

Quality Function Deployment for Motorised Wheelchair

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Abstract — Design of Motorized Wheelchair (MWC) available in India is typical imitations of Wheelchair accessible in foreign countries. As such, there is no systematic approach in the Design and development of Motorized Wheelchairs for Indian users. This paper addresses the application of Quality Function Deployment (QFD) and House of Quality matrix for the Design and development of Motorized Wheelchairs. The discussion of QFD analysis result will identify features for higher customer satisfaction. The paper presents findings of QFD analysis and the design strategies to develop an user friendly Motorized Wheelchair

Keywords — Quality Function Deployment, Motorized Wheelchair, House of Quality, Interactive Design.

I. INTRODUCTION

World Health Organization estimates one billionth of the world population (around 15%) shows some form of disability, and 110 - 190 million people are affected by severe difficulties in functioning [1]. The Global Disability Summit in 2018 (GDS18) also mentions that, out of one billion, 800 million are in developing countries. The data mentioned from the Population Census and National Sample Survey Organizations Board Survey on disability approximates 21 million Indian's (2% of the population) are disabled. The census of disabled Indian population deduces that the rate of disability increases rapidly every year [2]. Also, the number of aging population with chronic health conditions accelerates around the world [3]. Hence disability is a significant barrier that prevents a person from leading a healthy social life. . Impairment also results in a poor quality of education, which leads to unemployment and poverty.

Low-cost wheelchairs can play a significant role in improving this situation and lifestyle of Persons with Disability (PwD). Calladi Motorworks, Freedom Wheelchairs, Elumalai WheelChairs and Mass-Lift Chennai are some Motorised Wheelchair manufacturers in the Indian Market[4–7]. Some of the foldable Motorised Wheelchairs they manufacture are Garuda by Callidai Motor Works which can fold backward,

and Freedom Wheelchairs have X-frames that fold side- ways[4, 5].

II. INTERACTIVE DESIGN IN PRODUCT DEVELOPMENT

(Interactive Design is a structured design approach that evolved from the research and development of cross functional teams [8]. This method ensures better innovative design by user integration in the product development process. Interactive design delivers powerful ways for collaborating design process. In this approach the stake-holders requirements are identified and it is then transformed to technical specifications. This is achieved based upon real understanding of needs of users along with benchmark existing products or competitors available in the market. This method enables the design cross-functional team to get into an agreement, come out with better design concepts and technological options even much prior to the manufacturing of the prototype. For achieving this, the team should use a range of interactive tools such as questionnaires, simulations, analytical methods, numerical analysis, and appropriate design tools to enhance product safety continuously, user experience, product efficiency to minimize life cycle cost by innovative cutting edge solutions [9]. Decisions made during the early stage of concept development can influence operational and maintenance functions. This can significantly affect the system's life-cycle cost. Cost-cutting by applying innovative design and manufacturing techniques at early stages of the Product Life Cycle [10].

A. Quality Function Deployment

Quality Function Deployment (QFD) translates customer requirements into appropriate technical specifications of products [11]. QFD effectively manages product development and process objectively. It is also a customer-oriented development process. Researchers agree that QFD can reduce the duration and number of iterations in product development. Manufacturers such as General Motors, Ford, Motorola, Xerox, Kodak, and IBM apply QFD to enhance the competitive- ness of

the product [12]. Initially, the QFD approach decides the stakeholders and requirements. This study presents users within the range of 25-35 years. Referring to similar surveys and feedback is collected using google forms [13].

