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Innovative Wheelchair Design to Reduce Health Issues among Nurses During Patient Transfer

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ABSTRACT

Nurses have the risk of experiencing work-related musculoskeletal disorders and also several other health issues due to patient-handling activities, such as lifting, moving, and repositioning. This research aims to design a wheelchair that helps nurses reduce the risk of injury when carrying out patient transfer activities and assists patients during their hospital treatment. The study integrates the Kano Model with Quality Function Deployment and tests the transfer wheelchair design using static load analysis simulation using the Fusion 360 program with 80kg patient loading. The research involved 188 respondents, including nurses and patients, and discussions were also held with doctors to gather user needs in the design of transfer wheelchairs. The three most significant values for wheelchair design priority are transfer wheelchairs made of strong materials, which facilitate the transfer process from and to the wheelchair, and transfer wheelchairs that are comfortable to use. The design of this transfer wheelchair has been tailored to the anthropometry of the Indonesian population and the spatial constraints of hospital beds, bathroom doors, and toilets. The innovative features of the developed design include a hydraulic system and a seat that can be opened and closed to facilitate patient transfer activities.

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1. Introduction

Nursing provides care to individuals, families, and groups in both health and illness. Nursing services are a form of professional service that is integral to health services based on nursing science and skills for individuals, groups, or communities in both healthy and sick conditions [1]. Nurses are one of the hospital's resources and play a significant role in determining the quality of a hospital's services.

Nurses providing medical services to patients have various tasks, one of which includes manual handling activities. Manual patient handling is a critical challenge in the healthcare sector [2], [3] due to many physical risk factors associated with work-related musculoskeletal disorders (WMSDs), such as heavy exertion (e.g., handling overweight and obese patients) and uncomfortable postures (e.g., deep bending and twisting) during handling tasks [4]-[6].

Several studies indicate various complaints related to nurses' activities. Patient handling activities, includ-

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ing lifting, transferring, and repositioning, pose various physical risks associated with Work-Related Musculoskeletal Disorders (WMSD) [6]-[9]. WMSD is very common among healthcare workers. The total number of documents related to WMSD cases among nurses in the United States is 17,240 or 140.5 per 10,000 workers, and the most affected body part is the lower back, followed by the shoulder [10]. Other research shows that Low Back Pain (LBP) is a common issue in the nursing profession [11]. The research explains that the causes of LBP among nurses in Hong Kong are psychological stress related to work and activities in patient handling. The activities referred to include transferring patients to wheelchairs, moving patients from beds to chairs, positioning patients in beds, and assisting patients in walking [11]. LBP is one of the most common causes of musculoskeletal disorders [12]. The complaints faced by nurses were also obtained based on interviews with a rehabilitation medicine specialist at a hospital in Semarang, Indonesia. Handling patients results in nurses having a high risk (around 70%) of experiencing a Herniated Nucleus Pulposus (HNP), also known as a pinched nerve.

Patient transfer is one of the activities frequently performed by nurses, often performed using wheelchairs. Based on interviews with several inpatient nurses at the hospital, some medical conditions of patients that necessitate moving them with the help of a wheelchair include patients who will undergo surgery, experience mild stroke symptoms, mothers who will give birth, patients who will undergo examinations in specialist clinics and patients that have mobility impairments.

Mobility or mobilisation is the individual's ability to move quickly, freely, and orderly to achieve a goal, which is to meet their life needs, either independently or with the help of others and only with the aid of tools [13]. Mobility impairment or immobility is a condition in which a person cannot move freely due to conditions that hinder movement (activity) [14].

According to an interview with a rehabilitation medicine specialist, a wheelchair is necessary to care for patients who are immobilized. The need for a wheelchair arises from transfer activities, which involve moving the patient from one location to another, such as from a bed to another bed, wheelchair, bathtub, or toilet [8]. A wheelchair is one of the health aids that is utilized for enhancing mobility for people with disabilities, such as patients who are not allowed to engage in much physical activity, individuals with physical disabilities (especially those with leg disabilities), people who are at high risk of injury if they are walking alone, persons with disabilities, and the elderly, allowing them to move from one place to another, whether on flat surfaces or from lower places to higher ones [15].

A preliminary study, conducted through interviews with patients, doctors, and nurses, revealed several complaints about the wheelchairs currently used in the hospital. The complaints include difficulties during patient transfer (from bed to chair, chair to toilet or shower), the wheelchair still shifting even when locked, no place to put an infusion, lack of comfort, and the wheelchair remaining heavy, especially when pushing uphill or downhill.

Several previous studies have shown the condition of wheelchair users because some users can transfer themselves, while others need assistance from others [16], barriers in the transfer process for wheelchair users [17], [18] the transfer process for elderly patients [19] the risk of nurses experiencing musculoskeletal injuries due to their work when moving patients [20], and several designs of assistive devices to facilitate the patient transfer process [9], [16], [21], [22].

The wheelchair used in hospitals today cannot be used when patients want to take a shower or use the toilet, because it cannot fit through the bathroom door, and the height of the wheelchair is different from the height of the toilet. Additionally, nurses must assist patients when transferring them if they use the current wheelchair.

This research aims to develop a transfer wheelchair that facilitates the movement of patients, nurses, and doctors when transferring from one location to another, according to their individual preferences. The wheelchair to be developed is a manual wheelchair that requires assistance from another person, such as a nurse, to push or move. The specific objective of this research is to develop a transfer wheelchair for hospitalized patients, assisting nurses in transferring patients between the bed and wheelchair, as well as between the wheelchair and the toilet. This design enhances the current hospital wheelchair by considering the desires of its users, specifically nurses and patients.

