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Development of an Innovative Wheelchair-Bed for Enhanced Patient Care in Bangladesh: Integrating Comfort and Accessibility Features

Rupok Islam Avi*, R. Rafiul Haque Ayon, Md. Ariful Haque, Shahed Mahmud, Idrak Al Rakin, Shah Md Tasrifur Rahim, Md Fardin Islam
Department of Industrial & Production Engineering, Rajshahi University of Engineering & Technology. Rajshahi-6204
*Corresponding Author. E-mail: rupokislamavi.ruet@gmail.com

Abstract

The incorporation of sophisticated functionalities into assistive devices like wheelchairs has grown progressively essential in meeting the varied requirements of patients who are incapable to move around in Bangladesh. This study investigates the development of a wheelchair-bed with advanced features in order to enable patients who are immobile to have better mobility and comfort. A thorough customer survey reveals a strong desire for enhanced comfort and accessibility features, which are presently absent from current products. The customers' needs are gathered and examined for integration into the product through the use of the Kano Model Assessment, Function Structure Diagram, and Quality Function Deployment (QFD). The Kano Model is employed to organize the product's features, and QFD helped to create the functional structure by translating customer requirements into technical specifications. The function structure also facilitates in designing the product and conducting stress analysis on various parts. This study determines the comfort and satisfaction levels associated with the 180 reclining feature & commode facility integrated in wheelchair. Ultimately, the wheelchair, designed in alignment with customer requirements and competitive analysis, considerably elevates patient care standards while profoundly enhancing the quality of life for individuals with disabilities.

Keywords: Wheelchair-bed, Product design, QFD, Assistive technology, Kano mode

1. Introduction

Disability is a physical or mental condition (the result of impairment) that limits someone's capacity to do daily tasks. Neurological and orthopedic conditions are the top two drivers of physical limitations. Disabled people with orthopedic suffer from the disability of the musculoskeletal system which includes the bones, joints, and soft tissues such as muscles, ligaments, and tendons while also including injuries through birth abnormalities or trauma. Neurological disabilities include disorders of the brain, spinal cord, and peripheral nerves. This is due to interruptions in transmitting signals between the brain and the body.

Wheelchairs are life savers for disabled people because they improve mobility, increase independence, and optimize health outcomes. This allows persons with physical disabilities to perform everyday casual and professional tasks, move through different environments, and engage in social, academic, or occupational activities. The National Survey on Persons with Disabilities (NPSD) 2021 found that 2.80% of the population in Bangladesh is disabled, with a higher prevalence among males (3.29%) than females (2.34%)[1]. Disability is present in 0.87 % of the population aged 0-4 years; this percentage increases to 9.90 % for those aged 65 and older. Male gender predominates across all types of disability and the most common form of impairment among males is the mobility impairment type (1.19 percent), followed by blindness (0.39 percent), deaf-blindness (0.26 percent), and hearing loss (0.19 percent). Only 18.47% of disabled people have assistive tools at all. The major causes for non-utilization are economic factors (24.42%), followed by lack of family help (13.76%), and negative perception of the utilization of this tool (11.65%) [1]. The proposed convertible wheelchair bed is intended to enhance the quality of life for people with restricted mobility. It does this by including features like a 180-degree recline that facilitates a smooth transition from a seated to a supine position, built-in waste disposal and cleaning mechanisms that improve hygiene and convenience. These developments effectively close critical gaps in current assistive technologies by providing greater autonomy, comfort, and respect.

2. Literature Review

Wheelchairs increase access to mobility and independence for persons with disabilities. Several wheelchair designs proposed to meet the variety of users demands. A bed with a commode along with a side turning mechanism to prevent and assist patient care is introduced by Andhare and Onkar (2021)[2]. Akhil et al. (2020) explored an indoor-to-outdoor transformable wheelchair with a removable section that supported the toilet access and it improved indoor maneuvering and transferability [3]. Kumar et al. (2022) focused on an inexpensive bathroom assistive wheelchair, highlighting its ability to allow elderly and disabled patients to easily defecate [4]. Robotic Self-Transfer Device for Wheel Chair Users was introduced by Krishnan and Pugazhenthi (2017) which offered independence in daily activities [5]. Yoon et al. propose a smart multifunctional wheelchair that folds to fit over a public toilet [6]. Áfio et al. addresses the disability access to toilet facilities in healthcare units and community spaces, focusing on design for people who use a wheelchair [7]. Malassigné(2001) et al. describe a wheelchair commode and cleaning system integration, also illustrate developments in the design of new commode-shower wheelchairs[8].

