Development of Systems of Alternative Motorization for Conventional Wheelchairs

Flávia Bonilha Alvarenga
Campinas State University
flavia@fem.unicamp.br

Franco Guiuseppe Dedini
Campinas State University
dedini@fem.unicamp.br

Abstract: In this work the main objective is the development of systems for the motorization of conventional wheelchairs. Most of the simplest types of wheelchairs now available in Brazil do not allow the pure and simple conversion to motorization. In this aspect, the problem comes as a challenge because the great variety of models and types of wheelchairs and the lack of a rigorous normalization demand the use of technologies so as to search for solutions and apply methodological know how and a systematical approach of project. In this way, first a study will be carried out on the wheelchair, consisting of: history, origin, type and characteristics. The following step will be to search for possibilities of motorizing conventional wheelchairs, their limitations and applications. Eventually, after the definition of a basic type to serve as a model, the systematical approach of the project will be applied for the development of a product and the execution of a prototype in scale or its function for the evaluation of possibilities. In the development of the product, a methodology and system of project will be used. The objective of this work is study the possibilities of motorizing a conventional wheelchair. This article analyses the possibilities of motorization.

1. Introduction

Wheelchairs and similar technologies are advancing at an accelerated pace. The research on the use of wheelchairs has evolved to focus on long-term usage and the prevention of secondary disability, and to provide greater personal freedom. Advances in medicine have made it possible for more people with disabilities to live longer and healthier lives (COOPER, 2000).

This has resulted in a demand for better products that adapt over an individual's life span and that facilitate the ability to participate in a greater variety of activities.

Advanced engineering techniques have been applied to promote the goals of wheelchair users, their families, and the communities in which people live. Recognizing the challenges of designing and developing devices and techniques to improve wheelchair designs and in some cases to create entirely new technologies has created an interest among engineers worldwide in the field of rehabilitation engineering. By improving the functional capabilities of people with disabilities, community integration, employment, and full participation in life is more likely to occur. This special issue represents a significant effort to attract scientists (COOPER, 2000) and engineers working on system, processes, and technologies to promote the independence and well being of people with disabilities.

For many people, recapturing independence is their single most significant achievement. The purpose of this project is the analysis of the possibilities of conventional wheelchair motorization.

The main objective is to demonstrate that it is possible to motorize a conventional wheelchair. The important design considerations, the system design and an experimental prototype will be discussed. The contribution of the project is the modeling, simulation and control of hybrid mobility systems. The important design considerations, the system design and an experimental prototype of a chair will also be discussed.

2. Wheelchairs

Despite rapid scientific and technological progress in allied disciplines, there has been very little innovation in wheelchair design over the last 200-300 years. The folding wheelchair came in 1933, and powered wheelchairs were developed in the early 1970. New materials such as plastics, fiber-reinforced and composites and beryllium-aluminum alloys have found their way into the design and manufacture of lighter, stronger and more reliable wheelchairs. The wheelchair industry has also benefited from the development of lighter, efficient, durable and reliable motors, better amplifiers and controllers and most important of all, superior batteries (WEELMAN, 1995).

There is considerable research and development activity focused on wheelchairs. Since the user is in intimate physical contact with the chair for extended periods of time, the contact surfaces especially the seat requires a certain degree of customization to ensure comfort. Commercially available standup wheelchairs afford better seating and reaching, relief from pressure sores, and better health (WEELMAN, 1995). They also allow users to operate equipment designed to be operated by standing people and improve the quality of social interaction with non-disable standing people.

See Table (1) for a brief survey of available solutions. However, most of these solutions are not appropriate.

he conventional wheelchair is comprised of four ground engaging and narrow width wheels. Two of them with large diameter are mounted on an axle positioned below the seat portion of the chair. The other two with smaller diameter (usually castor wheels) may be positioned on front or behind the large ones. The occupant of the wheelchair is seated in a way so that the lower portion of his/her legs will be generally perpendicular to the ground. The wheelchair can be powered manually either by the occupant, another person or a motor (BECKER, 2000a).

Conventional wheelchairs are difficult to maneuver in confined spaces because they only have two degrees of freedom (forward /backward movement and steering) (COOPER, 2000). While motorized wheelchairs with sophisticated controls are well suited for locomotion on prepared surfaces, most are unable to surmount common obstacles such as steps and curbs. Previous research in rehabilitation engineering has concentrated primarily on constructing a better wheelchair. Many special purpose aids, such as stair climbers and customized outdoor buggies, have been developed to solve these problems, but they tend to be customized to a particular environment and are not versatile.

The wheelchairs can be classified into three different classes (BECKER, 2000b):

Manual:

- Standard – four wheels with support for the arms and support for the backs. Example: Standard, Everyday Chairs, Child/Junior Chairs, Specialty Chairs;
- Lightweight/ Sports Chairs – without arm support and with support of the lowest backs;

Powered:

- with maximum speed varying from 6 to 15 km/h;

Table 1 – A survey of available methods (technology) for enhancing mobility.

Solution	Advantages	Disadvantages
Architectural modifications (curb, cuts, ramps, accessible elevators)	Usually low cost to consumers. Assists all ages and abilities. Often a simple technology with low maintenance. High consumer acceptance.	Regulations do not apply to private or historic buildings. Apply only in limited measures to apartment buildings. Many buildings do not comply with the law. Not applicable in most outdoor settings.
Transfer technologies	Can transfer to the vehicle most appropriate for the environment.	May require assistance with a transfer.
Stair climbing wheel-chairs	Allow access to certain wheelchair inaccessible environments.	Does not generalize to other environments, does not work on all types of stairs, often a bulky addition to the wheelchair, slow to deploy, poor maintenance.
Customized chairs (out door buggies)	Optimized for the environment.	Requires transfer.
Curb climbers	Low cost. For example, golf carts, outdoors chairs and special purpose sand buggies.	Suitable for only small obstacles, due to power limitations of the wheelchair.

