameters would include the following:

- Accurate residual energy monitor (specifically a “gas gauge”) – capable of translating energy into time (hours/minutes) and distance (miles/feet) parameters.
- Provide numeric readout instead of single light or LED bars, or other user-friendly readouts.
- Monitor battery status in terms of cycle life. Monitor condition of battery rather than capacity (could be built into intelligent charger) -- Most critical aspect of monitoring is to monitor condition of battery – e.g., know when it is time to get a new battery.
- Monitor related power system issues – including power-train and accessory power.
- Record accumulated “watt hours” to establish battery performance.
- Power monitor should be readily accessible but non-obtrusive.
- Power monitor needs to accommodate monitoring of power requirements of accessory devices such as augmentative communication, cellular telephones, etc.
- Best solution should be “systems” approach so that monitor is part of total power/drive-train “system” – this will optimize power system (battery) performance as defined by manufacturer’s specifications.
- Monitor should be “integrated into the wheelchair” to ensure it collects and tracks information related to chair use over time.

4. Power Management and Monitoring System

- Power monitoring and management should be approached as a system, resulting in a system's level solution. Battery, charger and monitor should all be integrated into power management system. This would avoid compatibility issues for components.
- Most of the users felt there was a need to integrate the power wheelchair with computers, cell phones and other electronic accessories and to develop a standard communication protocols and interfaces.
- Retrofitting of various components and devices from parallel industries that can be modified for the wheelchair industry represent significant business opportunities.
- For all technologies, commercial viability is heavily dependent upon third-party reimbursement. Challenge manufacturers to collect data to make evidence-based arguments to justify higher reimbursement by third-party systems. Analogous to Cooper’s demonstration of life cycle of lightweight wheelchairs. Must be done within parameters of reimbursement system, to provide current practice data for cost-effectiveness studies.

Problem Statement 1: Battery Monitoring Technologies

We seek technologies that will help people using powered wheelchairs and scooters to more accurately monitor the state of charge in lead-acid batteries.

Description of the Problem

Power wheelchairs are used predominantly by people with both lower and upper extremity impairments resulting from cerebral palsy, high-level spinal cord injury, or muscular dystrophy. There are more than 93,000 power wheelchair users in the United States. The "standard power wheelchair" accounted for $166 million in Medicare expenditures in 1997. Scooters are used primarily by people with the ability to walk short distances but who require assistance when shopping or interacting within the community — wishing to remain active despite growing physical limitations. Scooters are used commonly by elderly persons. It is estimated that 64,000 scooters are currently in use in the United States. In the near term, lead-acid battery and charger technology is expected to remain the standard for power wheelchairs and scooters. Power wheelchair and scooter users, need accurate knowledge of a battery's state of charge. Fear of being stranded can limit a user's independence and access to environments. Minimally, being stranded is an inconvenience to the user. At worst, being stranded is a serious threat to the user's safety. A gauge that routinely and accurately tracks power discharge and remaining power and then translates this into a measure of remaining capacity would substantially improve the user's independence and would be welcomed by manufacturers, service providers, and clinicians. The power monitor should also track a battery's rate of degradation and alert the user when battery replacement is necessary.

Current State of the Technology

Deep discharge wet and gel electrolyte, lead-acid batteries are the standard power source for nearly 100,000 users of powered wheelchairs. They include Group 22NF (for standard chairs), Group 24 (for large/hi-performance chairs), and Group U1 (for children's chairs) batteries. Most power indicators for wheelchair batteries are simple voltmeters. They are widely used because they are inexpensive, robust and compact. However, voltmeter based monitors are at best inaccurate and at worst misleading indicators of remaining battery capacity. A voltage monitor produces instantaneous variations in state-of-charge readings, in response to loads placed on the battery during typical daily use. No means exist to translate remaining power into estimates of remaining capacity or range. This inadequacy forces the user to estimate the time/distance remaining through trial and error.

Battery monitors used in other industrial applications have some of the capabilities being sought for lead-acid batteries. For example, the computer industry uses an SMBus for monitoring a battery's status. In this case, both the power-monitoring and charging systems are paired with the battery technology. The power monitor tracks the flow of current into and out of the battery. The battery's full charge level is also tracked, so the power monitor can assess battery degradation over time. This monitoring/charging system has the additional feature of being programmable, so that key parameters can be entered and the charging system accurately matched to battery performance specifications.

Technology Needs and Barriers

Information gathered from users, manufacturers, clinicians, and other stakeholders has identified characteristics of an ideal motor. Minimum requirements are identified as items that “must” be addressed to make a design acceptable; other attributes that will benefit the design are identified as items that “should” be addressed. Specifically, an ideal monitor…

1. Must be compatible with wet (open or closed) or gel electrolyte, lead-acid battery technology.
2. Must provide an accurate and instantaneous measure of residual power—analogous to a fuel gauge.
3. Should translate the battery power into a percent of capacity, time (hours/minutes) or distance (miles/feet) remaining, depending upon the user’s preference.
4. Must monitor power use by the wheelchair and its accessory devices (e.g., augmentative communication systems, cellular telephones, laptop computers).
5. Must compile the charge/discharge/recharge history to develop an energy consumption profile for wheelchair user.
6. Must meet or exceed all relevant ANSI/RESNA standards for operating parameters. See http://www.fda.gov/cdrh/modact/recstand.html#phymed.
7. Must protect the user from shock hazards and the manufacturer from liability.
8. Must not interfere with wheelchair controller functions.
9. Must have easily seen, accessible, yet unobtrusive display and control features. The display should be numeric or have other user-friendly characters, rather than using lights or stacks of LED bars.
10. Should analyze the history of power consumption to track the battery’s condition (e.g., degrading charge capacity, accumulated watt-hours).
11. Could integrate monitor functions into an intelligent battery charger or wheelchair controller.

Problem Statement 2: Battery Charger Technologies

We seek technologies that will help improve the battery recharging process for people using powered wheelchairs and scooters.

Description of the Problem

Power wheelchairs are used predominantly by people with both lower and upper extremity impairments resulting from cerebral palsy, high-level spinal cord injury, or muscular dystrophy. There are more than 93,000 power wheelchair users in the United States. The "standard power wheelchair" accounted for $166 million in Medicare expenditures in 1997. Scooters are used mostly by people with the ability to walk short distances but who require assistance when shopping or interacting within the community and wish to remain active despite growing physical limitations. Scooters are used commonly by elderly persons. It is estimated that 64,000 scooters are currently in use in the United States. In the near term, lead-acid battery and charger technology is expected to remain the standard for power wheelchairs and scooters.

Existing chargers compromise battery performance and integrity, in part, because they do not promote effective power management by the users. Improper battery charging reduces battery life and increases replacement costs. Two factors can significantly improve charging practices. First, chargers need to be more convenient. Most wheelchair battery chargers are too large to be portable or placed on-board, while smaller chargers that are available are not considered to be durable and reliable by some Forum participants. Wheelchair users' mobility depends upon their wheelchair. A charger that is readily available and reliable would have a significant impact on a user's independence and access to environments. The user may be seated in the wheelchair during the charging process. Any portable or on-board charger must protect the operator from hazards such as electric shock and explosion. Second, chargers should provide users with accurate, real-time information on battery charge status; both during the charging process and while the wheelchair is in use. Existing chargers do not provide accurate information on the level of charge, and some may not automatically charge the battery completely. Improper charging (either over or under charging) degrades expected battery life span.

Powered wheelchair manufacturers would enthusiastically welcome an improved battery charger. Existing chargers for various kinds of batteries contain some of the capabilities of the ideal charger as specified by the wheeled mobility stakeholders; however, no existing chargers adequately meet all of the user's needs.

Current State of the Technology

Deep discharge wet and gel electrolyte, lead-acid batteries are the standard power source for nearly 100,000 users of powered wheelchairs. They include Group 22NF (for standard chairs), Group 24 (for large/hi-performance chairs), and

Group U1 (for children's chairs) batteries. A battery's life span strongly depends on its pattern of daily use and charging. Forum participants indicated that lead-acid battery life under ideal conditions is four or five years. Forum participants indicated that typical lead-acid battery life is perhaps two years.

Most battery chargers are based on linear charging technology, which converts line voltage (115 VAC to 24 VDC), and use relatively large and heavy transformers. A few chargers are based on switch-mode technology, which does not use a transformer and are relatively smaller and lighter. A typical charger uses a constant, tapered or pulsed current profile. Some chargers automatically stop charging when the battery is fully charged (typically sensing a predetermined voltage level) in order to prevent overcharging the battery.

An important problem for both wet and gel, lead-acid batteries is the buildup of lead sulfate deposits on the battery plates (plate sulfation). Plate sulfation reduces charging efficiency, decreases performance (capacity and peak power delivery), and shortens battery life. Operation in high temperatures, prolonged high current draw, and incomplete charging all increase the rate of plate sulfation. Due to internal power losses, plate sulfation also takes place during battery storage. Recently, a patented "pulse technology" (http://www.pulsetech.net) has been shown to clean away plate sulfation and dramatically improve the efficiency, performance, and life span of lead-acid batteries. Pulse (plate cleaning) technology has also been integrated into chargers.

Technology Needs and Barriers

Information gathered from users, manufacturers, clinicians, and other stakeholders has identified characteristics of an ideal charger. Minimum requirements are identified as items that "must" be addressed to make a design acceptable; other attributes that will benefit the design are identified as items that "should" be addressed. Specifically, an ideal charger…

- Must be small enough for on-board integration (approximately 6x4x2 inches) and sufficiently lightweight for pocket portability. On-board versions should be compatible with existing powered wheelchairs.
- Must charge both wet (sealed and open) and gel electrolyte, lead-acid batteries and be adjustable for different input voltages (i.e., 115, 220, 230). Charging protocols should maximize the expected life span of the battery.
- Must work under surge current conditions—i.e., meet current UL/CSA requirements for power-line operated equipment, including FCC Part 15 for radiated and conducted electromagnetic interference —and recharge rapidly for all load conditions.
- Must meet or exceed ANSI/RESNA standard (Part 14) of charging to 80% of capacity in eight hours.
- Must meet or exceed all ANSI/RESNA standards for operating parameters—e.g., storage and operating temperature range, vibration, drop see http://www.fda.gov/cdrh/modact/recstand.html#phymed.

- Must protect the operator from all shock hazards while permitting the user to remain in their wheelchair during charging. Should include ground-fault-interrupter (GFI) for added safety.
- Should have a simple user interface—e.g., standardized plugs with formable bodies, barrel connectors, retractable cord, easy access from sitting position, and silent operation for overnight charging in bedroom.
- Must monitor battery status and alert the user when a new battery is needed or when the battery charge level decreases to 60% of full charge. Should notify the user to charge their battery on a daily basis, and should eliminate user-based charging errors.
- Must sense charge rate and charge level and automatically provide an optimal charge profile. Should collect/store daily charging history for use by support service providers and battery manufacturers.
- Should cost less than $50 to $70 to manufacture—existing chargers sell between $150 and $250

D. Motors and Drive Trains

- **White Papers**
- **Forum Data**
- **Problem Statement 1: Motors Problem**
- **Problem Statement 2: Transmissions Problem**

White Paper: Motors and Drive-train

TECHNOLOGY AREA

Motors, drive trains and external drive motor systems were identified by consumers, clinicians, researchers and manufacturers as having significant technical problems whose solutions could meet significant consumer needs and represent significant business opportunities within the wheelchair industry.

THE NEED

Power wheelchairs are used predominantly by people with both lower and upper extremity impairment resulting from cerebral palsy, high-level spinal cord injury, or muscular dystrophy. There are over 93,000 power wheelchair users in the U.S. alone. The "standard power wheelchair" accounted for $166 million in Medicare expenditures in 1997. For the purposes of this program, scooters have also been included for consideration due to the many common technological needs. Scooters are most commonly used by people with the ability to walk short distances but who require assistance when shopping or interacting within the community -- wishing to remain active despite growing physical limitations. It is estimated that 64,000 scooters are currently in use in the United States.

The propulsion system of powered wheelchairs typically consists of a pair of motors, one for each drive wheel, and a drive train consisting of gears, belts and other mechanical elements that couples the motor's shaft to the drive wheel shaft.

Most wheelchairs utilize two permanent magnet DC motors (PM motors), with two 12 volt batteries providing a 24 volt supply. PM motors have a linear torque-speed profile making them easy to control. A DC-DC converter drives each motor with a high frequency, square wave, pulse train that rapidly turns each motor on and off. Speed and torque generated by each motor is controlled by modulating the pulse width. Solid state relays are generally used to switch supply voltage polarity to change the running direction of PM motors.

Scooters have both three- and four-wheel configurations using direct or belt/chain drive systems. They use either one or two motors and are powered by a 12 or 24 Volt power supply. Most scooters are rear wheel drive for increased traction while the front wheel drive systems are lighter and as a result may have difficulty maintaining traction on inclines or rough terrain.

Free running under no load, PM motors can attain an efficiency of about 70%. Under loads typical for power wheelchairs, these motors are about 45% efficient. A drop in motor efficiency increases the current drawn from the battery and decreases battery life and efficiency.

The wheelchair's control module converts positional information from the joystick into power signals to the motors. Control modules are microprocessor based and have many adjustable parameters. Many control modules utilize feedback to sense whether the motor is responding properly to the joystick position. Such control systems adjust motor torque so as to maintain near constant speed while the load varies in response to changes in the terrain (incline, bumps) and surface (linoleum, carpeting, concrete, grass, sand).

Adjustable controller parameters include high/low speed range selection, maximum high speed, maximum low speed, maximum acceleration and turning speed, tremor dampening (low pass averaging of joystick position), maximum power delivered under high torque, and energy saver (reduces speed and increases range when the battery is low).