Yukawa et al. (2010) present a complete assistance system that consists of a small mobile robot outfitted with an autonomous portable toilet and an electric wheelchair with a reclining seat that can serve as a portable bed[9] Advanced features include navigation, obstacle avoidance, and customized control options are available in smart robotic wheelchairs, which significantly boost user experience and performance[10]. On the other hand, low-cost, environmentally friendly wheelchair prototypes like bamboo wheelchairs designed for environments with limited resources focus on adaptability and affordability and have garnered favorable user feedback regarding their potential to lower health risks associated with immobility[11].

Wheelchair technology has advanced, yet there may still be gaps in meeting the full range of demands for people who are unable to move. Though there are many advantages to the current solutions such as multipurpose wheelchairs and assistive devices-they frequently do not incorporate all the elements required for the best possible patient care and comfort. By presenting an innovative wheelchair-bed design that not only meets mobility and defecation needs but also incorporates extra features including a 180-degree decline capability, a cleaning system, and a cup holder. Through the application of the Kano Model and Quality Function Deployment (QFD) to prioritize these features and the competitive analysis of market positioning, this research endeavors to offer a comprehensive solution that improves the quality of life for immobile patients.

3. Methodology

The methodology involves conducting a customer survey, applying the Kano model for feature prioritization, performing Quality Function Deployment (QFD), functional structure development and conducting 3D modeling and stress analysis for design validation.

Survey

A customer feedback survey was conducted which included responses from 105 participants. Among them mostly were between the ages of 45 and 60. The data was quite satisfactory because 83.8% of participants used wheelchairs or had family who did. It was noticeable that the absence of accessible features and discomforts with contemporary wheelchairs leads to overall dissatisfaction among users. Respondents highly demanded improved features, such as a 180-degree recline, a defecation system, leg, arm, headrests, a cup holder, and a self-cleaning system in a wheelchair. This indicates that the wheelchair designs that are now in use need to be upgraded regarding accessibility and comfort.

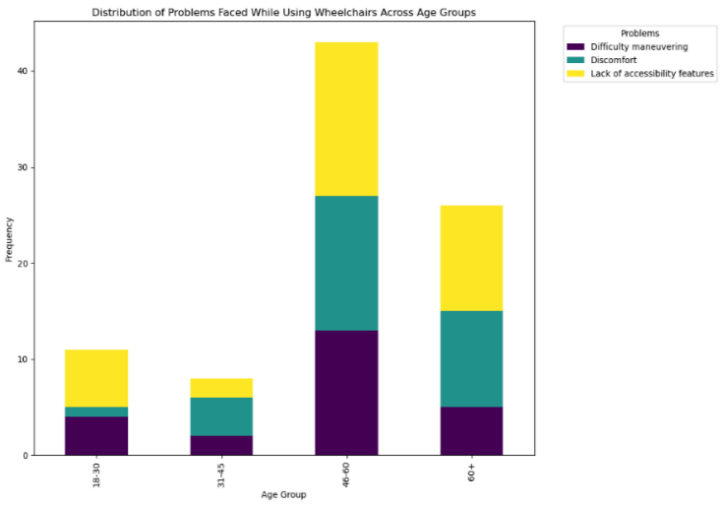


Fig. 1. Problems of current wheelchair users

Kano Model

We did the Kano model customer need analysis which is a tool that differentiates potential features according to users' needs. Based on our survey, we took our 4 popular features and asked 100+ qualified respondents about a pair of functional and dysfunctional perception questions for each feature.

To better comprehend the needs and pleasures of the users, we conducted both discrete and continuous analyses.

Continuous Analysis

The respondents' functional and dysfunctional scores for comparing the features are averaged in four quadrants, Must-be, One dimensional, Attractive, and Indifferent. Fig. 2 shows the result of the continuous analysis.

