

## DESIGN AND DEVELOPMENT OF AN ELDERLY-FRIENDLY SMART BED USING QUALITY FUNCTION DEPLOYMENT

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**Abstract:** *This study aimed to design and develop an elderly-friendly smart bed using the Quality Function Deployment (QFD) methodology to systematically translate user needs into technical design specifications. Data were collected from elderly users through interviews and questionnaires to identify customer requirements related to functionality, safety, materials, usability, and intelligent systems. The collected data were analysed using the Product Planning Matrix and the Design Deployment Matrix within the House of Quality framework. The results identified several critical technical requirements, particularly intelligent safety systems, smart convenience features, structural durability, and material quality. Based on these findings, an elderly-friendly smart bed prototype was developed using kiln-dried and chemically treated rubberwood integrated with assistive intelligent systems. The product evaluation indicated a high level of user satisfaction, with an overall mean satisfaction score of 4.29 out of 5.00. The highest-rated features included smart convenience functions, protective corner padding, intelligent safety systems, and structural stability. The findings suggest that QFD provides an effective framework for translating elderly user requirements into practical design solutions. This study contributes to elderly-friendly smart furniture development by integrating safety, assistive technology, and sustainable material considerations into a unified product design framework.*

**Key words:** *quality function deployment, house of quality, smart bed, elderly users, rubberwood furniture, elderly-friendly design.*

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## 1. Introduction

The global trend of population aging is accelerating rapidly, with both the number and proportion of elderly individuals rising significantly. In 2022, the global population aged 60 years and over reached 1.109 billion, representing approximately 14% of the total population. In Thailand, the elderly population is approximately 13 million, or 19% of the national population, and is projected to increase to 18.9 million, accounting for 31.44% by 2042 [23]. This demographic shift marks Thailand's definitive transition into a fully aged society. Currently, the elderly population includes approximately 6.8 million individuals aged 60-69 years, 3.5 million aged 70-79 years, and 1.7 million aged 80 years and over. These figures are approximate and derived from national statistical reports, where rounding may result in minor discrepancies between subgroup totals and the overall population. Meanwhile, birth rates and the proportion of younger populations continue to decline steadily [11].

In light of this demographic transformation, ensuring the well-being and quality of life of older adults has become increasingly critical. One key determinant of elderly health is sufficient rest, with medical guidelines recommending 7-9 hours of sleep per day to support physical restoration and reduce health risks [1]. Therefore, the design and development of furniture, particularly elderly-friendly smart beds, is vital. These products must incorporate elderly-friendly design strategies that address the physical, emotional, and safety-related requirements of aging users.

The Quality Function Deployment (QFD)

methodology offers a systematic and structured approach to translating user needs into technical design specifications. Utilising the Voice of Customer (VOC) (i.e., user needs), QFD facilitates a clearer understanding of end-user expectations, thereby enabling the development of products that effectively meet user needs in a tangible and measurable manner.

Previous research has demonstrated the successful application of QFD in a variety of product development contexts involving elderly users. For instance, QFD combined with ergonomic principles has been used to develop fruit-picking tools adapted to varying tree heights, thereby enhancing usability and user satisfaction [4]. Similarly, QFD and anthropometric data have been employed to design ergonomic desks and chairs for students, reducing musculoskeletal discomfort and improving functionality [8]. Another study integrated QFD with the Kano model and Pugh concept selection to develop a smart refrigerator for older adults, focusing on safety, simplicity, and personalisation through voice control and touchscreen interfaces [12].

Further applications of QFD include the design and prototyping of palm wood furniture [17], the development of school furniture optimised for student comfort and posture [19], and the creation of Scandinavian-style wardrobes that combine minimalist aesthetics with functional usability and high-quality materials [7]. A related study applied QFD to determine the technical requirements for school furniture based on student needs, confirming the effectiveness of QFD's in enhancing product quality, functionality, and production efficiency [10].

Building upon these studies and addressing persistent gaps in elderly-friendly furniture design, existing QFD-based research has primarily focused on conventional furniture products and has not comprehensively integrated intelligent systems, assistive functions, and safety mechanisms tailored specifically for elderly users. To address this limitation, this study applies the Quality Function Deployment (QFD) methodology to develop an elderly-friendly smart bed that integrates safety features, assistive technologies, and user-centred design considerations within a unified framework. In addition, rubberwood was selected as the primary material due to its availability, cost-effectiveness, durability, and suitability for structural furniture applications. Therefore, this study aims to identify the specific needs of elderly users and translate these needs into technical design specifications through the application of Quality Function Deployment. The findings are expected to contribute to elderly-friendly smart furniture development and sustainable product design for aging societies.

## 2. Materials and Methods

### 2.1. The Design and the Product Matrix

This study applied the Quality Function Deployment methodology by incorporating two main steps: the Product Planning Matrix and the Design Deployment Matrix. The first matrix, referred to as Matrix 1 (Product Planning Matrix or House of Quality), was used to translate customer needs into technical requirements. The second matrix, referred to as Matrix 2 (Design Deployment Matrix), was applied to convert technical requirements into detailed part

characteristics for prototype development. The overall research process was divided into two main stages.

### 2.2. Preparatory Phase for QFD Application

#### 2.2.1. Identification of Customer Requirements

To identify customer requirements related to elderly-friendly smart bed products, the study employed both structured interviews and open-ended questionnaires. These instruments were administered through both on-site and online platforms. A total of 246 participants were selected, and the sample was calculated using Cochran's sample size formula for an unknown population size, with a 95% confidence level ( $P = 0.20$ ,  $Z = 1.96$ , and  $d = 0.05$ ), as shown in Equation (1) – [24].

$$n = \frac{P \cdot (1-P) \cdot Z^2}{d^2} \quad (1)$$

$$n = \frac{0.20 \cdot (1-0.20) \cdot 1.96^2}{0.05^2} = 246$$

where:

$n$  represent the sample size [persons];

$P$  – the proportion of the target customer group;

$Z$  – the critical value corresponding to the desired confidence level;

$d$  – the allowable margin of sampling error.