2. Literature Review

2.1 Kano Model

The Kano model, developed by Noriaki Kano, is a two-dimensional diagram that categorises product attributes based on how well the product satisfies customer needs [23]. Kano model, starting with identifying user needs and translating them into attributes, then these attributes are used in the Kano questionnaire and categorised based on must be (M), one dimensional (O), attractive (A), and indifferent (I) using tabulation of surveys. From those categories, the better and worse values will then be calculated to determine the position of the attributes in the Kano diagram.

2.2 Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a method used to enhance the quality of goods and services by understanding customer needs and linking them to technical specifications. The QFD method comprises four phases: the first phase is product planning (house of quality), which translates to customer needs. The second phase is product design, which converts technical characteristics into measurable component characteristics. The third phase is process planning, which identifies manufacturing process stages and translates them into parameters for each process. The fourth phase is process control planning, which designs a system to monitor and manage the production process [24]. The matrix house of quality (HOQ) is the most widely recognized form of QFD representation. HOQ is a structured, systematic expression of a product or process to understand aspects of the entire new product planning process, service, or process [25].

2.3 Integration of the Kano Model and QFD

QFD is a powerful and structured method for capturing the voice of the customer and ensuring that quality is built into the product. As the ultimate goal of QFD, customer satisfaction must be achieved totally and effectively, and the Kano model can be utilized to differentiate customer needs and gain a more imaginative understanding of these needs [26]. To achieve total customer satisfaction, it is essential to determine the attention required for each attribute to reach the desired satisfaction levels. Figure 1 illustrates a process model demonstrating how the Kano model can be integrated with QFD [27].

The first step in this process is to gather customer requirements or the voice of the customer and customer complaints through interviews, the distribution of questionnaires, or brainstorming sessions. These inputs are then interpreted by researchers into need attributes. The next step is to analyze which attributes would be beneficial if developed. Then, the Kano model continues to classify needs statements into attractive, one-dimensional, and must-be categories. These attributes are then included in the HOQ matrix to translate them into technical characteristics. The integration of Kano and QFD can be seen in Figure 1[27].

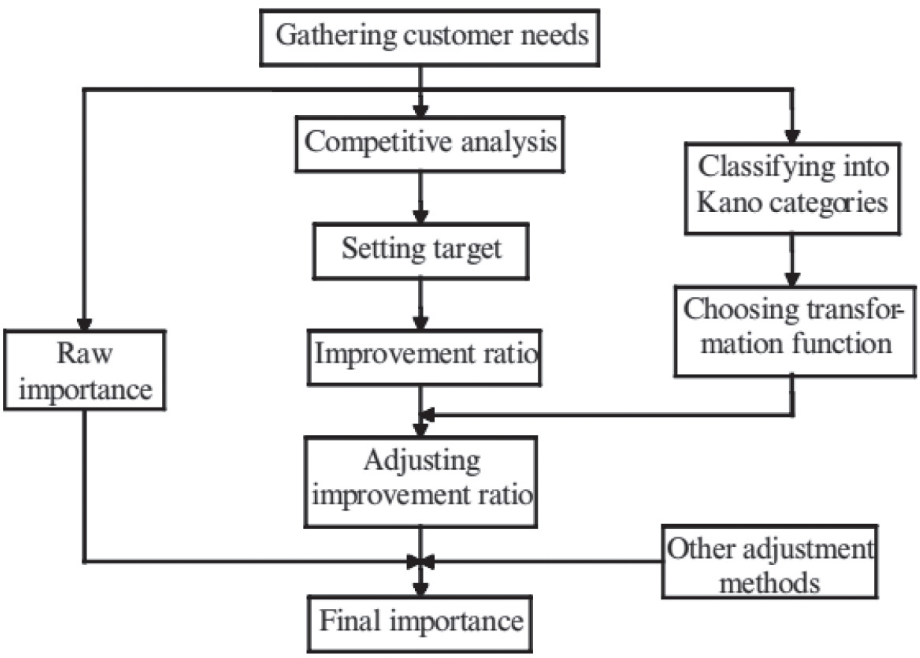


Figure 1. Integration of Kano and QFD

2.4 Finite Element Method

An object consists of an infinite number of elements. With infinite elements, analysing the stress or deformation will be challenging. It can be assumed that an object consists of finite elements to facilitate the analysis. The finite element method is a method that approximates by assuming an object consists of a finite number of elements. The elements are considered separate and connected by points called nodal points, forming a mesh. The smaller the element's size, the smaller the error that occurs.

Figure 2 illustrates the principles of the finite element method. In the image, an object consisting of an infinite number of elements (continuum elements) is made into a finite number of elements, also known as discretisation. Despite being divided into small components, the object is still treated as a whole part [28].

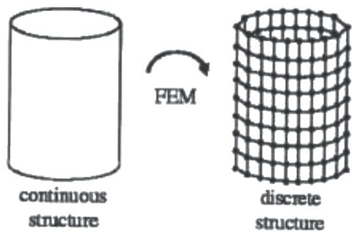


Figure 2. Element Discretization Process with the Element Method

3. Materials and Methods

This research uses a non-random sampling technique with a purposive sampling model. Based on the Lemeshow formula calculation [29], the minimum number of respondents required for data processing is 138, and this research used 188 respondents, including patients and nurses. The profile of the research respondents can be seen in Table 1. Based on interviews with nurses and hospital patients regarding the utilization of wheelchairs during transfer activities, there are several complaints. The complaints can be seen in Table 2.