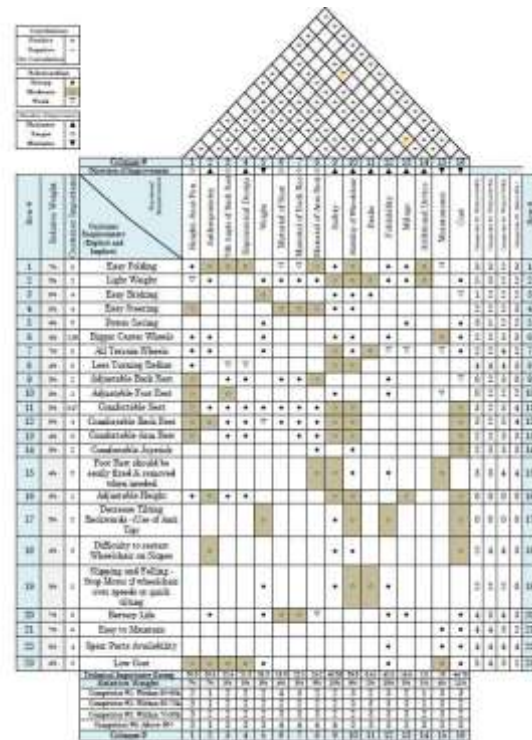
B. Identifying User Needs

A custom questionnaire is designed by researching journals [12], consulting users, and therapists. The surveys sent to Motorized Wheelchair user through Google Forms, and asked to key in the weightage within a scale of 1 (Not Important) to 5 (Very Very Important) for each users requirements. Thirty-one users responded to the questions and the summary is in Table.1. All the results obtained gave an average rating from 2.9 to 4.1. So the scores are assigned from 1 to 5 by making intervals within 2.9 to 4.2[10].

TABLE 1: IDENTIFIED CUSTOMER REQUIRMENTS WITH THEIR IMPORTANCE RATING (1-5)

Sl.No	Requirements	Rating
1	Easy Folding	5
2	Light Weight	2
3	Easy Breaking	4
4	Easy Steering	4
5	Power Saving	3
6	Bigger Caster Wheels	2.96
7	All Terrain Wheels	5
8	Less Turing Radius	3
9	Adjustable Back Rest	2
10	Adjustable Foot Rest	2
11	Comfortable Seat	4
12	Comfortable Back Rest	4
13	Comfortable Arm Rest	3
14	Comfortable Joystick	2
15	Foot Rest easy to fix and remove	3
16	Adjustable Height	2
17	Decrease Tilting Backwards - Anti Tip	2
18	Difficulty - Wheelchair on Slopes	3
19	Slipping,Over Speeds, Tilts - Stop Motor	2
20	Battery Life	5
21	Easy to Clean	4
22	Spair Parts Availability	4
23	Low Cost	3

Product Design Targets achieved by users needs and also benchmark with existing products available from the market. Cross-functional team with design engineers and therapists will finalize on the product design requirements. The identified design requirements with ratings are in Fig. 2.



C. House of Quality

House of Quality refines design requirements (DR) by considering customer requirements (CR) or feed-backs, Benchmark with the competitor product. Cross- functional team assesses the competitor’s products and suitable scores for each product to determine CR and DR. The process aids to benchmark the product un- der development. Fig.1. House of Quality encapsulates the whole process of identifying CR and DR. House of Quality also helps to correlate the product to be de- signed with the help of forming relations of CR and DR through matrices. The cross-functional team assesses competitors products features to benchmark with new product under development.[14].

III. IDENTIFTICATION OF DESIGN REQUIREMENTS RELEVANT FOR INDIAN USERS USING THE QUALITY FUNCTION DEPLOYMENT (QFD) METHOD

On QFD - House of Quality chart in Fig. 1, the central matrix shows the relationship strength of customer requirements versus functional requirements. The symbol in matrix represents whether the functional requirements meet the target value significantly, moderately, slightly, or no impact at all. The symbols in the triangle region show a positive, or negative correlation between the parameters as changes in parameters influence the functional requirements. Customer importance ratings procured through the systematically developed questionnaire is also in the chart. The chart also presents ”Weighted Importance” and

”Relative Importance” rows, which shows the overall result of QFD analysis concerning customer needs and functional requirements. The highest score requires more attention in the development stage as it can improve customer satisfaction.