Participants aged 55-59 years were included in this study because this group represents pre-elderly individuals and older adults who may begin experiencing age-related physical and ergonomic changes. In addition, they are considered potential future users of elderly-friendly

furniture products. Therefore, including this age group helped broaden the understanding of user needs related to aging and assistive furniture design.

Following the completion of the interviews and open-ended questionnaires, the collected Voice of Customer (VOC) was used, i.e., user needs data were carefully reviewed, rephrased, and organised into product requirement attributes. This process employed simple grouping and classification techniques to facilitate the systematic identification and classification of customer needs. Based on the refined insights from the initial data analysis, a second set of structured questionnaires was developed to evaluate customer satisfaction levels with various product attributes relevant to elderly-friendly smart beds. The questionnaire employed a 5-point Likert scale ranging from 1 = very low importance/satisfaction to 5 = very high importance/satisfaction.

The inclusion criteria required participants to be individuals aged 55 years and over who had experience using household furniture products and were capable of independently completing the questionnaire. Participants with severe cognitive impairment, communication difficulties or incomplete questionnaire responses were excluded from the study.

### **2.2.2. Questionnaire Validity and Reliability Assessment**

The questionnaire was evaluated for content validity using the Index of Item-Objective Congruence (IOC) by three experts in industrial engineering and product design. All questionnaire items achieved IOC values greater than 0.50, indicating acceptable content validity.

Reliability testing was conducted using

Cronbach's alpha coefficient to assess the internal consistency of the questionnaire. The obtained Cronbach's alpha value was greater than 0.80, indicating satisfactory reliability for data collection and analysis.

### **2.2.3. Analysis of Customer Requirement Importance Scores**

The importance scores of customer requirements were calculated using the geometric mean. While Likert-scale data are ordinal in nature and are commonly analysed using arithmetic mean or median, the geometric mean was employed in this study to better preserve proportional relationships among importance ratings and to reduce the influence of relative variability across attributes. In the context of QFD, where importance scores are used as weighting factors in subsequent matrix calculations, the geometric mean provides a multiplicative aggregation that reflects relative differences more consistently than additive measures. This approach has been adopted in previous studies involving judgment matrices and weighting procedures [3]. Furthermore, a comparison with arithmetic mean-based aggregation was conducted, and no significant differences in ranking patterns were observed. Therefore, the geometric mean was considered appropriate for this study. These importance scores, denoted as importance scores (IMP: Importance Weight), were subsequently used as weighting factors within the Product Planning Matrix of the QFD process. The use of geometric mean-based weights ensures proportional consistency in the HOQ calculations.

## 2.3. Application of the Quality Function Deployment Technique

### 2.3.1. The Main Elements of the House of Quality

Upon completion of the data preparation phase and the calculation of geometric mean scores, the results were incorporated into the House of Quality (HOQ), a matrix linking user needs and technical requirements to guide the design of elderly-friendly smart beds.

### 2.3.2. Implementation of the Product Planning Matrix

The Product Planning Matrix, commonly referred to as the House of Quality (HOQ) [9, 20], was developed by converting the Voice of Customer into measurable performance metrics, known as technical requirements

(design features) or Substitute Quality Characteristics (SQC). These SQCs were articulated as design features. Once the SQCs were established, corresponding target values and improvement ratios were calculated. This was followed by the determination of importance weights for each performance metric.

The SQCs, along with their respective importance scores, were used to identify and prioritise critical design specifications for the product. These importance scores were derived using the geometric mean, ensuring that proportional relationships among customer requirements were preserved and consistently reflected in the weighting process within the HOQ calculations. The Product Planning Matrix consists of six main sections, as illustrated in Figure 1.

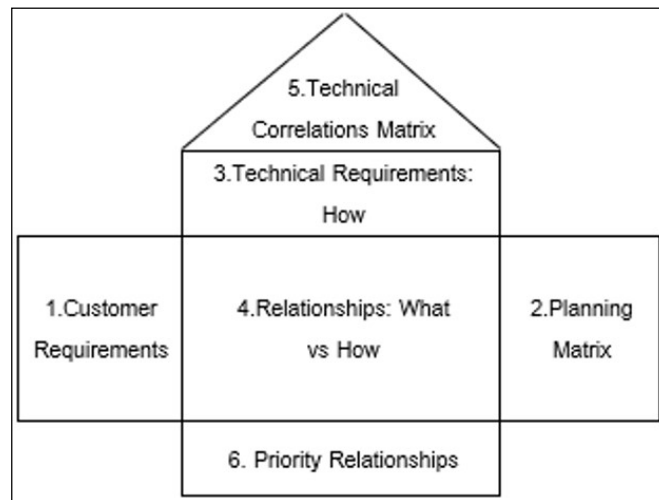


Fig. 1. *Elements of the House of Quality (HOQ)*

The implementation process of the Product Planning Matrix within the Quality Function Deployment framework was conducted through the following six key steps [2, 5, 6, 14, 21]:

#### 1. Identification of Customer Needs (user needs (WHATs))

Customer needs, obtained during the preparatory phase through interviews and open-ended questionnaires, were listed in

the first section of the House of Quality (HOQ). These needs, collectively known as the Voice of Customer, serve as the foundational input for subsequent technical analysis and design decision-making.

### 2. Construction of the Planning Matrix

This matrix serves as a central component in QFD, linking customer needs to the technical strategies intended to address them. It ensures that design and development efforts are consistently aligned with user expectations and requirements.

### 3. Definition of Technical Requirements (HOWs)

Technical requirements, also referred to as design , represent measurable engineering characteristics that directly correspond to customer needs. These were generated through brainstorming sessions involving multidisciplinary experts from design, manufacturing, and user advocacy teams. The brainstorming sessions involved five specialists comprising two industrial engineering experts, one furniture design specialist, one manufacturing engineer, and one smart system developer. All specialists had more than five years of professional experience in product development, furniture engineering, or elderly-centred assistive system design. Once identified, the technical requirements were entered into the third section of the HOQ. For each technical requirement, a specific target value was defined preferably in measurable terms and recorded in the sixth section. Additionally, a directional indicator was assigned to represent the desired trend for improvement using standard notations: ↑ (The more, the better), ○ (Nominal is best), and ↓ (The less, the better).

