Chapter 2: Literature Review

History of Wheelchairs and Power Add-On Units

Wheelchairs have evolved very little over the past 1000 years. Most of the design changes have occurred within recent decades as shown in the following outline of wheelchair history.

6th Century A.D. - Earliest recording of a wheelchair; a Chinese engraving picturing a man in a chair with three wheels (Kamenetz, 1969).

16th Century A.D. - Wheelchairs were well-developed in Europe and commonly found in drawings and literature (Kamenetz, 1969).

American Civil War - The first appearance of wheelchairs in the United States. The chairs were of bulky wooden construction with two large drive wheels and two small caster wheels (McFarland and Wilson, 1986).

1869 - The first wheelchair patent was issued in the United States (Hotchkiss, 1993).

1903 - An electrically-driven wheelchair operating on a 12-volt battery and a 3/8 horsepower motor was used to give people rides. At the time it was not used for handicapped mobility but it did pave the way for future developments (Kamenetz, 1969).

1909 - Compact wheelchairs were developed using metal tubing instead of the traditional bulky wood components (Kamenetz, 1969).

World War I - The first electric wheelchairs were used for the handicapped. A battery and motor were applied to existing wheelchairs with a simple one-speed on/off switch (Kamenetz, 1969).

1937 - The patent for a wheelchair with a folding X-brace frame was issued to two engineers named Everest and Jennings. Though previous chairs had been foldable top-to-bottom, the side-to-side folding position of the cross frame allowed the drive wheels to remain in place. This basic concept is still the standard for manual wheelchairs today (Hobson, 1990).

1940 - The first patent was issued for an electric wheelchair (Hobson, 1990).

1950 - Sam Duke received a patent for a releasable add-on power drive applied to a manual wheelchair (the unit was actually permanently fitted to the chair with U-bolts) (Kamenetz, 1969).

1960's - Folding wheelchairs were commonly fitted with electric drives. The drive units were still very heavy and quite difficult to put on and take off. At that point both joystick and steering column mechanisms were available (Kamenetz, 1969).

1970's - Wheelchair frames made of aircraft quality aluminum were introduced to the market and started a revolution of ultralight wheelchairs. The technology has aided in the reduction of the overall weight of many types of wheelchairs (Hobson, 1990).

1980's - Most electric wheelchairs on the market were still bulky, heavy, and required a special vehicle for transportation. The power components of the chair were integrated into the frame which has been strengthened to support them (Hobson, 1990).

1990's - The popular electric wheelchairs on the market are foldable though they require removal of at least the legrests and batteries.

The Americans with Disabilities Act (ADA) and a growing awareness for the rights of the disabled have greatly improved research and design efforts in the assistive technology industry. Interest has also increased in this area due to the current trend toward the "graying of America" as the average age of Americans increases (COMSIS, 1988).

Products Currently on the Market

The ensuing discussion addresses those products which may compete for the same market as the new invention. For a general overview of the current manual and power wheelchairs available, see Appendix B: Wheelchairs Circa 1997.

Power Add-On Units (PAUs)

Table 1 includes a list of products which have recently been for sale or are currently listed on the market. The PAUs are designed to temporarily convert a manual wheelchair to a power wheelchair (one exception: the REDPAK 07RP is considered a permanent conversion). Most operate at approximately five miles per hour with a power source of two, 12-volt batteries.

Table 1. Power Add-On Units

Product	Drive Mechanism	Retail Price	Availability
FORTRESS 1000FS by FORTRESS	Friction Drive	$2795.00	Currently Unavailable
DAMACO D90 by DAMACO	Friction Drive	$3010.00	Available
FREEDOM ASSIST by Camp Int'l	Added Drive Wheel in Rear	$1675.00	Currently Unavailable
ROLL - AID by Stand-Aid of Iowa	Tiller Drive	$2195.00	Available
REDPAK 07RP by Redman	Replaces Rear Wheels	$2881.00	Currently Unavailable
PAPOOSE by Redman	Friction Drive w/ Lever Handles	$2150.00	Currently Unavailable

Note: Information is based on product literature and communications with customer service representatives.

Fortress 1000 FS. Figure 3 shows the drive system for the Fortress 1000 FS. Frictional rollers, driven by two separate motors, rotate in contact with the large rear drive wheels of the wheelchair. A joystick is used for steering and speed control and a simple switch on the joystick box disengages the electrical drive system. This allows for manual chair operation while the 1000 FS is still in place. With batteries, the add-on unit weighs approximately 77 pounds.

