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Smart Kitchen Counter Innovation for Elderly Users Based on Quality Function Deployment and Internet of Things System

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Abstract: This study aims to design and develop a kitchen counter product for elderly users by applying the Quality Function Deployment (QFD) technique to address user requirements. The study began with a survey of elderly users' needs, including design, facilities, usability, product quality, and materials. The collected data was analyzed using the QFD product planning matrix and the design deployment matrix to translate customer requirements into technical design specifications. The results indicated that the participants reported a mean perceived satisfaction score of 4.42 out of 5.00 after observing a demonstration of the prototype and its functions in an actual kitchen environment. The five product attributes with the highest satisfaction scores were lighting within overhead cabinet storage compartments, operational safety, ease of maintenance, structural strength, and electrical outlet safety systems, with mean scores of 4.62, 4.57, 4.56, 4.54, and 4.53, respectively. These findings demonstrate that Quality Function Deployment (QFD) is an effective approach for translating user requirements into product design, particularly in the development of kitchen counter products for elderly users. The resulting design was perceived as having the potential to improve safety and convenience for elderly users during kitchen activities. However, further hands-on usability and long-term field testing are required to verify its effectiveness under actual use conditions.

Keywords: Product design; quality function deployment; kitchen counter; elderly; internet of things (IoT)

1. Introduction

According to global demographic reports, both the number and proportion of older adults have been increasing rapidly worldwide. The global population aged 60 years and above has reached approximately 1.109 billion people, accounting for 14% of the total global population [1]. Similarly, the number of older adults in Thailand has been steadily increasing. Recent statistics indicate that Thailand currently has approximately 6.8 million people aged 60–69 years, 3.5 million people aged 70–79 years, and 1.7 million people aged 80 years and above. At the same time, declining birth rates and a decreasing child population have been observed annually, leading Thailand to become a fully aged society [2]. Given this demographic transition, ensuring the well-being and quality of life of older adults has become increasingly important. Consequently, the design and development of products suitable for elderly users have become essential, particularly furniture that is frequently used in daily life [3].

Among the various areas within the home environment, the kitchen represents an important space where older adults perform essential daily activities such as food preparation and cooking. However, many older adults

experience age-related physical limitations, including reduced muscle strength, impaired vision, decreased balance, and restricted mobility. These limitations may increase the risk of accidents within the kitchen environment. In addition, conventional kitchens in many households are not designed to accommodate the specific needs of elderly users. For instance, inappropriate counter heights, storage areas located at excessive heights, and limited workspace may create usability difficulties. As a result, older adults often experience inconvenience when performing daily kitchen tasks and may increasingly rely on assistance from others.

Therefore, the design of kitchen counter furniture for elderly users requires a product development process that effectively addresses customer requirements. One widely adopted approach in product design and development is Quality Function Deployment (QFD), which systematically translates customer needs into product design specifications. QFD enables designers to capture and analyze the Voice of Customer (VOC), allowing a clearer understanding of the actual needs of target users and facilitating the development of products that better satisfy customer expectations. Moreover, QFD provides a systematic method for converting customer requirements into technical product characteristics, ensuring that the design and development process aligns closely with consumer expectations. Consequently, newly developed products can achieve higher levels of usability, suitability, and customer satisfaction.

Previous studies have demonstrated the successful application of QFD in various product design and development contexts. For example, QFD combined with ergonomic principles based on anthropometric measurements has been applied to develop mango harvesting tools. In the original design, the harvesting tool could not adjust its operating length, resulting in difficulties when harvesting mangoes from trees of varying heights. The improved design was able to better meet users' needs and enhance usability [4]. Similarly, QFD has been applied to the ergonomic design of school desks and chairs based on students' anthropometric data. The results indicated that appropriately designed furniture could improve usability while reducing the risk of musculoskeletal disorders among students [5]. In another study, QFD was integrated with Kano's model and concept selection techniques to design an intelligent refrigerator for elderly users. The proposed design emphasized safety, ease of use, and support for elderly lifestyles. The results revealed that personalized design features, touch-screen interfaces, and voice control systems were key factors influencing sustainable user experiences for older adults [6]. QFD has also been applied in furniture design using the House of Quality (HOQ) to translate user requirements into technical specifications. For instance, a study on furniture developed from oil palm wood demonstrated that the application of QFD improved the alignment between product design and user expectations, achieving an average satisfaction score of 4.76 [7]. Furthermore, the Quality Function Deployment (QFD) has been employed to develop classroom furniture by systematically translating students' needs such as seating comfort, appropriate dimensions, and additional functional features into technical design specifications using the House of Quality (HOQ) matrix. The results indicated that QFD could effectively support furniture design that meets user needs while improving product quality at relatively low development costs [8]. In addition, QFD has been applied to the design of Scandinavian-style wardrobes by incorporating customer requirements such as simplicity, functional convenience, and high-quality materials. These requirements were translated into technical specifications to guide the design and manufacturing processes. The study demonstrated that QFD contributes to the development of products that satisfy customer preferences in terms of both functionality and aesthetics while also reducing design errors and development time [9]. Thus, the purpose of this research was to promote the potential development and create new opportunities for senior citizens to learn together and benefit from playing with elderly toy products. Different types of raw materials, such as rubberwood sawn timber, plywood, and wood-plastic composites, are evaluated based on their mechanical, physical, and chemical properties. The best material was selected to produce elderly toy products through engineering product design and development. The experimental results were compared to product standards for wooden toys. This finding is important for the elderly to be part of society as healthy individuals at every stage of their development.

Although numerous studies have applied QFD in product design and development, limited research has specifically focused on the design of kitchen counter furniture tailored to the physical capabilities and usability requirements of elderly users. Addressing this research gap is important to ensure that kitchen environments better support the safety, usability, and daily activities of older adults [10]. Therefore, this study

aims to investigate customer requirements and to design and develop kitchen counter furniture specifically for elderly users by applying the Quality Function Deployment (QFD) approach in order to effectively respond to the needs of older adults and enhance their safety and usability in kitchen environments.

2. Research Methodology

This study employed the Quality Function Deployment (QFD) technique to translate customer requirements into technical design specifications for the development of kitchen counter furniture for elderly users. The QFD approach was implemented through two primary matrices: the Product Planning matrix and the Design Deployment matrix. These matrices were used to systematically transform customer needs into product design characteristics and technical specifications. The research procedures are described as the following steps.

2.1 Preparation Prior to the Application of the Quality Function Deployment Technique

2.1.1 Customer Requirement Survey

Customer requirements were investigated through interviews and open-ended questionnaires in order to capture the Voice of Customer (VOC) related to kitchen counter furniture for elderly users. Data collection was conducted using the first questionnaire (Questionnaire Set 1), which consisted of open-ended questions designed to explore users' needs, expectations, and concerns regarding kitchen counter furniture.

The survey was administered through both on-site and online data collection methods to obtain responses from a diverse group of participants. A total of 246 participants were included in the study. The sample size was determined using W.G. Cochran's formula for an unknown population size with a confidence level of 95%.

The parameters used in the sample size calculation were defined as follows: P = 0.20, Z = 1.96, and d = 0.05. The sample size calculation is presented in Equation (1) [11].

$$n = \frac{P\,(1\text{-}P)\,Z^2}{d^2} \tag{1}$$

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

Where n is the sample size, P is the proportion of the target customer population, Z is the statistical confidence level, and d is the acceptable margin of sampling error.

Subsequently, the Voice of Customer (VOC) obtained from the target customers was refined and reorganized. The customer requirements were then classified into customer requirement attributes using quality management tools, including the Affinity Diagram and Tree Diagram, in order to organize and clarify the key product characteristics systematically. Based on these identified requirements, Questionnaire Set 2 was developed to assess the level of satisfaction across various factors influencing the design of kitchen counter furniture for elderly users.