### 4. Development of the Relationship Matrix

Positioned at the centre of the HOQ, this matrix establishes the correlation between customer needs (WHATs) and technical requirements (HOWs). The strength of each relationship was evaluated using a standard scoring system derived from Japanese QFD methodology: 0 = No relationship, 1 = Weak relationship, 3 = Moderate relationship, and 9 = Strong relationship. This assessment requires expert judgment to determine the degree to which each technical requirement contributes to customer satisfaction.

### 5. Technical Correlation Matrix (correlation matrix between technical requirements)

This matrix identifies interrelationships among the technical requirements themselves. It helps engineers assess whether certain technical features reinforce or conflict with others. Correlations are denoted by the following symbols: O = Strong positive correlation, X = Negative or conflicting relationship, and Blank = No correlation.

### 6. Calculation of Priority Relationships

This step quantifies the relative significance of each technical requirement in satisfying customer needs. Two types of importance scores are calculated: Absolute Importance Weight: The raw score that reflects how much each technical requirement contributes to addressing customer needs; and Relative Importance Weight: The proportional score expressed as a percentage of the total, used to rank the technical requirements in order of priority.

These values were computed using Equations (2) and (3) to inform resource allocation and guide design focus in the product development process.

$$IMP = \sum A \times B \quad (2)$$

where:

*IMP* represent the importance weight of a technical requirement;

*A* – the relationship scores between the technical requirement and the corresponding customer need;

*B* – the initial ranking value used to prioritise technical requirements.

$$\%IMP = \frac{IMP}{\sum IMP} \cdot 100 \quad (3)$$

where:

*%IMP* represent the relative importance weight of a technical requirement, expressed as a percentage of the total [%];

$\sum IMP$  – the total sum of all absolute importance weights assigned to the technical requirements.

### 2.3.3. Application of the Design Deployment Matrix

The Design Deployment Matrix represents the second step of the Quality Function Deployment process. It serves to translate technical requirements derived from the Product Planning Matrix into detailed part characteristics for practical product development. The implementation involved the following sequential steps:

#### 1. Selection of Technical Requirements

All technical requirements identified in the Product Planning Matrix (House of Quality; HOQ) were selected to ensure comprehensive coverage of customer expectations. These requirements were transferred to the leftmost column of the Design Deployment Matrix for further evaluation and analysis.

#### 2. Importance Weights (IMP)

The relative importance weights for each technical requirement, previously calculated during the product planning stage, were entered adjacent to their corresponding technical items in the matrix. These weights indicate the priority of each requirement in terms of its impact on fulfilling customer needs.

#### 3. Specification of Part Characteristics

Part characteristics were identified through brainstorming sessions that included design engineers, manufacturing specialists, and representatives from the elderly user group. These characteristics were defined to represent product functions. For each part, measurable target values and improvement directions were established using standard indicators:  $\uparrow$  = The more, the better,  $\circ$  = Target value is optimal, and  $\downarrow$  = The less, the better. These specifications guided the formulation of technical performance criteria and future improvement strategies.

#### 4. Development of the Relationship Matrix

The relationships between technical requirements and part characteristics were evaluated using a numerical scoring system: 1 = Weak correlation, 3 = Moderate correlation, and 9 = Strong correlation. This matrix served as a tool to assess the degree of influence each part feature has in achieving customer satisfaction, thereby informing design decisions with quantitative support.

#### 5. Calculation of Priority Relationships

The significance of each part characteristic was determined through weighted calculations, following a similar method to that used in the Product Planning Matrix.

These calculated scores revealed which part features had the greatest impact on fulfilling user needs and thus warranted prioritisation in the subsequent design and prototyping phases of the elderly-friendly smart bed, constructed primarily from rubberwood.

#### **2.4. Product Design and Prototyping**

Based on the analysis of VOC data (user needs) and the outcomes of the two Quality Function Deployment phases, multiple bed design concepts were initially developed. Through a structured evaluation process, the design team selected the most feasible and functionally appropriate concept for prototyping. The final prototype was fabricated primarily from rubberwood, which was selected based on its mechanical strength, durability after kiln-drying and chemical treatment, and suitability for precision assembly required in elderly-friendly smart furniture systems. The final prototype was fabricated in accordance with the prioritised technical requirements and part characteristics identified in the Design Deployment Matrix, ensuring that the product closely aligned with user needs and performance expectations.

#### **2.5. Product Satisfaction Evaluation**

Following the development of the prototype, a satisfaction survey was conducted using a structured 20-item questionnaire. The same sample group ( $n = 246$ ) from the VOC phase participated in this evaluation. The prototype evaluation was conducted in a simulated residential environment designed to resemble typical bedroom usage conditions for elderly users. Participants were allowed to physically interact with the prototype and evaluate its

functionality, usability, safety, convenience, and overall satisfaction through structured assessment questionnaires administered after the testing session. Descriptive statistical analysis was employed to calculate the mean scores and standard deviations for each product attribute, providing a quantitative assessment of user satisfaction with the elderly-friendly smart bed prototype.

#### **2.6. Ethical Considerations**

All participants voluntarily participated in this study. Informed consent was obtained prior to data collection. Participant information was treated confidentially and anonymously, and no personally identifiable information was disclosed. The study involved questionnaire-based evaluations with minimal risk and was conducted in accordance with institutional research ethics guidelines for human-related research.

### **3. Results**

#### **3.1. Preparatory Phase Results**

The initial Voice of Customer survey involved both manufacturers and users of rubberwood furniture. A total of 246 participants were sampled, comprising 50.80% male and 49.20% female respondents, with the majority falling within the 55-59 age group. Open-ended responses were compiled, reviewed, and categorised using quality tools to identify core customer expectations. These were grouped into six major categories – Design, Materials, Smart Systems, Usability, Quality, and Others – as shown in Figure 2, resulting in a total of 19 distinct consumer needs. These identified needs were subsequently used to develop a closed-ended

questionnaire aimed at assessing the perceived importance of each factor influencing user satisfaction with elderly-friendly smart bed products. The hierarchical structure of customer requirements was further developed, as presented in Figure 3.