Others:

- Scooters;
- Wheelchairs for bath;
- Chairs that position the individual on foot, specialty chairs, etc.

3. Manual Wheelchairs

The object of this topic is to provide the reader with a basic introduction to manual wheelchairs.

A manual wheelchair requires good upper body strength. Some manual wheelchairs are called lightweight wheelchairs. The new materials that are used today for the frame and wheels of the chairs are lightweight. These chairs can weigh from 12 lbs. to 45 lbs. Power "add-on" units with a battery can be added to a manual chair. The small power unit is helpful for long or difficult pushes (ABLEDATA, 1994a).

Thirty years ago there was no need for a "fact sheet" on manual wheelchairs. Someone needing a wheelchair at that time simply would have gone to a doctor and received a prescription for a wheelchair, and that chair would have been fairly standard in size and appearance. It would have been a heavy, metal chair with black or dark green upholstery. Nothing else was available (ALVARENGA AND DEDINI, 2001).

Figure 1: Manual Wheelchair

That era has passed, and today's active wheelchair user has literally hundreds of options available. Manual wheelchairs come in sporty styles and stylish colors, and can be made of lightweight composite materials, which greatly reduce their weight. The challenge today is to select the wheelchair, which most directly meets an individual's needs [5,6].

4. Cost of Manual Wheelchairs

The cost of a manual wheelchair can go from approximately US$500.00 for an institutional chair to more than US$4.000.00 for a customized lightweight wheelchair with "all the trimmings." Most lightweight manual chairs, depending upon the manufacturer, are in the US$1.800.00 to US$2.800.00 range. The price of a conventional wheelchair in Brazil is around R$ 130.00. These figures should not be used, however, to suggest an "appropriate price" for a wheelchair for any specific individual; special accessory needs or customization required to accommodate specific disabilities could put the actual purchase price much higher (ABLEDATA, 1994a).

Therefore, as most of the wheelchairs in Brazil are manual and the price of the manual wheelchair is more accessible than the motorized one, the possibility of motorizing manual conventional wheelchairs has a successful chance.

5. Powered Wheelchairs

Until 1993, there were two basic styles of powered wheelchairs on the market: The traditional style and the platform-model powered chair. The traditional-style chair, the most common design in use today, is similar in appearance to a standard everyday wheelchair and is reinforced to tolerate the extra weight of a power and control system. These chairs usually are powered by a battery attached behind or underneath the seat of the wheelchair (ABLEDATA, 1994b).

A power wheelchair uses a battery to power or move the chair. This type of chair is heavier because of the power supply and control systems added to the chair. A power wheelchair can have different types of switches to control speed and direction. Switches can be controlled by the movement of one's hand, head, or chin. Some manufacturers even offer voice-activated systems. Seats on some power chairs can raise and lower, recline, or tilt in space (ABLEDATA, 1994b).

The platform-model powered chair consists of a seating platform located over a power base. A variation on the power base concept is a chair that includes built-in lifts to allow the user to raise and lower the seating platform. In 1993, a round-based powered chair called the Hoveround emerged on the market, effectively creating a new classification of powered chair (ABLEDATA, 1994b).

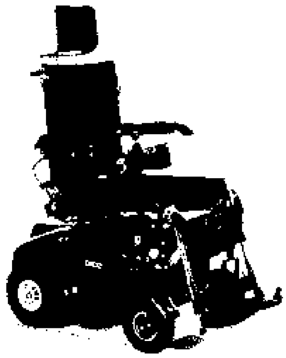


Figure 2: Powered Wheelchair

Powered wheelchairs are systems of high cost and are usually prescribed to users that do not possess strength or motive coordination to work a conventional chair manually. The choice for this chair type should take into account the user's sensorial and motor abilities, as well as their desire to move around in an independent way. The wheelchair can fill in for the users' deficiencies regarding the propulsion of the vehicle, however the user should possess a notion of space and a cognitive factor that allows the use of the vehicle (ABLEDATA, 1994b).

The weight of a motorized wheelchair together with the user can reach more than 120 kg and, maximum speeds, in the order of 2 to 15 km/h (ALVARENGA, 2002).

6. Cost of Powered Wheelchairs

Anyone who has purchased or is considering the purchase of a powered wheelchair should be aware of the expense of buying and maintaining them. The purchase price of a powered wheelchair is rarely less than US$3.500.00; for the more deluxe models or those with specialized adaptations, the price can exceed US$12.000.00 and be as high as US$20.000.00 or more (ABLEDATA, 1994b). Thus, a powered wheelchair is a major financial investment. As any major financial decision, the purchase of a powered wheelchair should be undertaken with the utmost care to ensure the product meets the needs of the individual who will be using it.

7. Wheelchair users

A lot of priority in access issues appears to be given to wheelchair users. This may be partly due to the fact that a single step onto a pavement or into a building can create a total no go area for most wheelchair users.

Many wheelchair users can get up a 12mm (1/2") step but even this can cause difficulties or at least a bump and jarring. A number of wheelchair users have spine problems, which means that bumping and jarring can cause considerable pain and may put them out of action for several days.

Wheelchair users are expected to climb steep ramps, squeeze through narrow openings, beg for things out of their reach, crane their necks upwards to join in conversations, push open heavy doors with one hand while trying to move and steer their wheelchair with the other one (ALVARENGA, 2002). Most of these indignities are due to the thoughtlessness of companions or designers. They do not necessarily want everything done for them but a few changes in the environment built around them would give them back their independence and self-respect. It is up to service providers, developers and designers to make their world a better place.

