APPLICATION OF TOOLS OF THE QUALITY (QFD) IN THE DEVELOPMENT OF THE CONVENTIONAL WHEELCHAIRS MOTORIZATION ALTERNATIVES

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Abstract. *Transportation is vital to full integration into modern society. Mobility is an important issue for people with disabilities. The analysis of wheelchair users requirements its one of the most important factors for effective special needs developments. The experiences of the wheelchair users are feed back to the development achieve real improvement. The objective is to collect information and ideas, which could be used to better coordinate efforts to improve the interaction of the equipment with the wheelchair users needs. The tools of quality (Brainstorming, Morphological Method) are applied to organize the information. The method Quality Function Deployment (QFD) it's be applied to transform the desires and the consumers' needs in technical requirements of engineering. The objective of this work is the application of tools the quality in the development of the conventional wheelchair motorization alternatives.*

Keywords*. QFD, Wheelchair, Disabled People, Mobility, Motorization.*

1. INTRODUCTION

Wheelchairs and similar technologies are advancing at an accelerated pace. The research on wheelchair use 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 their life span to the individual, 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.

The choice of a wheelchair can depend on the nature of the user's handicap, on the activities that he or she practices and on the environment. A person having little activity outside the home may thus choose a wheelchair without a motor, whereas someone who wishes to travel over long

distances may chose a motorized wheelchair. Motorized wheelchairs require no physical effort on the part of their users and can thus be used very easily by severely handicapped persons. However, as they are bulky, it is often difficult to use them in a confined space such as a dwelling. They are, furthermore, difficult to transport and expensive.

For many people, recapturing independence is your single most significant achievement.

The main contribution of this project is to apply tools of the quality in the development of the conventional wheelchair motorization alternatives. The important design considerations, the system design and an experimental prototype of a chair will discussed.

2. WHEELCHAIRS

The 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 fashion such that his/her lower legs will be generally perpendicular to the ground. The wheelchair can be powered manually either by the occupant, another person or by a motor (Alvarenga and Dedini, 2001)

Conventional wheelchairs are difficult to maneuver to constrained spaces because they only have two degrees of freedom (forward /backward movement and steering) (Weelman et.al, 1995). While motorized wheelchairs with sophisticated controls are well-suited locomotion on prepared surfaces, most are unable to surmount common obstacles like steps and curbs. A power wheelchair uses a battery to power or move the chair. This type chair is heavier because of the power supply and control systems added to the chair (Kumar; Rahman and Krovi, 1999).

Figure 1. Manual Wheelchair

Figure 2. Powered Wheelchair

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.

A review of the types of wheelchairs and mean dimensions of wheelchairs were studied (Alvarenga, 2002), to get a base technique for the development of solutions.

The price 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. The price of a conventional wheelchair in Brazil is around R$ 130,00 to R$ 3.100,00.

The purchase price of a powered wheelchair rarely is 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. In Brazil the price is around R$ 4.980,00 to R$ 8.279,00.

The cost of a motorized wheelchair is an investment very loud; soon most of the users ones opt for the conventional manual wheelchair.

3. METHODOLOGY

Assistive technology plays an important role for independent living of people with special needs. Therefore it is a key issue to identify the problems that come up in the everyday use of assistive technology. The analysis of user requirements is one of the most important factors for effective special needs developments. The user involvement in every step of the development procedure is meaningful (Bühler, 1996). Especially the experiences of long-term users are very unexpected inputs (Bühler, 1996). Although some research activities with the user involvement are going on, it still needs more concern in industry and appropriate methodologies have to be established. This experience may stimulate researchers and industrialists to initiate user involvement within their activities.

3.1 Feedback of User Requirements

The direct involvement of users provides important guidance during the design process towards user-friendly and effective products (Bühler and Schmidt, 1993). The use of assistive technology is very common today, but often leads to problems in practice. Concerning independence many problems remain unsolved. Therefore it is a key issue to find out what the practical problems with already used technology and which problems have not been addressed by now. The concept of evaluation and assessment together with the end users is a driving force to the development and use of new technology for people with special needs. It stars with a user- based analysis. In case of emerging technology it discusses user requirements with users and staff and gives them an idea what is possible from technology. Prototyping and test of technology with users during the development (Bühler, 1996).