<b>Design</b>	<b>Materials</b>	<b>Quality</b>
1. Variety of Shapes	1. High-Quality Materials	1. Product Quality
2. Appropriate Dimensions	2. Insect-Resistant Materials	2. Load-Bearing Capacity
3. Aesthetic Appeal	3. Natural and Environmentally Friendly Materials	3. Long Product Lifespan
4. Colour Variations		4. User Safety
<b>Smart Systems</b>	<b>Usability</b>	<b>Others</b>
1. Intelligent Safety System	1. Number of Users	1. Reasonable Pricing
2. Smart Bed for Convenience	2. Ease of Maintenance	2. After-Sales Service
3. Performance of the Intelligent System	3. Additional Functional Accessories	

Fig. 2. *Consumer needs affinity diagram*

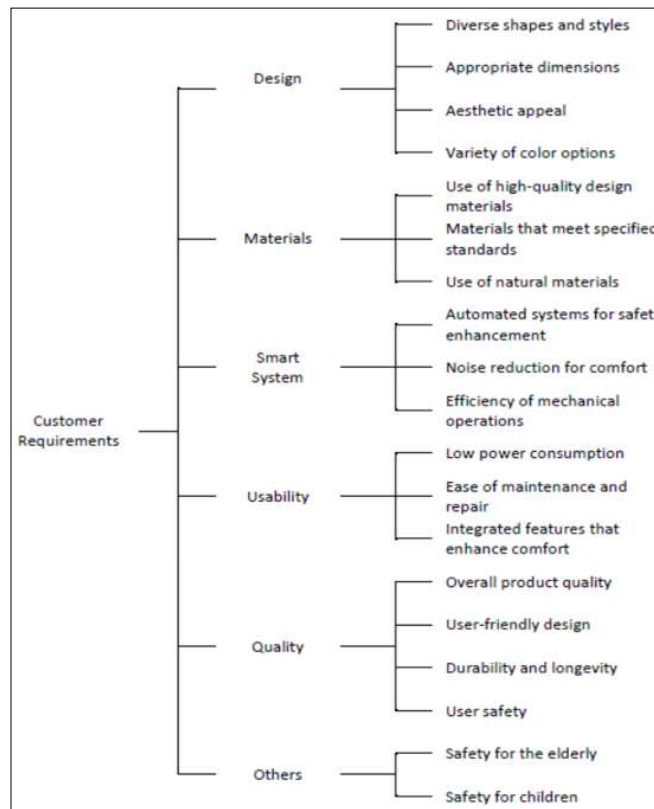


Fig. 3. *Tree diagram representing the product attributes of the elderly-friendly smart bed*

*Technical requirements and target values for the elderly-friendly smart bed* Table 1

No.	Technical requirement	Technical target value	Direction of improvement
1.	Number of users	Designed for single-person use	○
2.	Aesthetic appeal	Over 80% of target users perceive the product as aesthetically pleasing	↑
3.	Colour variety	More than one colour option available	○
4.	Shape variety	More than one shape option available	↑
5.	Ergonomic design	Designed in accordance with ergonomic principles	○
6.	Quality of materials	Dried and treated rubberwood used	↑
7.	Insect-repellent materials	Materials can resist insect infestation for more than five years	↑
8.	Main material	Rubberwood is used as the primary material	↑
9.	Safety-enhancing materials	Impact-absorbing materials are included	↑
10.	Smart features for convenience	Smart system includes multiple usability features	↑
11.	Smart safety system	Integrated smart safety monitoring features	○
12.	Additional accessories	Includes add-ons to enhance functional utility	○
13.	Ease of maintenance	Design minimises corners or gaps that are difficult to clean	○
14.	Load capacity	Supports weight of no less than 200 kilograms in accordance with safety standards	↑
15.	Product lifespan	Product lifespan exceeds 10 years	↑
16.	Smart system performance	High precision, speed, and system stability	↑
17.	Assembly quality	No defects observed in assembled components	↑
18.	Installation of smart systems	Installed and tested by certified professionals	○
19.	Price	Reasonably priced according to quality and materials used	○
20.	After-sales service	One-year warranty provided	○

### 3.2. Results from the Application of the Product Planning Matrix

#### 3.2.1. Customer Needs Identification

Customer requirements were categorised into six primary groups, resulting in a total of 19 distinct needs. These needs were placed in the left-hand column of the Product Planning Matrix, as illustrated in Figure 4.

#### 3.2.2. Development of the Planning Matrix

Following the identification of customer needs, the geometric mean importance score (IMP) derived from the second set of structured questionnaires was assigned to each respective customer need and inserted into the left-hand side of the House of Quality.

### 3.2.3. Identification of Technical Requirements

Technical requirements were determined through brainstorming sessions involving a multidisciplinary team comprising researchers, design experts, manufacturing specialists, and elderly user representatives. Each technical requirement was paired with a clearly defined, measurable target value and a directional indicator for improvement. A total of 20 technical requirements, along with their associated target values and improvement directions, are detailed in Table 1 and Figure 4.

### 3.2.4 Construction of the Relationship Matrix

A relationship matrix was developed to assess the degree of correlation between customer needs (Section 1 of the HOQ) and technical requirements (Section 3 of the HOQ). Relationship scores were determined

using pairwise comparisons during expert brainstorming sessions, as shown in Figure 4.

### 3.2.5. Technical Correlation Matrix

The roof of the House of Quality was used to represent the technical correlation matrix. This matrix was established via cross-functional brainstorming to identify interdependencies, both synergistic and conflicting, among technical requirements. The interactions are illustrated in Figure 4.

### 3.2.6. Prioritisation of Technical Requirements

Technical priorities were computed using data from the Product Planning Matrix, with scores ranked based on absolute importance. The importance ratings of customer requirements are presented in Table 2 and visualised through a Pareto Diagram in Figure 5.