8. Ergonomic aspects

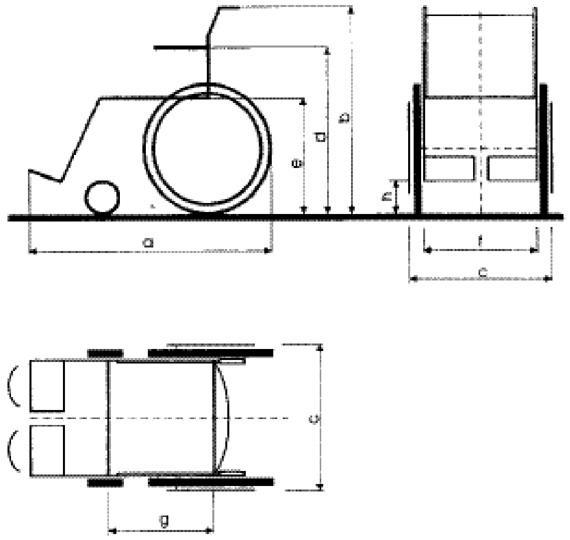
The integration of the disabled into the able bodied population, requires shaping common life and the work environment for this specific population. For this purpose, it is necessary to determine the anthropometric characteristics of the disabled people.

JAROSZ (1996) obtained anthropometric data of adult wheelchair users. The study embraced 170 disabled people (101 men and 69 women) using wheelchair and having the upper extremities sufficiently efficient to perform professional activities. The subjects were aged 18-39, the age of optimum professional capacity.

Mean dimensions of the wheelchairs were assumed according to studies conducted in the Institute of Industrial Design (JAROSZ, 1996). See Figure 3.

JAROSZ (1996) concluded that the measurements of wheelchair users are different to the able bodied users. So disabled people require special products and special workspace. The maximum sagittal reach and the maximum transverse reach of the disabled are smaller than the able bodied. It happens because of the lack of exercises and the atrophy of the members.

Many wheelchair users have to perform daily and professional activities exclusively in the wheelchair. Therefore, the wheelchair user should be treated as an integral unit together with the chair (the human-chair system) (ALVARENGA, 2002).



a- total length	1250 mm
b- total height	950 mm
c- total breadth	660 mm
d- arm rest height	760 mm
e- seat height	530 mm
f- seat breadth	430 mm
g- seat depth	430 mm
h- foot rest height	300 mm

Figure 3: Mean dimensions of wheelchair (JAROSZ, 1996).

9. Morphological Method

The wheelchair is arguably the most important therapeutic tool in rehabilitation. There are currently 1.6-2.0M wheelchair users in the USA. Manual rear-wheel-drive wheelchairs represent the majority (~75%) of prescription wheelchairs (KIRBY, 1996). The cost of a motorized wheelchair is a very high investment, thus most users opt for the conventional manual wheelchair (Alvarenga, 2002).

The motorization of the manual conventional wheelchair enables disabled people to perform many activities in their daily lives thus improving the quality of their lives (ALVARENGA, 2002). The objective of this article is to study the possibilities of motorizing a conventional wheelchair. The alternative motorization types, their limitations and applications are also presented.

Morphology is the science of relationships between ideas and actions, founded and developed by Swiss (American) astrophysicist Fritz Zwicky. The resulting technique of creativity aims at replacing the subconscious mind, which is driven and therefore arbitrary, with a random production of ideas by a conscious, systematic approach (ZWICKY, 1948). When handling this data, it is possible to analyze the possibilities of motorization of conventional wheelchairs For this purpose, the Morphological Method is applied. See Table (2).

Many configurations were explored and some were discarded because they were not versatile enough. Four possibilities were chosen (ALVARENGA, 2002):

- Motorize the rear wheels of the conventional wheelchair;
- Substitute the two rear wheels for two motorized ones;

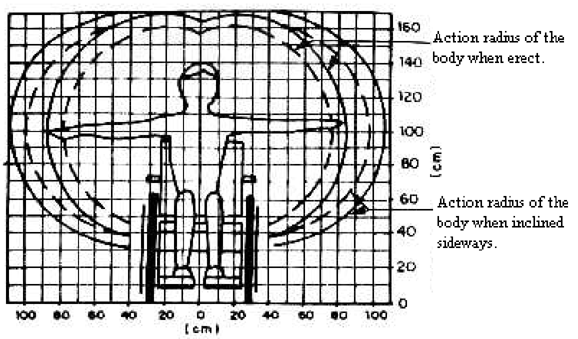


Figure 4: Maximum Sagittal. Reach (ABNT, 1994).

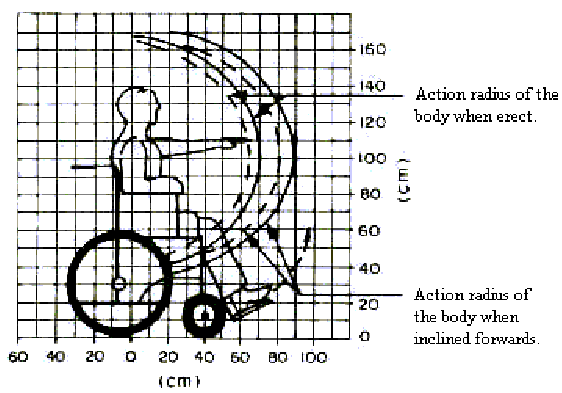


Figure 5: Maximum Transverse. Reach (ABNT, 1994).