When Fortress released the Commuter (a transportable electric wheelchair), the need for an add-on power device was apparently not anticipated. For this reason, the Fortress 1000FS was removed from the market. However, a customer service representative has explained that consumers are still requesting an attachment which will convert a manual wheelchair to a power wheelchair (Fortress customer service representative, personal communication, January, 1994).

Fortress has recently been purchased by a company named Orthofab. Since the acquisition, Orthofab has decided to no longer carry any power add-on unit products or transportable wheelchair products. (Orthofab customer service representative, personal communication, May, 1996).

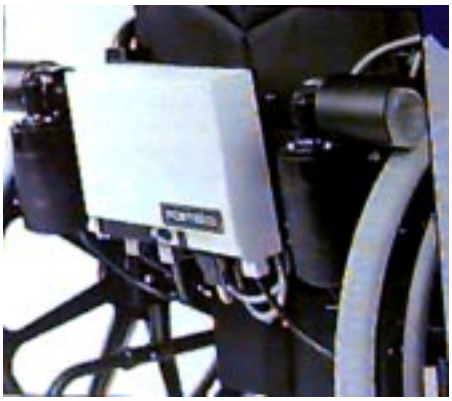

Figure 3. Fortress 1000FS add-on power attachment. Taken from product literature (PICT, 89 k).

Damaco D90. Like the Fortress 1000 FS, the Damaco D90 is a friction-drive unit located on top of the wheelchair drive wheels. Figure 4 pictures the unit and accessories separated from the chair. Total weight of the system is 61 pounds and it provides a manual mode of operation while attached.

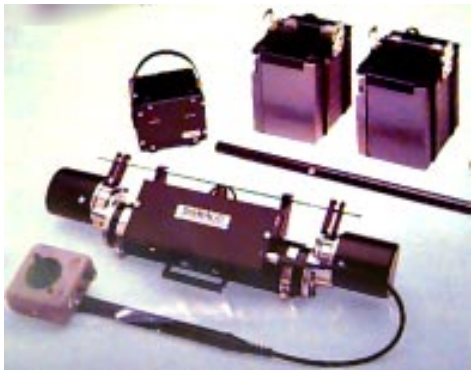

Figure 4. Damaco D90 power attachment. Taken from product literature (PICT, 104 k).

A home health care representative explained the downfalls of the Damaco D90. There are several parts which remain on the wheelchair permanently even when the apparatus is removed. These parts are extremely difficult to affix to the chair in the first place; requiring disassembly of the wheelchair frame. The units also require extensive maintenance as they tend to break down often. Also, placement of the batteries was described as a "back-breaking" chore (K. Davidson, personal communication, February, 1994). In addition, the Damaco D90 requires holes to be drilled into the wheelchair frame. This invalidates any warranty which may come with the wheelchair and therefore the consumer is no longer protected against wheelchair breakdowns (Quickie customer service representative, personal communication, May, 1996).

Freedom Assist. The Freedom Assist is an add-on power device designed to increase the ability of the wheelchair to traverse rough terrain and obstacles. It is a rear mounted unit which is driven by a single drive wheel. The Freedom Assist lasts for four miles on a charge and is currently not distributed.

Roll-Aid. Stand Aid of Iowa, which developed the Roll-Aid, is operated by Kleinwolterink who holds the patent for this invention (Kleinwolterink, 1991). The product, pictured in Figure 5, attaches itself when the operator reverses the tiller drive into position under the wheelchair. When secured, the Roll-Aid raises the front caster wheels off the ground leaving only three wheels in contact. This unstable, three-wheel stance is especially problematic (can result in a turnover) when traversing slopes sideways or on fast turns.

An additional point to consider with the Roll-Aid is the weight of the components. The unit breaks down into components for transportability with the heaviest component weighing 35 pounds. This is a significant handling concern when considering the independence of the wheelchair operator. The product is also not capable of switching between manual and power operating modes while the unit is attached. This minimizes opportunities for the operator to exercise and introduces the possibility of leaving the user stranded in the case of a malufunction or loss of battery charge.

Figure 5. Roll-Aid add-on power drive. Taken from product literature (PICT, 149 k).

Papoose and Redpak 07RP. The Papoose is a friction drive with the roller wheels located at the front of the wheelchair drive wheels. Lever handles are used to bring the motor-driven rollers in contact with the wheelchair drive wheels.