The drive train is a mechanical system that transfers rotational power from the motor to the drive wheels. There are two types of drive trains 1) direct transfer and 2) indirect transfer.

For a direct drive transfer system, the motor shaft is directly coupled to the drive wheel shaft (through gears for instance). Direct drive transfer requires a low speed, high torque motor and is mechanically efficient. However, the gears in the direct drive system are prone to wear and/or breakage and make them expensive to repair.

For an indirect drive transfer system, the motor is coupled to the drive wheel shaft through a system of gear train and flexible machine element (belts or chains). The gear train and belt typically serve to reduce the motor speed while proportionately increasing motor torque. They also act as a “shock absorber” when the drive wheels are stuck or under heavy load. Excessive stress on the system can cause an increase in noise and misalignment of the drive system. However, realignment is easily done and the cost of maintaining the system is relatively low if adjustments are made on a regular basis.

The size and weight of the gear train is proportional to its speed reduction ratio. There are two types of gear trains 1) involute geared and 2) worm geared.

Involute gear drives have a power transfer efficiency of 90-95% but are larger, heavier and noisier than worm gear drives. Involute gear drives are used on fixed frame power wheelchairs with both motors perpendicular to the orientation of the drive wheels.

Worm gear drives are relatively smaller, lighter and quieter than involute gear drives and approximately 70-80% efficient. With worm gear drives both motors are oriented parallel to the drive wheels. Worm gear drives are used on folding frame power wheelchairs. In addition, more space is generally available for respirators, power seating, and storage.

The chatter and swiping of gears, and friction associated with motor and idler bearings are potential sources of vibration and noise.

Wear and failure of components in the typical motor and drive system is a significant problem. Maintenance costs for a power wheelchair are estimated in excess of $1000 over a five-year period. Motor and drive system repairs often cannot be completed by technicians “in the field” and must be returned to the manufacturer for service. Many users elect to operate their motor until failure and purchase a replacement motor as opposed to being both inconvenienced and paying high maintenance costs.

The torque delivered by motors and drive trains, places constraints on the environments (terrain and surfaces) that a power wheelchair user can access, work or recreate in. The speed and efficiency of motors and drive trains, constrains the travel distance and time between battery recharge.

The size and configuration of the battery, motors and drive trains constrains the physical dimensions of the wheelchair's power base and impacts a user's ability to access home, work, recreational and educational environments.

Seat height impacts a users access to desks and tables (for instance). Vans generally require extensive modification to accommodate the seated height of a power wheelchair user.

BASIS FOR DISCUSSION

The goal of the Forum is to select a high-priority problem and begin to develop a problem statement that specifies requirements for a commercially viable solution. The following points are provided to help Forum attendees prepare their opinions and input on these important topics.

Motors

Statement of the Problem

Many new innovations in motor technology are occurring for power wheelchairs, electric vehicles, electric bikes and scooters. Many of these motor technologies are more efficient over a wider range of torque and speeds than PM motors which are the dominant motor technology for the power wheelchair industry. New motor technologies have not fully penetrated the power wheelchair market because of factors such as cost, size, weight, and voltage supply requirements. Further innovations are necessary to remove these market and technical barriers

Current Solutions

Most power wheelchairs and scooters currently utilize PM motors with iron magnets, brushes and indirect drive trains. Recent innovations within the power wheelchair and scooter industry includes the use of rare earth magnets; and brushless, gearless, direct drive motors.

Rare earth magnets support much higher magnetic fields than iron magnets. Motors utilizing rare-earth magnets are smaller and lighter than analogous motors with iron magnets. Alternatively, motors utilizing rare-earth magnets are more powerful than motors with iron magnets of a similar size. Brushless motors are more efficient than brush motors (brushes introduce electrical power loss). Brushes are also subject to wear and require regular inspection and replacement.

Gearing and belts in the indirect drive train are a source of mechanical power loss. Highly efficient, gearless, direct drive motors have recently appeared in the power wheelchair market. These motors can be mounted in close to the drive wheels and allow good access to the under seat compartment. However, these motors tend to be relatively large and expensive.

It is impossible to discuss even a fraction of the motor innovations which might have application to the power wheelchair industry. However, the following list includes some of the motor technologies that have been suggested.

- A brushless, gearless motor, entirely contained within the power wheelchair's drive wheel has recently been introduced by a European company.

- Pancake stepping motors efficiently generate high torque, even at high speeds. These motors are durable and reliable. "These motors are designed primarily for applications requiring accurate positioning, high torque and very thin, low profile packaging."

- Disc-armature DC motors have high power to weight ratio and efficiency. They are "ideal for battery traction applications where energy efficiency across the full speed range is of primary importance."

- Alternating current, three phase, squirrel cage induction motors (SCIM) are inexpensive, efficient, highly reliable and have a torque speed characteristic very adequate for vehicle propulsion. Commercially available induction motors typically require a 120 V or 240 V power supply. For this reason, these motors have not been considered suitable for power wheelchairs.

Issues to Consider

- What technical barriers prevent innovative motor technologies from penetrating the power wheelchair and scooter markets?

- What system requirements (battery, controller, performance, …) of these innovative motor technologies represent significant technological barriers?

- What market barriers prevent innovative motor technologies from penetrating the power wheelchair and scooter markets?

- What motor technologies exist in parallel industries (for example electric vehicles) which might be successfully transferred to the powered wheelchair industry, perhaps providing economies of scale?

- Which user populations would most benefit from improved motor technologies? In what ways would they benefit?

Transmissions

Statement of the Problem

Innovative motor technology may eventually displace PM motors in power wheelchairs and scooters. However, PM motor technology is reliable, inexpensive and already incorporated into most power wheelchairs. A PM motor with an indirect transfer drive is inefficient in environments requiring significant low speed, high torque operation. Incorporating a transmission mechanism into the drive train would allow the PM motor to run efficiently for all speeds and torques and extend the serviceable lifetime of PM motor technology within the wheelchair and scooter industries.

Current Solutions

Patents have been granted for power wheelchairs which utilize transmissions in their drive trains. With the exception of one top-of-the-line power wheelchair which utilizes a transmission these power wheelchairs have generally not been successful in the marketplace.

Industry and technical experts suggested that the need for transmissions is quite great. These experts felt that transmissions have not succeeded primarily because of concerns for complexity, reliability, maintenance and cost.

Issues to Consider

- What technical barriers prevent transmissions from being designed and integrated into drive trains?
- How would the incorporation of transmissions into drive trains impact speed, torque and steering control?
- What system requirements (configuration, fixed or folding frame, …) are likely to impact transmission design?
- Is power efficiency loss through the transmission likely to be a significant problem?
- What business opportunities could be realized if a drive train incorporating a transmission was successfully designed?
- Which user populations would most benefit if a drive train incorporating a transmission was successfully designed? In what ways would they benefit?
- What transmission technologies exist in parallel industries which might be successfully transferred to the powered wheelchair industry, perhaps providing economies of scale?

External Drive Motor Systems

Statement of the Problem

Many consumers purchase manual wheelchairs but find over time that their physical abilities have decreased to a level where they cannot comfortably self-power the wheelchair. Shoulder and arm related disorders are often caused by the use of self-propelled manual wheelchairs and may add to the overall discomfort of self-ambulation. Motors and drive systems for retrofitting manual wheelchairs are currently manufactured and are the topic of many patent applications and successful USPTO filings. Product literature and patent information refer to these as “power assist” or “power conversion” systems.

Current Solutions

External motor sources are being applied to manual wheelchairs in an effort to reduce or relieve stress on the user during periods of physical fatigue, rough terrain or steep inclines. These systems can be applied or disengaged as required by the user. Removal of the system allows the user to fold the manual wheelchair with little or no additional inconvenience than folding their regular chair. The more common configuration uses dual motors that apply direct roller pressure to the rear drive wheels while other systems allow a combination of user applied propulsion that is monitored by the feedback circuitry of the control system. As the control system recognizes a reduction in velocity or acceleration it will augment power as required.

A few applications in front tiller designs have been attempted in the marketplace. Manufactures of this design use a front section similar to the front of a front-wheel drive scooter that attach to the cross bars on a manual wheelchair frame. This tiller system applies the power and acts as the steering mechanism, similar to how a scooter user would drive. These units provide control over speed, turns, and forward or reverse direction.

Issues to Consider

- What are the implications of external drive motor systems from the perspective of the user, reimbursement and safety?
- What technologies are required in the wheelchair design to accept external drive motor systems?
- What are the power requirements of external drive motor systems and what should be considered acceptable ranges for travel under normal circumstances?
- How does the end user know the range of the external drive motor system?
- What steering and braking issues are important in the use of these systems?

- What external drive technologies exist in parallel industries which might be successfully transferred to the wheelchair industry, perhaps providing economies of scale?

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Forum Data: Motors and Drive Trains

A. MOTORS

1. Priority Customer Needs

- Need user selectable gear ratio (keep chair from “shutting down” under high loads)
- Need increased range (allow power wheelchairs and scooters to be used as alternative transportation)
- Reduce motor and drive train noise (squeals, grinding, clicks, …)
- Reduce brush and gear wear (common problems requiring maintenance)
- Reduce build-up of heat in motors (cause of overloading and meltdown)
- Reduce repair time
- Improve reliability (fewer mechanical breakdowns)
- Need more durable gear box and drive train
- Need service technicians who are better at identifying mechanical problems
- Need better diagnostic equipment to help technicians identify problems
- Need “mechanisms” to insure that service technicians receive manufacturer training (possibly have a national certification for technicians that receive training)
- Dealers should have an annual inspection policy or program
- Need improved product literature (e.g. product’s intended use; maintenance schedule, …)
- Need information disclosure standards (e.g. motor and drive train testing, durability, appropriate use of technology, …)
- Need insurance to cover reimbursement for preventive maintenance
- Need to reduce the time between a repair and the insurance reimbursement for the repair
- Need a mechanism that allows the user to independently disengage the motor and drivetrain
- Users need to recognize motor limitations (e.g. controller cannot protect motors if the user repeatedly overloads the motor (heat, terrain, surface properties)
- Scooter users would like longer lasting, more durable motors/electronics
- Scooters need better steering control when motor power fails

2. State of Existing Technologies

- DC, brushed, iron permanent magnet (PM), internally rotating motors are currently the standard motor for the power wheelchair and scooter industry

- Any PM motor (with its drive train) has a speed/torque trade off. The PM motor (with its drive train) is maximally efficient at only one speed. Efficiency drops off rapidly away from this speed.
- Typical efficiency for DC, brushed, PM motors (with worm or involute drives) is roughly 60% with light loading and much less than 60% with heavy loading
- “Rare earth” permanent magnets are a major improvement over iron permanent magnets but don't eliminate the speed/torque trade off (the PM motor is still maximally efficient at only one speed)
- Under low load (e.g. indoor/hard, flat ground etc.), the motor usually operates near its maximum efficiency.
- Under Heavy load (e.g. outdoor, climbing, soft ground etc.), the motor usually operates near its minimum efficiency.
- Typical current draw for DC, brushed, PM motors in power wheelchairs - 6,7,8 amps
- Typical range for power wheelchairs with DC, brushed, PM motors - 15 to 20 miles per full charge
- Typical durability for DC, brushed, PM motors - may last 10 years (good motors, not abused)
- Currently, the combined weight of the motor, drive train and battery is used to stabilize power wheelchairs and scooters (keep them from tipping during use)
- Motors used in power wheelchair and scooter industries are derived from other industries (i.e. forklift, golf cart, bicycle, washing machines, windshield washers,…)
- DC, brushless, gearless, rare earth, permanent magnet motors are now appearing in market
- Brushless motor designs has the advantage that it provides better heat loss (windings are on outside). So the motors can be pushed harder before they’re damaged by heat buildup. They also have higher efficiency (no power loss at brushes).
- Gearless motor design does not have a gearbox. This eliminates noise and power loss that occurs through gear train.
- Use of high-energy magnet materials. (exotic [e.g. rare earth] magnet materials improves motor efficiency and reduces required motor size.)
- Some controllers may cause one motor to fail before another.
- Controllers are often designed to control a wide range of motors.
- When the motor is heavily loaded, the motor’s current draw pulls down the battery voltage. Controller electronics (generally) treat this as a low voltage battery condition and “shut down” the wheelchair.
- Controllers automatically "step back" (reduce current to the motors) when motors are overloaded. However, repeated overloading through inappropriate use can still overheat motors and decrease motor life.
- Brushes wear out which causes noise. They need to be frequently replaced.
- Soft brush material is quieter but wears faster and needs more frequent replacement
- Shunt wires wear and may hit and damage the commutator

- Minor repairs and maintenance (e.g. replace brushes) is done by service technicians (rather than caregiver or end-user)
- For significant repairs, the motor and gearbox are removed as a unit from the power wheelchair and sent back to the manufacturer to be rebuilt or replaced.
- Modern shipping capabilities makes sending repairs to the manufacturer possible.
- American chairs tend to utilize lighter motors, with higher operating speeds
- European chairs tend to utilize bigger, heavier, more powerful motors