Table 2 – Morphological Method (ALVARENGA, 2002).

Parameters	Partial Solutions					
Motorization	Substitute one caster wheel	Substitute two caster wheels	Motorize two rear wheels	Add a fifth motorized wheel	Substitute the two rear wheels for two motorized ones	Motorized Platform
Transmission	Belt	Gear	None	Chain	Diameter of the wheel	Pulley under pressure
Amount of motors	1	2	3			
Drive System	Differential of rear Wheel	Differential of caster wheel				
Speed	2 km/h	6 km/h	10 km/h	15 km/h		
Load capacity	50 kg	70 kg	85 Kg	95 kg		
Amount of batteries	1	2				
Running time	2 hours	3 hours	4 hours	6 hours		
Energy Accumulator	Steering wheel of inertia	Battery	Spring	Capacitor	Compressed air	None
Sistem to set in motion	Joystick	Push rim	Button	Magnetic field	Voice	Turn of the wheel hub
Recharge	Alternator	Cell photo-electric	AC 220/110V	None		
Brake system	Lever	Invert rotation	Reduction of motor	Manual (push rim)	Lock motor	Magnetic
Drive system control	Joystick	Voice	Manual	Sensible screen	Ball roll-on	keyboard
Assembling of the kit on chair	Fastener	Fitting with a locking system	Screw	Fitting with a locking system with pressure	Powered wheel hubs	
Assembling of the drive system control	Fastener	Fitting with a locking system	Screw	Velcro	Pressure	Lever arrested in the frame

◆ A motorized wheel installed with elevation of the front part of the wheelchair;

◆ Motorized wheelchair platform.

10. Analysis of the Solutions Found in the Morphological Method

The objective of this item is to analyze and to compare the four solutions found in the Morphological Method.

The solution for motorizing the two rear wheels by means of pulleys that transmit the power of the motor to the wheels is a good alternative for motorization. So as to be easily removable from the wheelchair, the intention is to use the kit when necessary. A lever puts the pulleys in contact with the back wheels however, the disadvantage of this system is that the pulley is directly in contact with the wheel, which unfortunately carries dirt and/or even cutting and sharp objects coming from the environment in which it circulates. This could damage the transmission system. Another disadvantage is that the transmission supplies a very small shipment capacity, approximately 50kg, which does not fit the general public the majority of times. In addition, the system offers a maximum speed of 2 km/h, which is not always what is desirable. (ALVARENGA, 2002). See Figure 6.

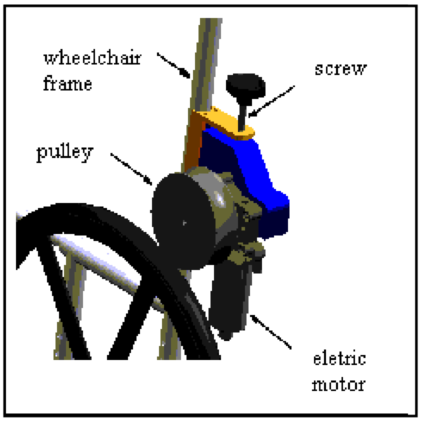


Figure 6: Motorizing the rear wheels.

To substitute the two rear wheels for two motorized ones (Figure 7, 8) is quite an interesting option. The manual wheels are removed and the motorized wheels are "plugged in". With a turn of the wheel hub, users can choose between a manual or power operation. The joystick control is mounted onto the wheelchair frame. This component is quickly released for easy removal. The nylon battery pack is attached using Velcro straps. Only the battery pack needs to be removed to fold the wheelchair.

Another advantage is that motorization kit can be retrofitted to most manual wheelchairs, and this system bears all the advantages of a powered wheelchair. The disadvantage is that in order to set up the motorization kit, it is necessary to disassemble the chair, removing the conventional wheels and adapting the motorized wheels and this cannot be done by the person who is sitting in the chair. There is also the problem of carrying "extra" weight when using the chair in the manual way, which is totally undesirable for the wheelchair users.

To install a motorized wheel with the elevation of the two front wheels is an option that turns the configuration of the wheel chair into a tricycle. This system excludes the front wheels that can affect the movement and the stability of the chair (BECKER , 2000b). The control of the direction is only in this wheel that is at the same time both motor traction and director. It is a system that is easy to build and it is also adaptable to most chairs. However, to set it up means it is necessary that the user vacates the chair, causing dependence on another person.

The motorized wheelchair platform is the most interesting solution to be developed. It presents the flexibility of using it when necessary, in other words, for ramps, to travel long distances, etc. (ALVARENGA, 2002). The problem of

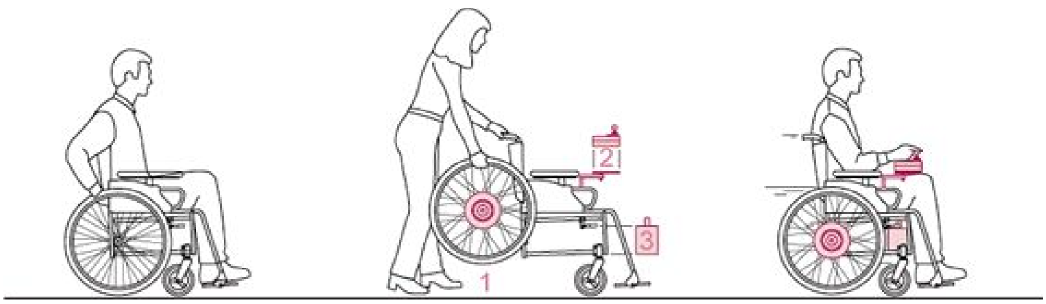


Figure 7: Substitute the two rear wheels for two motorized ones.