2.1.2 Analysis of the Importance Scores of Customer Requirements

The importance scores of customer requirements were calculated using the geometric mean method. This method was selected because it is appropriate for determining the central tendency of comparative rating scale data, particularly for datasets containing only positive values [12]. The geometric mean therefore provides a reliable measure for representing the relative importance of customer requirements. The geometric mean values obtained from the questionnaire responses were subsequently used as the importance weights (IMP) in the Quality Function Deployment (QFD) product planning matrix.

2.2 Application of the Quality Function Deployment Technique

After the necessary preparations were completed, data were collected through a questionnaire survey. The responses were analyzed using the geometric mean. Subsequently, the resulting values were incorporated into the House of Quality (HOQ) for the design of a smart kitchen counter for elderly users.

2.2.1 Application of the Product Planning Matrix

The application of the Quality Function Deployment (QFD) technique in the product planning matrix, also known as the House of Quality (HOQ) [13-14]. begins by translating the Voice of the Customer (VOC) into performance measures representing the substitute quality characteristics (SQCs). These characteristics represent measurable product attributes expressed as technical requirements. Once the substitute quality characteristics are identified, the target values and improvement ratios are determined. Subsequently, the importance ratings of the performance measures are calculated. Both the substitute quality characteristics and the importance ratings of the performance measures serve as key indicators for determining the design requirements. Therefore, the application of the product planning matrix involves constructing the House of Quality, which consists of six major sub-matrices, as illustrated in Figure 1.

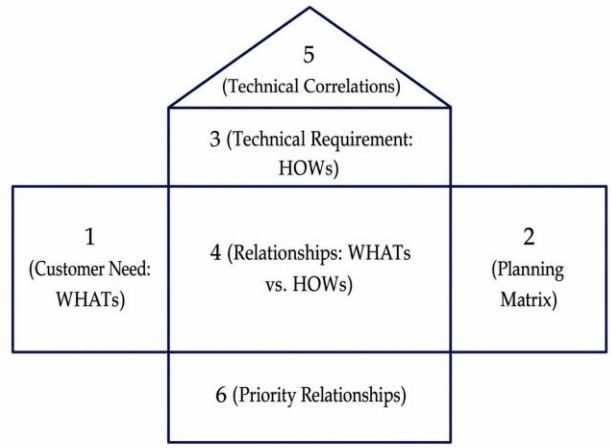


Figure 1. Components of the product planning matrix

Components and Procedure of the Product Planning Matrix. The procedure for constructing the product planning matrix in the House of Quality (HOQ) consists of the following six steps [15-19].

1) Identification of Customer Needs.

Customer needs obtained during the preparation stage are listed in the first section of the House of Quality (HOQ). This step represents the Voice of the Customer (VOC), which reflects users' expectations and requirements for the product.

2) Construction of the Planning Matrix.

The planning matrix is developed to evaluate and prioritize customer needs. This matrix typically includes elements such as importance ratings, current product performance, competitive benchmarking, improvement ratios, and sales points.

3) Determination of Technical Requirements.

In this step, the technical requirements of the product are defined. These requirements represent the engineering characteristics (ECs) required to fulfill customer needs. The identification of these characteristics is conducted through brainstorming among the research team. The resulting technical characteristics are then placed in the third section of the House of Quality. Subsequently, measurable technical targets are established and incorporated into the sixth section of the HOQ. In addition, the direction of improvement is specified to indicate the desired direction of the target values, including higher is better, nominal is best, and lower is better.

4) Construction of the Relationship Matrix.

This step determines the relationships between customer needs and the engineering characteristics, corresponding to the interaction between the first and third sections of the House of Quality. The purpose of this matrix is to indicate how each technical characteristic contributes to satisfying customer expectations. The strength of the relationship is typically evaluated using the numerical scale 0, 1, 3, and 9, representing no relationship, a weak relationship, a moderate relationship, and a strong relationship, respectively.

5) Technical Correlation Matrix.

This section forms the roof of the House of Quality and illustrates the correlations among the engineering characteristics. It identifies whether technical characteristics support or conflict with one another and indicates the strength of their relationships. In this study, the symbol "O" represents a strong correlation, "X" represents a weak correlation, and a blank cell indicates no correlation.

6) Determination of Priority Relationships.

This step determines the priority levels of the engineering characteristics to identify which aspects require the greatest attention during product development. This process consists of two components: (1) Absolute importance weight of technical requirements, which indicates the priority ranking of technical requirements in responding to customer needs, and (2) Relative importance weight of technical requirements, which expresses the absolute importance weights as percentages. These values can be calculated using Equations (2) and (3), respectively.

$$IMP = \sum (A \times B) \tag{2}$$

Where IMP is the absolute importance weight of the technical requirements, A is the relationship value between the technical requirements and customer needs, and B is the importance rating of customer needs.

$$\%IMP = \left(\frac{IMP}{\sum IMP} \right) \times 100 \tag{3}$$

Where %IMP is the relative importance weight of the technical requirements, and ∑IMP is the sum of absolute importance weights of the technical requirements.

2.2.2 Application of the Design Deployment Matrix

The Design Deployment matrix is used to decompose the product into its components for further analysis. This matrix focuses on identifying subcomponents that satisfy the technical requirements derived from the product planning matrix in the House of Quality (HOQ). The procedure for implementing the Design Deployment matrix consists of the following five steps:

1) Selection of Technical Requirements.

The technical requirements were selected from the product planning matrix, also known as the House of Quality (HOQ). These requirements were then translated into part characteristics to ensure that customer needs could be effectively satisfied. In this study, all technical requirements that significantly influence customer needs were selected. Subsequently, these technical requirements were placed in the left-hand column of the Design Deployment matrix.

2) Assignment of Importance Values.

The importance values (IMP) were incorporated into the Design Deployment matrix. These values were obtained from the relative importance weights of the technical requirements derived from the product planning matrix. The importance values were positioned on the left side of the Design Deployment matrix, adjacent to the corresponding technical requirements.

3) Determination of Part Characteristics.

The part characteristics were defined through expert discussion to analyze the relationships between the part characteristics and the technical requirements that influence customer needs. Subsequently, measurable target values for the part characteristics were established. In addition, the improvement direction was specified to indicate the desired trend of the target values, including higher is better, nominal is best, and lower is better.

4) Construction of the Relationship Matrix.

The relationship matrix was constructed to evaluate the relationships between the technical requirements and the part characteristics. The strength of these relationships was assessed using numerical scores of 1, 3, and 9, consistent with the procedure used in the product planning matrix.

5) Determination of Priority Relationships.

The priority relationships were calculated using the same procedure applied in the product planning matrix. The Design Deployment matrix enables the identification of which part characteristics have the greatest influence on customer satisfaction. Furthermore, the relative importance weights of the part characteristics were calculated to measure the degree of importance of each characteristic. These part characteristics and their corresponding relative importance weights were subsequently used in the design and fabrication of the aluminum kitchen counter for elderly users.

2.3 Product Design and Fabrication

Based on the survey data and the application of the Quality Function Deployment (QFD) technique in two phases, a kitchen counter for elderly users was designed using rubberwood or other hardwood materials commonly available in southern Thailand. The research team developed several alternative design concepts based on the technical requirements and customer needs identified through the QFD analysis. Subsequently, the most appropriate design concept was selected as the prototype, and the kitchen counter was fabricated according to the selected design specifications.

Design
1. Diversity of design/form 2. Aesthetically pleasing design/ form 3. Appropriate size in accordance with user ergonomics 4. Attractive colors and patterns

Smart Facilities
1. Intelligent control system 2. Intelligent safety system 3. Accuracy and stability of the intelligent system 4. Modernity of the intelligent system

Quality
1. Standardized intelligent system control devices 2. Long service life 3. Defect-free product

Usability
1. Multifunctional features 2. Usable space 3. Ease of use

Materials
1. Use of high-quality materials 2. Strength and durability materials 3. Safety of materials 4. Resistance to mold growth

Others
1. Reasonable price 2. After-sales service availability 3. Ease of maintenance and repair 4. Availability of a product user manual

Figure 2. Affinity diagram of consumer requirements

2.4 Product Satisfaction Evaluation

After the smart kitchen counter prototype for elderly users had been fabricated, an observation-based product satisfaction evaluation was conducted with the same group of 246 participants. The evaluation was performed in an actual kitchen environment to allow the participants to observe the prototype under conditions representative of its intended setting.