The Redpak 07RP converts a manual chair into a power chair by replacing the rear wheels with smaller, motor-driven wheels. It has two motors, is controlled by a joystick, and it does not have a manual mode once converted.

Redman no longer carries either the Papoose or the Redpak 07RP. The decision to discontinue the products was based on a managerial perspective that the company was "trying to do too much." A Redman customer service representative explained that the market for the products was quite large and that poor sales were not the reason the products were discontinued (Redman customer service representative, personal communication, May, 1996). Both the Papoose and the Redpak 07RP are pictured in Figure 6.

Papoose Redpak 07RP (PICT, 306 k)

Figure 6. Redman add-on power devices. Taken from product literature.

Previous PAU Evaluation

An evaluation of five PAUs was conducted by Gaal and Johnson (1993) at the Wheeled Mobility Center of San Francisco State University. The evaluation included the Damaco D90, Roll-Aid, Freedom Assist, Redman Papoose, and a prototype PAU developed at the university called the "Click 'N' Zoom." The Click 'N' Zoom PAU consists of two drive wheels, each with an independent motor, in frictional contact with the ground between the drive wheels of the wheelchair (behind the seat). The unit is controlled with an integrated joystick box and controller.

Gaal and Johnson refer to the Freedom Assist PAU as the "Samson Power Drive U1" developed by Tzora Industries of Israel, and the Redman Papoose as the "Sweeney AZ-100" developed by Arizona Freedom Wheels. These different product names are assumed to be representing the same two products due to the identical appearance of each.

Major results from the study are listed here concerning operation in power mode, safety, attachment and detachment characteristics, and suggested design criteria for future PAU development efforts. It should be noted that of the PAUs discussed in the evaluation, only the Roll-Aid and Damaco D90 are believed to be currently available on the market.

Roll-Aid. The evaluation determined that the Roll-Aid PAU performed much better in terms of its power operation than the other PAUs. This is a promising find due to the similar tiller operation mechanism utilized by the new PAU design. The Roll-Aid was also found to have braking described as "too abrupt" and concern was expressed for tipping instability with the three-wheeled stance. The large number of parts and extensive weight (one part weighs 35 pounds) found the Roll-Aid to be one of the most difficult PAUs to stow.

Damaco D90. While the Damaco D90 performed the best operating in reverse, the evaluators describe the controller as "unsophisticated" and claim this is responsible for a jerky ride at high speeds.

Redman Papoose. The Papoose produced the best results when tested for braking and high speed turns, and was found to require less dexterity to attach than all but the Click 'N' Zoom. It was also easy to switch to manual operation, but it does not offer powered operation in reverse.

Freedom Assist. The Freedom Assist had many drawbacks including no powered reverse, the requirement to shut off power before braking, and difficult turning control. The evaluators concluded that the Freedom Assist was the least safe of all tested PAUs based on these control problems.

Click 'N' Zoom. Evaluators explain that the prototype has minimal dexterity requirements for attachment and detachment and it performs well under wet conditions. The Click 'N' Zoom evaluation determined that the drive wheels scuffed against the ground on turns resulting in loss of traction, vibration, noise, and floor abuse. It is also not capable of switching to a manual operating mode while attached.

Recommended Design Criteria. It was found that PAUs which operate with a friction drive against the wheelchair tires (Damaco D90, Redman Papoose, Fortress 1000 FS) perform poorly in wet conditions. The study concluded that designs incorporating direct friction against the wheelchair tires "should either be avoided, or designed to be largely insensitive to wet riding conditions."

Gaal and Johnson stress that new PAUs should be made with the following characteristics:

-- safe operation, including tipping stability.
-- the ability to switch between power and manual operating modes while seated (without removing the PAU).
-- features permitting easy stowage and transportation in automobiles, public vehicles, and airplanes.

In addition, they specify two target user groups as defined by expert panels. These groups match the defined market the new PAU design effort has outlined and includes:

Group A: relatively independent manual wheelchair operators who require occasional assistance for long distances, difficult terrain, or tiring days.

Group B: power wheelchair or scooter operators who require a transportable chair, need occasional manual exercise, or don't have the financial resources for an integrated power wheelchair.

Gaal and Johnson propose that PAU design efforts should develop PAUs separately for each group based on the different needs and capabilities of the wheelchair users in each category. Recommendations for a Group A PAU product include a simple and rugged design which offers easy switching between manual and power modes with no part weighing more than 20 pounds. The new PAU prototype matches these design criteria.