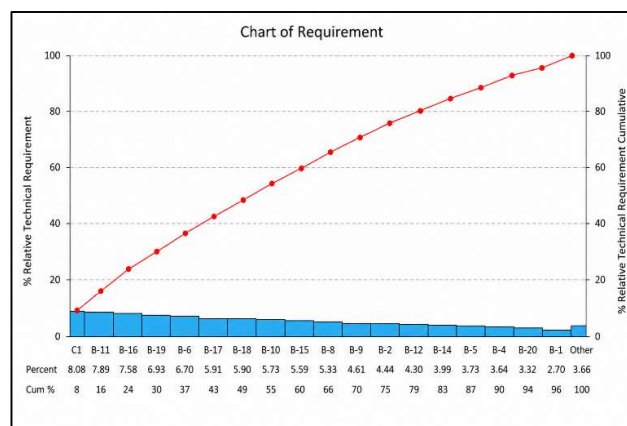


Fig. 5. Ranking of the importance weights of technical requirements

An approximately 80% cumulative importance criterion was applied to identify the most critical technical attributes for product development. The selected factors

represent the dominant technical attributes contributing to the majority of the cumulative importance within the Pareto analysis framework. Based on the Pareto

analysis, 13 critical technical requirements were identified. The highest-priority requirements included intelligent safety systems, intelligent system performance, product cost, material quality, assembly quality, intelligent convenience systems,

and product lifespan. These findings indicate that safety, usability, durability, and smart functionality were the most influential factors in the development of the elderly-friendly smart bed.

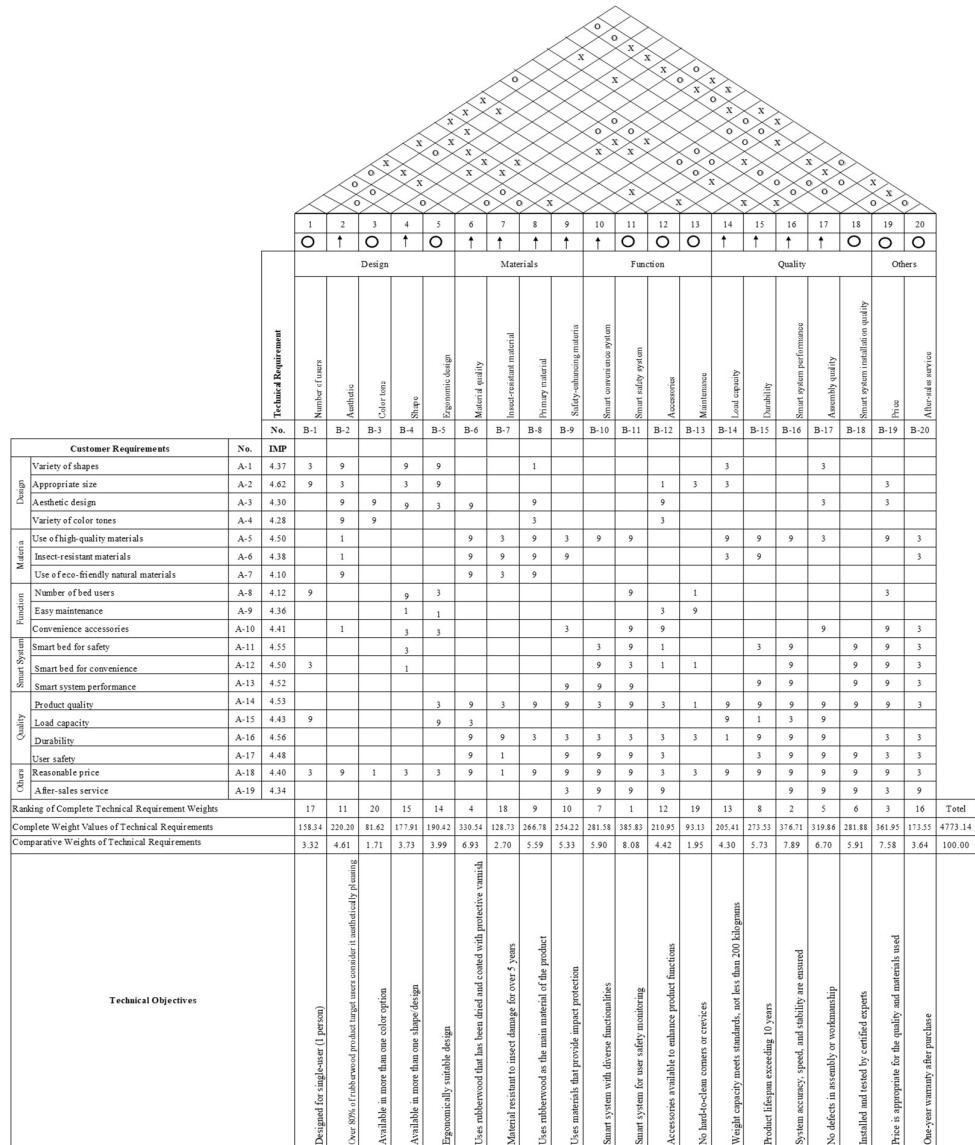


Fig. 4. Product planning matrix for the elderly-friendly smart bed

*Absolute and relative importance weights of technical requirements* Table 2

No.	Technical requirement	Absolute tech.	Percentage	Cumulative percentage
1.	Intelligent safety system	385.83	8.08	8.08
2.	Performance of intelligent system	376.71	7.89	15.98
3.	Price	361.95	7.58	23.56
4.	High-quality materials	330.54	6.93	30.48
5.	Quality of assembly	319.86	6.70	37.18
6.	Quality of intelligent system installation	281.88	5.91	43.09
7.	Intelligent system for convenience	281.58	5.90	48.99
8.	Product lifespan	273.53	5.73	54.72
9.	Primary structural material	266.78	5.59	60.31
10.	Safety-enhancing materials	254.22	5.33	65.64
11.	Aesthetic appeal	220.20	4.61	70.25
12.	Additional accessories	210.95	4.42	74.67
13.	Load-bearing capacity	205.41	4.30	78.97
14.	Ergonomic design	190.42	3.99	82.96
15.	Variety of forms	177.91	3.73	86.69
16.	After-sales service	173.55	3.64	90.32
17.	Number of users	158.34	3.32	93.64
18.	Insect-resistant materials	128.73	2.70	96.34
19.	Ease of maintenance	93.13	1.95	98.29
20.	Colour variation	81.62	1.71	100.00

### 3.3. Results of Design Deployment Matrix Application

#### 3.3.1. Selection of Technical Requirements and Geometric Mean Scores

All technical requirements identified in the Product Planning Matrix were incorporated into the Design Deployment Matrix. Each was considered essential and directly influential in meeting customer expectations. The corresponding geometric mean values, representing the relative importance of each technical attribute, were placed in the left-hand column of the Design Deployment Matrix, as illustrated in Figure 6.