The participants did not directly operate the prototype. Before completing the questionnaire, they attended a demonstration conducted by the research team. The demonstration presented the physical characteristics and main functions of the prototype, including the storage-compartment lighting system, drawer opening and closing mechanisms, electrical outlet safety system, emergency assistance function, gas and smoke detection system, smart home and mobile application connectivity, and automatic waste-bin system. The participants also observed the product dimensions, workspace, storage accessibility, materials, structural design, and safety-related features.

Following the demonstration, the participants completed a questionnaire assessing their perceived satisfaction with 22 product attributes. The questionnaire used a five-point rating scale. The collected data were analyzed using descriptive statistics, including the mean and standard deviation. Because the participants observed a demonstration rather than directly operating the prototype, the resulting scores were interpreted as perceived satisfaction with the demonstrated design and functions and not as the results of a formal hands-on usability test.

3. Results and Discussion

3.1 Preparation Prior to the Application of Quality Function Deployment

The customer needs survey included both manufacturers and users of kitchen products. A questionnaire was developed to collect the required data, and the sample size was determined, resulting in a total of 246 respondents. The sample comprised 59% male and 41% female respondents, with the majority aged between 55 and 59 years. The collected voice of customer (VOC) data was then analyzed by organizing and refining the statements of customer needs. Subsequently, these needs were categorized using the Affinity Diagram and Tree Diagram techniques. The analysis resulted in six main categories of customer requirements, including product design, smart systems, quality, usability, materials, and other related factors. In total, 22 customer requirements were identified, as presented in Figures 2 and 3. These identified customer requirements were then used to develop a questionnaire to evaluate the importance level of factors influencing customer satisfaction with the kitchen counter for elderly users. The findings were subsequently used as input for the Quality Function Deployment (QFD) analysis in the following stage.

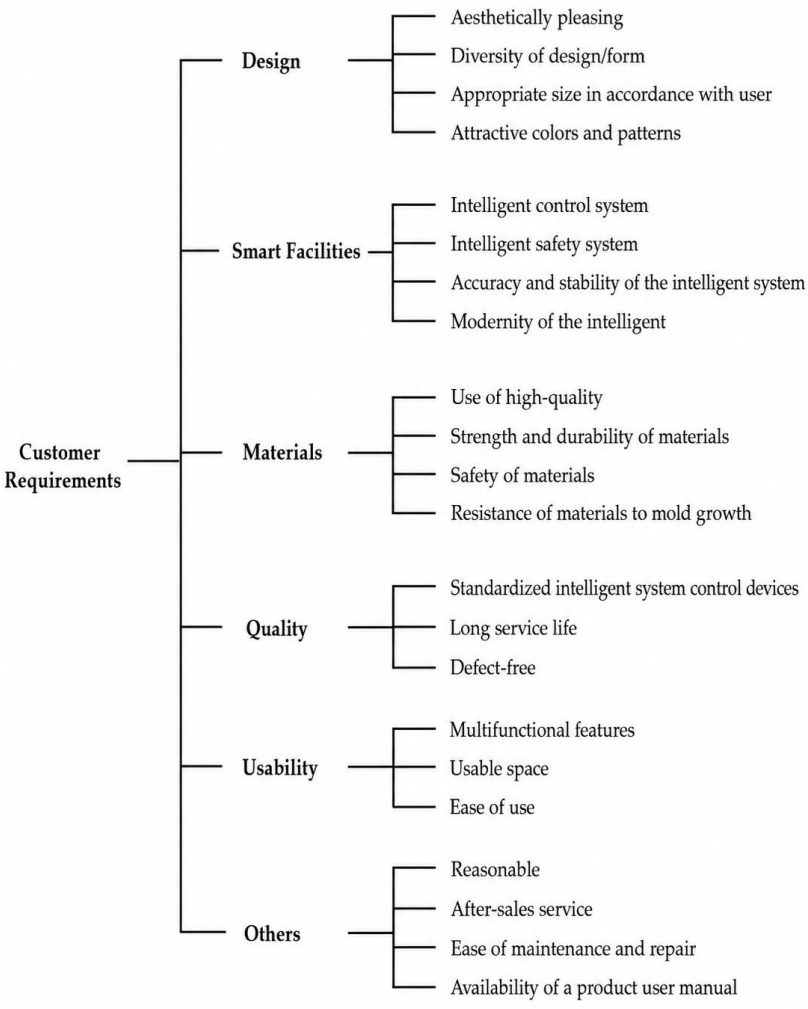
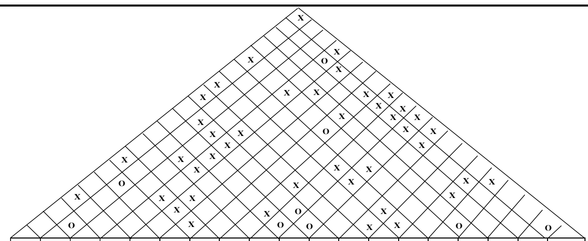


Figure 3. Tree diagram of consumer requirements



				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
				↑	○	○	○	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	○	○	○	↑	↑	
				Product Characteristics							Product Durability				Functional Features			Product Quality				Others	
			Technical Requirement	Variety of Product Designs and Shapes	Product Dimensions	Product Weight	Product Finishing	Operational Safety	Kitchen Counter Workspace	Convenience for Older Adults	Product Surface Finish	Structural Strength	Product Service Life	Load-Bearing Capacity of Materials	Ease of Cleaning	Ventilation	Resistance to Mold, Termites, Wood Borers, and Insects	Smart System Functionality	Smart System Security	Product Color	Manufacturing Quality	1. Price Appropriateness	
			No.	B-1	B-2	B-3	B-4	B-5	B-6	B-7	B-8	B-9	B-10	B-11	B-12	B-13	B-14	B-15	B-16	B-17	B-18	B-19	
Customer Requirements		No.	IMP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Design	Attractive Product Design and Appearance	A-1	4.75	1	1		3				3							1		1	3	3	
	Variety of Product Designs and Shapes	A-2	4.52	9	1			1	1	3		1	1	1	1	1		3			3	3	
	Ergonomically Appropriate Dimensions	A-3	4.52	3	9	3		9	3	9					1							1	
	Attractive Colors and Patterns	A-4	4.49	1			9			1										9	3	1	
Convenience Fea	Intelligent System Operation Control	A-5	4.52					3		3			3					9	3		1	3	
	Intelligent Safety System	A-6	4.43					3		3			1					3	9		1	3	
	Intelligent System Accuracy and Stability	A-7	4.47					1		1								3	1		1	3	
	Advanced Intelligent System Technology	A-8	4.42					3		9								9	3			3	
Usability	Multifunctional Features	A-9	4.44	3	1		1		1	9						1		3			1	3	
	Adequate Usable Workspace	A-10	4.49	3	3	1	1		9	3		1										1	
	Ease of Use	A-11	4.48	1	1			1	1	9								3	1			1	
Quality	Standard-Compliant Intelligent Control Components	A-12	4.53					9		3			3					3	3			3	
	Long Product Service Life	A-13	4.48				1					3	9	1			9	3	1			1	
	Defect-Free Product	A-14	4.46					9				1	3	1			3				9	3	
Materials	High-Quality Materials	A-15	4.57				1	3			1	9	9	3			3	1	3			3	
	Material Strength and Durability	A-16	4.57	1	3	3		3				9	9	3			3		3			3	
	Safe Materials	A-17	4.57					9		1	3								3			1	
	Mold-Resistant Materials	A-18	4.55							1	3	1	1	1	3		9			3		3	
Others	Reasonable Price	A-19	4.54	3	3		3	1	3	3	1	3	3	1			3	3	3	3	3	9	
	After-Sales Service	A-20	4.60										1					3	1			3	
	Ease of Repair and Maintenance	A-21	4.60	1	1			3		3	1		3		9	3	1	9	3				
	Product User Manual	A-22	4.71					1	3	3			3	3				9	3				
Rank of Absolute Technical Importance				9	11	18	13	3	12	2	17	8	5	15	16	19	7	1	6	14	10	4	Totel
Absolute Technical Importance Weight				118	104	32	86	267	95	288	55	127	223	64	64	23	140	295	181	72	113	244	2592
Relative Technical Importance Weight				4.5	4	1.2	3.3	10	3.7	11	2.1	4.9	8.6	2.5	2.5	0.9	5.4	11	7	2.8	4.4	9.43	100
Technical Target				More than one design configuration is available.	Overall dimensionsheight 130 cm, depth 60 cm, and total width 300 cm.	Total product weight 150 kg.	Decorative materials are incorporated to enhance structural strength, safety, and aesthetics.	Rounded edges or protective edge coverings are provided to minimize impact-related injuries.	The kitchen counter provides adequate food preparation and cooking space, with dedicated storage for kitchen ute and seasonings.	Automatic lighting is activated when storage compartments are opened, with an automatic opening and closing system designed for ease of use.	The product surface is smooth, residue-free, and protected with a surface coating.	The product is designed with a robust structural framework.	Product service life exceeds 5 years.	The product supports a load capacity of at least 150 kg.	The product is designed for easy cleaning and maintenance.	Ventilation openings are incorporated to promote adequate airflow.	Surface-coated materials provide resistance to mold, termites, wood borers, and insects for more than 5 years.	The product incorporates more than two intelligent functions.	Standard-certified components are used and installed by qualified professionals.	The product is available in multiple color options and finished with food-grade coating.	The product is manufactured and assembled with high precision.	The product offers a price that is appropriate for its quality and intended functionality.	