3.2 Study on the Use of Wheelchairs

In the area of wheelchairs different levels of expertise of users exist. Therefore it is possible to take advantage of this knowledge and to analyze the situation based on long-term use. Bühler (1996) in your study did the investigation of wheelchairs considered chairs in everyday use and the needs and wishes of the users. About 370 users of wheelchairs were addressed in a vocational training- center, in a school, at work places and in living facilities include those of elderly people. This group contains a variety of different impairments and disabilities of different ages and represented a large spectrum of users. Summarized results from the inquiries about wheelchairs: Insufficient seating and posture was the main problem with the basic standard wheelchairs. Many of users gave priority to high maneuverability instead of stability of movement. A lot of suggestions and wishes considered the operability in everyday use: space for luggage, an individual key, spacing for walking aids, integrated charging device, etc. Reliability got the highest attention with electrical wheelchairs. A lot of users also mentioned battery related problems like charging, maintenance or estimation of distance within range (Bühler, 1996).

3.3 QFD (Quality Function Deployment)

The motorization of conventional wheelchair is needed that provides independence, safety and improve accessibility to wheelchairs users.

The first step is to characterize wheelchair frames and determine the feasibility of adding a motorization kit. A survey data was developed to record relevant wheelchair characteristics, and a database was constructed to maintain and organize the information (Bertocci; Karg and Hobson, 1996; Bertocci and Karg, 1997) This survey provided important information such as the location of the center of gravity and the nature of the existing frame configurations with respect to the ease of adding a motorization kit. Another initial step was gather information on the state of the technology in patents.

QFD (Quality Function Deployment) was developed in Japan during 60's by Akao and Mizuno as a method for product development, which aims at fulfilling customer demands. The QFD is a method, which enables to deploy customer requirements into measurable quality characteristics in order to create products and services, which satisfy those requirements. According to some authors (Dedini, 2000) QFD benefits include: reduction of engineering changes, complaints, project lead time and costs, increase of customer satisfaction, improvement of communication between departments, and possibility to transmit relevant quality information from the project to production.

The QFD is a design tool that involves a multidisciplinary design approach. It is a process for translating customer requirements into appropriate technical requirements at each stage of the product development process (Jacques et al., 1994). The process is accomplished trough a series of matrices and charts that deploy customer needs and related technical requirements trough the product development phases. The first step of the QFD process involves developing the matrix known as the House of Quality, which is a basic design tool.

3.3.1 Survey of User Needs

In this work it was made several interviews with the wheelchairs users to obtain the users' real needs in relation to the wheelchair, see Tab. (1). Semi-structured interviews are being conducted with disabled people. The principal structure of the questionnaires is shown in Tab. (1). The first part provides an overview of the user spectrum involved. The second part goes more into technical details and seeks information relating to user experience.

Table 1. Principal structure of the questionnaires

Part 1	**Part 2**
Particulars	Kind of use
Kind of impairment	Ranges of activity
Period of time of wheelchair use	Requirements
Number and kind of wheelchairs	Reliability
Manufacture and model	Security
King of use	Seating /Posture
Ranges of activity	Suitability for traffic
Contentment	Properties of moving
Problems	Usability
Suggestions for modifications	Comfort of motions
	Maintenance
	Practical experiences
	Open problems
	Special wishes

The questionnaires supplied the wheelchair users real needs that were input in the House of Quality.

After having concluded the construction of the matrix House of the Quality (Alvarenga, 2002) it was possible to analyze which the fundamental parameters for the success of the project. For the calculations is 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. Fig. (3) presents the wheelchair users' needs versus degree of importance.

Figure 3. House of Quality – Needs x Importance

Therefore, for the results of the matrix House of Quality, the decision was made of focusing the development of the product so that they can be guaranteed the following needs:

-To go up ramps and to possess agility;
-To be light;
-To be compact or to maintain the dimensions of the conventional wheelchair;
-To be a hybrid system (manual and motorized) and dismountable;
-To be easy to control;
-To be a reliable system;
-To be quick release for easy removal.