#### 3.3.2. Definition of Part Characteristics

Part characteristics were defined through

a series of brainstorming sessions involving the research team, design engineers, manufacturing specialists, and representatives from the elderly user group. These sessions aimed to explore the relationships between technical requirements and specific subcomponent features that address user needs. For each technical requirement, target values were established with a focus on measurability and practical feasibility. In addition, target direction indicators were assigned to clarify the desired trend of improvement:  $\uparrow$  = the more, the better,  $\circ$  = Target is best (nominal value), and  $\downarrow$  = the less, the better. In total, 23 subcomponent technical characteristics, along with their respective target values and direction indicators, as well as the relationships between technical requirements are shown in Table 3 and Figure 6.



*Technical requirements and target values of subcomponents*      Table 3  
*for the elderly-friendly smart bed*

No.	Technical requirement	Target value description	Target direction
1.	Smoke and temperature detection	Install sensors on the bed frame to detect abnormal heat and smoke levels	○
2.	Automatic emergency guide lighting	Install lights that automatically turn on when the elderly get out of bed at night	○
3.	Automatic power cut-off for short circuits	Integrate an automatic shut-off system in case of short circuits or electrical overload	○
4.	Component pricing	Set prices appropriate to material and component specifications	○
5.	Structural component quality	Use kiln-dried and chemical-treated rubberwood	↑
6.	Intelligent component quality	Utilise standardised and certified smart components	↑
7.	Component installation and assembly	Apply durable assembly techniques with secure joints	○
8.	Bed height adjustability	Implement systems allowing for height and tilt adjustments	○
9.	Voice control system	Enable operation of bed functions through voice commands	○
10.	Component durability	Ensure functional lifespan of no less than 10 years	↑
11.	Primary structural materials	Use rubberwood as the main material with supplementary materials as needed	○
12.	Protective corner padding	Round off all sharp edges and apply protective padding to all corners	↑
13.	Decorative materials	Use aesthetic or utility-enhancing materials for decoration	↑
14.	Usability-enhancing accessory materials	Include additional parts to support features such as cup holders	↑
15.	Structural reinforcement materials	Use additional materials to strengthen the bed structure	↑
16.	Component dimensions	Design all parts to match standard human body dimensions	○
17.	Variety of forms and shapes	Design adjustable or customisable forms to suit elderly preferences	↑
18.	Spare parts for warranty claims	Provide replaceable spare parts for broken or expired components	○
19.	Safety enhancement components	Include features such as wire guards to prevent impact and pest-related damage	↑
20.	Cable management system	Design secure and concealed spaces for wire storage to ensure safety	○
21.	Chemical treatment of wooden components	Ensure anti-termite coating effectiveness for at least five years	↑
22.	Ease of cleaning	Design structures to be easily cleaned and maintained	○
23.	Component colour scheme	Use colour combinations of at least two tones on bed components	↑

### 3.4 Prioritisation of Technical Requirements from the Design Deployment Matrix

To prioritise the technical requirements identified in the Design Deployment Matrix (Matrix 2), the attributes were ranked based on their Technical Priority scores, as illustrated in Figure 6 and summarised in Table 4. A Pareto diagram was constructed to visualise the cumulative importance of each attribute, as shown in Figure 7.

An approximately 80% cumulative technical priority criterion was applied to identify the most critical design elements, which is a commonly used approach in exploratory Pareto-based prioritisation studies. The selected factors represent the dominant technical attributes contributing to the majority of the cumulative technical importance within the Pareto analysis framework. Based on this threshold, a total of 14 key technical requirements were selected to guide product development.

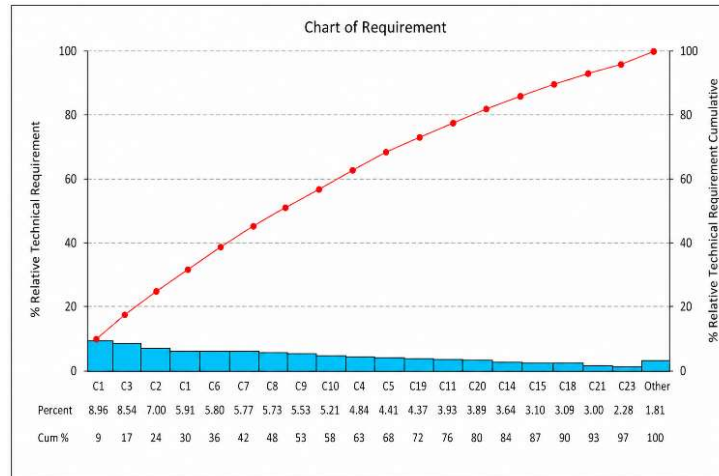


Fig. 7. Ranking of the importance weights of technical requirements

These requirements are detailed below:

1. Automatic Power Cut-Off in Case of Electrical Short Circuit: A built-in safety mechanism that disconnects electrical power automatically in the event of a short circuit or overload, ensuring user protection;
2. Automatic Emergency Guide Lighting: A lighting system that activates automatically when the user leaves the bed at night, improving visibility and reducing fall risk;
3. Smoke and Temperature Detection:

Integrated sensors capable of detecting abnormal temperature rises and smoke, providing early warnings to prevent emergencies. The sensor is placed in the under-bed compartment near the wiring, microcontroller and electronic modules for direct detection;

4. Quality of Intelligent System Components: Use of certified, performance-tested smart components that comply with safety and reliability standards;

Ranking of absolute and relative importance weights of technical requirements for the elderly-friendly smart bed