Figure 4. Product planning matrix for the kitchen counter designed for the elderly

Table 1. Technical requirements and target technical values of the kitchen counter furniture product.

No.	Technical Requirements	Target Technical Values	Improvement Direction
1	Diversity of design/form	More than one design configuration	↑
2	Product dimensions	Height ≤ 130 cm, depth ≤ 60 cm, total width ≤ 300 cm	**O**
3	Product weight	Total weight ≤ 150 kg	↓
4	Product finishing	Use of additional materials for decoration and structural reinforcement	↑
5	Operational safety	Rounded edges or protective edge coverings to prevent impact injuries	**O**
6	Kitchen counter workspace	Adequate space for food preparation and cooking, including storage for kitchen utensils and condiments	**O**
7	Elderly-friendly usability	Automatic lighting when storage compartments are accessed; easy-to-use automatic opening and closing mechanisms	↑
8	Product surface	Smooth surface with no residue accumulation and protective surface coating	↑
9	Product structural strength	Product structure must be strong and stable	↑
10	Product lifespan	Service life longer than 5 years	↑
11	Load-bearing capacity	Able to support a load of at least 150 kg	↑
12	Ease of cleaning	Easy to clean	**O**
13	Ventilation	Ventilation openings for air circulation	↑
14	Resistance to mold, termites, borers, and insects	Surface coating capable of preventing mold, termites, borers, and insects for more than 5 years	↑
15	Smart system functions	More than two intelligent functions	**O**
16	Safety of the intelligent system	Standard-certified equipment installed by qualified professionals	**O**
17	Product color	Available in various colors and coated with food-grade paint	**O**
18	Manufacturing precision	Precise forming and assembly	↑
19	Price suitability	Price appropriate to quality and functionality	**O**

3.2 Results of the Product Planning Matrix Application

The construction of the Product Planning Matrix consists of the following six steps.

1) Customer Needs.

Customer needs, consisting of 22 requirements grouped into six main categories, were placed on the left-hand side of the product planning matrix, as shown in Figure 4.

2) Construction of the Planning Matrix.

After identifying the customer needs, the importance values (IMP) obtained from the geometric mean of the second questionnaire survey were assigned to each corresponding customer requirement. These values were positioned on the left side of the House of Quality (HOQ) within the product planning matrix.

3) Technical Requirements.

The technical requirements were determined through brainstorming sessions involving the research team, design experts, fabrication specialists, and representatives of elderly users. This process aimed to analyze the relationships between customer needs and potential technical solutions capable of effectively satisfying those needs.

Subsequently, measurable target values were established for each technical requirement, and the direction of improvement was specified to indicate the desired design trend. In total, 19 technical requirements were identified. The corresponding technical target values and improvement directions are presented in Table 1. The overall structure of the matrix is illustrated in Figure 4.

4) Relationship Matrix.

The relationship matrix was constructed to evaluate the relationships between customer needs (Section 1) and technical requirements (Section 3) within the product planning matrix. The relationship scores were determined through pairwise comparisons conducted during expert brainstorming sessions.

5) Technical Correlation.

The technical correlation matrix, located in the roof section of the HOQ, was developed through brainstorming sessions involving relevant stakeholders. This step aimed to determine the interrelationships among technical requirements contributing to customer satisfaction.

6) Determination of Priority Relationships.

Figure 4 presents the product planning matrix, or House of Quality (HOQ), developed for the kitchen counter designed for elderly users. The technical requirements were ranked according to their Technical Priority scores, as presented in Table 2 and Figure 5. The prioritization results were further illustrated using a Pareto diagram. For the Product Planning Matrix (Matrix 1), a threshold of 80% of the Technical Priority score was established as the selection criterion. Based on this criterion, 11 technical requirements were identified as the most significant factors to be considered in the product design. The technical requirements with the highest priority were ranked as follows: 1) Functionality of the smart system 2) Ease of use for elderly users 3) Operational safety 4) Price suitability 5) Product lifespan 6) Safety of the smart system 7) Resistance to mold, termites, wood-boring insects, and pests 8) Product structural strength 9) Diversity of design and form 10) Manufacturing precision 11) Product dimensions After constructing all six sub-matrices of the product planning matrix (HOQ), the prioritized technical requirements were subsequently used as inputs for constructing the Design Deployment Matrix, which represents the second phase of the Quality Function Deployment (QFD) process.

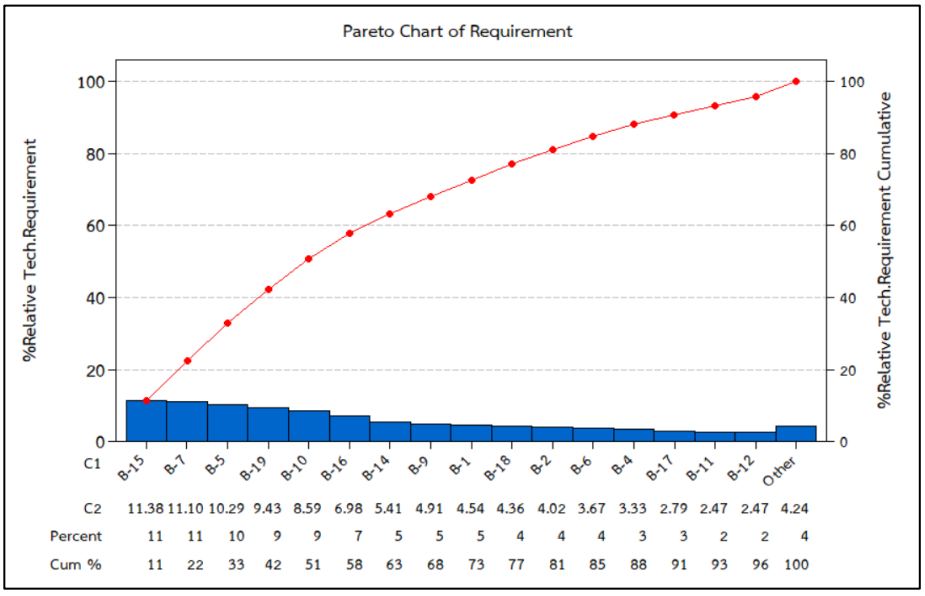


Figure 5. Ranking of the absolute and relative importance weights of technical requirements

Table 2. Absolute and relative importance weights of the technical requirements for the kitchen counter product for the elderly.