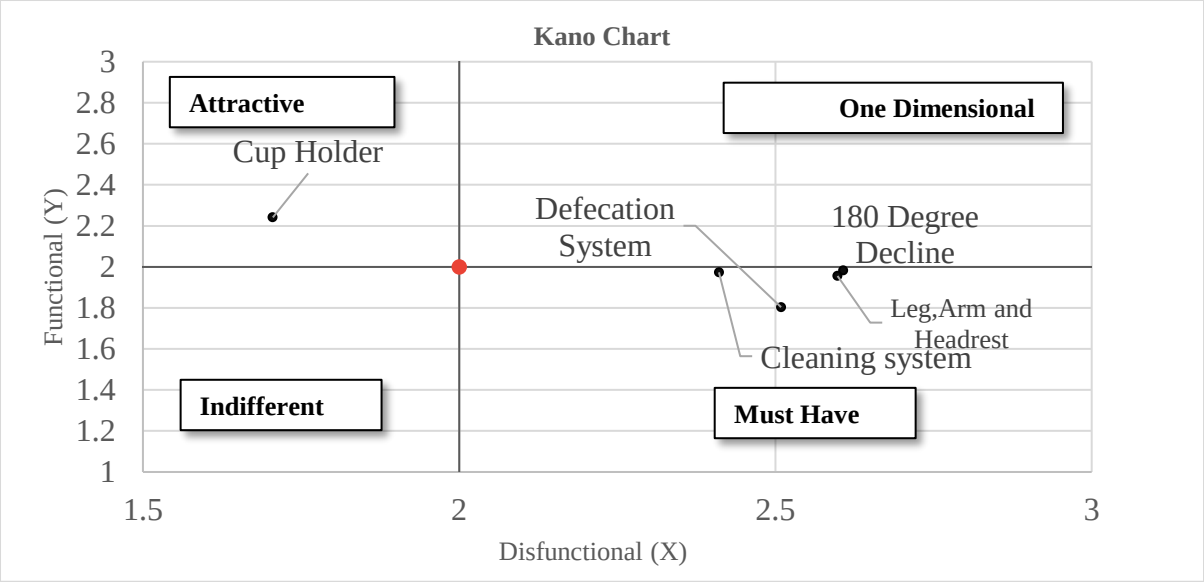


Fig. 2. Continuous analysis of kano model

The chart indicates that the most critical features in the wheelchair bed (those placed in the One Dimensional and Must Have categories) include the Defecation System, 180 Degree Decline, Leg, Arm, and Headrest, and Cleaning System. These features are essential for user satisfaction and should be prioritized in design. In contrast, while features like a Cup Holder can enhance the product's appeal, they are not as critical and can be considered secondary additions.

Discrete Analysis

The customers' answers were projected and evaluated for every feature of our product. In table 1, the features are categorized to represent the largest proportion of the respondents. Discrete Analysis is the preferred way of looking at Kano results as the cut-offs and numerical weights of different categories are not calibratable for each study in continuous analysis.

Table 1. Findings of discrete analysis

Feature Name	M	O	A	I	R	Q	Evaluation
180 Degree Decline	44.54%	14.29%	8.04%	26.79%	3.57%	0.00%	Must Be
Defecation System	43.75%	11.61%	8.04%	30.36%	5.36%	0.00%	Must Be
Leg, Arm, and Headrest	39.29%	14.29%	8.93%	34.82%	0.89%	0.00%	Must Be
Cup Holder	17.86%	15.18%	30.36%	29.46%	4.46%	0.00%	Attractive
Cleaning System	40.18%	9.82%	13.39%	32.14%	3.57%	0.00%	Must Be

Function Structure Diagram

Fig. 3 below shows a function structure diagram, which is a graphical representation of the functions our product performs on its inputs and outputs. The main aim of our product is to enhance the mobility and comfort of users. The primary function is achieved through key subsystems: the Reclining Mechanism for backrest adjustment with a safety lock, the Leg, Arm, and Head Rest for adjustable support, the Defecation System with a removable waste container, the Cleaning System featuring a jet spray and waste collection tray, and the Brake System, which includes both manual brake levers and a wheel brake system for user safety.