Table 4

No.	Technical requirement	Absolute tech.	Percentage	Cumulative percentage
1.	Automatic power cut-off in case of short circuit	559.89	8.96	8.96
2.	Automatic emergency guide lighting	533.67	8.54	17.50
3.	Smoke and temperature detection	437.34	7.00	24.50
4.	Quality of intelligent system components	369.60	5.91	30.41
5.	Installation and assembly of each component	362.33	5.80	36.21
6.	Adjustability of bed height and position	360.88	5.77	41.98
7.	Voice control functionality	357.84	5.73	47.71
8.	Lifespan of components	345.47	5.53	53.24
9.	Cost of individual components	325.53	5.21	58.45
10.	Structural component quality	302.17	4.84	63.28
11.	Safety enhancement components	275.74	4.41	67.69
12.	Primary structural materials	272.85	4.37	72.06
13.	Cable management system	245.76	3.93	75.99
14.	Usability-enhancing accessory materials	243.15	3.89	79.88
15.	Structural reinforcement materials	227.40	3.64	83.52
16.	Spare parts covered under warranty	193.57	3.10	86.62
17.	Protective corner padding materials	193.38	3.09	89.71
18.	Wooden component chemical coating	187.66	3.00	92.71
19.	Decorative materials	142.36	2.28	94.99
20.	Colour quality of components	113.05	1.81	96.80
21.	Variety of structural shapes	83.04	1.33	98.13
22.	Ease of cleaning	65.64	1.05	99.18
23.	Component dimensions	51.19	0.82	100.00

5. Installation and Assembly of Individual Components: All components are installed and assembled by certified professionals to ensure alignment, stability, and safe usage;
6. Adjustable Bed Height and Angle: The bed offers both vertical and angular adjustment capabilities to enhance comfort and accommodate diverse physical conditions. The adjustment mechanism is integrated into the upper bed unit, which is mounted on the main bed platform;
7. Voice Command Control System: A smart interface enabling hands-free operation through voice recognition technology for enhanced user convenience;
8. Component Durability: Each part is designed for long-term durability,

reducing the frequency and cost of replacements;

9. Cost of Components: Components are evaluated and selected based on material type and size to ensure cost-effectiveness and market accessibility;
10. Quality of Structural Components: Structural parts are engineered to meet load-bearing, durability, and safety standards;
11. Additional Safety Components: Safety-enhancing elements are integrated to prevent damage from wear and tear, extending the overall product lifespan;
12. Primary Structural Materials: The bed frame is constructed using kiln-dried, chemically treated rubberwood, reinforced with additional materials for superior strength and durability;
13. Cable Management Design: A built-in cable management system is included to protect electrical wires from external hazards and pests, reducing maintenance needs;
14. Convenience-Enhancing Materials: Additional materials are incorporated to improve usability and comfort, particularly catering to the needs of elderly users.

These prioritised technical attributes provide a comprehensive foundation for the

next stage of product development. They ensure that the elderly-friendly smart bed design not only meets the functional and ergonomic expectations of elderly users but also addresses safety, usability, cost-efficiency, and long-term performance.

### 3.5. Product Design and Prototyping Results

Based on the analysis conducted using the Quality Function Deployment methodology, the technical requirements and corresponding target values identified through the Product Planning Matrix (Matrix 1) and the Design Deployment Matrix (Matrix 2) were employed to guide the product design phase. These technical specifications served as essential inputs for the product development team in conceptualising and visualising the design of the elderly-friendly smart bed.

The finalised design was developed into a functional prototype that was designed in accordance with the defined technical criteria. The prototype incorporated the prioritised design attributes identified through the QFD process, ensuring that user requirements were effectively addressed. The resulting prototype of the elderly-friendly smart bed is illustrated in Figure 8.



a.



b.

Fig. 8. *Prototype of the elderly-friendly smart bed:*  
a. bed frame without mattress; b. smart bed with integrated intelligent systems

### 3.6 Evaluation of Consumer Satisfaction with the Product

Following the design and prototyping of the elderly-friendly smart bed, a consumer satisfaction survey was conducted using a structured questionnaire comprising 20

items. The questionnaire was administered to a sample of 246 participants. The collected data were analysed to compute the mean satisfaction score for each item, as well as the overall consumer satisfaction percentage for the developed elderly-friendly smart bed, as presented in Table 5.

*Analysis of consumer satisfaction with the developed elderly-friendly smart bed* Table 5

No.	Consumer requirement	Mean satisfaction score ( $\bar{X}$ )	Standard deviation (SD)
1.	Designed for single-user application	4.12	0.74
2.	Diverse structural forms including headboard	4.26	0.65
3.	Aesthetic appeal and pleasing design	4.41	0.57
4.	Appropriate dimensions for elderly users	4.40	0.65
5.	Use of rubberwood as primary material	3.94	0.99
6.	High-quality rubberwood (kiln-dried & treated)	4.46	0.56
7.	Reinforced structure materials	4.16	0.74
8.	Protective corner padding	4.48	0.56
9.	Auxiliary features (storage, phone holder)	4.03	0.79
10.	Adjustable bed levels	4.20	0.73
11.	Smart system installed by professionals	4.26	0.66
12.	Smart convenience features (lighting, voice control)	4.50	0.49
13.	Smart safety features (auto shut-off, sensors)	4.47	0.49
14.	High-performance smart system (accurate, fast)	4.36	0.50
15.	Concealed and secure cable management	4.38	0.52
16.	Stable and secure assembly	4.46	0.53
17.	Weight capacity up to 200 kg	4.25	0.77
18.	Ease of maintenance	4.31	0.64
19.	Durable lifespan	4.18	0.67
20.	Pest-resistant materials	4.39	0.51

The evaluation results highlighted the top five features that received the highest consumer satisfaction ratings. The most highly rated feature was the intelligent

convenience system, which included motion-activated lighting when users exited the bed and voice-controlled functionalities, achieving a mean score of 4.50. The second

highest-rated feature was protective padding at the bed's corners, designed to prevent injury, which scored 4.48. The intelligent safety system, incorporating automatic power shut-off and integrated smoke/temperature detection, ranked third with a score of 4.47. In fourth place was the structural stability and precision of assembly, which received a score of 4.46. Finally, the use of high-quality rubberwood, which was kiln-dried and chemically treated for enhanced durability, also earned a score of 4.46.