Figure 8: Substitute the two rear wheels for two motorized ones.

carrying weight that is usually criticized by the users does not occur with the use of the platform, because the weight of the platform is necessary to transfer the center of mass of the system forward in order to provide stability. And when the user needs to use the wheelchair manually, he spares the platform, not carrying surplus weight. The platform should possess an intelligent system to obey the user's commands and to obey commands pre-established in its programming (ALVARENGA, 2002).

The system's E-motion is equipment that can be used for conventional wheelchairs, and it can be set up in most chairs. The equipment offers three potency levels that can be selected by means of a button (Figure 9). The first stage offers 30% attended potency and it is used indoors. The second stage provides 50% potency outdoors on level ground while the third stage 100% on irregular ground. The sensibility (Figure 9) can be adjusted independently in each wheel through the sensors that are located in the wheels. The brake system is also servo assisted and the user works it through the hoop propeller. The batteries are inside the hubcaps of the wheels (Figure 9) and the system possesses a visual indicator that shows the load of the battery and a sound indicator that is activated when the battery reaches a certain load level.

n all the models found in the current market, the problem of the weight that is added occurs with some manual wheelchairs when the motorization is dispensable, that is to say, when the user wants to use the chair manually.

In this work a platform for wheelchairs was idealized. The user in his/her conventional chair goes to the platform and places the front wheels of the chair into the slots fitted for them on the platform which supports the front wheels.. At this moment, (when the wheels are already locked) a sign informs the user that the system is ready to be used. A command is made using a joystick (that is used to travel in the trajectory defined by the user) that is available on the platform and that the user should place on the arm of the chair using Velcro. This way the user can choose the position

Figure 9: Selecting the potency, the sensibility and dismounting the batteries' E-motion.

Table 3 – Comparison of the models of alternative motorization.

Characteristics	JWII	E-Fix E20	AACD	E -motion
Speed	6 Km/h	1.5 a 6.5 Km/h	maximum : 2 Km/h	0 a 6.5 Km/h
Motors	2 x 60Watts	2 x 75 Watts	2 x 30 Watts	2 x 150 Watts
Batteries	-	2 x 12 V / 12 Ah	12/9 A	2 x 24 V / 2.4 Ah
Autonomy	2 h	16 Km	2 h	13 Km
Weight Kit	17.2 Kg	26.7 Kg	11 Kg	24 Kg
Capacity	-	-	50 Kg	-
Motorization	On the wheel hubs	On the wheel hubs	Pressure in the wheels	On the wheel hubs
Price	-	US$ 7.450.00	R$ 700.00	US$ 5.995.00

of the control (right or left). After use, the platform is disconnected, and the wheelchair becomes manual again.

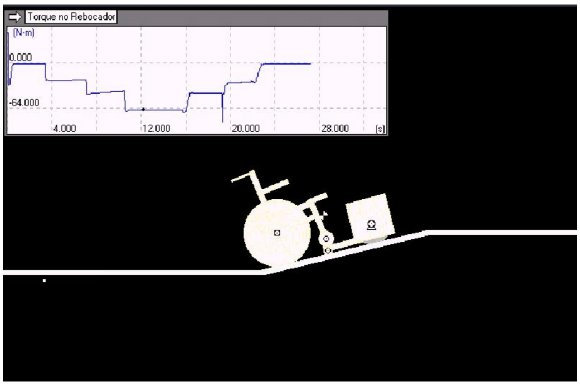


Figure 10: Simulation of the wheelchair platform.

The motorized wheelchair platform was simulated in the software Working Model so that the specified values were tested. The purpose would be for the group to go up ramps with a 10% inclination. The drawing used as a model is very simple, even so its dimensions and specifications were respected. The user's weight was considered and in the simulation it is visualized as a force of 1.000N, see Figure 10.

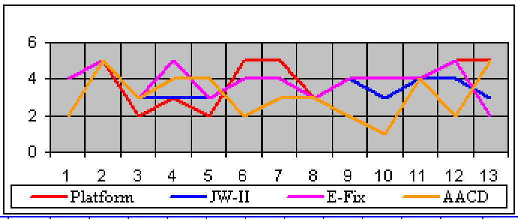
11. QFD (Quality Function Deployment)

QFD (Quality Function Deployment) was developed in Japan during the 60's by Akao and Mizuno as a method for producing development, which aims at fulfilling customer demands. The primary objective of this method is to assure quality as of the early stages of project development (AKAO, 1996). The QFD is a method, which enables the deployment of customer requirements into measurable quality characteristics in order to create products and services, which