3. Ideal Technology Requirements

- Increase the average motor plus drive train efficiency by 25% - 30% (major impact)
- Constant (overall) motor plus drivetrain efficiency independent of loading (clearly an "ideal" target)
- Continuously variable gear ratio independently controllable for both wheels.
- Create a true electrical transmission within the motor.
- Motor design should be smaller and shorter
- Motor should be durable
- Motors (and drive train) should be compatible with portable/collapsible wheelchair design
- Range of 50 kilometers (about 31 miles) per full battery charge under typical use
- Motor (and drive train) should be able to generate a high startup torque (e.g. problem for gearless, brushless motors)
- Lighter overall weight for motor plus battery and drive train is very desirable
- Motor design should increase under seat space
- Motors should be close to the wheels or a part of the wheel design
- Motors should be easily removable by user to facilitate folding of chair for transportation
- Motors should be easily removable by service technician to facilitate maintenance/repair
- Two motor designs are strongly preferred over one motor designs for power wheelchairs
- Motors need good heat dissipation (cooling system, increase surface area, heat sinks, …)
- The user should be protected from dissipated motor heat
- High quality manufacturing (low infant mortality rate)
- Uniform manufacturing (produce identical motors with matched performance)
- Sensors should provide information so that controller can compensate for motor imbalance. (e.g. optical encoders on the motor shafts)
- Sensors should track motor current draw to provide wear status and current motor state
- Sensors should provide self-diagnostic and warning information

- Technicians shouldn't require extra training to utilize or understand diagnostics
- Need to replace “standard” casters with wheels having driving and steering capabilities. This will improve the stability and control of the wheelchair
- Need to incorporate power steering rather than using drive wheels to steer (powered steerable wheels probably has same power draw as current system)
- Need standardized interface between motors/drive train and wheels
- Need portable battery charger on the chair
- lower cost (apply savings to other areas that need improvement - i.e.: seating)

Other Suggestions

To achieve the above mentioned ideal technology requirement, some suggestions were made. These suggestions are listed below:

- Possibly use “motor with redesigned pole structure.” (Requires advanced motor design concepts)
- Possible use “poly-phase, AC motor drive” system. (Should have improved efficiency and power torque curve)
- Possibly use “hydraulic motor” and drive train system.
- Possibly develop the motor technology in a small company under an SBIR or STTR
- Approach sources of advanced motor technology: federal labs, military (Advanced Vehicle Systems), Allison Motor, Blue Bird (manufacturer)

4. Barriers to Realization of Ideal Technology

- Motor and drive train design specifications for power wheelchairs are unique (i.e. no parallel motor specifications exist for other industries with the possible exception of electric bikes)
- Need CAD/CAE design tools (and sufficient expertise) to produce advance motor designs (Advanced motor design tools are available in other industries. These tools must be adapted to meet the unique and specific needs of the power wheelchair industry.)
- Some motor designs require complex controllers (e.g. brushless motors have more complex controllers)
- Reimbursement constraints (e.g. manufacturers may not be able to get reimbursed for more expensive motors)
- Industry must first perceive the need for advanced motor design. (Need paradigm shift. Industry may believe that current and emerging motor technology is appropriate.)
- Small power wheelchair market makes it difficult for a manufacturer to recoup the cost of innovation.
- Use of lightweight motors and drivetrains may reduce wheelchair stability (without parallel redesign of the power wheelchair. Such redesign may represent a hidden cost.)

- High tooling costs to start up the production of a new motor
- High maintenance costs for new motor technology
- Need demonstration prototypes and limited production runs to test, redesign and develop motor technology
- Innovative motor design is very costly.
- Need funding for and research into efficient motor structures meeting the specifications of the power wheelchair industry
- On-board chargers - regulatory issues heat/location
- Need a steering committee composed of all stakeholders (further develop design criteria, action plan, …)
- Need an action plan (the tasks, “staffing,” timelines and deliverables required to complete the transfer of motor technology.)

B. TRANSMISSIONS

1. Priority Customer Needs

- Need to improve wheelchair performance under high load/high torque conditions (e.g. heavy loads such as soft surfaces or inclines)
- Need the ability to access difficult terrain, grades and surfaces
- Need to increase overall wheelchair range
- Need to improve battery performance (e.g. reduce peak current draw, increase battery life, range - increased time between charges, …)
- Need to improve overall motor and drive train efficiency
- Need to decrease motor size
- Need to increase under-seat space
- Need to maintain good control of the wheelchair for all speeds and torque’s (e.g. concern for steering control during gear changes)
- Need to maintain stability in rough terrain (e.g. concern for tipping during gear changes on inclines, changing surfaces)

2. State of Existing Technologies

- Users can select either a high or low operating speed for most wheelchairs. (This is not equivalent to a transmission and provides no gain in overall efficiency.)
- One high-end power wheelchair does have a transmission-like drive system. All other power wheelchairs use direct drive, indirect drive or gearless drive systems.
- Variable-pitch belt technology can act like a transmission but is very inefficient.
- Most scooters utilize a single motor and differential rear wheel drive
- Low cost, front wheel drive scooters are also common

- Scooters with rear wheel drives have the “gear head” attached to the wheel
- Worm gears are quieter but less efficient than involute gears
- Wheelchair manufacturers define motor specifications for the motor manufacturers (i.e. motor manufacturers are responsive to the specific technology needs of power wheelchair and scooter industries)

3. Ideal Technology Requirements

- Transmission should improve overall motor plus drivetrain efficiency (Overall efficiency improvement of 25%-30% would be very significant. In bench testing, transmissions have been shown to double the average efficiency of typical PM motors. Employment of transmissions can make the same size battery go twice as far.)
- Manual two-speed transmission (User manually shifts gears. Short term solution. Perhaps achievable in 18-24 months).
- Automatic two-speed transmission (Gears shift in response to torque or other demands. Intermediate term solution.)
- Transmissions employing continuously variable gear ratios would be a step up in performance and complexity from manual or automatic two-speed transmissions.
- Electronic transmission (Transmission is integral to motor function. “Gear shift” is managed by the wheelchair controller. Long term solution.)
- Transmission should provide more torque under high loads.
- Transmission should shift very smoothly.
- Transmission should be reasonable size/compact (no larger than the current gear box). It should not increase the height and width of the chair.
- Incorporation of the transmission into a power wheelchair design should not require redesign of the power base.
- Transmission should (if desired) support the utilization of smaller motors (e.g. improved efficiency at high torque should allow the utilization of smaller, less powerful motors.).
- Transmission should be reliable and durable (Improve the overall reliability of motor and drivetrain.).
- Transmission should be low cost (design, testing, tooling and production should be relatively inexpensive.)
- Transmission should be low noise.
- A number of transmissions are likely to be needed in order to meet diverse performance requirements. (Match transmission to performance requirements.)
- Focus on key innovations rather than being too broad (conservative engineering)

4. Barriers to Realizing Ideal Technology

- The motor, drive train, controller and power base are typically designed as an integrated system. Adding a transmission to this system is likely to add to the complexity of this system. This could keep the manufacturers away from including transmission as a part of the wheelchair.
- A transmission will add to the general design and performance complexity of the propulsion system.
- Steering and acceleration for wheelchairs that incorporate transmissions has to be safe. (Erratic steering or acceleration is not acceptable. Diminished user safety is not acceptable.)
- A mechanism (mechanical, electronic, …) to coordinate transmission gear shifting for both wheels must be developed. Absence of coordination between the wheels can lead to erratic acceleration and steering. (e.g. In cases where there is absence of coordination between wheels, if one wheel encounters an obstacle and slows down, the other wheel keeps on moving at the same higher speed. The result is that wheelchair turns involuntarily. This can be avoided by having a coordinated transmission shifting between both wheels so that both wheels will move at the same speed.)
- There may be an added cost for wheelchairs that incorporate transmissions. Funding / reimbursing agencies must be convinced of the need and value of transmissions. (e.g. Medicare payment structure might not immediately support the added cost for transmissions.)
- There may be high tooling costs to develop transmission.
- Industry must first perceive the need for transmissions. (Need paradigm shift. Industry may believe that current technology is appropriate.)
- Need collaboration between user, clinicians, researchers, manufacturers and fundraisers to help fund development/raise public profile
- Need consumer involvement to raise profile/modify Medicare/Medicaid payment structure

Problem Statement 1: Motors Problem

We seek innovative motor technologies for power wheelchairs and scooters.

Description of the Problem

Power wheelchairs are used predominantly by people with both lower and upper extremity impairments resulting from cerebral palsy, high-level spinal cord injury, or muscular dystrophy. There are more than 93,000 power wheelchair users in the United States. The “standard power wheelchair” accounted for $166 million in Medicare expenditures in 1997.

Scooters are used mostly by people with the ability to walk short distances but who require assistance when shopping or interacting within the community — wishing to remain active despite growing physical limitations. Scooters are used commonly by elderly persons. It is estimated that 64,000 scooters are currently in use in the United States.

Currently, the brushed, direct current, internally rotating, permanent magnet motor (PM motor) is the industry standard. Under light loading, the PM motor and its drivetrain can have an overall efficiency of about 60% to 70%. Under loads typical of power wheelchairs, the overall motor and drivetrain efficiency can drop to about 45%. The standard PM motor and drivetrain places undesirable constraints on the performance and design of power wheelchairs and scooters. Motor and drivetrain efficiency impacts battery performance (e.g., capacity, peak current, life span, and time between recharge) and the overall performance (e.g., range, speed) of the wheelchair system. Whether a power wheelchair or scooter is appropriate for general transportation or short distance mobility in “non-challenging” environments is determined by the characteristics of its motor, drivetrain, battery and power management systems.

The speed and torque delivered by wheelchair motors and drivetrains have a major impact on a user’s ability to access home, work, recreational, and educational environments. The ability to negotiate inclines (e.g., ramps, curbs) and difficult surfaces (e.g., gravel, soft soil, sand) is limited by available torque.

The size and configuration of motors, drivetrains, and batteries constrain the physical dimensions of a wheelchair or scooter (e.g., weight, width, height). Seat height, which is dependent upon power base configuration, limits access to desks, tables, and transportation. Vans often require extensive and costly modification in order to accommodate the seated height of a power wheelchair user. Increased under-seat space would allow users to better transport ventilators and oxygen tanks, thus improving their independence.

Maintenance costs for a power wheelchair are estimated to be in excess of $1,000 over a 5-year period. Motor and drive system repairs often cannot be completed by technicians “in the field” and must be returned to the manufacturer for service. The chatter and swiping of (some) gears and the friction associated with motor and idler bearings are potential sources of vibration and noise. Brushes wear out, cause noise, and need to be replaced regularly. Brushes made from softer materials are quieter but wear faster. Many users elect to operate their motor until failure and then purchase a replacement motor rather than be inconvenienced and pay for expensive maintenance.

Current State of Technology

The propulsion system of power wheelchairs typically consists of a pair of PM motors, one for each drive-wheel, and a drivetrain consisting of gears, belts, and other mechanical elements that couple the motor’s shaft to the drive-wheel shaft.

PM motors have a linear torque-speed profile that makes them easy to control. A DC-DC converter drives each motor with a high-frequency, square-wave pulse-train that rapidly turns each motor on and off. A microprocessor-based “control unit” controls the speed and torque generated by each motor by independently modulating the pulse-width into each motor. Solid state relays are generally used to switch supply voltage polarity to change the running direction of PM motors.

Any PM motor, with its drivetrain, is maximally efficient at only one speed. With light loading, PM motors, with their drivetrains, can attain an efficiency of about 70%. Under loads typical for power wheelchairs however, PM motors and their drivetrains are about 45% efficient. Rare-earth permanent magnets are major improvements over iron permanent magnets but don't eliminate the speed/torque tradeoff. The typical current draw for power wheelchairs with PM motors is 6-8 amps with a typical range of 15 to 20 miles—when supplied by two fully charged, 12 Volt, group 24 batteries. A drop in motor efficiency increases the current drawn from the battery, decreases battery life, and decreases battery efficiency. High-quality manufacturing practices are needed to produce PM motors with matched performance characteristics (i.e., matched motors have near identical mechanical outputs for an identical electrical input).

A wheelchair’s control module converts positional information from the joystick into power signals to the motors. Control modules are microprocessor-based and have many adjustable parameters. Many control modules use feedback to sense whether the motor is responding properly to the joystick position. These control modules adjust motor torque to maintain near-constant speed while the load varies in response to changes in the terrain (e.g., incline, bumps, linoleum, carpeting, concrete, grass, sand). Controllers automatically "step back" (i.e., reduce current to the motors) when motors are overloaded. However, repeated overloading through inappropriate use can still overheat motors and decrease motor life. Controllers are often designed to control a wide range of motors. Some controllers may cause one motor to fail before the other.

Recent innovations within the power wheelchair and scooter industry include the use of rare-earth magnets and brushless, gearless, and direct-drive motors. Motors that use rare-earth magnets can be smaller and lighter than analogous motors with iron magnets. Alternatively, motors that use rare-earth magnets can be more powerful than motors with iron magnets of a similar size. Brushless motor designs have better heat dissipation characteristics because windings are on the outside. These motors can be pushed harder before they are damaged by heat buildup and are more efficient because there is no power loss through the brushes. Gearing and belts in the indirect drivetrain are a source of noise and mechanical power loss.

Highly efficient, gearless, direct-drive, rare-earth magnet motors have recently appeared in the power wheelchair market. These motors can be mounted close to the drive-wheels and allow good access to the under-seat compartment. However, these motors tend to be relatively large and expensive. A European company has recently introduced a brushless, gearless, rare-earth magnet motor contained entirely within a power wheelchair's drive-wheel.

Other motor technologies suggested for power wheelchairs and scooters include pancake stepping motors; disc-armature DC motors; and alternating–current, three-phase, squirrel-cage induction motors (SCIM).

Technology Needs and Barriers

Motor and drivetrain specifications for power wheelchairs are unique—i.e., no similar motor specifications exist for other industries with the possible exception of electric bikes. For power wheelchairs, two-motor designs are strongly preferred over one-motor designs. It is expected that advanced motor design concepts and tools, now used in other industries, will be required to meet the unique and specific needs of the power wheelchair industry. During group discussions, motors with "redesigned pole structure," "poly-phase, AC motors" and "hydraulic motors" were all suggested.