Table 1. Profile of Research Respondents

Description	Total	Percentage
Respondent Type		
Patient	89	47,34%
Nurse	99	52,66%
Gender		
Female	130	69,15%
Male	58	30,85%
Number of respondents	188	

The results of in-depth follow-up interviews to identify user needs will then be interpreted into user needs, which will be used as attributes in constructing

Table 2. Complaints of Wheelchair Users in the Hospital

Users	Complaint
Patient	Sitting too long makes my butt and back sore.
	I'm not comfortable with the wheelchair seat because it's not cushioned.
	It would feel safer if the wheelchair were equipped with a seatbelt.
	The wheelchair cannot be used when wanting to use the bathroom/toilet.
	The wheelchair cannot be adjusted in height, making it difficult to change positions.
	It does not have a place to hang an infuse
	Wanting a wheelchair to have a storage compartment
	The wheelchair still often shifts even when it is in lock mode.
Nurse	Transferring from the bed to the wheelchair (or vice versa) while embracing the patient becomes very heavy due to the load on the nurse's back.
	The existing wheelchair is still heavy when used to push patients up or down the stairs.
	It does not have a place to hang an infuse
	The size of the chair seat needs to be increased for patients who are overweight.
	The height of the wheelchair cannot be adjusted to the size of the bed or toilet, making the transfer process difficult.
	The backrest height is insufficient for stroke patients.
	The current size of the wheelchair cannot fit through the bathroom/toilet door.
	Not having a place to store patient medical records.
	There has been no height adjustment when the patient occupies the chair.

the Kano Model questionnaire and as input in the HOQ matrix. The research variables for the Kano questionnaire can be seen in Table 3.

The subsequent stage involves constructing the HOQ matrix to prioritize attributes, which will then inform product design. The QFD methodology is extensively employed to ascertain the design attributes of newly conceived or enhanced items. The pivotal phase in QFD is the formulation of the HOQ. The outcomes derived from the Kano Model are incorporated into the HOQ.

3. Result

3.1 Kano Model Results

This study involved 188 participants, including nurses and inpatients who used wheelchairs during hospital treatment. Of the 188 respondents, 47% were patients, and 53% were nurses. The percentage of nurses in this study was more significant because research into the design of transfer wheelchairs began with nurses' complaints regarding handling patients, including lifting, moving and repositioning, which caused various physical risks related to work-related musculoskeletal disorders.

The results of the KANO model processing revealed that 14 attributes fall into the Must-be category, while seven fall into the One-dimensional category. Respondents in the must-be category will feel dissatisfied if the performance of those attributes is poor or not met. However, satisfaction will not increase if the attributes are met because consumers consider those attributes to be a given. Therefore, the organization must maintain the characteristics that fall into the must-be category. Figure 3 shows the Kano diagram resulting from the data processing.

Based on the Kano diagram in Figure 3, all indicators fall into the one-dimensional and must-be quadrants, indicating that all indicators proceed to the following data processing stage because they are essential for nurses and patients.

3.2 QFD Results

The questionnaire used in the preparation of QFD is divided into two parts, the first meaures the level of importance and the second measures the level of satisfaction using a 1 to 5 measurement scale. A score of 1 represents very unimportant or very dissatisfied, 2 represents unimportant or dissatisfied, 3 represents somewhat important or somewhat satisfied,

Table 3. Kano Indicators

No	Indicators	Reference
1	Difficulty during the transfer process from/to a wheelchair	[30]
2	The problem when standing up after sitting down	
3	Problems with performing toilet/bathroom activities	
4	Uncomfortable seating	
5	Not easy to carry/not practical	
6	Heavy when pushed	
7	There is no safety feature (seat belt).	
8	Bad backrest angle	
9	The wheelchair does not fit the body's dimensions.	
10	The wheelchair is not light.	
11	Cost/price of a wheelchair	[30], [31]
12	Ease of maintenance	
13	Ease of use	[31]
14	Comfortable when used	
15	Strong material	
16	Movable/portable facilities	
17	Wheelchair locking mode	Interview with the user
18	Adjustable wheelchair height	
19	The size of the wheelchair that fits the bathroom/toilet door	
20	A place to put the infusion	
21	A place to put documents	