No.	Technical Requirement	Absolute Tech.	% Relative Tech.
1	Smart system functions	295	11.38
2	Elderly-friendly usability	287.8	11.10
3	Operational safety	266.8	10.29
4	Price suitability	244.4	9.43
5	Product lifespan	222.8	8.59
6	Safety of the intelligent system	181	6.98
7	Resistance to mold, termites, borers, and insects	140.3	5.41
8	Product structural strength	127.3	4.91
9	Diversity of design/form	117.5	4.54
10	Manufacturing precision	112.9	4.38
11	Product dimensions	104.3	4.02
12	Kitchen counter workspace	95.18	3.67
13	Product decoration	88.28	3.33
14	Product color	72.43	2.79
15	Material load-bearing capacity	84.1	2.47
16	Ease of cleaning	84.43	2.47
17	Product surface quality	55.32	2.13
18	Product weight	31.78	1.23
19	Ventilation	22.76	0.88

3.3 Results of the Design Deployment Matrix Application

The application of the Design Deployment Matrix in this study consists of four main components, which are described as follows.

1) Selection of Technical Requirements and Importance Weights.

The technical requirements and their corresponding importance weights obtained from the Product Planning Matrix were selected for use in the Design Deployment Matrix. All technical requirements identified in the previous matrix were retained, as each requirement was considered important and directly related to customer needs. Subsequently, the technical requirements, together with their geometric mean importance values, were placed on the left-hand side of the Design Deployment Matrix, as illustrated in Figure 6.

2) Part Characteristics.

The part characteristics were determined through brainstorming sessions involving the research team, design experts, fabrication specialists, and representatives of elderly users. This process aimed to analyze the relationships between part characteristics and customer requirements in order to identify design components capable of supporting the technical requirements. Afterward, target values for each technical specification were established, with efforts made to define these values in measurable terms. In addition, the direction of improvement was specified to indicate the trend of design development. As a result, a total of 18 part characteristics were identified. The corresponding technical target values and improvement directions are presented in Table 3, while the structure of the Design Deployment Matrix is illustrated in Figure 6.

3) Relationship Matrix.

The relationship matrix was constructed to evaluate the relationships between technical requirements and part characteristics within the Design Deployment Matrix. The relationship scores were determined through pairwise comparisons based on brainstorming sessions involving the research team and relevant technical experts. The results of the relationship evaluation are illustrated in Figure 6. The prioritized part characteristics obtained from the Design Deployment Matrix were subsequently used to guide the detailed design and component development of the kitchen counter for elderly users.

Table 3. Technical requirements and target values of subcomponents of the kitchen counter product

No.	Technical Requirements	Target Values	Improvement Direction
1	Adjustable storage compartment height	The height of storage compartments can be adjusted	**O**
2	Drawer opening and closing assistance function	Use of motors or sensors to assist in opening and closing drawers	**O**
3	Lighting in storage compartments and overhead cabinets	LED lighting installed in storage areas under overhead cabinets or counters to enhance visibility during food preparation	↑
4	Sterilization and antimicrobial system	UV sterilization function and air purification system	↑
5	Easy maintenance system	Components can be easily removed for repair or cleaning	↑
6	Smart home and application connectivity	Compatible with smart home systems and controllable via a mobile application	**O**
7	Materials and surface coating	Use of coated materials resistant to scratches, heat, and water	**O**
8	Emergency assistance system	Emergency call button or SOS signal connected to caregivers	**O**
9	Electrical outlet safety system	Electrical outlets installed on the counter with protective covers and automatic power cut-off in case of moisture	**O**
10	Water leakage detection system	Sensors installed under the counter to detect water leakage with sound or application alerts.	**O**
11	Service life of materials and components	Use of standardized materials with a service life of at least 5 years	↑
12	Gas and smoke detection system	Warning system activated when gas or smoke exceeds the specified level	**O**
13	Automatic trash bin	Sensor-based opening and closing system to reduce contact with waste and minimize bending	**O**
14	Maintenance alert system	Notification system for water filter replacement	↑
15	Drawer opening and closing mechanism	Spring or magnetic system to reduce the force required for operation	**O**
16	Waste separation compartment	Separation of food waste and general waste	**O**
17	Quality of intelligent system components	Intelligent system components meet standard quality requirements	↑
18	Coating treatment for wood materials and components	Protective coating to prevent termites, borers, and insects with durability of more than 5 years	↑

4) Priority Relationships.

The priority relationships were calculated based on the Design Deployment Matrix, as illustrated in Figure 6. The technical requirements were ranked according to their technical priority scores, and the results are presented in Table 4. In addition, the results were visualized using a Pareto diagram, as shown in Figure 7. For the technical requirements in the second matrix of the QFD process (Design Deployment), a selection threshold was established at 80% of the cumulative technical priority score. Based on this criterion, a total of 13 technical requirements were selected for use in the product design stage. The highest-ranked technical requirements are listed below: 1) Electrical outlet safety system 2) Protective coating for wooden materials and components 3) Lighting system inside storage compartments and overhead cabinets 4) Height level of storage

compartments 5) Drawer opening and closing mechanism 6) Emergency assistance system 7) Smart home and application connectivity system 8) Odor and smoke detection system 9) Service life of materials and components 10) Assisted drawer opening and closing function 11) Easy maintenance system 12) Sterilization and antimicrobial protection system 13) Automatic waste bin. The prioritized part characteristics were subsequently used to guide the detailed design and development of the kitchen counter for elderly users.