After the QFD, it was noticed that the use of the wheelchair motorized in this public is very small, due to the participate lack, difficulty of transporting, weight excessive, cost very loud and the user's impossibility to do physical exercises.

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

3.4 Creativity

Brainstorming is an excellent way of developing many creative solutions to a problem. It works by focusing on a problem, and then coming up with very many radical solutions to it. Ideas should deliberately be as broad and odd as possible, and should be developed as fast as possible. During brainstorming sessions there should be no criticism of ideas.

It was made a brainstorming with the students of graduation of the Mechanical Engineering Faculty - Unicamp, where several ideas appeared, that were selected and organized (Alvarenga, 2002).

4. MORPHOLOGICAL METHOD

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 to replace subconscious mind driven and therefore arbitrary, random production of ideas by a conscious, systematic approach (Alvarenga and Dedini, 2001).

To select and to organize the ideas of the brainstorming, the morphologic method is applied. See Tab. (2).

Table 2. Morphological Method

Parameters	Partial Solutions									
Motorization	Substitute one caster wheel	Substitute two casters wheels	Motorize two rear wheels	Add a fifth motorized wheel	Substitute the two wheels rears for two motorized	Motorized tug	Motorized backpack	Motorize one rear wheel	Motorized kit to push the wheelchair	Motorized Platform to carry the wheelchair
Amount motors	1	2	3	4						
Load capacity	50 kg	85 kg	100 Kg	130 kg						
Transmission	Belt	Gear	None	Chain	Diameter of the wheel	Pulley under pressure				
Energy Accumulator	Steering wheel of inertia	Battery	Spring	Capacitor	Compressed Air	None				
Number of batteries	1	2	3							
Battery pack	1x 24Volt	2x 12Volt								
Battery pack weight -each	10 kg	11 kg								
Battery charger	Alternator	Cell photo-electric	Charging Current	None	Automatic charger	Vehicle converter	Carry along in rear compartment			
Battery weight	1 kg	1,5 kg	2 kg							
Operating Voltage	12 Volt	24 Volt								
Speed	2 km/h	6 km/h	6.5 km/h	7.2 km/h	10 km/h	15 km/h				
*Driving range (per charge)	9 km	16 km	24 km							
Running time	2 hours	3 hours	4 hours	6 hours	7 hours					
Drive System	Differential of rear wheel	Differential of caster wheel	Rear wheel drive	Drive unit						
Turn on	Joystick	Push rim	Button	Magnetic field	Voice	Turn of the wheel hub				
Brake system	Lever	Invert rotation	Reduce of motor	Manual (push rim)	Lock motor	Magnetic	Security key lock			
Controller	Joystick	Voice	Manual	Sensible screen	Ball roll-on	Keyboard	Eye	Card	Rear Wheels	
To arrest the kit in the wheelchair	Fastener	Fitting with locking	Screw	Fitting with pressure	Hook	Clamp	Quick release			
Place of assembly of the kit	Behind the chair	Motorized wheels plugged in	Powered wheel hubs	Below of the seat	In the wheelchair frame	None				
Adding the direction control	Fastener	Fitting with locking	Screw	Velcro straps	Pressure	Lever arrested in the frame	None			
Total weight (excluding wheelchair)	11 kg	17 kg	24 kg	27 kg						

* Dependent upon terrain, weight of occupant and support level.

Combining the motorization types with the parameters, several solutions appear. Handing these data it is possible to analyze the possibilities of the conventional wheelchair motorization. Many configurations were explored and some were discarded because it was not versatile enough. Some solutions are presented:

- Motorize the rear wheels of the conventional wheelchair;
- Substitute the two rear wheels for two motorized;
- A motorized wheel installed with elevation of the front part of the wheelchair;
- Motorized tug;
- Motorized backpack;
- Motorized platform to carry the wheelchair.

5. ANALYSIS OF THE SOLUTIONS FOUND IN THE MORPHOLOGICAL METHOD

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

The solution of motorizing the two rear wheels through pulleys that under pressure in the wheels works the motorization is an alternative that have advantages of the motorization kit to be easily removable of the wheelchair and tends the option of using the kit when necessary. A lever puts the pulleys in contact with the back wheels the disadvantage of that system is due to the contact of the pulley directly with the wheel (that unfortunately carries dirt and/or even cutting and sharp objects coming of the middle in that it circulates and could damage like this the transmission system. Another disadvantage is that the transmission supplies a very small shipment capacity, approximately of 50kg, the one, which the chosen white public if it doesn't frame. In addition the system offers a maximum speed of 2 km/h that not always it is desirable (Alvarenga, 2002). See Fig. (4).