The technical importance rating in Fig. 2 shows the relative weight-age of functional requirements score after QFD exercise. In functional requirements, ”Cost” secured maximum weight-age. Then the scores obtained were for safety, stability, Anthropometry, Weight, Fold- ability, and Mileage in descending order. Brake and additional device secured minimum score. Mileage in descending order. Brake and additional device secured minimum score.

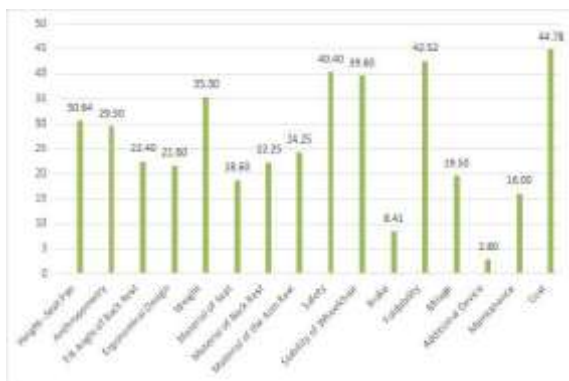


FIGURE 2. Technical Importance Rating

IV. RESULT & DISCUSSION

A. Determination and Assessment of Functional Requirements from Customer Requirements

In Fig 1. Customer requirements and needs are collected through the survey. The QFD Matrix lists frequent responses. A group of experts (Multidisciplinary QFD Team) from Management, Marketing, Design, Production, and Sales, etc., brainstorm the Technical or functional requirements. Target values are set for each Functional Requirement to determine the direction of improvement for better customer satisfaction. The sections below will analyze each Functional Requirement versus Customer requirements and its reasons for its inter-relationships for the functional requirements scored 25 and above [15].

B. Cost

Cost-effectiveness secured Highest Technical Importance Rating, which is 44.78. Even though it is the last Functional Requirements, Highest rating brought it to the limelight as the first one to discuss. Let’s examine each relevant customer requirements to cost to analyze why reducing cost needs

considerable attention from the design team. Reducing the weight of the Wheelchair can cause a significant increase in price. For example, titanium is much expensive than aluminum, stainless steel, and mild steel. So keeping a balance of cost and weight can reduce the importance of the Motorized Wheelchair. A combination of these materials also can reduce weight significantly and according to strength requirements—for example, seat with meshed cloth, legs from aluminum, and armrest made out of plastic. From customer requirement Power saving, the QFD team put strong relation to cost in the case of Motorized Wheelchair. As we all know, when weight decreases, power-saving increases. Bigger caster wheels can also increase the cost, so the QFD team assigned a strong relationship with the two parameters. Bigger caster Wheels can make the Wheelchair All-Terrain, which is liked by the Indian users. Batteries with higher Ampere give the Wheelchair in- creased range, and this will increase the cost significantly when cells like Lithium Polymer increase the value of a Motorized Wheelchair. The Indian users also want to reduce maintenance, and this will eventually re- duce the cost of the Motorized Wheelchair in the long run. The design team can also look out for cheaper ad readily available spares while designing the Motorized Wheelchair.

C. Foldability

Foldability is one of the essential features as per Customers Requirement survey. Technical Importance Rating for foldability scored 42.5 points after careful assessment in QFD Matrix. As the feature folding is vital for the ease of travel of the Motorized Wheelchair user. For Indian users, they need the Wheelchair to fit in the boot of a small car. While improving fold- ability, there is a chance of an increase in weight as it sometimes requires special attachments to lock the movement of the legs. Bigger caster wheels can hinder easy folding as it involves design adjustments in the length of the legs and seat pan to accommodate the caster for easy folding. Adjustable Back Rest and Foot Rest design require extra attention in case of foldable type wheelchairs as it may interfere while folding. A full proof mechanism of foldability is necessary for the safe travel of the wheelchair user. The Battery life should not affect as the feature of foldability can cause a significant increase in weight. The use of readily available and low-cost spare parts is a must in case of new ways of folding.