Information gathered from users, manufacturers, clinicians, and other stakeholders has identified characteristics of an ideal motor. Minimum requirements are identified as items that "must" be addressed to a make a design acceptable; other attributes that will benefit the design are identified as items that "should" be addressed. Specifically, an ideal motor…

1. Must have an average efficiency of at least 75% under typical power wheelchair loading. Near-constant motor efficiency, independent of loading, would be the ideal. The ideal motor would enable a power wheelchair to have a range of at least 30 miles (when supplied by two fully-charged, Group 24, 12 Volt batteries) while providing improved access to difficult terrain and surfaces.

2. Must have the performance characteristics of “a true electrical transmission” with “a continuously variable gear ratio.”
3. Must not have complex control requirements. Each motor should be independently controllable.
4. Must generate a high startup torque.
5. Should incorporate sensors that provide information to compensate for motor imbalance, diagnostics, steering, acceleration, and wear status. Use of these diagnostics by technicians must not require extra training.
6. Must have good heat dissipation characteristics. In particular, the motor should not be easily damaged by heat buildup or likely to injure the user.
7. Should have the following physical characteristics:

- reduced motor weight—a typical PM motor (with gearbox) weighs between 15 and 35 pounds
- reduced motor size—a typical PM motor has a length and width (diameter) from about 4 inches by 8 inches up to about 9 inches by 8 inches with a square or round cross-sectional profile.
- Should require little maintenance and be very durable—comparable to PM motor maintenance and durability.
- Should be located close to the wheels or be a part of the wheel design.
- Should be compatible with portable/collapsible power wheelchair design. Motors should be easily removable by the user in order to facilitate folding of the wheelchair (for transportation) or to facilitate repair by a service technician.

Problem Statement 2: Transmissions Problem

We seek innovative transmission technologies for power wheelchairs and scooters.

Description of the Problem

Power wheelchairs are used predominantly by people with both lower and upper extremity impairments resulting from cerebral palsy, high-level spinal cord injury, or muscular dystrophy. There are more than 93,000 power wheelchair users in the United States. The “standard power wheelchair” accounted for $166 million in Medicare expenditures in 1997.

Scooters are used mostly by people with the ability to walk short distances but who require assistance when shopping or interacting within the community—wishing to remain active despite growing physical limitations. Scooters are used commonly by elderly persons. It is estimated that 64,000 scooters are currently in use in the United States.

Currently, the brushed, direct current, internally rotating, permanent magnet motor (PM motor) is the industry standard. Under light loading, the PM motor and its drivetrain can have an overall efficiency of about 60% to 70%. Under loads typical of power wheelchairs, the overall motor and drivetrain efficiency can drop to about 45%. The standard PM motor with drivetrain places undesirable constraints on the performance and design of power wheelchairs and scooters.

Motor and drivetrain efficiency impacts battery performance (e.g. capacity, peak current, life span, and time between recharge) and the overall performance (e.g., range, speed) of the wheelchair system. Whether a power wheelchair or scooter is appropriate for general transportation or short distance mobility in “non-challenging” environments is determined by the characteristics of its motor, drivetrain, battery and power management systems.

The speed and torque delivered by wheelchair motors and drivetrains have a major impact on a user’s ability to access home, work, recreational, and educational environments. The ability to negotiate inclines (e.g., ramps, curbs) and difficult surfaces (e.g., gravel, soft soil, sand) is limited by available torque.

The size and configuration of motors, drivetrains and batteries constrain the physical dimensions of a wheelchair or scooter (e.g., weight, width, height). Seat height, which is dependent upon power base configuration, limits access to desks, tables, and transportation. Vans often require extensive and costly modification in order to accommodate the seated height of a power wheelchair user. Increased under-seat space would allow users to better transport ventilators and oxygen tanks, thus improving their independence.

Maintenance costs for a power wheelchair are estimated to be in excess of $1,000 over a 5-year period. Motor and drive system repairs often cannot be completed by technicians “in the field” and must be returned to the manufacturer for service. The chatter and swiping of (some) gears and the friction associated with motor and idler bearings are potential sources of vibration and noise. Brushes wear out, cause noise, and need to be replaced regularly. Brushes made from soft material are quieter but wear faster. Many users elect to operate their motor until failure and then purchase a replacement motor rather than be inconvenienced and pay for expensive maintenance.

Current State of Technology

The drivetrain is a mechanical system that transfers power from the motor to the drive-wheels. Power wheelchairs use direct and indirect transfer drivetrains. The drivetrain is composed of gears, belts, chains, and other mechanical elements that serve to reduce motor speed while proportionally increasing motor torque.

For direct-drive transfer, the motor is directly coupled to the drive-wheel—i.e., through a gear train. Direct-drives require a low-speed, high-torque motor and are mechanically efficient. However, gears in a direct-drive system are prone to wear and/or break and can be expensive to repair. For indirect-drive transfer, the motor is coupled to the drive-wheel through a gear train and flexible machine elements, such as belts or chains. These mechanical elements act as a “shock absorber” when the drive-wheels become “stuck” or are under a “heavy load.” Excessive stress on the drive system can cause an increase in noise and misalignment. However, realignment is usually easy and the cost of maintaining the system is relatively low if adjustments are done regularly.

Involute gear drives have a power transfer efficiency of 90 to 95% but are larger, heavier, and noisier than worm gear drives. Involute gear drives are used on fixed-frame power wheelchairs with both motors perpendicular to the orientation of the drive-wheels. Worm gear drives are relatively smaller, lighter, and quieter than involute gear drives and are approximately 70 to 80% efficient. With worm gear drives, both motors are oriented parallel to the drive-wheels. Worm gear drives are used on folding-frame power wheelchairs. Because of their smaller size, worm gear drives enable more space to be available for respirators, power seating, and storage.

In bench testing, transmissions have been shown to double the average efficiency of PM motors under typical loads. Patents have been granted for power wheelchairs that use transmissions in their drivetrains. However, there is only a single, top-of-the-line power wheelchair now in the marketplace that uses a transmission-like drive system. All other power wheelchairs use direct-drive, indirect-drive, or gearless-drive systems. Variable-pitch belt technology can act like a transmission but is inefficient. Users can now select either a “high” or “low” operating speed for most wheelchairs. This capability is not equivalent to a true transmission and provides no gain in overall efficiency.

Technology Needs and Barriers

Industry and technical experts suggest that the need for transmissions is great. These experts believe that transmissions have not succeeded because of concerns for control, safety, complexity, reliability, maintenance, and cost. The motor, drivetrain, controller, and power base are typically designed as an integrated system. A transmission may add to the design and performance complexity of this system; however, a transmission could enable manufacturers (if desired) to use smaller motors because of improved motor efficiency under high loads. Multiple transmissions are likely to be needed in order to match drivetrain capabilities to user performance requirements.

Information gathered from users, manufacturers, clinicians, and other stakeholders has identified characteristics of an ideal transmission. Minimum requirements are identified as items that “must” be addressed to a make a design acceptable; other attributes that will benefit the design are identified as items that “should” be addressed. Specifically, an ideal transmission...

1. Must improve the average overall system efficiency—i.e., motor plus drivetrain—to at least 70%. Near-constant drivetrain efficiency, independent of loading, would be ideal. In particular, the transmission should deliver high torque under high loads.
2. Must provide a coordinated transmission gear shifting for both wheels. The control of steering and acceleration for wheelchairs that incorporate transmissions must be safe and reliable. Diminished user safety is not acceptable.
3. Should have the following performance characteristics:
   - Short-term: a manual two-speed transmission in which the user shifts gears would constitute a reasonable solution. For a manual transmission, shifting should be very smooth and a reasonable mechanism should exist whereby persons with varied and limited functional abilities could perform such shifting.
   - Intermediate-term: an automatic two-speed transmission (perhaps where gears shift in response to torque or other mechanical demands) would constitute a reasonable solution.
   - Long-term: an automatic transmission, employing a continuously variable gear ratio, would constitute a step up in performance and complexity over both manual and automatic two-speed transmissions.
   - Must be similar in size to current power wheelchair gearboxes (i.e., roughly 5 inches by 5 inches).

- Must not require the power base to be redesigned. In particular, incorporation of the transmission should not require an increase in the height or width of the wheelchair.
- Must be durable, reliable, and quiet.

E. Materials and Components

- **White Papers**
- **Forum Data**
- **Problem Statement 1: Improved Tires Problem**

White Paper: Materials and Components

TECHNOLOGY AREA

As with any product, the selection of materials for wheeled mobility products impacts both the manufacturer and the enduser. Materials impact characteristics such as durability, strength, cost, appearance, design and manufacturing flexibility, and weight. Although there have been significant improvements in materials for wheeled mobility, excellent improvement opportunities still exist. Some of the areas that could benefit from new technologies include:

Frames — Strength-to-weight ratio, reduced manufacturing steps, finish characteristics.

Tires and Wheels — Improved wear without compromising ride and traction, non-conductive, non-marking, durable.

Seating Materials — Comfort, durability, appearance, ease of cleaning, fire retardant qualities.

THE NEED

Materials have been the basis of major evolution in wheelchair products. Newer chairs benefit from specialty designs originally intended for sports activities — racing, basketball, etc. Specifically, the development of lighter-weight products based on advanced materials has been one of the biggest breakthroughs in wheelchair technology. High-performance materials have enabled designs offering comparable strength with greatly reduced weight and thus smaller and more maneuverable products, a direct benefit to users. Most of the users who have benefited from reduced weight materials have been in manual chairs, where the frame is a major portion of the mass. For power wheelchairs, unfortunately the frame is often a small part of the total mass, which is dominated by components like batteries. In many cases, costs have been reduced when materials have enabled new manufacturing methods and reduced material, machining, and assembly costs. Reduced costs translate into benefits not only for manufacturers but also endusers and third-party reimbursers. One example of this is the use of injection-molding processes for power scooter bodies that greatly reduces not only weight but also assembly time and thus manufacturing costs.

Today, even with the excellent material improvements over previous product generations, there are still significant needs for materials. Some of the newer, lighter chairs have not maintained previous levels of durability required for long-term use. In addition to improvements in the frame, both manual and power chairs stand to benefit from better materials for wheels, tires, and seating.

Increased chair and component life translates to reduced costs for endusers, third-party reimbusers, and manufacturers, especially if parts fail within a product's warrant period. Material cost has often been a direct trade-off with certain performance improvements. For example, the use of composite materials may require hand lay-up or other expensive fabrication processes. These higher costs may translate into significantly higher retail sale prices, or more frequently result in selection of a cheaper, lower-performance material. During the stakeholders' forum, we will be discussing these types of trade-offs related to materials.

BASIS FOR DISCUSSION

The following problems have been identified from literature and communication with experts, endusers, and manufacturers. The goal of the forum discussions is to select a priority, high-impact problem and to begin to develop a problem statement that specifies the requirements for a commercially viable solution. The problem statement will be used to solicit solutions from technology producers. Please come prepared to discuss these topics and to choose the most important. It would greatly benefit discussions if manufacturers come prepared to discuss non-competitive issues regarding materials and related manufacturing methods that are limiting manufacturing and design improvements.

FRAMES

Statement of the Problem

There is a need for frame materials that reduce weight, increase aesthetics, enable novel designs including modular components, maintain durability, fit manufacturing requirements, and do not increase cost.

Current Solutions

Most chairs today are made of tubular aluminum or alloy steel. Some frame designs have incorporated advanced materials such as plastics, titanium, composites, and alloys like chrome-moly; however, the majority of chairs do not use these high-performance materials due to the high cost. A good example of how advanced materials and manufacturing methods can reduce cost is the reduced assembly and associated costs resulting from the use of injection molding to create a unibody for power scooters.

Issues to Consider

Material improvements can enable frame designers to reduce weight and cost while increasing durability, functionality and aesthetics of the chair. This can be achieved by using materials that offer a greater strength-to-weight ratio, improved processing characteristics, and better mechanical performance; however, incorporating high-performance materials, such as titanium, results in increased cost. Also, the strength and durability of a frame design is not strictly dictated by material strength; fatigue strength is strongly influenced by tubing dimensions and shape, welding characteristics, and other assembly-related design aspects. Modular design may provide the solution. There are several advantages associated with modular design, the biggest one being the ease of replacement and repair.

Modularity may provide for easy transportation and handling of chairs, especially light weight chairs. Modularity may not address some of the issues relating to product customization and specific end user needs. One expert reported that up to 50 % of chairs are customized. Also, to ensure the safety of the wheelchair users when they are travelling in public or private transportation, caster assemblies and frames should be strong enough to withstand the shocks which they are subjected to during a crash.

Aesthetics of a wheelchair are directly related to the frame design and materials. Chairs in the European market are aesthetically better than in the U.S. This is largely due to the fact that the higher-cost aesthetic features are not accepted by third party reimbursement agencies in the U.S. Based on these issues, please consider the following questions:

- Are aesthetics, strength, weight, and cost of the wheelchair frame issues for both manual and power wheelchairs?
- Is there market potential for improvements to wheelchair frames in general? Will third party reimbursers fund these improvements?
- Is modularity a good option for addressing the need for customization and serviceability? How modular would a design need to be? What would the benefits be to: manufacturing? use? cost?
- Will manufacturers be willing to adopt modularity, considering that modularity might open gates for the competition from low-end manufacturers?

Also, a better understanding of frame dynamics, especially for power chairs, is needed. It is still unknown whether frame design can help in reducing or perhaps eliminating vibration. There is a need to determine a vibration standard for the wheelchair industry. The current vibration standards are based on standards for trucks and other heavy vehicles. A wheelchair user has different stability requirements than a heavy vehicle user and so there is a need to develop a more appropriate standard.