	Custumer Needs	Importance weight	Potency	Turn diameter	Attack angle	Weight	Dimensions	Reliability	Useful life	Amount of motors	Autonomy	Noise level	Availability	Control system	Cost	Platform	JW-II (Yamaha)	E-Fix	AACD dispositive	Objective	Percentage	Points of Sale	Importance	Weight	Normalized weight
			1	2	3	4	5	6	7	8	9	10	11	12	13	A	B	C	D	E	F	G	H	I	J
1	Agility	27	●							●						3	4	4	3	3	1.0	1.2	27	32.4	5.9
2	To go up ramps	30	●							○						5	4	4	3	5	1.0	1.5	30	45.0	8.2
3	Maneuverability	23		●			○			○						4	5	5	4	3	0.7	1.2	23	19.3	3.5
4	Cross obstacles	18	○		●		△									2	3	3	2	2	1.0	1.0	18	18.0	3.3
5	To be light	30	○			●	○									1	2	3	4	2	2.0	1.2	30	72.0	13.2
5	Compact dimensions	30		△		○	●									3	3	5	4	3	1.0	1.2	30	36.0	6.6
6	Easy maintenance	26						●					○			5	3	2	3	4	0.8	1.0	26	20.8	3.8
7	Durability	26							●				△			5	3	3	1	5	1.0	1.2	26	31.2	5.7
8	Flexible motor system	30								●	○				△	5	3	3	4	5	1.0	1.5	30	45.0	8.2
9	Running time	26						○			●					4	4	4	2	3	0.7	1.5	26	27.3	5.0
10	To be silent	30										●				4	4	4	3	3	0.7	1.0	30	21.0	3.8
11	Few breaks	26						○					●			5	4	4	3	5	1.0	1.5	26	39.0	7.2
12	Several speeds	27	○							△				●		4	5	5	1	4	1.0	1.2	27	32.4	5.9
13	Control ease	30												●		5	4	4	3	5	1.0	1.2	30	36.0	6.6
14	Parking brake	20												△		5	4	4	2	4	0.8	1.2	20	19.2	3.5
15	Indicator of load of the battery	25						△						△		5	5	3	1	3	0.6	1.0	25	15.0	2.7
16	Alert system in case it falls	16												△		5	1	1	1	2	0.4	1.0	16	6.4	1.3
17	Low price	20							○						●	5	2	2	5	5	1.0	1.5	20	30.0	5.6
																									100.0
																							Total	546.0	

Relationship

●	Strong = 9
○	Medium = 3
△	Week = 1



	1	2	3	4	5	6	7	8	9	10	11	12	13
Platform	4	5	2	3	2	5	5	3	4	3	4	5	5
JW-II (Yamaha)	4	5	3	3	3	4	4	3	4	3	4	4	3
E-Fix	4	5	3	5	3	4	4	3	4	4	4	5	2
Dispositive AACD	2	5	3	4	4	2	3	3	2	1	4	2	5
Importance Absolute	738	237	162	360	447	475	294	699	324	270	338	574	210
Relative (%)	14.4	4.6	3.1	7.0	8.7	9.2	5.7	14.0	6.3	5.3	6.5	11.2	4.0
Ranking	**1**	**11**	**13**	**6**	**5**	**4**	**9**	**2**	**8**	**10**	**7**	**3**	**12**

Figure 11: House of Quality

satisfy those requirements. According to some authors (CHENG et al.,1995; OHFUJI AND AKAO, 1997) QFD benefits include: reduction of engineering changes, complaints, project lead time and costs, increase of customer satisfaction, improvement of communication between departments, and possibility of transmitting relevant quality information from the project to production.

Due to its benefits, QFD has started to be used by companies around the world besides Japan. In the USA, for instance, QFD began in the early 80's. In the same decade, some countries in Europe also initiated the use of the method. The dissemination of QFD in Brazil is more recent, in the 90's (MIGUEL AND CHENG, 2001).

The QFD is a process a translating customer requirements into appropriate technical requirements at each stage of the product development process (DEDINI AND CAVALCA, 2001). In this work several interviews with the wheelchairs users were made in order to obtain the users' real needs in relation to the wheelchair (DEDINI AND CAVALCA, 2001).

After having concluded the construction of the Matrix House of Quality (ALVARENGA, 2002), it was possible to analyze which were the fundamental parameters for the success of the project.

For the calculations shown in the lines of absolute and relative importance it can be noticed that in the project the characteristics that should be privileged are the potency, the amount of motors (system to possess the flexibility in being manual and motorized), the control system and the reliability of the product.

Therefore, for the results of the Matrix House of Quality, the decision was made focusing on the development of the product so that the following needs can be guaranteed (ALVARENGA, 2002):

- To go up ramps and to possess agility;
- To be a hybrid system (manual and motorized) and collapsible;
- To be easy to control;
- To be a reliable system.

12. Value Engineering (VE)

The analysis of the value is a method used to identify and to remove unnecessary costs in the elaboration of projects, manufacture of products, or in the execution of a service.

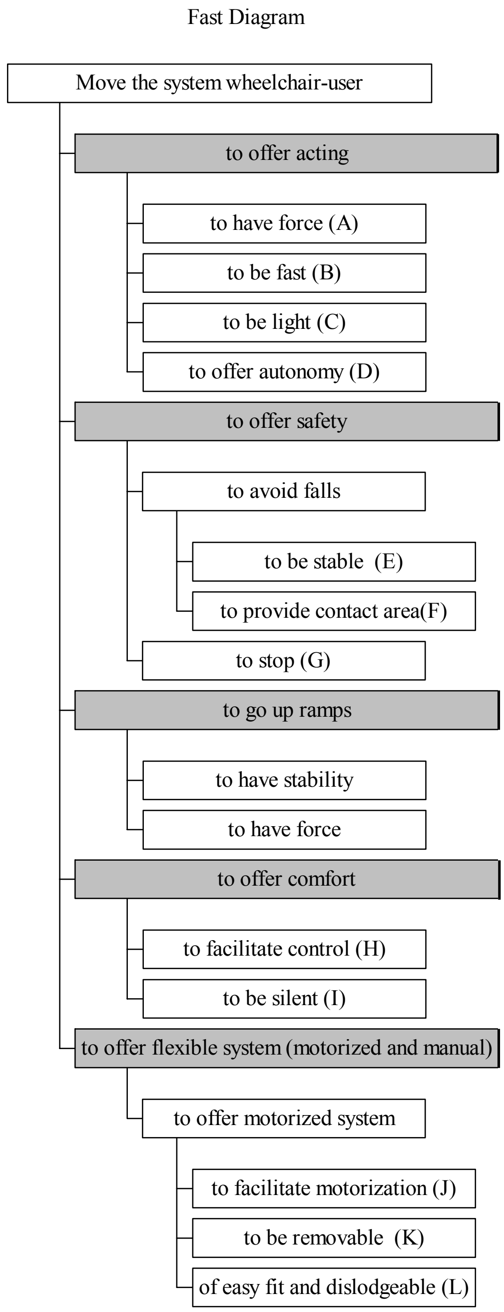


Figure 12: Fast Diagram (ALVARENGA, 2002).