A similar solution is the motorized backpack. The motorized backpack is mounted in the frame coasts of the chair. The motors set in motion the rear wheels. The kit is easily removable for the user. However must be a stability study kit-chair.

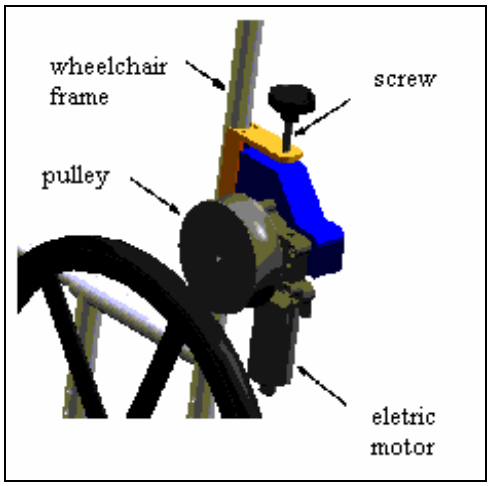

Figure 4. Motorize of the rear wheels.

To substitute the two wheels rears for two motorized (Fig.(5), (6)) it is a quite 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 manual and power operation. The joystick controller is mounted to the wheelchair frame. This component is quick release for ease removal. The nylon battery pack is attached using Velcro straps. To fold the wheelchair, only the battery pack needs to be removed.

Figure 5. Substitute the two wheels rears for two motorized.

Another advantage is that motorization kit can be retrofitted to most of manual wheelchairs, and this system, bearing all the advantages of powered wheelchair. The disadvantage is that to set up the motorization kit it is necessary to disassemble the chair, removing the conventional wheels and adapting the motorized wheels and the seating user cannot make this in the own chair. It is also the problem exists of carrying "extra" weight when it is if using the chair in the manual way, that it is totally undesirable for the wheelchairs users.

Figure 6. Substitute the two wheels rears for two motorized.

To install a wheel motorized with elevation of the two wheels fronts is an option that turns the configuration of the wheel chair in a tricycle. That system excludes the front wheels that can affect the movement and the stability of the chair. The control of the direction is only in this wheel that is at the same time motor traction and director. It is a system easy construction and it is also adaptable to most of the chairs, however to set up it is necessary that the user leave of the chair, causing another person's dependence.

The system E.motion, Fig. (7), possesses the flexibility of power and manual drive in the manual wheelchair. E.motion can be installed on almost any manual wheelchair with a simple bracket installation and its quickly dismantles for transporting. See Fig. (7). Slight pressure to the push-rims propels the wheelchair any direction. Also assists the user when ready to stop. Batteries are mounted in the wheel hubs and can be removed while seated. Indicator lights display battery level. Acoustic signal reminds the user to charge the batteries when low. Wheels are easily removed with the quick release mechanism. Manual wheels are interchangeable with E.motion wheels in most cases. Push-rim sensitivity is adjustable to meet the needs of the user. Each wheel is set to compensate for individually different skill levels. E.motion reduces manual effort up to 80%.

Figure 7. Characteristics of E.motion.

The motorized platform possesses four wheels, being two motors. The user sets in motion a button and the platform transforms into a ramp. The user goes up in the platform and fitted the wheels of its chair in the devices. Thus the user controls the motorized platform to transit freely.

In all the models found in the current market the problem of the weight that is added exists to wheelchairs same manual when the motorization is dispensable, that is to say, when the user wants to use the manual way of the chair.

The motorized tug of wheelchairs is the most interesting solution to be developed in this work. It presents the flexibility of using it when necessary, that is, in ascents of ramps, to travel long distances (Alvarenga & Dedini, 2001). The problem of carrying weight that is criticized usually by the users doesn't exist in the platform, because the weight of the platform is necessary to transfer the center of mass of the system forward larger proportionate stability. And when the user needs to use the wheelchair manually, he spares the motorized tug, not carrying weight surplus.