		Subcomponent Technical Requirements	Height Adjustment System for the Kitchen Counter	Assisted Drawer Opening and Closing Function	Motion Detection and Safety System	Sterilization and Antimicrobial Protection System	Maintenance Alert System	Smart Home and Mobile Application Connectivity System	Energy-Saving System	Advanced Materials and Surface Coatings	Emergency Assistance System	Power Outlet with Protective Cover	Water Leak Detection and Alert System	Service Life of Materials and Components	Odor and Smoke Detection System	Automatic Waste Bin	Maintenance Notification System	Drawer Opening and Closing Mechanism	Waste Separation Compartments	High-Quality Smart System Components	Protective Coating Treatment for Wood and Components	
		No.	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10	C-11	C-12	C-13	C-14	C-15	C-16	C-17	C-18	C-19	
Technical Requirements	No.	IMP	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	
Smart System Functionality	B-15	11.38	3	9	9	3	3	9	1		9		9		9	1	9					
Convenience for Older Adults	B-7	11.10	9	3	1		1	9	3		9	3	3		1	9		9	3			
Operational Safety	B-5	10.29			9	3	3	1		1	9	9	1	1	3		1			9	3	
Resistance to Mold, Termites, Wood Borers, and Insects	B-19	9.43	1	1	3			3	9	3	1	1		3			1			9	1	
Price Appropriateness	B-10	8.59			3		9		1	9			3	9			9			3	3	
Product Service Life	B-16	6.98			3	1					9		3	1	3		3			9		
Smart System Security	B-14	5.41				9	3			9			1	1							9	
Structural Strength	B-9	4.91	9	3						9			1	9			9			3	3	
Variety of Product Designs and Shapes	B-1	4.54	3	3						3				1							3	
Manufacturing Quality	B-18	4.36	3	3		3				3				3		1				3	3	
Product Dimensions	B-2	4.02	9											3								
Kitchen Counter Workspace	B-6	3.67										1										
Product Finishing	B-4	3.33																			3	
Product Color	B-17	2.79								1											3	
Load-Bearing Capacity of Materials	B-11	2.47	9	3			1							3	1							
Ease of Cleaning	B-12	2.47				9				3							1		9			
Product Surface Finish	B-8	2.13								3				3							9	
Product Weight	B-3	1.23	1												1					3		
Ventilation	B-13	0.88				9								3								
Rank of Absolute Technical Importance			4	10	3	14	12	7	16	6	1	15	9	8	13	17	5	18	19	2	11	Totel
Absolute Technical Importance Weight			274.00	193.99	281.13	163.91	172.12	240.90	138.14	252.06	367.18	139.01	203.04	218.59	169.03	115.64	267.05	99.90	55.53	297.57	193.72	3842.51
Relative Technical Importance Weight			7.13	5.05	7.32	4.27	4.48	6.27	3.60	6.56	9.56	3.62	5.28	5.69	4.40	3.01	6.95	2.60	1.45	7.74	5.04	100.00
Subcomponent Target			Manual kitchen counter height adjustment	Motor- or sensor-assisted drawer opening and closing system	Automatic lighting and fall detection system	UV sterilization and air purification system	Automatic maintenance reminder	Smart home and mobile application connectivity	Motion sensor-based automatic lighting control	Antibacterial and scratch-resistant materials	Emergency assistance (SOS) system	Countertop power outlets with protective covers and automatic power cut-off	Water leak detection and alert system	Minimum service life of 5 years	Gas leak and smoke detection system	Touch-free sensor-operated waste bin	Automatic water filter replacement reminder	Spring- or magnetic-assisted drawer mechanism	Waste separation compartments	Rigorously tested smart system components	Long-term protection against termites, wood borers, and insects	

Figure 6. Design translation matrix of the kitchen counter product for the elderly

Table 4. Ranking of the absolute and relative importance weights of the technical requirements for the kitchen counter product for the elderly

No.	Technical Requirement	Absolute Tech.	%Relative Tech.
1	Electrical outlet safety system	367.18	9.58
2	Protective coating treatment for wood materials and components	297.57	7.74
3	Lighting system in storage compartments and overhead cabinets	281.13	7.32
4	Adjustable height of storage compartments	274.00	7.13
5	Drawer opening and closing mechanism	267.05	6.95
6	Emergency assistance system	252.08	6.58
7	Smart home and mobile application connectivity system	240.90	6.27
8	Gas and smoke detection system	218.59	5.69
9	Service life of materials and components	203.04	5.28
10	Drawer opening and closing assistance function	193.99	5.05
11	Easy maintenance system	172.12	4.48
12	Sterilization and antimicrobial system	163.91	4.27
13	Automatic trash bin system	169.03	4.40
14	Water leakage detection system	139.01	3.62
15	Materials and surface coating	138.14	3.60
16	Maintenance alert system	115.64	3.01
17	Waste separation compartment in the trash bin	99.90	2.60
18	Quality of intelligent system components	55.53	1.45

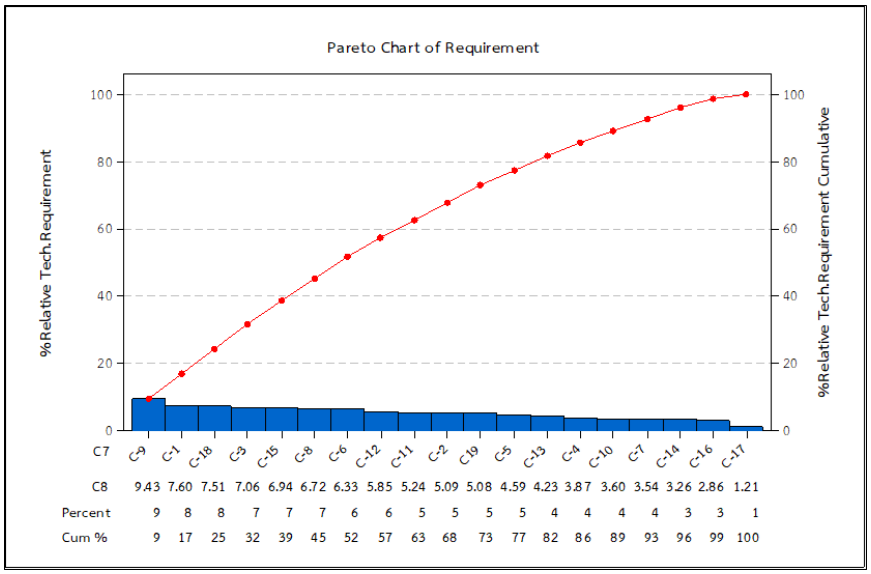


Figure 7. Ranking of the absolute and relative importance weights of the technical requirements

3.4 Product Design Results

The results obtained from the Quality Function Deployment (QFD) analysis were subsequently used to support the product design stage. The technical requirements and their corresponding target values derived from the QFD process were applied as key design inputs. These inputs were obtained from Matrix 1: Product Planning and Matrix 2: Design Deployment. The design requirements derived from these two phases were then integrated to guide the development of the kitchen counter for elderly users. The details of the product design based on the QFD results are presented below.

3.4.1 Results of QFD Application in the Product Planning Matrix. The QFD analysis in the Product Planning Matrix revealed the prioritized importance weights of the technical requirements. Based on the ranking of these relative importance weights, 11 technical requirements were identified as the key target specifications for developing the conceptual design. These prioritized requirements served as the primary design guidelines for developing the kitchen counter for elderly users.

1) Smart system functionality

The system incorporates at least two intelligent functions to enhance operational efficiency and user convenience.

2) Convenience for elderly users

Automatic lighting is activated when storage compartments are used, and the opening and closing mechanisms are designed to operate automatically and be easily accessible to elderly users.

3) Operational safety

The structure is designed with rounded edges, or edge-protection materials are applied to minimize the risk of injury from accidental impacts.

4) Cost–performance balance

The design ensures an appropriate balance between cost, quality, and functional performance.

5) Product service life

The design targets a service life of more than five years.

6) Smart system safety

The intelligent system utilizes standardized equipment and components, and installation is performed by qualified professionals to ensure safety and reliability.

7) Resistance to fungi and insects

Surface coating treatments are applied to protect the materials from mold, termites, wood-boring pests, and other insects for a period exceeding five years.

8) Structural strength

A strong and durable structural framework is incorporated to ensure stability during use.

9) Design variety

Multiple design configurations are provided to accommodate different user preferences and application contexts.

10) Manufacturing precision

The forming and assembly processes are performed with high precision to ensure product quality and aesthetic appearance.

11) Product dimensions.

The dimensions are determined based on ergonomic considerations, with a maximum height of 130 cm, a maximum depth of 60 cm, and a maximum width of 250 cm.

3.4.2 Results of QFD Application in the Design Deployment Matrix. The results of the Quality Function Deployment (QFD) analysis in the Design Deployment Matrix revealed the prioritized importance weights of the component-level specifications for the kitchen counter designed for elderly users. Based on the ranking of these relative importance weights, 13 component-level design requirements were identified as key specifications for developing the product concept. These requirements were subsequently used to inform the development of the conceptual design. The details of these 13 design specifications are presented below.

1) Electrical outlet safety feature

The kitchen counter is equipped with electrical outlets installed on the counter surface. Each outlet includes a protective cover and an automatic power cut-off mechanism that is activated when moisture is detected to enhance user safety.

2) Protective coating for wooden materials and components

Wood surfaces and structural components are treated with protective coatings to prevent damage from termites, wood-boring insects, and other pests, ensuring a service life of at least five years.

3) Illumination in storage compartments

LED lighting is installed inside storage compartments, particularly beneath overhead cabinets or counter units, to improve visibility during cooking and food preparation.