- Is vibration still a problem in manual and/or power chairs?
- Does the frame design contribute to vibration? If yes, then how can vibration damping be achieved with respect to frame design and materials?
- How should the vibration standards for wheelchairs be defined and who should define them?

Both limited sales volume and small production volume, resulting from limited commonality in parts across product lines, contribute to manufacturers' hesitation to develop and implement novel designs. Manufacturers will often hesitate in redesign without proven demand, a situation that delays design evolution. The evolution of frames based on designs originally developed for high-performance sports models illustrates the tendency to introduce revolutionary concepts into niche, rather than broad markets. Standardization of components/frame across various product lines could help increase production volume of any component/frame.

- What is the barrier that prevents manufacturers from standardizing their components across various product lines?
- Are current issues related to frame designs and materials related more to material performance, manufacturing processes, or design demands?
- Is there a need for adjustability options such as multiple axle placements?

Tires/Wheels

Statement of the Problem

There is a need for improved tire wear without compromising ride and traction. Tires must be functional on varied surfaces — sand, rugs, snow, and smooth and rough surfaces — and must be non-marking. Tires should allow discharge of static electricity to prevent shocks to the user and damage to the electronics associated with power chairs. At the same time, tires and wheels should be light and inexpensive.

In a 1994 study related to power wheelchairs, users reported that tires were the second most frequent repairs behind batteries. Wheels have yearly maintenance problems 24% of the time. Although significant research has had a positive impact on manual wheelchair tires, little advancement has occurred with power chairs tires. This problem stems from the varied wheel diameter and the design and performance parameters associated with power chairs. Also, power wheelchairs introduce much larger stresses on the wheels and tires than manual chairs due their heavier loads.

Current Solutions

Common materials used include rubber, urethane, polyurethane, composite nylons, and kevlar-reinforced thin tubes. Research is in process on solid polyurethane foam tires, which combine the best features of the pneumatic (comfort, low rolling resistance) and solid tires (low maintenance). These materials have a microcellular structure that reduces weight while maintaining wear and rider comfort. One problem with the new solid tire designs is the tendency for the tire to become unseated from the rim. Radial tires, semi-pneumatic designs, and inserts are also being researched.

Issues to Consider

In the area of tire and wheel performance, the main issues are reliability and durability without losing comfort and safety. Pneumatic tires provide great comfort but are a potential inhibitor of independent living, due to flat tire etc. The goal is to achieve the comfort level offered by pneumatic tires along with the reliability and durability offered by solid tires.

Increase in durability will also provide economic relief to the enduser. At present, power wheel chair tires cost almost $100. This is a big expenditure considering that present tires have a short life span and are therefore replaced quite frequently. There is a need to innovate or use materials and design that can bring down the cost of the tire, increase the durability of the tire while maintaining reliability and comfort level. And most importantly, tires should be non-marking. Black tires meet most of the requirements of an ideal tire but suffer from the big disadvantage that they are marking and are therefore not used in the industry.

- Are the problem of static charge build up and durability more critical to the power wheelchair industry than manual wheelchair industry?

- Are the newer solid urethane and polyurethane foam tires meeting users' needs adequately? If not, why not?

An issue relating to wheel improvement brings into question if it is beneficial to reduce the wheel weight for power chairs. Spoke wheels performs well but requires a lot of maintenance. Probably an ideal wheel will be one that has the weight and power of spoke wheels while the cost and maintenance of plastic wheels. A misaligned wheel requires a lot more effort to push. It is frame structure that mainly controls wheel alignment. For manual wheelchairs, wheels should require minimum effort to push. Technology innovation, like geared hub wheels, is required to make the wheels easier to push. Though considerable improvements have been done in the wheel bearing, it is still a high maintenance item. Further improvement is required in this field.

- For power chairs, is weight irrelevant? Is the goal for wheel materials to merely match the weight and strength of spoke wheels but improve in the area of cost and maintenance?
- Wheel misalignment affects tires wear rate as well as rolling resistance. Is this a serious problem?

In the literature we found articles that cited the major barrier in the area of tires and wheels as the fact that the total market is not large enough to support investment in R&D by traditional tire and wheel manufacturers. Some believe that development of better tires will require government funding for research at universities. Another concept discussed in the literature is that all wheelchair manufacturers should cooperate to develop a specification with a single tire supplier who could then address the industry's problem.

- Is an industry consortia on tires and wheels feasible as a means to develop adequate R&D to meet the industry's needs?
- Are varied customer needs a problem inherent in tire and wheel product selection? Could modularity apply to tires/wheel systems?

Seating

Statement of the Problem

Seating materials and components have a significant impact on cost and customer satisfaction. Pressure sores is a very big problem for wheelchair users. The chair needs to fit the user well even when there are changes with clothing, physique, or age. Seating materials must withstand daily use in varied weather and climate and thus must be durable. Customer preference regarding aesthetics and comfort also are important variables. A well-designed suspension can contribute a lot towards the designing of a comfortable seating system. Cushions can reduce shocks considerably. Upholstery must allow for air circulation and provide user comfort, yet it also must be able to be wiped clean or laundered easily for hygienic and aesthetic reasons. Fire retardance is essential for users who smoke or are around smokers; seating material must not ignite. Ride quality and durability are tightly linked to selection of seating materials and design of seating systems.

Current Solutions

Seating comes in many forms: sling-type, armchair, plastic bucket, automotive-type, and custom. The materials used for these seating systems vary greatly, including wood, leather, plastics, textiles, foams, and gels. Simple seats can be made from plastic molding with no cushioning or upholstery; whereas others, like the automotive-type, may incorporate a sophisticated design with subforms, multiple types of cushioning materials, and upholstery. Air permeable fabrics based on a pore size that does not permit liquid to pass have best solved the conflicting needs for comfort — relating to breathability of a seating material — and for waterproof characteristics.

Issues to Consider

To accommodate the various requirements of the enduser, seating system needs to be adjustable/adaptable. Modular seating can lead itself to adaptive seating. Seating is most comfortable when there is a zero shear force for back upholstery and head rest. Sensors and actuators could be used on the seating system to achieve this zero shear force target. Similarly there is a need for an improved suspension system which can improve the ride quality. An active suspension system can reduce vibration a lot but due to the cost factor is suitable for niche market only. A suspension system that is variable — capable of being soft for mobility comfort and hard for enduser transfer — may have benefit to the end user.

- Have aspects of custom seating, that could benefit the broader market, been adopted by manufacturers? If not, what prevented their use?

- Is the “pressure sore” problem being adequately addressed by the industry? If no, why not?
- Is there a need for adjustability / adaptability features in seating systems? If yes, how could these features be best integrated?
- Are varied customer needs a problem inherent in seating designs?
- What are the issues regarding shock absorption at the casters versus shock absorption at the main axle?

The Reference List

1. Clifford E.Brubaker (1989). Wheelchair IV, Report of a conference on the state-of- the-art of Powered Wheelchair Mobility, December 7-9, 1988.RESNA Press.

Forum Data: Materials and Components

A. TIRES

1. Priority Customer Needs

- Self cleaning tires
- Tires that can allow the user to reach home in case tires go flat
- Tires should be less expensive
- Tires should be non-marking
- Tires should be conductive
- More reliable (e.g. less likely to puncture)
- More durable – tires should have a typical life of at least one year or 1000 miles minimum
- Tires should be maintenance free (no need to add air, clean, etc.)
- Tires should enhance driving performance
- Tires should have low rolling resistance
- Tires should not "dry out" and crack
- Tires should provide good traction on all surfaces-sand, rugs, snow, smooth and rough surfaces etc.
- Tires should provide smooth and quiet ride on all surfaces and environments
- Tires should have seasonal adaptability i.e. tires should be able to perform equally well in all seasons like summer, winter etc.
- Manual wheelchair tires should provide good gripping in case user wants to use the tires directly to push the wheelchair instead of pushrim
- MEMS - Sensors in tires to let the user know when the tires are getting low. This should come at a low cost.

2. State of Existing Technologies

- Polyurethane tires with sealed air tube inside do not require any maintenance. They have many desirable tire properties but don't have good traction and are slippery to grip. Thus they provide compromised performance.
- Tubeless inserts are heavy and difficult to install.
- Pneumatic tires have the highest performance but the poorest durability and reliability.
- Some manual wheelchair tires get dry on their sides with use. This creates blisters etc. on the hands of user who directly pushes on tires.
- Some manual wheelchair tires have too smooth side walls. Therefore user have hard time propelling such tires as their hands slip when they propel such tires directly.
- Mountain bikes manufacturers are working on self-shedding (self-cleaning) tire designs.
- MEMS technology is available for tire applications but is likely to have a very high cost ($6000).
- Electrically conductive tires are available but at a very high cost.

- Solid tires are maintenance free but do not provide adequate shock absorption. This leads to uncomfortable ride.
- Back and front wheel size affects rolling resistance. In case wheels are required to be replaced, any deviations of size of the new wheels from older wheels impacts the rolling resistance. This change in rolling resistance is uncomfortable and dangerous for the wheelchair user.

3. Ideal Technology

- More durable tires, which have at least a minimum life, span of 1000 miles or a year.
- Tires should have low rolling resistance
- Tires should have high traction on all surfaces (possibly through "intelligent" adaptation of tire properties or configuration).
- Tires should be non-marking on all surfaces.
- Tires should be conductive so as to prelude the buildup of static charge.
- Tires should run smoothly and quietly.
- Tires should have low turning resistance.
- Tires should not dry out on their sides.
- Manual wheelchair tires should have side-walls with high coefficient of friction so as to provide good gripping.
- Tires should have resilience (conformability) comparable to pneumatic tires.
- Tires should be self-cleaning.
- Tires should have all season adaptability (perform well in all seasons and environments).
- Tires should be completely maintenance free.
- Tires should have "run flat" capability i.e. tires should be capable of travelling over a certain minimum distance in case they go flat so that the user is not left stranded in some unsafe place.
- Tires and wheels should be of some standard size (probably size of bicycle tires). This will improve tire availability and serviceability. In addition, tires will be produced more economically.
- Tires should have the performance characteristics of a pneumatic tire but the durability characteristics of a solid tire.
- Tires should provide good shock absorption.

4. Barriers to Realization of Ideal Technology

- Small market for the wheelchair tires prevents manufacturer from investing their money into research in this field. This disadvantage may be overcome for manual wheelchair tires by leveraging bicycle tire market.
- Current reimbursement policy also hinders development in this area. Industry in U.S. is governed by “K” codes.
- There is resistance to change on the part of manufacturer.
- Consumers are not vocal about their wheelchairs, cost, things that break etc.
- Some wheelchair users use parking brakes to slow down the chair. This leads to more wear of the tires. Users should be educated about the efficient use of tires.
- Tires and wheels need to be aligned properly. Any misalignment increases the tire wear, which reduces the life cycle of the tire.

B. FRAMES

1. Priority Customer Needs

- Need lighter weight, low cost, adjustable frames. Such frames would serve the broad manual wheelchair market.
- Frames should be shock absorbing.
- Need modular wheel chair frame- a chair that can grow.
- Clinicians should be able to make custom changes to the chair frame using some software.
- Wheelchair frames should be crashworthy.
- Tie down points needs to be standardized. Integration of tie down points or other docking interfaces to secure wheel chair in transport.
- Forward/backward adjustable axle are required even in low cost manual wheelchair
- Need for improved joining methods for dissimilar metals
- Accessory items on the wheelchair should be ergonomically located. Frame should probably be provided with standard mount points so that it may be easy to reach these accessory items.
- Wheelchair frames should be designed such that it can easily accommodate new component. (e.g. mount points should be provided at suitable locations, frame tubing should be accessible)
- Mountings and mount points for the seat and back should be strong

2. State of Existing Technology

- The commodity wheelchair (K-1), being price sensitive, uses no advanced materials.
- K-5 chairs use some advanced materials but truly advanced materials are used primarily in high end wheelchair market.
- Most of the wheelchairs are need to be customized at the point of sales to accommodate user specific needs.
- Manufactures claim to have access to high performance materials (e.g. titanium, chrome-molybdenum etc.) and to advanced composites (e.g. kevlar, carbon fibers etc.).
- Kevlar and carbon reinforced products are expensive and difficult to manufacture. These products are therefore restricted to niche market.

3. Ideal Technology

- Manual wheelchair frames should be of less weight and low cost.
- Frames should be shock absorbing.
- Frames should be modular.
- Frames should be crashworthy.
- Frames should have standard tie down points so as to secure the wheelchair in transport.
- Forward/backward adjustable axle should be provided even in low cost manual wheelchair.
- Frames should have standard mount points, which are located such that the accessory items can be reached ergonomically.
- Frames should easily accommodate new component/accessory item.
- Frames should have strong mounting and mount points for the seat and back.
- Method for joining dissimilar metals should be more efficient.

4. Barriers to Realizing Ideal Technology

- Current “K” classification is based on chair design developed 15-20 years back. There is need for coordinated efforts to change reimbursement policy. Current policy and HCFA do not foster innovation, consumer exploration of new products/designs.
- Changing to new production processes and equipment is very costly.
- The market is very price sensitive, which means that better technology, has to be made available at either no increase in cost or a very moderate increase in cost.
- There are technologies (e.g. for bonding dissimilar materials, advanced materials etc.), that exist in federal labs but would be very costly to incorporate into wheelchair products at present.