The evaluation also suggests a design with the ability to attach and detach while the operator is seated in the wheelchair. Currently, the new PAU prototype is designed to be attached and detached by an operator seated next to the wheelchair. Future design iterations may focus more on variations of this feature. The most important aspect of this concept as gleaned from the evaluation data, is actually the ability to independently attach and detach the PAU. This is one of the features of the current PAU prototype and results of the usability evaluation which includes these tasks, are explained in a later section.

Another conclusion of the report is that a PAU design should accommodate wheelchairs with cambered wheels or some other rear axle position that has been optimized for manual propulsion. Due to the attachment location and operation characteristics of the new design, it is not anticipated that varying rear axle arrangements will impact the performance of the PAU. The suggested retail price for PAUs intended for use with Group A operators is less than $1000. Much of this estimate is based on the fact that the device would not be a necessity, and therefore may not be covered by insurance.

For Group B operators, Gaal and Johnson recommend a joystick control with an attachment system designed for an untrained assistant to use. In addition, they suggest automatic braking and a retail price less than $2800 for the PAU, or $3700 for a combination PAU and wheelchair. This is based on the $3700 cap of support offered by Medicare (according to the 1993 report). Also, one expert commented during the

evaluation that Medicare will only provide funding for a powered wheelchair once every seven years. Therefore, a product should be designed for a life of at least seven years.

Transportable Power Wheelchairs

Electric wheelchairs which are sold as a unit, yet are foldable for transporting, have been placed on the market within the past decade (beginning around 1990). For transport, the legrests, armrests, batteries, and in some cases the drive unit, are removed from the chair and it is folded to be placed in a trunk or back seat of a car. Each wheelchair has two motors driving the rear wheels which are powered by two, 12-volt batteries. Table 2 lists models which are available or recently removed from the market, and the current prices for the units.

Table 2. Transportable Power Wheelchairs

Product	Price	Availability
INVACARE Power 9000	$4000.00	Available
QUICKIE P100	$3800.00	Available
QUICKIE P110	$3850.00	Available
QUICKIE P200	$6300.00	Available
DAMACO Electro-Lite	$4785.00	Available
FORTRESS Commuter	$3520.00	Currently Unavailable

Note: Information is based on product literature and communications with customer service representatives.

Invacare Power 9000. The Power 9000 is only operable in a power mode (there is no accommodation for manual operation) and is controlled by a joystick as are all of the transportable wheelchairs. With the accessories detached for transportation in an automobile, the chair weighs approximately 50 pounds.

Quickie P100 and P110. These Quickie transportable chairs are also unable to switch between manual and power modes. Without batteries, both wheelchairs weigh approximately 65 pounds.

The P100 is one of the power chairs which is not foldable. Instead, the frame is compact and the back folds down onto the seat to allow stowage in the back of a roomy vehicle (e.g., a hatchback car).

The Quickie P110 is similar to the P100 except that it has a folding frame instead of the compact solid frame. This allows the P110 to lie flat in a car trunk or slide behind a car seat.

Quickie P200. The P200 is a modular electric wheelchair with a main selling point that it is very fast and maneuverable. With a relatively small overall size and a top speed of 7 1/2 miles per hour, it is definitely the "race car of wheelchairs."

Quickie also claims that the chair can be easily stowed in the back of a vehicle for convenient transportation. It makes use of a compact frame like the P100 which easily separates from the power drive system. However, the power drive unit which must be lifted into the vehicle, weighs over 100 pounds and is quite bulky. It certainly could not be accomplished by one person with even full physical capabilities. This was verified by the research team which briefly obtained and evaluated the P200 at the Human Factors Engineering Center.

Damaco Electro-Lite. The Electro-Lite, with large rear drive wheels (see Figure 7), is capable of engaging and disengaging the electric-drive mode of operation. Once the batteries, power unit, and footrests have been removed from the chair, it weighs only 33 pounds. This lightweight folding design allows easy placement behind the seat of a car by the operator (given sufficient strength and coordination abilities). However, the location of the power unit makes this sequence difficult for the operator to independently accomplish while seated in the chair or the automobile.

Figure 7. Damaco Electro-Lite transportable wheelchair.
Taken from product literature (PICT, 116 k).

Fortress Commuter. The Commuter maintains the ability to alternate between manual and power modes with a simple switch. It also provides assistance with placing and removing the batteries with a mounting "slide guide." The "slide guide" design provides rails to help maneuver the battery boxes while they are attached and detached. The Commuter, pictured in Figure 8, weighs 89 pounds without batteries. Though it folds to a size capable of placement behind a car seat, the weight of the chair may make this very difficult to accomplish independently.