D. Safety & Stability

Safety and stability score 40.4 and 39.6 subsequently in the Technical Importance Rating scale. Maximum security and balance is something essential a Motorized Wheelchair should offer. The Motorized Wheelchair safety and stability improve if it can undergo tests as per ISO and ASME standards

before it reaches the end- user. Additional mechanical brakes increase the safety of the user as it provides better control during travel, especially on slopes and uneven surfaces. Emergency brakes can also aid the user just in case of an accident. Caster wheels with more width and diameter offer better stability to the Wheelchair. Footrest obstructs the user from getting on and off the Wheelchair. So adjustable or removable footrest provides better comfort and safety. Better design of the footrest avoids the legs getting caught up while getting on and off the Motorized Wheelchair. Anti-tip prevents accidental back- ward tilting of the Wheelchair in slopes. A motor powerful enough to drive the Wheelchair on an uneven surface and when caster gets stuck at small hindrances.

E. Height, Seat Pan & Anthropometry

Height of the seat, dimensions of the seat pan, and Anthropometry subsequently scored 30.6 and 29.5 points in the House of Quality Matrix. Design with Anthropometric data may sometimes affect the foldability. Right Anthropometric constraints can also change the weight of the Motorized Wheelchair. Bigger caster wheels or all-terrain wheels can alter the height of the Motorized Wheelchair. Adjustable height improves comfort and also increases the chances of the Anthropometric fit of the user

F. Weight of The Motorized Wheelchair

Technical Importance Rating for Weight scored 35 in QFD Matrix. Reducing the weight of the Motorized Wheelchair can increase the cost, as lighter metals like Titanium, Aluminum are expensive. If the motorized Wheelchair is lightweight, it will increase the power saving and eventually fetch more Battery life. Different types of caster wheels can vary the weight of the Motorized Wheelchair. So a careful assessment considering user requirement is required to justify appropriate caster wheels. On the contrary motorized Wheelchair gets stable ride as the weight increases.

G. Assessment of few Indian Motorized Wheelchair

The far-right and the bottom sections of the QFD Matrix assesses four types of Indian foldable Motorized Wheelchair. The QFD team determines Motorized Wheelchairs scores for each Customer and Functional Requirements. The process helps to set a benchmark on the areas to improve. After careful assessment of the QFD team scores from 0-5 is awarded for Customer and Functional requirements of Motorized Wheelchairs. The ratings for the Customer and Functional requirements are in Fig. 7& 8. The scores of the customer and functional requirements are from respective product specifications and visual inspection of the MWCs in Fig. 3-6. Further discussion emphasis on features with rating two and below two to improve user satisfaction and better user experience. The

Motorized Wheelchairs from Fig. 3-6 can fold while the user travels. The size of the folded MWC is one of the user concerns. Difficulty in



FIGURE 3. Vissco Zip Lite Power Wheelchair

Folding is another issue MWC users or the attendant faces. Better design changes and innovations are possible to improve the MWC foldability. The MWC in Fig.5 requires disassembling for travel. The weight of the MWC causes difficulty, especially while shifting the Wheelchair from the floor to the car or vice versa. The reduction of MWC weight could cause stability issues. So in case of a reduction of weight, appropriate design changes can increase the stability of the MWC



FIGURE 4. Ergonomic Steel Electric Battery Powered Wheelchair



FIGURE 5: Detachable Back Rest Motorized Wheelchair

Brake is another area of concern for the Indian Motorized Wheelchair. Most of the Indian Motorized Wheelchair stops as the resistance of the geared motor pitches in when the motor stops. Emergency brakes are available in some MWCs. The addition of a mechanical brake can improve the control and stability of the MWC in slopes and cases of emergencies. Adjustable backrest and footrest are features that require some design changes and innovations. Footrest hinders the user while getting on and off the MWC.