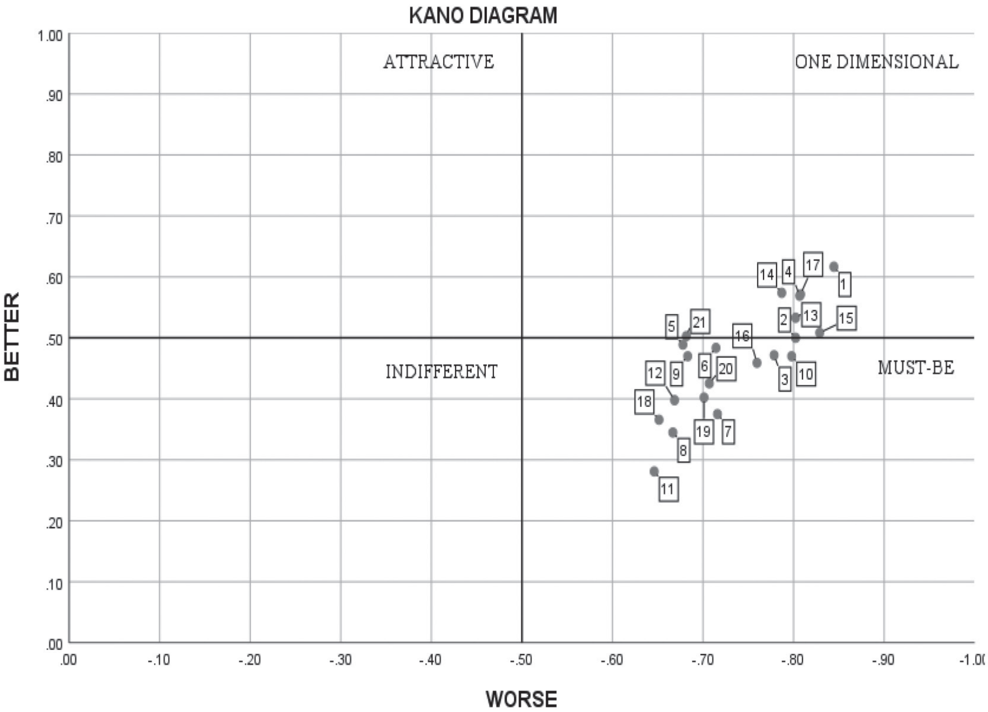


Figure 3. Kano Diagram

4 represents necessary or satisfied, and 5 represents very important or very satisfied. The outcome of the QFD method is the House of Quality (HOQ), which generates absolute importance values that determine the order of priority for technical responses to be prioritised in terms of quality. Thus, it is expected that there will be a significant increase in user satisfaction. The HOQ of this research is depicted in Figure 4.

3.3 Determination of Anthropometric Data

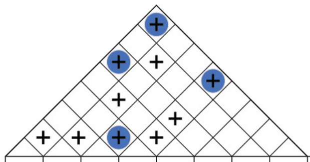
Anthropometry, the measurement of physical characteristics and capabilities of people, provides critical information for designing both work and non-work environments, as well as consumer products, clothing, tools, and equipment [32]. The transfer wheelchair design incorporates anthropometric data of Indonesian men adjusted to various percentiles [33]. Table 4 shows the dimension data of the transfer wheelchair based on Indonesian anthropometry. This study uses adult male anthropometry to guarantee comfort for both male and female users. The 50th percentile, reflecting average body size, is predominantly utilized. This wheelchair is not designed for overweight individuals, with a maximum weight limit of 80 kg for users.

Table 4. Design Wheelchair Dimension Data

Anthropometry	Percentiles	Anthropometric Dimensions	Dimensions Size
Seat seating length	50%	Popliteal length	42
Seat width	50%	Hip width	45
Backrest height	50%	Shoulder height in a sitting position	58
Armrest height from the seat	50%	Elbow height in a sitting position	26
Headrest height	50%	Head length	19
Headrest width	50%	Head width	25
Leg rest height	50%	Popliteal height	44
Leg rest length	5%	Footprint length	15
Footrest width	50%	Footprint width	14
Handle length	50%	Palm width	10
Handle height	50%	Standing elbow height	93
Armrest	95%	Forearm length-hand length	34

Symbol	Value	Definition
	0	No relationship
◢	1	Weak relationship
●	3	Medium relationship
○	9	Strong relationship

Simbol	Definition
⊕	Very Strong Positive Influence
+	Moderately Strong Positive Influence
	No Influence
−	Moderately Strong Negative Influence
⊖	Very Strong Negative Influence



Technical Response

Requirement Attributes	Dimension	Total mass	Material	Price	Wheel type	Adjustable height tolerance (cm)	Wheel size	Multi features	*User Importance*	*Kano Category*	*K-Value*	*User Satisfaction*	*Goals*	*Adjustment Factor*	*Improvement Ratio*	*Adjusted Improvement Ratio*	*Adjusted Importance*
Transfer wheelchairs can make it easier to transfer from/to a wheelchair	○		●						4.18	O	1	3.90	4	0.84	1.03	1.89	7.91
The transfer wheelchair can make it easier when standing up after a seated	○		○						4.10	O	1	3.74	3	0.80	0.80	1.44	5.92
The transfer wheelchair can facilitate in doing toilet/bathroom activities	○		○		●		○		4.28	M	0.5	3.65	4	0.78	1.09	1.46	6.25
The transfer wheelchair has a comfortable seat	○		○	●					4.21	O	1	3.94	3	0.81	0.76	1.38	5.79
The transfer wheelchair is easy to carry/practical	○	○	○						4.24	M	0.5	3.88	2	0.68	0.52	0.67	2.84
The transfer wheelchair is lightweight when pushed		○	○	●					4.27	M	0.5	3.90	4	0.71	1.03	1.34	5.73
The transfer wheelchair has safety features (seat belt)				◢				○	4.07	M	0.5	3.59	2	0.72	0.56	0.73	2.98
The transfer wheelchair has a headrest headrest	○	●						○	4.22	M	0.5	3.57	3	0.67	0.84	1.08	4.58
The transfer wheelchair fits the body dimensions	○								4.26	M	0.5	3.86	4	0.68	1.04	1.35	5.73
The transfer wheelchair is lightweight when carried		○	○	◢					4.07	M	0.5	3.90	4	0.80	1.02	1.37	5.60
The price of the transfer wheelchair is low			●	○				●	4.15	M	0.5	3.74	4	0.65	1.07	1.37	5.69
The transfer wheelchair is easy to maintain			○	◢					4.40	M	0.5	3.84	2	0.67	0.52	0.67	2.96
The transfer wheelchair is easy to use	○								4.45	O	1	4.07	3	0.80	0.74	1.33	5.92
The transfer wheelchair is comfortable to use	○		○	●	◢				4.45	O	1	4.06	4	0.79	0.98	1.76	7.83
The transfer wheelchair has strong materials			○	●					4.44	O	1	4.02	4	0.83	0.99	1.82	8.08
The transfer wheelchair is easy to move	○	●	○		○				4.48	M	0.5	4.03	4	0.76	0.99	1.32	5.89
The transfer wheelchair has a locking mode					●			○	4.29	O	1	4,02	4	0.81	0.99	1.80	7.60
Has adjustable height while the patient is still seated in the wheelchair			○	●		○		●	4.22	M	0.5	3.61	4	0.65	1.11	1.42	6.00
The transfer wheelchair size fit with bathroom/toilet doors	○				●		○		4.34	M	0.5	3.72	4	0.70	1.07	1.40	6.07
The transfer wheelchair has a place to put an infusion	○			●				○	4.31	M	0.5	3.65	4	0.71	1.09	1.43	6.16
The transfer wheelchair has a place to put documents	○			●				○	3.90	M	0.5	3.89	1	0.68	0.77	1.00	3.90
Absolute Weight	498.83	139.37	449.52	139.28	83.30	38.01	77.55	211.50									
Absolute Importance	673.13	158.88	606.83	193.19	120.66	54.02	110.92	261.73									
Ranking	1	5	2	4	6	8	7	3									