Since the acquisition of Fortress by Orthofab, the company has decided to no longer carry any power add-on unit products or transportable wheelchair products. (Orthofab customer service representative, personal communication, May, 1996). Consequently, this product is no longer available.

Figure 8. Fortress Commuter transportable wheelchair.
Taken from product literature (PICT, 89 k).

Patents pertinent to the field of the new design have been obtained through patent searches conducted by Dr. Casali and Sean McGinn, of Whitham, Curtis, Whitham, and McGinn Law Offices of Reston, Virginia. A comparison of the new PAU to patents of similar devices is provided in Appendix C: Patents for Add-On Power Devices. In the appendix, the major design and performance characteristics of the related patents and the new invention are outlined.

The Wheelchair Power Add-On Unit Consumer

It is the ultimate objective of this design and testing project to contribute a useful product to the enabling devices market. Therefore, the final consumer of the product must be considered through each of the stages of it's lifecycle. This is a basic premise of human factors engineering: designers consider the user an integral part of the system. The concept of the user as part of the system implies that the user's capabilities, limitations, needs, and wants, should all be considered in product development and marketing decisions. For this reason, a literature review concerning the power add-on unit (PAU) consumer was conducted prior to extensive design efforts. Information concerning these possible consumers has been continually collected throughout the research project and the results are presented in this section.

There are two basic scenarios which define the target consumer for the new wheelchair PAU. In the first situation, a manual wheelchair operator will purchase the power assist device for use with long trips and on days when the user is physically not up to par (Gaal and Johnson's Group A user). Since a high energy output is required for manual wheelchair operation, most of the estimated 1.2 million wheelchair users in the United States will require powered wheelchair mobility at least part of the time (Nicosia and Phillips, 1990).

The second proposed scenario for the PAU consumer is an integrated electric wheelchair operator (Group B as defined by Gaal and Johnson). Due to the large, heavy, and bulky configuration of the integrated wheelchair, a special vehicle, such as a van or bus equipped with a wheelchair lift, is needed to transport the chair from one location to another. A wheelchair operator who cannot afford a personal van for

transporting an electric wheelchair can purchase the new power assist device for use with a folding wheelchair that can be transported in a personal vehicle.

There is a potential market for the power assist device with a number of populations which can be identified more specifically than the proposed general scenarios. Some segments of the consumer market are not included in the overall statistics of wheelchair users. However they are categorized, understanding the different segments of the wheelchair consumer population will improve the knowledge base for design decisions, advertising strategy, and targeting specific consumers.

Specific Segments of the Wheelchair Market that May Use the New PAU

Potential assistive device users are categorized by Gitlin (1995) into five groups. Specifically, she identifies the categories as follows:

1) individuals who are caring for a family member (or other acquaintance),
2) older individuals for whom device use may promote safety or reduce the risk of injury,
3) individuals who experience age-related changes or functional decline,
4) those who have a first-time disability or experience multiple chronic conditions,
5) individuals who are aging with a disability.

A wide variety of potential power assist device consumer classifications exist within these five groups. For the purpose of identifying potential market segments, the last two categories will be restructured into those who experience multiple chronic conditions, and those individuals with a first time disability or are aging with a disability.

Each category is listed in Appendix D: Assistive Device Consumers, with more precise definitions of the different market segments which make up the consumer base. Many of these subdivisions of consumers have not been taken into account in population statistics for the disabled. In addition, consumers that fit into the category of Individuals with a First Time Disability or Who are Aging with a Disability, are carefully broken into disability classifications in Appendix E: Wheelchair User Disability Groups.

Additional Wheelchair Power Assist Device Consumers

There are groups in addition to those listed above that may constitute a significant percentage of the PAU market. The three segments within this category of consumer are:

1) third party purchasers of assistive devices (e.g. insurance companies, charitable organizations, government, etc.).
2) quantity purchasers for institutions such as nursing homes, hospitals, etc.
3) companies within private industry that are required to provide wheelchair-type mobility assistance (these may include airlines, large shopping centers, etc.).

These last two groups purchase equipment in mass quantities and can be studied separately to better understand their particular interests. It may even be beneficial to orient new design approaches around the requirements of a large purchaser.