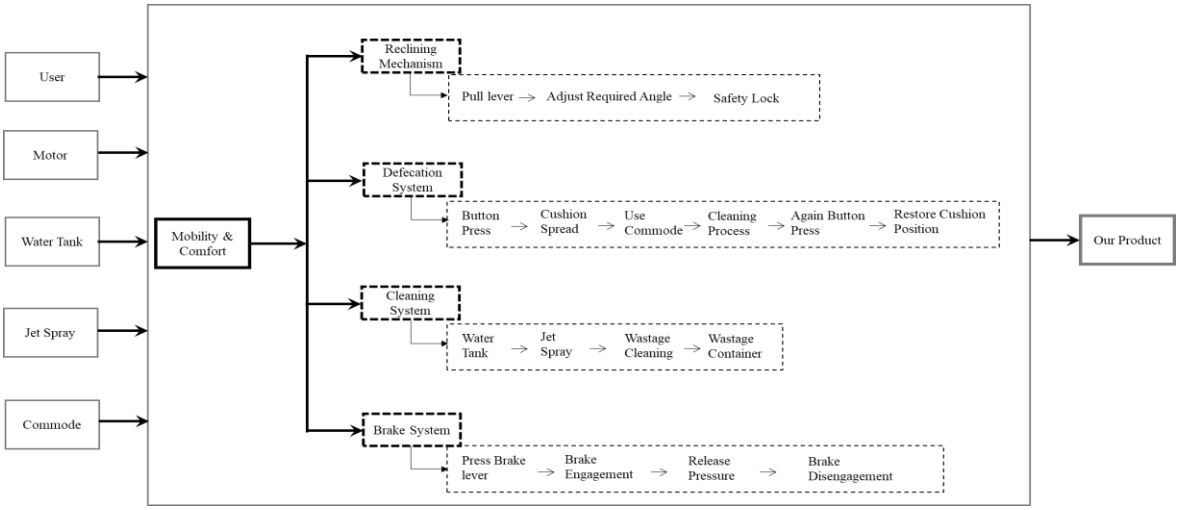
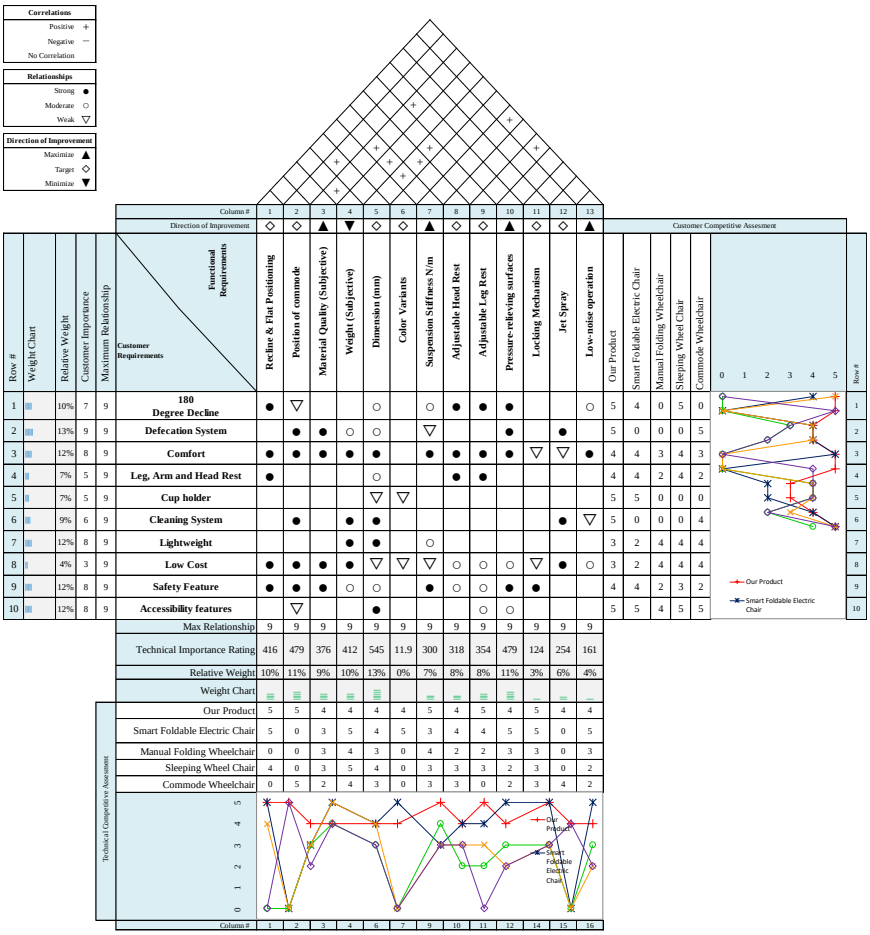