Other needs and Suggestions

- Armrest material should not “dry out”. User can get hurt when their hands rub on a “dry out” armrest.
- Scooter armrest needs to be more durable. Often the scooter armrest catches on the doors etc and the material of the armrest tears away.
- There is a need for armrest materials that will not stretch and crack. Such material can also be used backrest and the seat.
- There is a need for standard tie down point design on scooter. Scooters are frequently damaged due to the lack or bad design of tie down points.
- Public transportation workers don’t know how to help secure people in wheelchair or scooter.
- Caster rotation catches feet and causes injury
- Smaller casters provide good maneuverability but there performance is not good on rough terrain (gravel)
- Wheelchair should be designed such that a person in wheelchair is capable of picking up something from the floor.
- Skirt Guards should probably be inserted into the wheelchair design
- Footrest needs to be more adjustable to compensate for leg length.
- “Add on” become cost and maintenance issues. Efforts should be directed towards making anything build onto the chair instead of an “Add on”.
- To increase the stability of the chair, sensor technology can probably be employed. Sensors need to perform function such as sense the speed, turning radius, weight of the person in chair etc. This information can than be used to adjust the speed automatically, detect curve and act accordingly.
- There is a need for quicker and easier fastening
- There is a need for stronger fastening
- Seating material should not interfere with transfer
- Probably wheelchair users should have the option of leasing the chair.
- Policy research is needed to bridge gaps in reimbursement costs.
- Technologies in parallel industries which have the potential wheelchair application needs to be identified and transferred to the wheelchair industry.
- More active R&D collaboration between industry and fed labs is needed.

Problem Statement 1: Improved Tires Problem

We seek emerging technologies and new design concepts that will lead to improved tires for manual and power wheelchairs and scooters.

Description of the Problem

There are over 1.4 million wheelchair users of which 75% use manual versions. The remaining 25% use power wheelchairs. Power wheelchairs are used predominantly by people with both lower and upper extremity impairments resulting from cerebral palsy, high-level spinal cord injury, or muscular dystrophy. There are more than 93,000 power wheelchair users in the United States. The “standard power wheelchair” accounted for $166 million in Medicare expenditures in 1997. Scooters are mostly used by people who can walk only short distances but wish to remain active within the community (e.g., shopping, recreation). Scooters are used commonly by elderly persons. It is estimated that 64,000 scooters are currently in use in the United States. For both power and manual wheelchairs, tires need to function well for varied surfaces (e.g. sand, rugs, gravel, linoleum) and environments (e.g. hot, cold, wet, snow). Tires need to be conductive in order to prevent shocks to the user and damage to electronics. Tires need to be non-marking so that they do not damage the user's home, work and recreational environments. Because of the user's critical dependence on their wheelchair for mobility, tires need to have "run-flat" capabilities.

Specific performance needs for power wheelchair tires include reliability — good traction for all terrain and environments; durability — slow wearing; comfort — good ride and shock-absorption properties, and safety — puncture resistant. In a 1994 study related to power wheelchairs, users reported that tires were the second most frequent repairs behind batteries. At present, power wheelchair tires cost almost $100 each. For large, active users, tires might be replaced every 6 months. For the average user, tire replacement every 9 to 12 months is typical. Tire replacement is generally considered to be a “necessary repair” and is therefore reimbursable. In cases where tires are not reimbursable, tire cost represents a significant burden to the user. Improved tread design may be needed because tread configurations have an effect on rolling resistance, traction, tire life resulting from wear patterns, and dirt collection and release. Tires that somehow "adapt" their functional or physical properties in response to changes in environmental or surface conditions may be needed. Finally, tires need to be less expensive than current tires or extend tire life.

Current State of Technology

Common materials used in wheelchair tires include rubber, urethane, polyurethane, composite nylons, and Kevlar-reinforced materials. Most power wheelchairs currently utilize gray, soft rubber tires. These tires have good ride and shock-absorption properties and are non-marking. Unfortunately, they wear quickly, puncture easily and are quite expensive. Black tires- pneumatic tires made of rubber with embedded charcoal particles, were once the standard tire for the power wheelchair industry. These tires have many desirable characteristics such as good durability, puncture resistance, and good conductivity. Unfortunately, these tires mark surfaces readily and are no longer used.

Research is in progress on solid polyurethane foam tires. Embedding air within the micro-cellular structure produces tires with good wear, low rolling resistance and low maintenance. These tires do not however, provide adequate shock absorption; do not provide good traction; are slippery to grip by hand and have a tendency to become unseated from the rim.

Pneumatic tires offer excellent performance, but require high maintenance, are not durable, and track dirt. Pneumatic tires provide great comfort but are a potential inhibitor of independent living, because of the possibility of a flat tire or merely because of the requirement for periodic pressure check and inflation.

Power wheelchairs (primarily because of their large mass and small tire diameters), generate much larger forces on their wheels and tires than manual wheelchairs. Power wheelchairs are available in a range of wheel diameters and performance (speed, weight, torque) parameters, all of which impact tire requirements.

Shallow tread designs (such as found on manual wheelchair tires) can reduce rolling resistance but also tend to wear out quickly. Deeper tread designs can increase traction but tend to collect dirt/mud. Tires with gull-wing contours are available. On hard surfaces, the wheelchair rides on the central tire ridge while on soft surfaces, the tire sinks and the effective tire surface increases. Forum participants perceived that traction up inclines and steering on soft surfaces were both problems for this design.

The mountain bike industry is working on self-shedding tread designs, but the successful performance of these tires generally relies upon tires rotating at higher revolutions per minute s than is typical for wheelchairs or scooters.

Technology Needs and Barriers

There is clearly an opportunity to optimize all characteristics of wheelchair tires (considered as a system with wheels and suspension) to provide improved reliability, increased cleanliness, reduced maintenance, and enhanced driving performance for manual and electrically powered wheelchairs. Technologies being proposed as a solution to meet the existing limitations in wheelchair tires should address the issues previously presented. Specifically, an ideal tire...

1. Should have low rolling resistance and low turning resistance, while offering a high traction on all surfaces—possibly requiring “intelligent” adaptability.
2. Must enable a smooth and quiet ride—no squealing on all surfaces and environments.
3. Should be maintenance free—be self-cleaning, puncture proof, puncture resistant .

4. Must be capable of some motion even in damaged state—e.g., run-flat capability for pneumatic tires.
5. Must be durable—enable at least 1,000 miles between service or a 1-year life under typical to heavy use.
6. Must be non-marking, and electrically conductive to eliminate static charge buildup.
7. Must have side walls with a high coefficient of friction to improve tire traction over difficult surfaces (e.g. mud, snow, gravel).
8. Must operate well (traction, durability, etc.) in all seasons and environments (e.g. hot, cold, wet, sandy, snowy).

3. Post-Forum Activities

- **Locate Technology Solution**

- **Transfer the Technology Solution**

- **Appendices**

  - **A. Project Staffing**

  - **B. Attendees**
    - **Attendees by Technology Group**
    - **Evaluation**

  - **C. Project Web-Sites**

Locate Technology Solutions

Outcomes from the Stakeholder Forum and all prior work were used to generate problem statements. Problem statements outline the need for technology; technology state-of-the-practice for products currently in the market; specifications and parameters for the 'ideal technology solution;' and barriers/impediments that must be overcome to achieve this ideal technology.

Our partner, the Research Triangle Institute (RTI) has many years of experience transferring technology from the Federal Labs to private sector manufacturers. RTI and the T2 RERC are disseminating the problem statements to Federal Laboratories, advanced technology manufacturers, research institutions and other technology developers. Proposed technology solutions are being submitted to RTI in hard copy or through the RTI web-site. Initially, all submitted technology solutions are non-proprietary.

All proposed technology solutions are screened by the T2 RERC and the partner RERC. Appropriate technology solutions are then reviewed by technical and industry experts to confirm that these solutions address the problem and are technically feasible. Following the initial review, proprietary information may be requested from the technology developer. The protection of intellectual property is the responsibility of all parties involved in this exchange.

Transfer the Technology Solution

The T2 RERC, in partnership with AZtech Inc., will prepare a commercialization package that summarizes the end-user needs being met, market opportunity, problem statement, technical solutions, and the business plan for transferring the technology solution. A marketing plan will be developed to contact and present the commercialization package to targeted manufacturers.

The transfer of technology will be completed through mechanisms such as direct licensing of technology to a manufacturer; or a cooperative research and development agreement (CRADA) between a federal lab and a manufacturer. The Research Triangle Institute has extensive experience brokering technology transfers from federal laboratories to private manufacturers and is expected to play an important role in the final step of this project.

We expect to continue disseminating the problem statements indefinitely, or at least until an appropriate solution is identified and transferred. Anyone who has potential solutions to the problem statements developed from this project are encouraged to submit them to RTI via the Internet at (http://www.rti.org/technology/wheelchairs/ProblemStmts.cfm). The goal of this endeavor is to match new technologies or those that were originally used for other applications, with the problem statements and to facilitate the successful transfer of the technology into the marketplace.

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PROJECT SPONSORS

NATIONAL INSTITUTE ON DISABILITY AND REHABILITATION RESEARCH (NIDRR), U.S. DEPARTMENT OF EDUCATION

"The NIDRR mission is manifold: to provide for research and demonstration projects, training, and related activities; to maximize the full inclusion and integration into society, employment, independent living, of individuals with disabilities and to provide support to their families; to increase the economic and social self-sufficiency of individuals with disabilities of all ages, and to improve the effectiveness of services authorized under the Rehabilitation Act."

- Katherine Seelman Director, NIDRR

The NIDRR is the federal government's single largest funding source for assistive technology research and development programs. These programs include fifteen Rehabilitation Engineering Research Centers, each focused on a particular assistive technology industry or research topic.

MID ATLANTIC REGION OF THE FEDERAL LABORATORY CONSORTIUM

The Federal Laboratory Consortium (FLC) represents the resources of all of the Federal laboratories. In partnership with the T2-RERC, the FLC is seeking ways to integrate their laboratories' technologies with the needs identified by consumers, manufacturers, and researchers in the assistive technology industry.

Appendix B. Attendees

STAKE HOLDER FORUM ON WHEELED MOBILITY

Attendee - Contact Information

Attendees at the Forum were selected as representatives from one of five stakeholder groups identified by the T2 RERC in the development of the Demand-Pull Project.

The Wheeled Mobility categories are defined as:

1. Technical Experts: Persons who have per- formed extensive research in the areas of wheeled mobility products. The research performed by Technical Experts is directed towards the technical development or enhancement of products. The RERC on Wheeled Mobility was a major resource in this category, as well as representation from clinicians and technicians from health care suppliers and medical facilities.

2. Technology Producers: Innovators of core technologies that are incorporated into the design of wheeled mobility products. Participants in this category represent a company, a research facility, or individual innovator.

3. Technology Consumers: Also known as Product Producers, are companies that acquire technology for inclusion in the manufacture of wheeled mobility products. Many manufacturers who participated in this Forum played a dual role as Technology Consumer and Technology Producer.

4. Product Consumers: People that use wheeled mobility products in their day to day life. Many participants were people that use wheelchairs or scooters, as well as clinicians that prescribe wheeled mobility products.

5. Resource Providers: Resources to the industry as third party reimbursement sup- pliers, government agencies involved in products for persons with disabilities, community service suppliers and national agencies.

While some attendees could be placed into one or more category, they have, for the purposes of the Project, been designated into a single classification listed below.

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PRODUCT CONSUMERS

The T2 RERC has access to more than 80,000 consumers across the country who participate in the evaluation of new technologies as they are prepared for transfer into the assistive technology industry. In keeping with the T2 RERC's commitment to protecting the privacy of the consumer community in which it works, participants have been identified by name only.

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Mr. E. P. Dick Ms. J. Evans
Mr. R. McWilliams Ms. B. Momberger
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Michael Devlin
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Elain Treffler
Dr. Munshi
Dr. Gina Munshi
Dr. Gina Bertocci
Lowell Christianson
Amy Goldman
Bill Peterson
Sal Sheredos
Jeff Solash
Russ Videtti
Linda Fraas
Willia Mae Reed
Jill Timmerman
James Owens
Buffy Momberger
Danial Momberger
Paul Brickner

Wednesday

Bob Clarke
Frank Coombs
Susan Edgett
Patrick Wallace
Dr. Stephen Sprigle
Elaine Ashby
Dr. Rory Cooper
Dr. Tina Chu
John Bollinger
Larry Kynast
Nancy Starnes
Joey Wallace
Dr. Nancy Shinowara
James Spencer
Dr. Chuck Levy
Mark Schmeler
Janet Evans
Rick McWilliams
Pammy Corcoran
Betty Patterson

Power Management and Monitoring Technology Group

Tuesday	Wednesday
Ivan Clarke	
Steve Keyser	Dan Easley
Hymie Pogr	Dennis Sharp
Patrick Wallace	Paul Miller
Christopher Lucci	Sach Jain
John Inman	Dr. Munshi
Steve Khan	Elaine Treffler
Dr. Daniel Repperger	Scott Salis
Ed Snell	Scott Schilling
Dr. Jim Reswick	Amy Goldman
Scott Hall	Rich Dimmick
James Spencer	Brian Claybeck
Dr. Chuck Levy	Linda Fraas
Nigel Shapcott	Rob Robertson
Vanessa Riles	John Tague
William Cain	James Owens
E Paul Dick	Lois Quinn

Motors and Drive Trains Technology Group

Tuesday	Wednesday
Dan Easley	
Paul Miller	Ivan Clarke
Clarence Rivett	Steve Keyser
Dennis Sharp	Christopher Lucci
Stephen Stadelmeier	Dr. Geoff Fernie
Henry Tate	Ed Snell
Scott Salis	Dr. Jim Reswick
Scott Schilling	Lowell Christianson
Sach Jain	John Inman
Rich Dimmick	Robert Saba
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Brian Claybeck	Vanessa Riles
Rob Robertson	William Cain
John Tague	E Paul Dick
Pammy Corcoran	Lois O'Donnell
Lois Quinn	Paul Brickner

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Dr. Geoff Fernie	Guy Chiasson
Dr. Stephen Sprigle	Dr. Daniel Repperger
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Lois O'Donnell	Jill Timmerman
	Buffy Momberger
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REPORT: EVALUATION OF STAKEHOLDER FORUM ON WHEELED MOBILITY

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Tables

Introduction:

Achieving ongoing improvement through continuous self-study is key to quality assurance in any program. When this effort is integrated with external feedback from its stakeholders, as is the practice at the Rehabilitation Engineering Research Center on Technology Transfer (T2RERC), the program also validates itself in its broader context. As we at T2RERC implement our efforts to transfer technology through our Demand-Pull and Supply-Push models, we value, and systematically collect, information from our stakeholders at strategic and significant points during the process cycles of the two models. The Stakeholder Forum on Wheeled Mobility that was held at Pittsburgh, Pa. on May 25 and 26 is one such landmark, an event significant to the project's demand-pull process.