Another consumer which must be considered is the temporarily disabled assistive device user. A short term condition may not merit the expense required in purchasing a wheelchair and power add-on unit. However, there are distributors set up to lease equipment to the temporarily disabled. These leasing agents may be prime

consumers for the new PAU when it is viewed as a temporary item. The extreme cost advantage it has over electric wheelchair units makes the power assist device very attractive in the rental market. This position is enhanced when considering the transportability feature of the device and that the temporarily disabled user is not equipped to handle the special transportation needs of bulky electric wheelchairs.

United States Wheelchair Market

In the United States alone the wheelchair industry is a $475 million-a-year market (Henderson, 1995). This market includes over 100 wheelchair product companies (IDHP, 1991) and a network of some 6000 home health care distributors (Palmeri, 1993). Wheelchair sales are the main focus of health care product sales in the United States with several companies which dominate the market. These companies are discussed here with a short explanation of the marketing strategy which each organization employs. Wheelchair power add-on units and transportable wheelchairs produced by these companies are detailed above in the section entitled Products Currently on the Market.

Invacare, Incorporated

At this time, Invacare Corporation of Elyria Ohio is the leading manufacturer in the home health care business with sales of $411 million in 1994 (Butler, 1995). With wheelchairs constituting the majority of company sales, Invacare took the market over from Everest and Jennings through the early 1980's. In 1979, Everest and Jennings controlled 80% of the wheelchair market which they had monopolized for decades. The monopoly was broken in 1979 and many smaller companies took the opportunity to expand their stature in the wheelchair field (Hotchkiss, 1993). Invacare, which had been a small division of Johnson and Johnson, became independent and lead the competition. Invacare's strategy involved strengthening the distribution network through the home health care dealers, offering prepaid freight on guaranteed 48 hour deliveries, discounts for volume purchases, and money for financing and group advertising. In 1993, Everest and Jennings retained only 20% of the wheelchair market (Palmeri, 1993).

Quickie Designs, Incorporated

Quickie of Torrance, California is another innovative wheelchair company which is prospering in today's market. Owned by Sunrise Medical Incorporated, Quickie was cofounded by Marilyn Hamilton in the 1970's. Ms. Hamilton incorporated her hang-gliding experience into the wheelchair business by developing lightweight wheelchairs out of aircraft quality aluminum frames. Her idea reduced the overall weight of the wheelchair by 35 pounds and started the ultralight revolution. Being one of the original manufacturers to offer an array of colors for wheelchair frames, Quickie is now able to capture 60% of the ultralight market which is worth $80 million a year. Quickie is able to maintain this lead with a product which sells for more than twice the cost of its competitors (Hobson, 1990 and Palmeri, 1993).

Redman, Incorporated

One of the few long-standing wheelchair companies, Redman, is located in Tucson, Arizona. Redman has been in the business for over 30 years and boasts of a consumer-

oriented business operation. They currently provide over 1500 service representatives nationwide and emphasize dealing directly with the consumer.

Invacare, Quickie, and Everest and Jennings are the main wheelchair manufacturers in the United States. Companies in this industry grow not only through internal expansion, but through aggressive acquisition of other companies in the home health care business. For example, within the past two years, Invacare has acquired at least fifteen smaller companies in the health care market. Sunrise Medical, the parent company to Quickie, has a similar acquisition record over the past two years; though not as extensive as Invacare.

Many of the remaining home health care products companies either provide a specialty product or they distribute products from one of the companies discussed above (e.g. Sears, Roebuck and Company). The available power attachment products for manual wheelchairs have operational disadvantages, are expensive (an average cost of $2600) devices, and are without many options.

Estimated Market Size

The Gaal and Johnson (1993) PAU evaluation team indicated that data concerning the sizes of potential PAU markets are strongly needed. They were not able to produce good estimates of the numbers of potential consumers in the United States. However, through some informal inquiries, the researchers were able to identify some interesting estimates.

Among the experts participating in the PAU evaluation were two physical therapists who work at a very large rehabilitation hospital, and two wheelchair dealers who are major wheelchair suppliers for the San Francisco area. Each of the physical therapists estimated that, if available, his/her department would prescribe an "ideal" PAU approximately thirty times per year (with varying high and low estimates). One wheelchair dealer estimated potential sales of ten per year and the other estimated selling twelve PAUs per year. A separate wheelchair dealer encountered and interviewed at an Abilities Expo, claimed that he sells about fifteen of the Damaco PAUs per year. None of these numbers can be considered hard data to base projected sales upon, however, they do offer a starting point for establishing a need for PAUs on the market. With a possible consumer base of over 1,000,000 people, there is certainly room for innovative new products in the current market.