The concept of VE for the methodology of the Value Analysis is the degree of acceptability of the product by the consumer. The functions of the system increase and in order to facilitate the elaboration of the analysis, they were associated to letters. See Figure 12.

Applying the Fast Diagram to the motorized platform of wheelchairs, the following functions were obtained (ALVARENGA, 2002):

A. to be strong;

B. to be fast;

C. to be light;

D. to offer autonomy;

E. to be stable;

F. to provide contact area with the soil;

G. to stop;

H. to facilitate control;

I. to be silent;

J. to facilitate the motorization;

K. to be removable;

L. of easy fitting.

13. Matrix of resource consumption

The matrix of resource consumption is made up of the components in the lines and the lifted up functions in the Fast Diagram in the columns. Its basic function is to divide the cost of the isolated component among the functions that the same carries out, because the same component can exercise one or more functions inside a product. See Table 4.

Table 4 – Matrix of consumption of resources for motorized wheelchair platform.

Functions / Components	A	B	C	D	E	F	G	H	I	J	K	L	Cost
Motor	0.2	0.1		0.8									0.30
Transmission									1				0.06
Battery				1									0.15
Wheel					0.7	0.3							0.12
Control				0.2				0.8					0.20
Structure			0.6							0.4			0.10
Brake System							1						0.05
Assembly system											0.6	0.4	0.02
Percentage (%)	6	3	7	43	8.4	3.6	5	16	6	4	1.2	0.8	1
Ranking	5	10	4	1	3	9	7	2	6	8	11	12	

14. MUDGE Diagram

The Mudge Diagram is a numeric evaluation of the relationships of function importance. This technique makes comparisons in pairs, among all the possible combinations of the functions, also determining every moment that is the most important and punctuating that degree of importance (CSILLAG, 1996). To accomplish the analysis of the value of motorization of the conventional wheelchair, a research was made with wheelchair users. With the results of that research, the functions of the system of motorization of the chair were clear. Using methodologies such as the Fast Diagram and the Compare Method, the costs of these functions were obtained and the importance of each function for the user was quantified.

	B	C	D	E	F	G	H	I	J	K	L	TOTAL	%	Ranking
A	A2	C3	D2	E3	A3	A1	A1	A2	J2	K3	A1	10	8.77	6
B		C3	D1	E2	B2	B1	B2	B1	J1	K3	B3	9	7.89	7
C			D1	C2	C1	C1	C1	C1	J1	K3	C1	13	11.40	4
D				E1	D2	D2	D1	D1	J1	K1	D2	12	10.52	5
E					E3	E2	E1	E1	J1	E1	E1	15	13.16	3
F						G1	H1	F1	J2	K1	L1	1	0.88	11
G							G2	G3	J2	K3	G1	7	6.14	8
H								H3	J1	K3	H2	5	4.39	9
I									J2	K2	L2	0	0.00	12
J										J3	J1	17	14.92	2
K											K3	22	19.30	1
L												3	2.63	10
												114	100.00	

Figure 13: Mudge Diagram for motorized wheelchair platform (ALVARENGA, 2002).

The functions of larger importance for the disabled people were (ALVARENGA, 2002):

1. To be removable;
2. To facilitate the motorization;
3. Stability;
4. To be light;
5. To offer autonomy.

15. Comparison Graph

The Comparison Graph compares the relative costs (originating from the matrix of resource consumption) and the relative importance (originating from the medium line of the Mudge Diagram). The closer the functions lines, the greater the value of the product and consequently the more the consumer will notice.

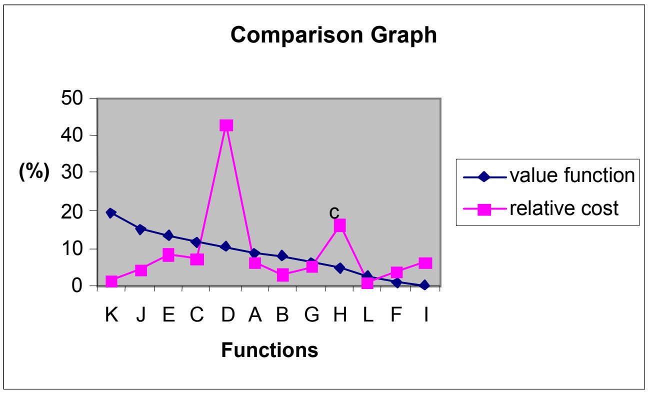


Figure 14: Comparison Graph for motorized wheelchair platform.

Analyzing the Comparison Graph, it can be concluded that the costs of the D, H, F, I functions should be reduced since the costs are larger than the value supplied by the consumer for this items. However, it is possible to improve the quality of the K, J, E, C, B items, because the consumers are willing to pay more for these functions (ALVARENGA, 2002).

The united use of QFD (Quality Function Deployment) and AV (Analysis of value) is valuable for the development of the product. From this union, a new tool appears QFDVA (Quality Function Deployment with Value Analysis) that seeks to obtain as much service for the customer's needs as supplying parameters of financial decision.