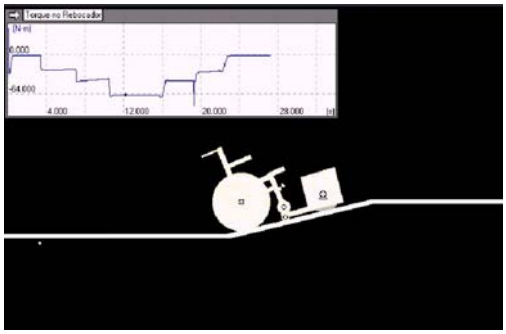

Figure 8. Simulation of motorized tug.

The motorized tug was simulated in the software Working Model 2D so that the specified values were tested. Being verified the group would correspond to the purpose of going up ramps with up to 10% of inclination. The drawing used as model is very simple, even so its dimensions and specifications were respected. The user's weight was considered and it is visualized in the simulation as a force of 1.000N, see Fig. (8).

6. CONCLUSION

This article showed the importance of the application of QFD in the development of products, especially for the motorization of conventional wheelchairs. The morphologic picture of this article can be used for other solutions that should be explored in the future.

The motorization of conventional wheelchair satisfies many factors that a wheelchair user needs for his mobility, like go up or down ramps, go long distances, autonomy.

The advantages of systems presented were: the flexibility as for the use, the user has conditions of choosing the motorization or manual locomotion. Other advantage is the easy removable of the system and the easiness of handling the control for all people.

The goal of this article was to present a design methodology for implementing the needs of wheelchair users. Preliminary experimental results and future research directions will develop.

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8. REFERENCES

Alvarenga, F.B., 2002, “Desenvolvimento de Sistemas de Motorização Alternativa para Cadeiras de Rodas Convencionais", Master Dissertation, Unicamp, Faculty of Mechanical Engineering, Department of Mechanical Design, Campinas,SP, Brazil, pp.192.

Alvarenga, F.B. and Dedini, F.G., 2001, “Analysis of the Possibilities of the Conventional Wheelchairs Motorization”, Proceedings of 16th Brazilian Congress of Mechanical Engineering,Vol.1, Uberlândia,MG, Brazil, pp.26-30.

Bertocci, G.E., Karg P.E. and Hobson D.A., 1996, “Wheeled Mobility Device Classification System and Database”, Technical Report#6, University of Pittsburg RERC on Wheelchair Mobility, Pittsburg, PA.

Bertocci, G.E. and Karg P.E., 1997, “Wheeled Mobility Device Database for Transportation Safety Research and Standards”, Assistive Technology , Vol.9, No.2, pp.102-105.

Buhler, C., 1996 “Approach to the Analysis of User Requirements in Assistive Technology”, Int. J. of Industrial Ergonomics, Vol.17, pp. 187-192.

Buhler, C. and Schmidt, M., 1993, “User Involvement in Evaluation and Assessment of Assistive Technology”, Proceedings of the European Conference on the Advancement of Rehabilitation Technology, The Swedish Handicap Institute Stockholm, Sweden, pp.26 – 28.

Cooper, R.A., 2000, “Wheelchairs and Related Technology for the Millennium”, Journal of Rehabilitation Research and Development, Vol.37, No.3.

Dedini, F.G., 2000, “Metodologia e sistemática de projeto”, Unicamp, Faculty of Mechanical Engineering, Department of Mechanical Design, Campinas,SP, Brazil, Apostila, 128p.

Jacques et al., 1994, “Application of Quality Function Deployment in Rehabilitation Engineering”, IEEE Transactions on Rehabilitation Engineering,Vol.2, No.3.

Kumar V., Rahman T., and Krovi, V., 1999 “Assistive Devices for People with Motor Disabilities”, In Wiley Encyclopaedia of Electrical and Electronics Engineering, Ed. J. G. Webster.

Weelman, P.et al.,1995, “Design of a Wheelchair with Legs for People with Motor Disabilities”, IEEE Trans. Rehabilitation Engineering , Vol. 3, No. 4.

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