T2RERC, and its partner organizations that sponsored the forum, owe the success of the event to the multiple stakeholders who enriched our self-study process by giving valuable information at various stages of this event. During the months *prior* to this two-day meeting, experts on Wheeled Mobility that we had identified as appropriate and valuable gave us high quality input through our interview sessions. This information framed the "whitepapers" under the four themes we had identified as significant to the problem of technology transfer for wheeled mobility. These papers fed the discussions that occurred later, at the Forum, by a larger group of stakeholders invited to participate. Their mixed perspectives generated the information needed for synthesizing "problem statements", the intended outcomes of the Forum.

On-site Evaluation of Forum – How we did it:

Targeted outcomes cannot be achieved at the desired quality level unless we ensure the quality of the processes that produced them. Thus, on-site, "formative" evaluation formed an important part of the Stakeholder Forum. And once again, we gained insights from our participant stakeholders who mirrored the strengths and weaknesses of the forum processes by giving us evaluative information during the forum. They enabled us to walk with the processes, improve them while they were still on the run and keep them appropriately focussed and directed.

Mixed stakeholder groups – product consumers (end-users with disabilities), product producers (manufacturers), technology producers, and resource providers (government officials) – participated in each of the four sessions that ran simultaneously each day. A team of two evaluators made direct observation of the interactions at these sessions, circulating from session to session and recording the unique features of each session. They observed what styles the moderators used, the way they used the audio-visual aids, and how effectively the team coordinated its three roles in order to monitor discussions, technical content and summarizing notes. They carried their observations back and forth between the live sessions, reinforcing their strengths and correcting process errors. Additionally, all participants evaluated the quality of each individual session, on a survey form, against their own expectations. We analyzed their responses and comments at the end of the day and fed them back to the moderating teams immediately, which enabled them to modify their second day sessions in accordance with the needs perceived on the first day.

Participant Stakeholders Appraise Forum Performance

In all, 46 participants consistently filled out all the evaluation forms expressing their satisfaction levels and making additional comments. They evaluated each individual session on content (if the topics were relevant, if the discussions went deep enough), purpose (how well it was achieved) and personal satisfaction (about feeling comfortable and being able to contribute). Overall, perceptions were very positive about all sessions, although not uniformly high across all of them, given the participant mix and differences in moderator styles. The evaluations ranged from reasonably satisfactory (3.5 points on a 5 point scale) to highly satisfactory (4.8 points). They were generally higher on the second day, indicating improvement of session performance and thus validating the value of on-site feedback to moderators.

Different stakeholder groups valued different aspects of the forum as its strength. But the opportunity to network with and learn about the ideas of other stakeholder groups was upheld as the forum's strength by all groups. 42 of the 46 survey responses, or 91%, indicated this as a benefit from the forum. Consumers appreciated learning about the state of the art of the technologies, and felt the "need to have more of these forums", and "looked forward to seeing some of the ideas in the future chairs being manufactured". One comment read, "Thank you very much for inviting me. Perhaps we can do this again. … the groups that I participated in were very technical but I believe that I was able to understand at least 75% of the information. I increased my knowledge and have a better understanding of what it takes to unite technology and materials". Technology Producers appreciated the opportunity to "meet a diverse group of people with common mobility interest", describing the forum as "unifying personnel of different fields under one roof which will and should help getting a proper network". The Manufacturer group, in addition, appreciated the opportunity of exposure to the consumer group, particularly impressed with the "mix of manufacturers, researchers, clinicians, and the most important group, the users." A Resource Provider, in appreciating the networking opportunity, acknowledged getting "good insight to issues dealing with wheel chairs".

Two other benefits or impacts of the forum that the total group of participants acknowledged were: exposure to new or innovative technologies (63%) and being able to identify the needs for new products or technology (57%). 18 participants (out of 46) felt they were able to identify new business opportunities and 17 felt they helped shape the direction for new product development.

Overall, the participants indicated very high satisfaction with the effective organization throughout, in particular with the helpful, friendly efficiency of the organizers (4.9 points). They considered the background information provided by the white papers as very appropriate and sufficient (4.2 points). Travel logistics as well as comfort and accessibility of the accommodations were also rated high (4 to 4.4 points), although specific stakeholders gave constructive suggestions for achieving perfectly accessible meeting and dining arrangements in the future.

Individual comments from different stakeholders that corroborated the above results described the event as "extremely professional", and pointed out as a strength of the forum our involving the RERC from Pittsburgh as our partner. Special mentions were also made of: the "overall structure" of the forum, the "motivation" of the moderators, the "model" we followed in the sessions that converged discussion to summaries, the quality of the background materials, among other things. As one Resource Provider observed, "providing a structure for groups to work within", having "focused objectives" and having "facilitators" were the strengths of our sessions.

Information related to the above findings are summarized in Tables 1, 2 and 3.

Self-evaluation by Forum Organizers

We also received self-evaluative feedback from the organizing members themselves. The moderators from AZtech, ILC and RTI, the graduate students from the RERC at Pittsburgh and the professionals from T2RERC sent their perceptions and evaluative comments electronically to the evaluation team, subsequent to the event. This information pointed to general satisfaction on everyone's part, the entire program considered professional, well run and effective. Having an on-site support system with resources and a work area, as well as getting continuous evaluation and feedback on site were particularly upheld as strengths. On the other hand, there were a few constructive comments related to either maintaining or improving "an already excellent process". These include: maintaining the present structured format of the sessions, making technical/laymen communication stronger by moderator training, more efficient recruiting and preparation of consumers for better validation of technical solutions, rethinking ways of efficiently involving our distant partners.

Information related to the above is summarized in Table 4.

Conclusions

After cross-analyzing the self-study information with the participating stakeholder perceptions, much as we happily conclude the high success level of the forum, we also recognize the value of the constructive suggestions made. In a spirit of improving our outcomes by enabling stakeholders to make their highest quality inputs, we acknowledge them as “lessons” for our future events and pledge our ongoing efforts towards excellence.

	Table 1: Stakeholder Ratings of Individual Forum Sessions on Wheeled Mobility									
		Gp.->	**Manual Propulsion**		**Power Management**		**Motors/ Drivetrains**		**Materials/ Components**	
			SESSION ONE (Tues)	**SESSION TWO (Wed.)**	**SESSION ONE (Tues)**	**SESSION TWO (Wed.)**	**SESSION ONE (Tues)**	**SESSION TWO (Wed.)**	**SESSION ONE (Tues)**	**SESSION TWO (Wed.)**
	Item		***mean (n=17)***	***mean (n=12)***	***mean (n=12)***	***mean (n=15)***	***mean (n=12)***	***mean (n=12)***	***mean (n=16)***	***mean (n=15)***
1	The group was well organized and run		4.1	4.6	4.7	4.2	4.3	4.5	3.6	4.1
2	The moderator's instructions were direct, simple and clear		4.6	4.5	4.5	4.1	4.4	4.4	3.9	4.1
3	The discussion content was relevant to me		4.2	4.0	4.4	4.3	3.7	4.1	3.6	4.1
4	The discussion addressed the appropriate issues for the topic		4.1	4.1	4.4	3.7	4.1	4.3	3.3	4.3
5	The discussion went into sufficient depth for the topic		3.9	3.8	4.3	3.7	3.6	4.4	3.6	3.9
6	The Group's purpose was clear		3.9	4.4	4.3	4.0	4.2	4.3	3.6	4.0
7	The group's purpose was achieved		4.0	3.5	4.4	3.6	3.5	3.7	3.3	3.9
8	I felt comfortable participating in the discussion		3.7	3.9	4.8	4.2	3.5	4.6	3.8	3.6
9	I felt that I		3.5	3.7	4.1	3.6	3.5	3.8	3.8	3.5

	made useful and relevant comments												

		Table 2: Stakeholder Ratings of Overall Forum Performance- Wheeled Mobility					
			consumers [n=18]	***Tech producers [n=11]***	***Manu-facturers [n=8]***	***Resource Providers [n=9]***	
			no.	***no.***	***no.***	***no.***	**TOTAL**
A		Participated in MWC Propulsion group	***8***	***3***	***4***	***7***	**22**
		Participated in Motor/DrTrains group	***9***	***4***	***4***	***1***	**18**
		Participated in Materials/Components group	***9***	***5***	***3***	***6***	**23**
		Participated in Power Management group	***9***	***5***	***4***	***3***	**21**
B		Is a clinician/therapist	***2***	***1***	***0***	***0***	**3**
			Mean	***Mean***	***Mean***	***Mean***	**GRAND MEAN**
C	1	Hotel rooms and facilities provided an appropriate environment for this Forum	***4.1***	***3.8***	***4.3***	***4.1***	**4.1**
	2	Hotel rooms and facilities were fully accessible	***4.0***	***4.0***	***4.0***	***4.1***	**4.0**
	3	The "White Papers" provided appropriate and sufficient background information	***4.4***	***4.3***	***3.9***	***4.3***	**4.2**
	4	Your travel accommodations to and from the Forum were reasonable and appropriate	***4.8***	***4.3***	***4.0***	***4.3***	**4.4**
	5	The staff(secretaries, moderators, students…) were helpful and friendly	***4.8***	***4.8***	***5.0***	***4.9***	**4.9**
			no.	***no.***	***no.***	***no.***	**TOTAL**
D		Helped me identify new business opportunities	***2***	***7***	***6***	***3***	**18**
		Exposed me to new or innovative technologies	***14***	***5***	***5***	***5***	**29**
		I helped shape the direction	***10***	***4***	***0***	***3***	**17**

		for new product development					
		I helped identify the needs for new products or technology	***13***	***6***	***4***	***3***	**26**
		Provided me an opportunity to network with or speak to manufacturers, researchers, clinicians, consumes and others	***16***				

Table 3. Stakeholder Comments on Forum Performance

Participant group	Which aspects of the Forum were most useful or well done?	Which aspects of the forum need to be improved?
Consumers	• networking opportunities • Most of the things we talked about were very interesting to me. • All of the aspects • Bathrooms on floor were great! Food was good. I liked the excitement of the session. The interaction between the participants was good. • Contacting customers was great! Need to have more of these forums. • I am more aware of the technologies that are out there and the ones that they are working to develop. • I am more aware of what is out there and what technologies they are currently working on. • Overall, the forum was very well presented and worthwhile. • All well done. Nothing really at use, at this point in time. • The food was exceptional and plentiful and the servers and volunteers couldn't have been more pleasant as well as helpful. They were cheerful as well as accommodating…….. I don't want to end on a negative note because I felt that my overall view of this forum was and is favorable, at the risk of being redundant I feel that topics were very informative. I always welcome the opportunity to acquire new knowledge and I did. Thank	Overall: • Everything was handled well. • I don't see any need for improvement. This is the first forum that I have participated in. So, I can't really say if it was run well or not. • I am new at this. I've never met a more appreciated group of people. Accessibility: • Accessibility in the forum rooms was somewhat a problem. You should probably have a disabled person scope out the site. • I was a little shocked when I first came into the hotel and saw steps. (I didn't see the lift but the staff was very helpful and showed me the lift). However, 2 elevators made transportation to and from other floors difficult. • The rooms for the various groups were a little small for wheelchairs[two] Comfort: • Most people in wheelchairs get extremely tired after sitting for a prolonged time along with getting tired I have pain and swelling to contend with. I know that it probably would be cost

	you very much for inviting me. Perhaps we can do this again. The staff and moderators were very good. The groups that I participated in were very technical but I believe that I was able to understand at least 75% of the information. I increased my knowledge and have a better understanding of what it takes to unite technology and materials. Buffets are difficult for people in wheelchairs – more help was needed in assisting and expediting the lines. The wait staff was wonderful and very helpful. • The forum was an excellent idea. I learned a lot in the groups I was in- especially in assisting me in my search for a new chair. I look forward to seeing some of the ideas in the future chairs being manufactured. The accessible bathrooms were very wonderful. • The presentations were very good. It was nice to hear the results of the other groups that I wasn't able to participate in.	prohibitive to have shorter days but more of them, so that the same amount of ground could be covered. • The days were too long. Needed to be spread out over 3 or 4 days • The temperature control was a little off. Sometimes the rooms got too hot and other times it was entirely cold. I sat in the rear of the conference room and was surprised that the hotel allows smoking in front of the doors. The smoke drifted into the room. I am allergic to smoke and it puts me into an asthma attack. <u>Meals:</u> • Buffets are difficult for people in wheelchairs – more help was needed in assisting and expediting the lines. The wait staff was wonderful and very helpful. The elevators were too small for wheelchair • The helping of wheel chair user with their meals and told it be buffet style. <u>Accommodation:</u> • Need to let local people know that they won't be staying overnight. They should have given better instructions on who was staying overnight • People need to be notified of all accommodations.