Relating the analysis of the value with the results of the House of the Quality, it can be noticed that in relation to the functions, it should reduce the costs. Functions D (to offer autonomy), F (to provide contact area with the soil) and I (to be silent) are of little importance for the consumer, according to the House of Quality. The cost can be reduced without larger consequences in relation to the consumers. However function H (to facilitate the control) is one of the most quoted parameters at the Matrix House of Quality occupying 3rd place (ALVARENGA, 2002).

As for the functions that can have investments for the improvement of quality, functions B (to be fast), J (to facilitate the motorization) and K (to be removable) that are directly related, are linked in agreement with the House of Quality, and with the requirements potency and amount of motors that occupy the first and second placement respectively in QFD. The same happens for function C (to be light) that is directly linked to the requirement weight that occupies the sixth in QFD (ALVARENGA, 2002).

16. Conclusion

A review of the types of wheelchairs was shown. The design and construction of the wheelchair and its component parts can have a marked effect on the performance, energy requirements and durability under various environmental conditions and use patterns The components include wheels, tires, castors, bearings, materials and seats. Each component must be considered in relation to the performance characteristics including rolling resistance, versatility, weight, comfort, stability, maneuverability, durability and maintenance. The motorization of conventional wheelchair satisfies many factors that a wheelchair user needs for his/her mobility, such as going up or down ramps, going long distances, autonomy.

Due to the large number of conventional wheelchairs in Brazil, this motorization will be of great viability and practice given that they can be assembled on a conventional wheelchair. The price of this procedure compared to powered wheelchairs is minimum because of the conventional wheelchair itself.

This article showed the importance of the application of QFD and of the Analysis of the Value in the development of products, especially for the motorization of conventional wheelchairs.

The chosen public for the production of the system of motorization of the wheelchair was the paraplegic adult. After the interviews, it was noticed that the use of the motorized wheelchair within this public is very small, due to the lack of participation, difficulty of transporting, weight excess, very high cost and the user's impossibility to do physical exercises.

Therefore, it was opted to use creative methods to motorize conventional wheelchairs. In this way, the user has the possibility to use the chair: manually or motorized, since the proposed models provide the two uses. The user possesses manual locomotion using the chair by exercising the arms, and in the case of ramps, long distances, it uses the motorization kit, working the motor through a control.

The advantages of a system of this type are: use flexibility, the user has conditions of choosing mechanization or manual locomotion. Another advantage is that the system can be easily removed and the ease of handling the control.

Preliminary experimental results and future research directions are to be developed.

Acknowledgements

This study was funded by CAPES (Fundação Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Brasil).

References

ABLEDATA Fact Sheet n°. 23 July 1994, Manual Wheelchair “www.abledata.com/text2/manwhch.htm”

ABLEDATA Fact Sheet no.24July 1994, Powerd Wheelchair “ www.abledata.com/text2/powwch.htm”.

AKAO, Y. Quality Function Deployment: integrating, customer’s requirements into product design. Cambridge: Massachusetts, Productivity Press, 1996.

ALVARENGA, F.B., “ Desenvolvimento de Sistemas de Motorização Alternativa para Cadeiras de Rodas Convencionais”, Dissertação de Mestrado, 2002, p.192. Unicamp, Brazil.

ALVARENGA, F. B. & Dedini, F.G. Analysis of the possibilities of the Conventional Wheelchairs Motorization, **Proceedings of COBEM 2001- XVI Brazilian Congress on Mechanical Engineering**, Uberlândia – MG, Brasil, Nov.26-30, 2001.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS, Rio de Janeiro NBR-9050: ***Acessibilidade de Pessoas Portadoras de Deficiências a Edificações, Espaço, Mobiliário e Equipamentos Urbanos***. Rio de Janeiro, 1994 , 56p.

BECKER, M., “Suspension system for an all-terrain wheelchair”, Resna, 2000a, pp462-464.

BECKER, M. “Aplicação de Tecnologias Assistivas e Técnicas de Controle em Cadeiras de Rodas Inteligentes”. Campinas: Faculdade de Engenharia Mecânica, Universidade Estadual de Campinas, 2000b, 136p., Tese (Doutorado).

CHENG, L.C. et al. QFD: planejamento da qualidade. Belo Horizonte: Fundação Christiano Ottoni, 1995.

COOPER, R.A. Wheelchairs and related technology for the millennium. **Journal of Rehabilitation Research and Development**, v.37, (3), 2000.

CSILLAG, J. M. **Análise do valor**: metodologia do valor. São Paulo: Atlas, 1996.

DEDINI, F.G. and Cavalca, K. L. **Metodologia e sistemática de projeto**. Campinas: Universidade Estadual de Campinas, Apostila, 2001, 128p.

JAROSZ, E. Determination of the workspace of wheelchair users. ***International Journal of Industrial Ergonomics***, v.17, pp.123-133, 1996.

KIRBY, R. L. Wheelchair stability: important, measurable and modifiable. Technology and Disability 1996; 5:75-80.

MIGUEL, P. A.C. and Cheng, L.C. QFD in Brazil: present status and future perspectives. In: 7th International Symposium on Quality Function Deployment.Tóquio, 2001. pp. 147-152.

OHFUJI, T., Ono, M. and Akao, Y. Métodos de desdobramento da qualidade. Belo Horizonte: Fundação Christiano Ottoni, 1997.

WEELMAN, P. et al., Design of a wheelchair with legs for people with motor disabilities, IEEE Trans. Rehabilitation Engineering , v. 3, (4) , 1995.

ZWICKY, F. The Morphological Method of Analysis and Construction. **Courant**. New York: Intersciences Publish, 1948, pp. 461-470.