Figure 4. House of Quality Matrix

3.4 Product Planning

In this study, the design of the transfer chair is intended to meet users' needs and desires. Patients and nurses are expected to be satisfied and comfortable during transfer activities. Figure 5 shows the design of the transfer wheelchair based on the integration of Kano with QFD.

Based on the three wheelchair designs created, the designs were presented to experts for selection and feedback. The selected experts are two Directors of Government Hospitals located in Central Java, Indonesia. The two responders were selected due to over a decade of expertise and positions as directors at a government hospital.

Based on discussions with these experts, the first wheelchair design was chosen, with several recommendations. The rationale for selecting the first wheelchair design is that it can be used by patients from both the front and rear, and its solid seat devoid of openings enhances patient safety by mitigating the risk of falls. The first recommendation was to ensure that the wheelchair backrest fully covers the buttocks area, as patients may feel uncomfortable if this area is exposed while seated. The second recommendation was to enhance the strength of the wheelchair frame by adding elbow supports. The results of the expert's recommendation can be seen in Figure 6.

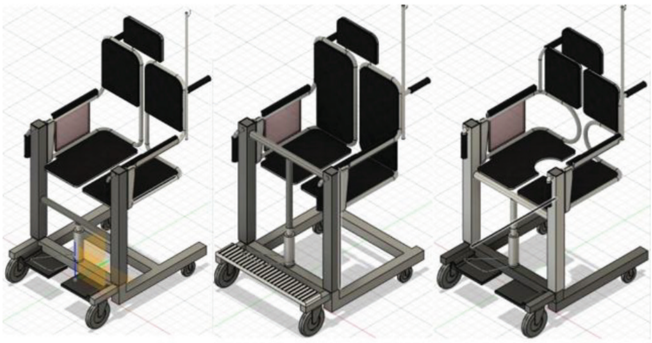


Figure 5. Three Options for Transfer Wheelchairs

Figure 6. Design of the Transfer Wheelchair Prototype

4. Discussion

This research aims to design a wheelchair that makes it easier for nurses to assist patients with transfer activities during inpatient treatment at the hospital. This is supported by research by Barbareschi & Holloway [18], which states that wheelchair users who require assistance from others will have more significant difficulties than users who can carry out transfer activities independently.

The analysis of the questionnaire administered to 188 respondents, utilizing the Kano technique, identified 21 critical factors for nurses and patients in selecting a wheelchair. The processing results with Kano show that all indicators fall into the one-dimensional and must be quadrants, meaning that all indicators are included in the following data processing stage because they are essential for nurses and patients. These indicators become attributes of user needs in data processing with QFD. QFD compiles need attributes classified as attractive, must-be, and one-dimensional in the Kano model with importance level, satisfaction level, k-value, goals, adjustment factor, improvement ratio, adjusted improvement ratio, and adjustment importance.

The adjustment importance value is used to provide the designer with information to prioritize the attributes of user needs; the higher the value, the higher the priority of the attribute needs according to the user. The three most significant values for adjustment importance that show priority in designing wheelchairs are transfer wheelchairs made of strong materials, ease of transfer process from / and to the wheelchair, and transfer wheelchairs are comfortable to use. The results from this QFD are used as input when designing the transfer wheelchair.

The priority is that this transfer wheelchair is made of strong materials. This transfer wheelchair uses material made of 304 stainless steel, which has the properties of corrosion resistance, temperature resistance, and strength, and can be used in medical devices. Medical-grade stainless steel (SS) is commonly used in manufacturing biomedical devices and implants. Corrosion is the' gradual degradation and destruction of metals due to their electrochemical interaction with the surrounding environment. Stainless steel used in the medical sector must exhibit enhanced corrosion resistance and biocompatibility compared to other industries [34]. Over the past century, researchers have persistently endeavoured to improve the corrosion resistance of stainless steel. In the 1920s, a type of stainless steel known as 304 austenitic stainless steel, containing 18% chromium and 8% nickel, was used for orthopaedic implants [35], [36]. The challenge in implementing a transfer wheelchair is to create a transfer wheelchair that is strong yet lightweight and waterproof, because it can be used when the patient is in the toilet.

To ensure the strength of the transfer wheelchair, the transfer wheelchair was tested using static load analysis simulation in the Fusion 360 program with a load of 80kg. The calculation simulation was divided into three parts: von Mises stress, deformation, and safety factor [37]. Based on the test results, it was found that the maximum Von Mises stress value occurred with an 80kg load at the connection location between the wheelchair and the wheel with a stress of 187.624 MPa. The transfer wheelchair frame material uses 304 stainless steel (AISI 304) with a yield strength of 215 MPa, which shows that the wheelchair design is safe to use. Testing the centre stability results in a maximum deformation value of 0.158 mm and a safety factor value of 1.146. This means the transfer wheelchair is safe because it has a value greater than 1. The results of the FEM simulation can be seen in Figure 7.