These findings suggest that the developed product effectively responds to the primary requirements of elderly users – particularly in terms of safety, usability, durability, and material quality – thereby enhancing user satisfaction and confidence in daily use.

#### 4. Discussion

The design of an elderly-friendly smart bed using the Quality Function Deployment methodology is consistent with findings from previous studies. Beyond this consistency, the present study contributes to the literature by extending QFD to elderly-friendly smart furniture design, where intelligent features, safety mechanisms, and assistive functions are systematically integrated within a unified framework. This goes beyond conventional QFD applications that primarily focus on physical or ergonomic aspects.

The high ranking of intelligent safety systems reflects the increasing concern regarding accident prevention and independent living among elderly users. Features such as automatic power cut-off systems, smoke and temperature detection, and emergency lighting directly address common household risks associated with aging, including falls, delayed emergency

response, and reduced mobility. These findings suggest that safety-oriented smart technologies are important design considerations in elderly-friendly smart furniture design, particularly for supporting confidence, reducing anxiety, and improving quality of life during daily activities.

The findings also reveal important trade-offs between safety enhancement, usability, and product cost. Although intelligent systems and reinforced safety components increase manufacturing complexity and production cost, elderly users perceived these features as highly valuable due to their contribution to safety, convenience, and long-term usability. Therefore, balancing affordability with essential smart functions represents an important consideration in future elderly-friendly smart furniture development.

For instance, Rawangwong et al. [16] applied QFD to the development of woven sedge handbags and demonstrated that the redesigned products effectively met customer expectations. Their study confirmed that QFD supports the translation of user needs into functional product features that align with consumer preferences. Similarly, Rawangwong et al. [18] employed QFD in combination with Kansei Engineering to design and prototype bamboo-based sofas. The resulting product effectively fulfilled customer expectations, reaffirming the suitability of QFD in various furniture design applications. A comparable outcome was reported by Pirom et al. [15], who applied QFD to the development of classroom tables and chairs for kindergarten students. The final designs incorporated attractive colours and multifunctional configurations, resulting in high user satisfaction. In a related study, Lyu et al. [13] integrated Kano's Model with QFD in the

development of office desks. Their research emphasised the importance of structural strength, flexibility, ergonomic design, and smart functionality – characteristics that significantly contributed to product appeal and market potential. Likewise, Sukhlal et al. [22] applied QFD to the design of modular kitchens, effectively translating customer needs into functional product features. Their findings demonstrated that QFD helped identify critical improvement areas based on VOC data, leading to more user-centred and practical kitchen designs.

Additionally, Homkhiew et al. [6] used QFD in the development of a plywood wardrobe and reported a substantial increase in user satisfaction. The average satisfaction score improved from 2.71 to 4.08, representing a 54.87% enhancement compared to the prior design iteration. Taken together, these studies validate the effectiveness of the QFD approach adopted in the present research. The findings also suggest that systematically translating customer needs into technical design specifications can support innovation and improve product functionality in alignment with user expectations.

From a methodological perspective, the use of the geometric mean for aggregating Likert-scale importance ratings was found to produce consistent prioritisation results when compared with conventional arithmetic mean-based approaches, supporting its applicability in QFD-based weighting analysis. Unlike conventional QFD-based furniture design studies, this research explicitly integrates material selection – specifically rubberwood – into the design framework.

The use of rubberwood is not merely a material choice but a design constraint that influences structural stability, durability, manufacturability, and cost efficiency.

These material characteristics directly support the integration of intelligent systems and safety features required for elderly users. In addition, these design features contribute to sustainability by extending product lifespan through durable materials, enabling component-level replacement via modular design to reduce material waste, and incorporating energy-efficient smart systems to reduce overall energy consumption during product operation. Therefore, material selection plays a critical role in linking user requirements with practical implementation. The use of rubberwood also supports sustainable furniture manufacturing due to its widespread availability, renewable nature, and efficient utilisation within the Thai furniture industry. Compared with imported hardwoods or synthetic materials, rubberwood provides a cost-effective and environmentally responsible alternative while maintaining sufficient mechanical strength and durability for elderly-friendly structural applications. These characteristics contribute to both economic feasibility and long-term sustainability in smart furniture development.

Despite the promising findings, this study has several limitations. The participant group was limited to a specific demographic and geographic context, which may affect the generalisability of the findings to broader elderly populations. In addition, the prototype evaluation primarily focused on user satisfaction and perceived usability, without long-term ergonomic assessment or clinical evaluation related to elderly health outcomes. Furthermore, the intelligent system functions implemented in the prototype were limited to basic safety and convenience features.

Future research may involve larger and

more diverse participant groups, long-term usability testing, ergonomic performance assessment, and integration of advanced technologies such as AI-based monitoring systems, IoT-enabled healthcare support, and personalised assistive functions for elderly users. Additional studies may also explore cost optimisation, sustainability assessment, and commercial scalability of elderly-friendly smart furniture products.

## 5. Conclusion

This study successfully applied the Quality Function Deployment (QFD) methodology to design and develop an elderly-friendly smart bed by systematically translating user needs into technical design specifications. The integration of the Product Planning Matrix and the Design Deployment Matrix enabled the identification and prioritisation of critical technical requirements related to safety, usability, intelligent systems, durability, and material quality.

The developed prototype demonstrated a high level of user satisfaction, particularly regarding intelligent convenience functions, intelligent safety systems, structural stability, and protective safety features. The findings suggest that QFD is an effective framework for elderly-friendly product development and supports the integration of smart technologies into furniture design for aging populations.

The scientific contribution of this study lies in extending QFD beyond conventional furniture design by integrating assistive technologies, intelligent safety systems, and sustainable material considerations within a unified elderly-friendly smart furniture framework. The study also demonstrates the practical potential of rubberwood as a sustainable and structurally suitable material for smart furniture manufacturing.

Overall, the proposed approach contributes to future elderly-friendly product innovation and provides a practical framework for the development of safe, functional, and sustainable smart furniture products.

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