		Instructions should be clearer to the persons giving out the info. <u>Groups representation:</u> • End user (consumer) needs to have input before the forum, on which aspects of the chair they feel is in need of breakthrough technologies for all degrees of disabilities. • You need to have third party payers represented. • I feel that it perhaps would be advantageous to have invited individuals from Medicare, HMO's, Medicaid, and some congressmen and senators, because no matter what the subject was, the bottom line is funding. Mainly the lack of it vs. the need of it. • Need more clinicians involved in forum to represent the consumer from a professional aspect, as well as other advocates. Funding and other financial perspectives should have a representative to answer questions in this area. • You need more consumers in each group • Afternoon session on day two did not offer much new insight with people. Just reading reports. We can read what groups came up with after the forum is over and we are

		mailed info. May have been better to use that time to rotate into a new group. That way we could have been directly involved in 3 groups instead of two
Technology producers	• The interaction times at meals and after meeting times was essential. • Diversity of people • Opportunities to meet a diverse group of people with common mobility interest. • Preparation of background materials • Unifying personnel of different field under one roof which will and should help getting a proper network. • The ability to network and learn about consumer needs • Meeting others. • The overall structure was well implemented.	• One issue that kept coming up was Medicare Reimbursement. It is a policy issue that involves consumer advocacy, dealer/ mfg support and research data to promote an attitude change in Medicare to update the kool chair. The kool is based on a 20 yr old design needs to be updated. I recognize grant recipients can't lobby directly but some forum is needed to upgrade the minimum Kool chair requirements. • Add payments group Medicare/Medicaid, Funding! • Reimbursement was a key issue throughout the groups – there may be a need to have an additional group which would address reimbursement. • More manufacturer participation. Scooters, vehicles, component supplies • Develop standard output, better organized, have groups review this information and assemble as groups (problem , solutions. fed lab

		direction). • Communication among the researchers, manufacturers and the end users. • More closely ensure that the facilities meet the needs of the participants • More respect for consumers. Perhaps a pre-session to help them not focus on their own situation as when they did – they were often readily cut off • A bit too "orchestrated", not enough user input, or an appropriate forum for it.
Manufacturers	• The mix of manufacturers, researchers, clinicians, and the most important group, the users. • Scribes did a fabulous job • Discuss and summarize model is very good • Moderators/organizer very motivated to do a good job • Very good interplay with people in varying interest. • Networking opportunities and manual wheel chair propulsion –geared systems wed at 9 am.	• In general the forum was really good – Honestly I am not sure that I know How to improve a forum like this – there are many different levels of understanding if I have one comment/request, --- more detailed discussions in some meetings to discuss potential solutions [to?] problems • More users, need their input most. • Need: more therapist, more people from funding area, more knowledgeable end users. • More attendance by funding - this is critical • Reality, discussions must focus on realizable goals

		• Some information in the "power" white paper was outdated as regards additional push for third party payer participation would be very helpful. • Materials and components. Tues. p.m. – not productive
Resource Providers	• Diverse participants. Structure for groups to work within. • Networking. • Explore in more detail available technology. • Focused objectives • Facilitators • Opportunity to network with others. Good insight to issues dealing with wheel chairs.	• Enhance greater consumer participation within groups. May be include third party funders as participants. • Facilities need to be larger to accommodate folks better. Need to have third party members present. • Consumers present were not encouraged to speak out and in one group were cut off. It would be interesting to hear them about how they felt they were heard. • Try to increase manufacturer/industry participation. • More FLC scientists/engineers • Better opportunities for networking – i.e., larger room for reception/dinner so mingling is easier. Encouragement for business reps to contribute more freely to discussion • It went well. However wrap up session by different groups should be

		no longer than 10-15 minutes each. Break too long. • Outcomes of breakouts unduly influenced by some participants – suggest each topic have 2-3 homogeneous groups that then come together as one heterogeneous group on the topic.

TABLE 4: In-House Evaluative Input - What worked and what did we learn?

Source: Comments from: *T2 RERC staff [n=9]; RTI reps [n=2];Pittsburgh grad students n=3; Total = 14*

SUMMARY OF KEY POINTS

The evaluative comments by T2RERC/ RTI/ RERC-Pittsburgh [grad students] point to general satisfaction on everyone's part - entire program considered very well run. In particular, NIDRR thought it extremely professional, with special compliments to T2RERC for taking the initiative and involving Pittsburgh RERC as a significant partner. The **"strengths**" of the Event are listed in the summary tables below. The recommendations are for <u>continuing these practices</u>. The "**lessons"** include any adjustments/ improvements" that should occur in order to make an "already excellent forum" [RTI comment] even better in the future.

	<u>STRENGTHS</u>	**<u>LESSONS</u>**
Locale of Event	• 1. Holding Forum in home city of partner RERC	• Select more accessible hotel. • Visit available options and verify accommodations for larger meeting rooms on the same floor, with easy access to each other, as well as other needs of the specific consumer attendees [vision /hearing-impaired]
On-site Project Support	• Having [a] the "war room"; [b] on-site tech support; [c] on-site evaluation [d] on-site facility management • Excellent staff cooperation and understanding as a "team".	• Make printer more accessible to computer[s] in the war room; • Encourage <u>all team members</u> to prioritize on-site customer needs
Forum Organization and Coordination	• Well run on the whole	• Record participant attendance, at arrival and at sessions • Rethink forum timing – more days? • Work out logistical details of team work - organizing upon

		arrival on site, master of ceremonies at initial meeting • Harmonize approach and philosophy among organizing partners; fully involve them, especially moderators, with development of white papers, scripts and moderating process; Train/prepare moderators. Partner RERC to participate as technical facilitator.
Registration of Participants	• Color coding and labeling participants by roles [consumer, manufacturer…] and sessions [motors, materials….]	• Place individual packages in envelopes for ease of manipulation • Set up registration earlier to permit initial clarifications / settling in • Master list at table to be checked off [and provide for session attendance checking]
Use of AV aids	• Use of computer based note-taking, projector and screen; • Flip chart note-taking and display of notes on walls for reference In <u>manual propulsion gp,</u> • Having two flipcharts and two computers running simultaneously • Display of visual illustrations on the screen for reference • Categorizing wall notes display	• Flip charts should be positioned better for easy view. • Make flip chart notes more legible, crisp and understandable • Categorize and color code flip chart notes [by discussion topic] as possible; • Consider using strengths of manual propulsion group. • Consider videotaping of sessions for process viewing and improvement • Consider using power point template for final reporting [last day]
Breakout sessions:	• Having a questioning format- "needs, state of	• Team player roles should be more clear in all groups

Organization and implementaiton	practice, ideal and barriers" - in script as a guideline in general • Having a team approach- scribe, technical support and note takers on flip chart. • Having a structure to hold an otherwise overwhelming number of topics • White papers well done • Having continuous evaluations and feedback • Having breaks of appropriate length for persons in wheelchairs • Frequent breaks after each sub-topic and use of break time to validate and integrate discussed ideas and points; [motors gp and manual propulsion gp]	• Prepare participants with more advance information [in an info package with white papers] about session process • differing moderating styles between sessions • session outlines, with definitions in the script 'guideline' • information about which technology areas to discuss • Especially provide previous preparation to consumers at recruitment; • Continue to consider attendee needs while planning breaks and transitions between sessions • Track attendance at sessions; • Provide for cross-interaction between group/session participants. Consider including a feature that enables two discussion groups to get together and compare notes to provide a joint report. Have all the teams either listen to a tape of the interviews, or be part of a tele-conference • Re-think Day 2 breakfast arrangements
Moderating Team Effectiveness at Breakout sessions	• Three of the four moderators were effective as facilitators despite differences in degree of "structure" in the use of the script guidelines. All three respected the planned discussion outline. • Support staff –	• Ensure that all group moderators are in tune with the approach. • All team members need to have an active part of in the development of background material, script writing, process, etc. • Re-think the degree of

	technical and flipchart note-takers and scribes – placed very well in the alcove of the session room • Worked effectively within the limitations of physical space and lack of role clarity due to moderator differences; • Pittsburgh grad students motivated and helpful; Felt most useful while actively note-taking, but benefited educationally when multiple note-taking freeing up time for listening to discussions	structure in the "script". Avoid too much freedom or too much restriction for the forum members; Define a good middle and have it practiced by each moderator before conducting a forum. • Involve technical experts from partner RERC from beginning, and have them participate as technical facilitators in every discussion. • Specify the roles of all Technical students, including their roles in developing the proceedings, so they know what is expected up front • Scribes should only use equipment they train with prior to the Forum
Reporting session	• Giving participants the opportunity to present their group findings worked well.	• Facilitate more interaction and additional input from participants • Re-think set up – including preceding lunch hour, and the design of the meeting rooms; Ex: board room style? Layout of the room with round tables? • Consider expanding meeting to three days. • Day 1 morning - each stakeholder group meets separately, sets its own expectations regarding participation. • Day 1 afternoon and Day 2 morning - breakout group meetings on each topic • Afternoon of day 2 - joint meeting of both groups within each topic to develop

		recommendations • Morning of Day 3- technology developers (labs) and product developers (companies) to develop a plan of action in response to recommendations. • Afternoon of Day 3- presentation of action plan (next steps). • Consider having a moderator in addition to the reporter, leading and eliciting interest/comments. • Plan for a PowerPoint template for the reports; it is more amenable to presentations[RTI]
Participant Interaction and Contribution to Forum Outcomes	• Mixing and providing opportunity for the various stakeholders to interact • Including consumers, in particular [input considered valuable and expected by a number of remarking manufacturers] • Consumers dedicated and interested to learn • Use of Scripts to aid in keeping the [mixed] groups (at least in the motor group) focussed. • The broad variety of input from the group, their ability to stimulate each other with thinking about various problems	• Continue to use scripts for moderating. • Consider making sessions a little less structured, perhaps with shorter scripts; and allow a more natural process for participants and more freedom for the moderator to adjust to the participants. • Better specify the type of technology solutions we were looking for – to avoid the problem of focusing on extremes [totally new technology vs. minor modifications to existing technology]. Include multiple reps from the same company to help balance off extreme positions • Better participant mix is needed - Increase presence of insurance companies or people in the Medicaid/ Medicare business; Consider that clinicians could bring

		consumer need-perspective to the table with greater knowledge of available product choices [RTI] • Generate white papers more contemporaneously with the expert and industry interviews for greater continuity [RTI] BEFORE THE SESSIONS: • Provide all participants with more information about the process, perhaps in the information packet. • From the perspective of sessions effectiveness, try to find “knowledgeable” consumers. Re-think recruitment procedures [***See details in the appropriate section in the appendix]*** including more information, pre-preparation or training to clarify expected roles and encourage participation. • Moderators to study expert interviews, industry interviews and related materials and get familiar with the needs and business opportunities identified by manufacturers • Consider some introductory sessions for the different stakeholder groups prior to the actual focus group meetings (perhaps Tuesday morning). In particular, have a pre-meeting/ coaching of consumers by the RERC [6] before participating [day before or morning of forum]. Consultation on what is available for their needs could be a benefit of their participation. AT THE SESSIONS:

		• Monitor any stakeholder attrition on day one, and make any adjustments necessary to ensure coverage in every group [NIDRR comment] • Moderators should; • Reiterate the roles of each stakeholder group in the meeting, then bring them up when the role gets achieved • Be sensitive to consumers feeling intimidated by experts, provide them with support and encouragement to participate, and then reward them when they do participate • Have technically oriented participants rephrase and explain things in layman terms in order to encourage the full participation of all stakeholders • Bring back technical considerations to the consumers for input from a functional viewpoint • Recognize and accommodate any consumer difficulty with some aspect of verbal communication; their lack of practice at forming and articulating their thoughts and their need for more time [to develop their thoughts] and support [when clarifying them] • Encourage more manufacturer participation - maybe touch on the “profit” that the new technology would generate for them. • Consider using some type of

		tool (game or group puzzle) that will not be offensive yet get the group together HAVE TIMELY FOLLOW-UP: [*See details in the appropriate section]*
RERC Partnership	• Most of the participating RERC staff made excellent and superb contributions to the session. On the whole it was very positive. [Especially in the Power Management group].	• Involve partner RERC more in all process steps beforehand; get everyone in better tune with the meeting -- and to buy in to the concept; have issues raised and resolved well before the session, so as not to confuse or disrupt the discussion trend during actual sessions

Appendix C: Project Web-Sites

RERC on Technology Transfer (T2RERC) & Related Partner Agencies

(**In alphabetical Order**)

AZtech Incorporated

http://cosmos.ot.buffalo.edu

Center for Assistive Technology - University at Buffalo (CAT/UB)

http://wings.buffalo.edu/ot/cat/index.htm

Federal Laboratory Consortium (FLC)

http://www.federallabs.org

Federal Laboratory Consortium - Mid-Atlantic Region

www.federallabs.org/Mid-Atlantic/start.html

Independent Living Center of Western New York (ILC)

http://cosmos.ot.buffalo.edu/html/ilc.html

National Institute of Disability and Rehabilitation Research (NIDRR)

http://www.ed.gov/offices/OSERS/NIDRR/index.html

RERC on Technology Transfer (T2-RERC) - University at Buffalo

http://cosmos.ot.buffalo.edu/t2rerc

RERC on Wheeled Mobility - University of Pittsburgh

www.rerc.upmc.edu

Research Triangle Institute (RTI)

www.rti.org

U.S. Department of Education (USDE)

http://www.ed.gov