The second priority is that the transfer wheelchair can facilitate the transfer process to and from the wheelchair. To facilitate the transfer process, this designed wheelchair has additional features that differentiate it from ordinary wheelchairs. The first feature is that this transfer wheelchair can be opened and closed on the seat, making it easier for nurses to move patients from wheelchairs to beds and toilets during patient transfer activities. Nurses no longer need to lift the patient manually if they want to move the patient; they open the seat, and after the patient moves to the desired place, the seat can be locked again. Additionally, Owen et al. [38] discovered that the compression forces were significant while patients were being transferred from their beds to wheelchairs and from their toilets to wheelchairs, with loads typically exceeding 3600 N. It was discovered that the patient's bed placement was significantly decreased to just 107 N.

The second feature is that this transfer wheelchair has a hydraulic lever that can go up and down. At the same time, the patient is seated, making it easier for nurses to adjust to the height of the bed, chair, or toilet when moving the patient to a different position. Often, transferring a patient to a bed, chair, or toilet is at a height different from that of a wheelchair, so the nurse has to carry the patient and increasing the risk of injury. Toro et al. [39] measured the effect of various environmental factors such as height differences, gap dimensions, presence of obstructions, and presence and height of front or side handles on wheelchair transfer performance. The results showed how the height difference between the wheelchair and the target seat, both higher and lower, had the most significant impact on the patient's ability to transfer. So, this transfer wheelchair has a hydraulic pump that can adjust to different heights. This hydraulic pump has a lever the caregiver can use to change the height as needed.

Figure 7. Stress, Deformation, and Safety Factors for Transfer Wheelchairs

The third feature is the smaller wheel size, which allows the wheelchair to fit under hospital beds and bathroom doors making it easier for nurses to assist patients during transfer activities. Although the wheel size is smaller, it is still strong enough to withstand a patient load of 80 kg. The current wheelchairs used in hospitals have a wheel size of 58.42 cm and a width of 64 cm, while the rear wheels of the designed transfer wheelchair have a diameter of 8.3 cm and a width of 53 cm. This smaller size enables nurses to more easily assist patients in transferring to a bed or toilet.

Because of these additional features, specific wheelchair components require routine maintenance and replacement [40]. Wheelchair maintenance involves routine examination and repair. Regular lubrication is essential for the hydraulic component to facilitate the raising and lowering process.

The third priority is that the transfer wheelchair is comfortable to use. This transfer wheelchair design has a removable headrest and seat belt. The headrest helps users feel more relaxed and reduces discomfort in the head, while the seat belt function prevents the patient's body from falling forward or even due to body weakness. There are locks on the front wheels of the transfer wheelchair, thus increasing the comfort of patients and caregivers during transfer activities because the chair will not move.

The current wheelchair dimensions prevent patients from using it in the bathroom due to their size exceeding that of the bathroom doors. This increases the risk of nurses experiencing work-related musculoskeletal disorders (WMSD) when assisting patients in bathroom activities. With the new transfer wheelchair design, the dimensions have been adjusted to anthropometry of Indonesian people as well as the size of bathroom doors and toilets in hospitals. According to Hwang et al. [8], nurses commonly perform manual handling activities, including lifting, repositioning, and moving patients from one bed to another (e.g., another bed, wheelchair, bathtub, or toilet).

The transfer wheelchair has a space to put the infuser and the patient's medical record. Some existing wheelchairs do not have a place to put the infusion and the patient's medical record, causing nurses to place it on the patient's thigh. This can lead to uneven infusion fluid flow, making the patient uncomfortable. User needs in designing wheelchairs to support health service facilities, when based on ergonomic aspects with practical attributes, namely available infusion bottle and available document storage [41].

This wheelchair design primarily facilitates nurses in patient transfer tasks, incorporates a foldable backrest and seat, includes a hydraulic pump for height adjustment, and provides storage for infusions and patient paperwork. A standard wheelchair in a hospital solely serves to carry patients and lacks elements to assist in the transfer procedure.

5. Conclusion

The Kano Analysis processing results show that all indicators fall into the one dimensional and must be quadrant, meaning that all indicators are included in the following data processing stage because they are essential for both nurses and patients. These indicators become attributes of user needs in data processing with QFD. The adjustment importance value is used as information for the designer to prioritize the user need characteristics; the higher the value, the higher the priority of attribute needs according to users. The three most significant values for adjustment importance indicate the priorities in designing the wheelchair.

The priority is that this transfer wheelchair should be made of strong materials. This transfer wheelchair uses material made of 304 stainless steel, which has the properties of corrosion resistance, temperature resistance, and strength, and can be used in medical devices. The second priority is that the transfer wheelchair should facilitate the transfer from / and to the wheelchair. To facilitate the transfer process, this wheelchair has additional features different from ordinary wheelchairs. The first feature is that this transfer wheelchair can be opened and closed on the seat, making it easier for nurses to move patients from wheelchairs to beds and toilets during patient transfer activities. The second feature is that the transfer wheelchair has a hydraulic lever that adjusts the height when the patient is seated, allowing the nurses to adjust to the height of the bed, chair, or toilet when moving the patient to a different position. The third feature is the smaller wheel size, which allows the wheelchair to fit under hospital beds and bathroom doors, helping nurses assist patients more easily during transfers.

The third priority is that the transfer wheelchair must be comfortable to use. This transfer wheelchair design has a removable headrest and seat belt. The dimensions have been adjusted to the Indonesian anthropometry and the size of the hospital's bathroom doors and toilets. Additionally, the transfer wheelchair has a place to put an infusion bottle and the patient's medical records. This wheelchair possesses commercial viability due to its utilization of readily available materials and its cost-effectiveness.