4) Adjustable storage compartment height

Storage compartments are designed with adjustable height mechanisms that allow users to modify the internal space according to their accessibility and usage requirements.

5) Drawer opening and closing mechanism

Drawers are equipped with spring-assisted or magnetic mechanisms to reduce the force required for opening and closing and improve usability for elderly users.

6) Emergency assistance feature

The product includes an emergency assistance button or SOS signal function that can be connected to caregivers or family members in emergencies.

7) Smart home and application connectivity

The product supports integration with smart home technologies and allows monitoring and control through a mobile application.

8) Gas and smoke detection feature

Gas and smoke detection sensors are integrated into the product to provide warning notifications when detected levels exceed predetermined safety thresholds.

9) Service life of materials and components

Structural materials and mechanical components are selected based on standardized quality criteria to ensure a service life of at least five years.

10) Automatic drawer opening and closing function

Motorized or sensor-based mechanisms are integrated to assist in opening and closing drawers automatically and reduce the physical effort required during operation.

11) Ease-of-maintenance design

The product is designed with detachable components that allow convenient maintenance, repair, and cleaning.

12) Sterilization and hygiene protection feature

The design incorporates ultraviolet (UV) sterilization and air purification functions to reduce microbial contamination and maintain hygienic conditions.

13) Automatic waste bin

The waste bin is equipped with a motion sensor that enables automatic opening and closing, minimizing contact with waste and reducing the need for bending during waste disposal.

In this study, the smart kitchen counter designed for elderly users incorporates technical specifications that integrate Internet of Things (IoT) technology and microcontroller-based control into the product. This integration enables the kitchen counter to process environmental data and respond automatically to user interactions. Such an approach is consistent with the concept of Smart Home Automation Systems [20], which employ sensors and intelligent control devices to improve convenience and safety for elderly users. The sensing components and intelligent devices are capable of detecting environmental conditions and abnormal events within the kitchen environment. These functions include smoke and gas leak detection, motion sensing, and water leakage monitoring, which help reduce the risk of accidents during kitchen activities [21]. In addition, the platform can transmit warning signals or notifications to users or caregivers through a mobile application in real time, enabling rapid responses to emergencies. In terms of implementation, the developed IoT platform utilizes ESP32 as the primary processing unit. ESP32 is a System-on-Chip (SoC) microcontroller featuring a dual-core Tensilica Xtensa LX6 processor with a maximum clock speed of approximately 240 MHz, along with built-in Wi-Fi and Bluetooth modules. These integrated communication capabilities enable the platform to connect to IoT devices and internet networks without requiring additional communication modules [22]. From a system architecture perspective, the design incorporates several sensing devices, including a PIR motion sensor for detecting user movement and automatically controlling cabinet lighting, an MQ-2 gas sensor for detecting smoke and gas to enhance cooking safety, a water leakage sensor, and a water flow sensor for monitoring abnormalities in the water supply system. In addition, a distance sensor is implemented to enable contactless operation through a no-touch control mechanism. Data collected from these

sensors is transmitted to the ESP32 microcontroller for processing. The processed data is then used to control various actuator devices, such as a servo motor for automatic opening and closing of the waste bin, a relay module for controlling electrical appliances, and a buzzer alarm for emergency notifications. Furthermore, the platform can be integrated with smart home environments such as Blynk or Home Assistant, allowing users or caregivers to monitor device status and control furniture operation remotely through an internet connection in real time. All smart functions were designed as an assistive layer, so that the drawers, cabinet lighting, and lightweight slow-motion waste bin lid remain fully and safely operable manually in the event of any sensor, actuator, or power failure. Critical alerts for gas, smoke, and water leakage are processed locally on the ESP32 and announced through the built-in buzzer, independently of internet connectivity, with mobile application notifications as a supplementary channel. For long-term deployment, periodic sensor inspection and calibration are recommended to maintain measurement accuracy and system stability. This capability represents a key characteristic of IoT-based architectures, which continuously collect sensor data, perform processing tasks, and communicate with external platforms. The implementation of the intelligent control architecture and sensor components in the developed kitchen counter is illustrated in Figure 8, which presents the product design and fabrication results based on the defined technical specifications. Therefore, the integration of IoT technology and microcontroller-based control into the kitchen counter developed in this research enhances the product by enabling it to function as smart assistive furniture designed to support elderly users. This approach improves both convenience and safety and contributes to the development of assistive product solutions for an aging society.

3.5 Prototype Fabrication Results

After the product design was completed based on the specifications derived from Matrix 1: Product Planning and Matrix 2: Design Deployment, the researchers proceeded with the fabrication of the prototype in collaboration with a furniture manufacturing facility. The product was produced according to the defined technical and design specifications, as illustrated in Figure 8.

3.6 Product Satisfaction Evaluation Results

Following the completion of the prototype, an observation-based satisfaction evaluation was conducted with 246 participants in an actual kitchen environment. Before completing the questionnaire, the participants observed the prototype and attended a demonstration of its physical features, safety mechanisms, accessibility features, and intelligent functions. The participants did not directly operate the prototype during the evaluation.

After observing the demonstration, the participants evaluated their perceived satisfaction with the 22 product attributes. The collected data were analyzed to determine the mean and standard deviation of each evaluation item, as presented in Table 4 and Figure 9. The overall mean perceived satisfaction score was 4.42 out of 5.00, indicating a high level of satisfaction with the observed design and demonstrated functions.

The attribute receiving the highest perceived satisfaction score was the lighting system installed in the storage compartments and overhead cabinets (M = 4.62). This was followed by the easy maintenance system (M = 4.58), operational safety (M = 4.57), product structural strength (M = 4.54), price suitability (M = 4.54), and the electrical outlet safety system (M = 4.53).