Fig. 3. Function structure of wheelchair-bed

Quality Function Deployment



Row #	Weight Chart	Relative Weight	Customer Importance	Maximum Relationship	Customer Requirements / Functional Requirements	Recline & Flat Positioning	Position of commode	Material Quality (Subjective)	Weight (Subjective)	Dimension (mm)	Color Variants	Suspension Stiffness N/m	Adjustable Head Rest	Adjustable Leg Rest	Pressure-relieving surfaces	Locking Mechanism	Jet Spray	Low-noise operation	Our Product	Smart Foldable Electric Chair	Manual Folding Wheelchair	Sleeping Wheel Chair	Commode Wheelchair	Row #
					Column #	1	2	3	4	5	6	7	8	9	10	11	12	13						
					Direction of Improvement	◇	◇	▲	▼	◇	◇	▲	◇	◇	▲	◇	◇	▲						
1		10%	7	9	**180 Degree Decline**	●	▽			○		○	●	●	●			○	5	4	0	5	0	1
2		13%	9	9	**Defecation System**		●	●	○	○		▽			●		●		5	0	0	0	5	2
3		12%	8	9	**Comfort**	●	●	●	●	●		●	●	●	●	▽	▽	●	4	4	3	4	3	3
4		7%	5	9	**Leg, Arm and Head Rest**	●				○			●	●					4	4	2	4	2	4
5		7%	5	9	**Cup holder**					▽	▽								5	5	0	0	0	5
6		9%	6	9	**Cleaning System**		●		●	●							●	▽	5	0	0	0	4	6
7		12%	8	9	**Lightweight**				●	●		○							3	2	4	4	4	7
8		4%	3	9	**Low Cost**	●	●	●	●	▽	▽	▽	○	○	○	▽	●	○	3	2	4	4	4	8
9		12%	8	9	**Safety Feature**	●	●	●	○	○		●	○	○	●	●			4	4	2	3	2	9
10		12%	8	9	**Accessibility features**		▽			●				○	○				5	5	4	5	5	10
					Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9						
					Technical Importance Rating	416	479	376	412	545	11.9	300	318	354	479	124	254	161						
					Relative Weight	10%	11%	9%	10%	13%	0%	7%	8%	8%	11%	3%	6%	4%						
					Weight Chart																			
					Our Product	5	5	4	4	4	4	5	4	5	4	5	4	4						
					Smart Foldable Electric Chair	5	0	3	5	4	5	3	4	4	5	5	0	5						
					Manual Folding Wheelchair	0	0	3	4	3	0	4	2	2	3	3	0	3						
					Sleeping Wheel Chair	4	0	3	5	4	0	3	3	3	2	3	0	2						
					Commode Wheelchair	0	5	2	4	3	0	3	3	0	2	3	4	2						
					Column #	1	2	3	4	6	7	9	10	11	12	14	15	16						

Fig. 4. Quality function deployment

Quality function deployment (QFD) is a methodology that provides a clear framework for addressing customer needs, beginning with a matrix called the House of Quality. Fig.4 shows the house of quality and table 2 shows the findings of QFD.

Table 2. Findings of QFD

Features Name	Technical Specifications	Direction of Improvement
Cost	14-17K BDT	Minimize
Recline & Flat positioning	Moveable and 180-degree decline	Target
Defecation system	Manually removable waste container integrated with a cushion-activated defecation system	Target
Breaking Mechanism	Manual brake levers for user control and wheel brake levers for enhanced stability and safety	Target
Material Quality	Lighter material with enough durability should be used for less weight and more strength.	Maximize

3D Modeling and Stress Analysis

Fig. 5 shows the exploded view of the 3D model of the wheelchair.