Figure 6. Express Power Wheelchair – Vermeiren

Design changes for easy attach and detach footrest or folding backward can improve the MWC user safety

and satisfaction. Footrest hitting the floor while travel from slopes to level floor. Design changes to avoid the footrest hitting the ground will improve safety. The adjustable height of the seat is also an essential feature as the height of the MWC user varies from person to person because of various disabilities like Cerebral Palsy, age, etc. Adjustable height increases the Anthropometric fit of the MWC to the end-user. Many motorized Wheelchairs available in India do not use anti-tip. Anti-tip is essential as it increases the safety of the MWC and protects the MWC user from accidents tilting backward. Following Indian Anthropometric measurements for MWC is vital for better fit and comfort for the user. Indian MWC measurements usually obtained from the MWC available in Foreign Countries and making changes according to user requirements is the method followed as of now. A systematic approach for improving Ergonomics is essential for better user comfort. Determining optimal cost through the right Engineering methods is also vital for Indian Motorized Wheelchairs.

IV. CONCLUSION

The research reported in this paper identified the design characteristics of higher importance. The identified attributes to be focused while designing the Mo Motorized Wheelchairs are Safety, Anthropometry, Stability, Fold-ability and Cost. During QFD the customer was very keen on improving fold-ability, reducing the cost, improving Ergonomics and Weight of the Motorized Wheelchair.

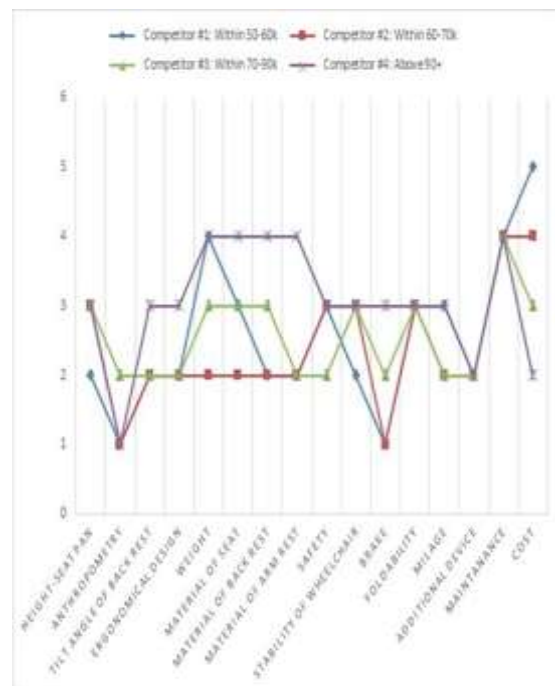


FIGURE 7: Assessment of Customer Requirements on Indian Motorized Wheelchairs

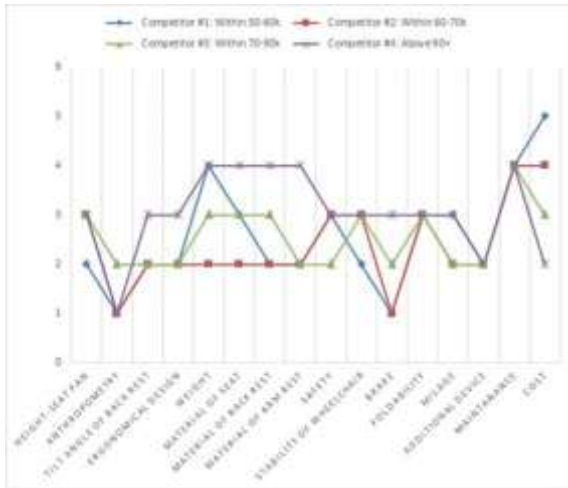


FIGURE 8: Assessment of Functional Requirements on Indian wheelchairs.

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