This transfer wheelchair has the potential to mitigate nurses' accidents associated with patient transfer operations. It features an open and closed seat and adjustable height capabilities. Further research that can be conducted includes testing the transfer wheelchair with users and adding new, more attractive features. Like having hand brakes and using patterned backrest materials that can breathe.

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References

[1] Permenkes RI, "Peraturan Menteri Kesehatan Republik Indonesia Nomor 26 Tahun 2019 Keperawatan. Kemenkes RI [Internet]. 2019;(912):1–159.," Permenkes RI No 26 Tahun 2019, no. 912, pp. 1–159, 2019, [Online]. Available: https://peraturan.bpk.go.id/Download/129882/Permenkes%20Nomor%2026%20Tahun%202019.pdf

[2] K. G. Davis and S. E. Kotowski, "Prevalence of Musculoskeletal Disorders for Nurses in Hospitals, Long-Term Care Facilities, and Home Health Care: A Comprehensive Review," Hum. Factors, vol. 57, no. 5, pp. 754–792, 2015, doi: 10.1177/0018720815581933.

[3] M. Ws, D. Kg, K. Bc, and A, "A Comprehensive Analysis of Low-Back Disorder Risk and Spinal Loading During the Transferring and Repositioning of Patients Using Different Techniques," Ergonomics, vol. 42, no. 7, pp. 904–926, 1999, doi: 10.1080/001401399185207.

[4] S. Nagavarapu, S. A. Lavender, and W. S. Marras, "Spine loading during the application and removal of lifting slings: the effects of patient weight, bed height and work method," Ergonomics, vol. 60, no. 5, pp. 636–648, 2017, doi: 10.1080/00140139.2016.1211750.

[5] N. Wiggermann, "Biomechanical Evaluation of a Bed Feature to Assist in Turning and Laterally Repositioning Patients," Hum. Factors, vol. 58, no. 5, pp. 748–757, 2016, doi: 10.1177/0018720815612625.

[6] N. Wiggermann, J. Zhou, and N. McGann, "Effect of Repositioning Aids and Patient Weight on Biomechanical Stresses When Repositioning Patients in Bed," Hum. Factors, vol. 63, no. 4, pp. 565-577, 2020, doi: 10.1177/0018720819895850.

[7] A. R. Budarick, U. Lad, and S. L. Fischer, "Can the Use of Turn-Assist Surfaces Reduce the Physical Burden on Caregivers When Performing Patient Turning?," Hum. Factors, vol. 62, no. 1, pp. 77–92, 2020, doi: 10.1177/0018720819845746.

[8] J. Hwang, V. A. Kuppam, S. S. R. Chodraju, J. Chen, and J. H. Kim, "Commercially Available Friction-Reducing Patient-Transfer Devices Reduce Biomechanical Stresses on Caregivers' Upper Extremities and Low Back," Hum. Factors, vol. 61, no. 7, pp. 1125–1140, 2019, doi: 10.1177/0018720819827208.

[9] C. Sun, B. Buchholz, M. Quinn, L. Punnett, C. Galligan, and R. Gore, "Ergonomic evaluation of slide boards used by home care aides to assist client transfers," Ergonomics, vol. 61, no. 7, pp. 913–922, 2018, doi: 10.1080/00140139.2017.1420826.

[10] J. Hwang, V. N. Kumar Yerriboina, H. Ari, and J. H. Kim, "Effects of passive back-support exoskeletons on physical demands and usability during patient transfer tasks," Appl. Ergon., vol. 93, p. 103373, 2021, doi: 10.1016/j.apergo.2021.103373.

[11] Y. B. Yip, "A study of work stress, patient handling activities and the risk of low back pain among nurses in Hong Kong," J. Adv. Nurs., vol. 36, no. 6, pp. 794–804, 2001, doi: 10.1046/j.1365-2648.2001.02037.x.

[12] C. G. Cunningham, T. Flynn, and C. Blake, "Low back pain and occupation among Irish health service workers," Occup. Med. (Chic. Ill)., vol. 56, no. 7, pp. 447–454, 2006, doi: 10.1093/occmed/kql056.

[13] P. C. Hayes and T. W. Mackay, Buku Saku: Diagnosis dan Terapi, 1st editio. Jakarta: EGC, 2009.

[14] H. Widuri, Widuri, Hesti. (2010). Asuhan Keperawatan Pada Lanjut Usia Ditatanan Klinik. Yogyakata: Penerbit Fitramaya. Yogyakarta: Penerbit Fitramaya, 2010.

[15] I. M. L. Batan, "Pengembangan Kursi Roda Sebagai Upaya Peningkatan Ruang Gerak Penderita Cacat Kaki," J. Ind. Eng. Res. Appl., vol. 8, no. 2, pp. 97–105, 2007, doi: 10.9744/jti.8.2.97-105.

[16] G. Barbareschi, T. J. Cheng, and C. Holloway, "Effect of technique and transfer board use on the performance of wheelchair transfers," Healthc. Technol. Lett., vol. 5, no. 2, pp. 76–80, 2018, doi: 10.1049/htl.2017.0075.

[17] M. Melkamu, B. D. Atsegeba, E. Dugassa, N. Lemma, and N. Feyissa, "Develop quality of system engineering process in bottled water manufacturing sectors," J. Eng. Manag. Ind. Technol., vol. 2025, no. 2, pp. 65–74, 2025, doi: 10.61552/JEMIT.2025.02.001.

[18] G. Barbareschi and C. Holloway, "Understanding independent wheelchair transfers. Perspectives from stakeholders," Disabil. Rehabil. Assist. Technol., vol. 15, no. 5, pp. 545–552, 2020, doi: 10.1080/17483107.2019.1594407.