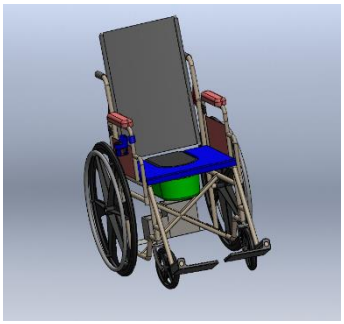


Fig. 5. 3D model of wheelchair

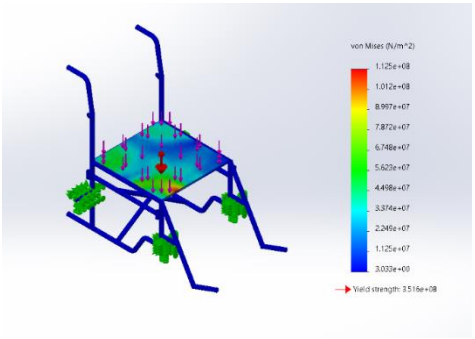


Fig.6. Wheelchair frame stress analysis

Stress analysis (Fig.6) was conducted to evaluate the structural integrity of the wheelchair frame under a load of 800 N (the weight of an average person sitting on the seat). It revealed that the majority of the wheelchair frame operates well within the material's yield strength, as indicated by the predominantly blue to green regions on the stress map. The highest stress concentration reached **1.125e+08 N/m²** in localized areas. Yield strength is found **3.516e+08 N/m².** The Factor of Safety(FOS) analysis indicated that most regions of the wheelchair frame maintain an FOS above the minimum requirement of 1. Areas critical to load-bearing such as the frame joints have higher safety factors. It ensures that it will perform well under maximum loads. The total displacement (URES) analysis shows minimal deformation in the supporting structure. The maximum displacement is concentrated at the center of the platform. The peak displacement is 6.309e+10 mm. From strain distribution, it was confirmed that the structural frame experienced negligible strain.

Reclining Strategy

Fig. 7. represents the reclining mechanism of our proposed wheelchair.

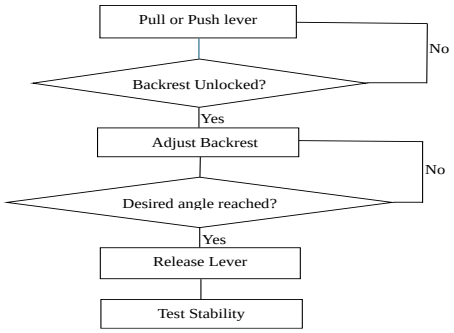


Fig. 7. Reclining strategy

4. Result

The suggested wheelchair satisfies customers' needs by addressing features like a 180-degree reclining mechanism, defecation system, adjustable supports, and a cleaning system. Our design satisfies critical safety and performance requirements according to the stress analysis. The highest stress concentration reached 1.125e+08 N/m² in localized areas, which remains below the yield strength of 3.516e+08 N/m².The maximum displacement is concentrated at the center of the platform. The peak displacement is 6.309e+10 mm which is acceptable and ensures that the structure maintains stability under load without excessive deflection. This design is suitable for manufacturing and use because it can withstand stresses well below their material limits with a high factor of safety. Displacement and strain evaluations show that it will operate within safe limits.

5. Conclusion

The primary purpose of this product is to improve the mobility, comfort, and hygiene of disabled individuals. According to customer surveys, ordinary wheelchairs are not comfortable for immobile patients. Defecating presents a special challenge for these people. This study evaluates customer satisfaction levels regarding the integration of a 180-degree reclining feature with the defecation system in this wheelchair. Kano model analysis shows that both of the features must be present for customer satisfaction, Stress analysis demonstrates that the suggested design is feasible for customer comfort & safety. Besides certain regions were found to lower FOS value, suggesting potential areas for design reinforcement to enhance overall safety but real world tests may lead to unanticipated challenges. The proposed design depends on light & durable materials which can cause increased production costs. Future research is necessary to incorporate more smart technologies to improve the functionality of this wheelchair.

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