[19] E. Ozawa et al., "Experimental study on physical burden of transfer assistance for excretion - Comparison between transfer-type wheelchair and ordinary wheelchair," J. Adv. Comput. Intell. Intell. Informatics, vol. 21, no. 2, pp. 363–370, 2017, doi: 10.20965/jaciii.2017.p0363.

[20] S. D. Choi and K. Brings, "Work-related musculoskeletal risks associated with nurses and nursing assistants handling overweight and obese patients: A literature review," Work, vol. 53, no. 2, pp. 439–448, 2016, doi: 10.3233/WOR-152222.

[21] A. A. R. Shikder, R. Saha, T. Islam, J. H. Emon, and M. H. K. Khan, "Sizing efficiency and cost reduction strategies in woven fabric manufacturing: A case study," J. Eng. Manag. Ind. Technol., vol. 2025, no. 1, pp. 21–28, 2025, doi: 10.61552/JEMIT.2025.01.003.

[22] M. J. J. Gumasing, A. C. Villapando, and K. C. Pernia, "An ergonomic design of wheelchair bed transfer for post stroke patients," ACM Int. Conf. Proceeding Ser., pp. 275–279, 2019, doi: 10.1145/3335550.3339900.

[23] N. Kano, N. Seraku, F. Takahashi, and S. Tsuji, "Attractive Quality and Must-Be Quality," J. Japanese Soc. Qual. Control, vol. 14, no. 2, pp. 147-156, 1984, doi: 10.20684/quality.14.2_147.

[24] V. Bouchereau and H. Rowlands, "Methods and techniques to help quality function deployment (QFD)," Benchmarking An Int. J., vol. 7, no. 1, pp. 8–20, 2000, doi: 10.1108/14635770010314891.

[25] L. Cohen, Quality Function Deployment: How to Make QFD Work for You. Addison-Wesley, 1995.

[26] W. E. Eureka and N. E. Ryan, The Customer-Driven Company: Managerial Perspectives on Quality Function Deployment, Subsequent. Amer Supplier Inst, 1994.

[27] K. C. Tan and X. X. Shen, "Integrating Kano's model in the planning matrix of quality function deployment," Total Qual. Manag., vol. 11, no. 8, pp. 1141–1151, 2000, doi: 10.1080/095441200440395.

[28] M. A. Choiron, A. Purnowidodo, and K. Anam, "Metode Elemen Hingga," Malang, 2014.

[29] Riduwan and Akdon, Rumus dan data dalam aplikasi statistika : untuk penelitian. Bandung: Alfabeta, 2010.

[30] S. Desai, S. Mantha, and V. Phalle, "Comprehensive needs assessment study and deployment of QFD Targeted at new wheelchair design," Iran. Rehabil. J., vol. 15, no. 4, pp. 377–388, 2017, doi: 10.29252/nrip.irj.15.4.377.

[31] H. Soewardi and M. K. A. Afgani, "Innovative Design of Ergonomic Wheelchair for Disabled People," IOP Conf. Ser. Mater. Sci. Eng., vol. 598, no. 1, p. 012033, 2019, doi: 10.1088/1757-899X/598/1/012033.

[32] V. Paquet and D. Feathers, "An anthropometric study of manual and powered wheelchair users," Int. J. Ind. Ergon., vol. 33, no. 3, pp. 191–204, 2004, doi: 10.1016/j.ergon.2003.10.003.

[33] E. Nurmianto, Ergonomi, Konsep Dasar dan Aplikasinya. Surabaya: Guna Widya, 1991.

[34] Y. Xu, Y. Li, T. Chen, C. Dong, K. Zhang, and X. Bao, "A short review of medical-grade stainless steel: Corrosion resistance and novel techniques," J. Mater. Res. Technol., vol. 29, pp. 2788–2798, 2024, doi: 10.1016/j.jmrt.2024.01.240.

[35] A. Bekmurzayeva, W. J. Duncanson, H. S. Azevedo, and D. Kanayeva, "Surface modification of stainless steel for biomedical applications: Revisiting a century-old material," Mater. Sci. Eng. C, vol. 93, pp. 1073–1089, 2018, doi: 10.1016/j.msec.2018.08.049.

[36] L. R. Park J, Biomaterials: an introduction, 3rd. ed. New York: Springer, 2007.

[37] S. Suryady and E. A. Nugroho, "Simulasi Faktor Keamanan dan Pembebanan Statik Rangka Pada Turbin Angin Savonius," J. Ilm. Multidisiplin, vol. 1, no. 2, pp. 42–48, 2022, doi: 10.56127/jukim.v1i2.94.

[38] B. D. Owen, A. Garg, and R. C. Jensen, "Four methods for identification of most back-stressing tasks performed by nursing assistants in nursing homes," Int. J. Ind. Ergon., vol. 9, no. 3, pp. 213–220, 1992, doi: 10.1016/0169-8141(92)90015-R.

[39] M. L. Toro, A. M. Koontz, and R. A. Cooper, "The impact of transfer setup on the performance of independent wheelchair transfers," Hum. Factors, vol. 55, no. 3, pp. 567–580, 2013, doi: 10.1177/0018720812460549.

[40] R. M. May, "Wheelchair Maintenance Training program (WMTP) Clinician ' s Reference Manual.," Wheel. Maint., 2017, [Online]. Available: https://www.physio-pedia.com/Wheelchair_Maintenance#cite_note-:1-2 [Accessed: 20-Dec-2024].

[41] E. I. Yuslistyari and M. J. Shofa, "Rancangan tempat tidur kursi roda ergonomis untuk menunjang fasilitas pelayanan kesehatan saat pandemi COVID-19," J. Penelit. dan Apl. Sist. Tek. Ind., vol. 15, no. 3, pp. 306–319, 2021, doi: 10.22441/pasti.2021.v15i3.007.