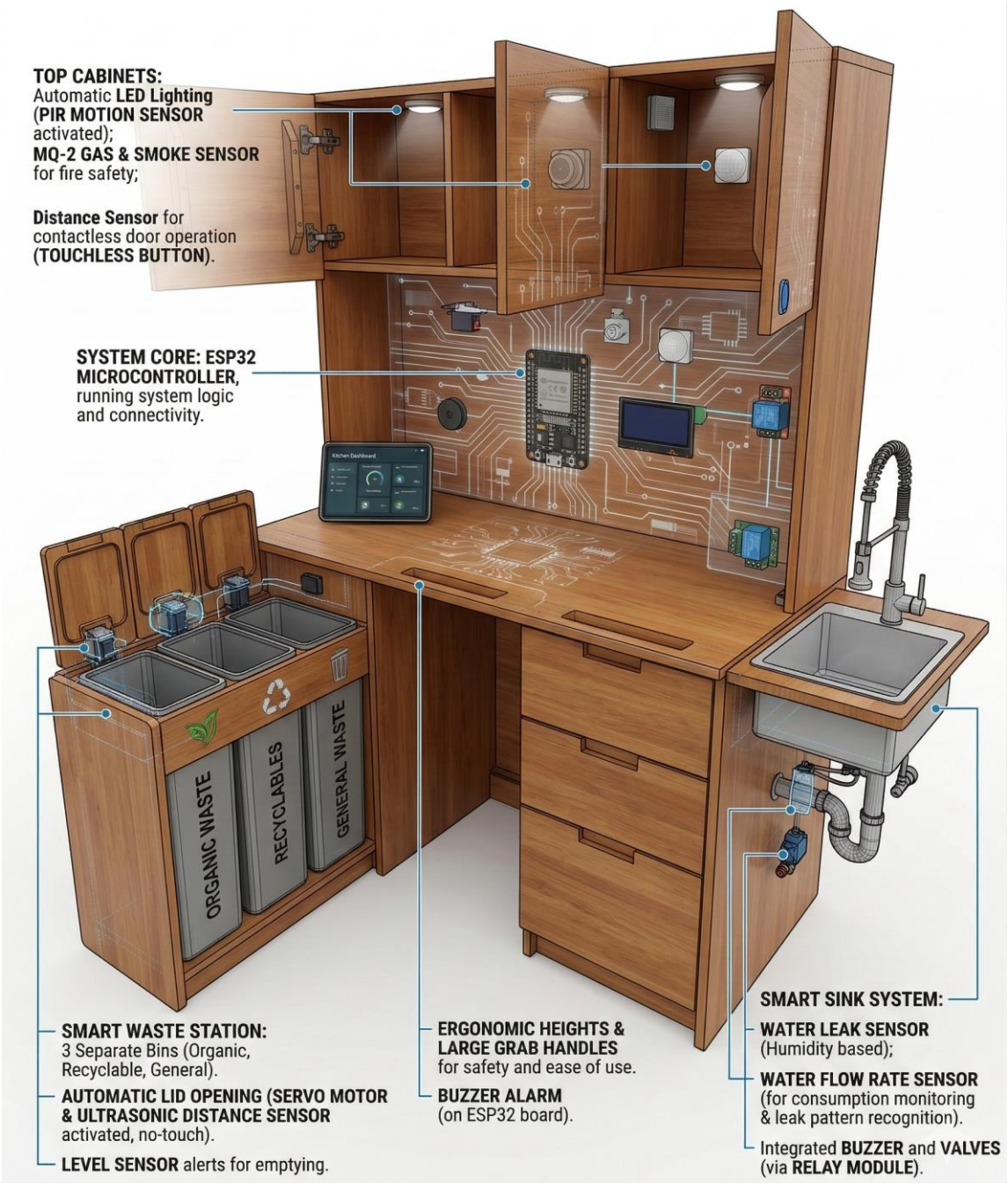


Figure 8. Smart kitchen counter product designed for the elderly

These results reflect the participants' perceptions after observing the prototype demonstration rather than their experiences from direct, independent, or long-term use. Therefore, the findings should be interpreted as preliminary evidence of user acceptance and perceived satisfaction with the product concept and demonstrated functions. Future studies should include hands-on task-based usability testing in which older adults directly operate the prototype under controlled and real-use conditions.

Table 4. Results of consumer satisfaction with the product

No.	Consumer Requirement Attributes	Mean Consumer Satisfaction ($\bar{X}$)	Standard Deviation (S.D.)
1	Smart system functions	4.25	0.96
2	Elderly-friendly usability	4.50	0.66
3	Operational safety	4.57	0.54
4	Price suitability	4.54	0.61
5	Product lifespan	4.45	0.77
6	Safety of the intelligent system	4.49	0.52
7	Resistance to mold, termites, borers, and insects	4.41	0.71
8	Product structural strength	4.54	0.50
9	Diversity of design/form	4.37	0.75
10	Manufacturing precision	4.49	0.70
11	Product dimensions	4.44	0.85
12	Electrical outlet safety system	4.53	0.71
13	Protective coating treatment for wood materials and components	4.37	1.00
14	Lighting system in storage compartments and cabinets	4.62	0.65
15	Adjustable height of storage compartments	4.24	0.73
16	Drawer opening and closing mechanism	4.33	0.70
17	Emergency assistance system	4.39	0.66
18	Smart home and mobile application connectivity system	4.18	0.86
19	Gas and smoke detection system	4.24	0.81
20	Service life of materials and components	4.33	0.80
21	Drawer opening and closing assistance function	4.45	0.76
22	Easy maintenance system	4.58	0.68

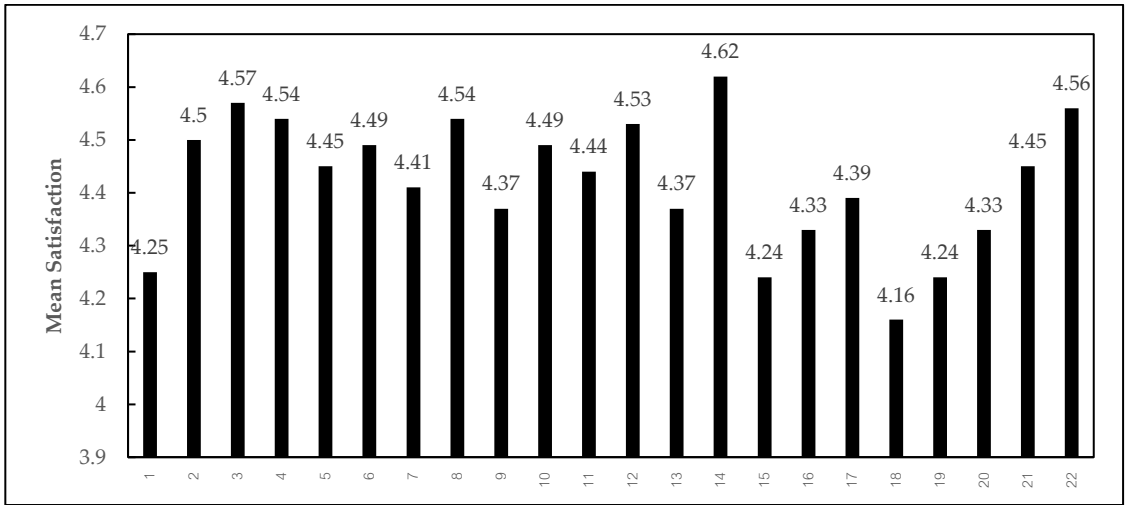


Figure 9. Consumer satisfaction with the smart kitchen counter product for the elderly

The design of kitchen counter furniture for elderly users using the Quality Function Deployment (QFD) technique produced findings consistent with previous studies. The results are in agreement with the study reported in [18], which applied the QFD approach to the design and production of a new plywood wardrobe. That study reported that the average satisfaction score of the redesigned prototype increased from 2.71 to 4.08, representing an improvement of approximately 54.87% compared with the original product. Comparable findings were reported in [23], which applied QFD in the design of a modular kitchen system. In that research, customer requirements were systematically translated into product characteristics. The study revealed that the application of QFD effectively identified key factors requiring improvement based on the voice of the customer, leading to a kitchen design that better addressed user needs and functional requirements. The present findings are also consistent with the research reported in [24] which focused on the

design and development of a kindergarten table–chair set using the QFD approach. The study indicated that the newly developed product incorporated visually appealing colors and flexible usage configurations, contributing to a very high level of user satisfaction with the redesigned product. The effectiveness of QFD has also been demonstrated in the development of Krajood (sedge) woven bags, as described in [25]. The study found that the redesigned product characteristics closely matched customer requirements, confirming that the application of the QFD methodology enables the development of products that effectively respond to consumer needs. Consistent findings were also reported in research on the design of bamboo-based sofa furniture, in which QFD was integrated with Kansei Engineering to translate users' emotions and preferences into design parameters. The results demonstrated that the newly developed product successfully met customer expectations and functional requirements [26]. A related study on office desk design applied the Kano Model in combination with QFD. The results indicated that users placed significant importance on product attributes such as structural strength, flexibility, ergonomic design, and intelligent functional features [27]. Overall, these studies collectively highlight the effectiveness of the Quality Function Deployment approach in translating customer needs into product design specifications. The findings of the present study further confirm that the developed kitchen counter for elderly users effectively addresses user requirements and therefore shows strong potential for practical implementation and commercial product development.

4. Conclusions

This study applied the Quality Function Deployment (QFD) method to the design and development of a kitchen counter for elderly users with the aim of enhancing consumer satisfaction and effectively addressing user requirements. Two QFD matrices were employed in the product development process: the Product Planning matrix and the Design Deployment matrix. These matrices were used to identify and translate customer requirements into specific product characteristics. These characteristics were subsequently used as the basis for developing the kitchen counter prototype. After the prototype was developed, an observation-based evaluation was conducted in an actual kitchen environment. The participants observed a demonstration of the prototype and its main functions but did not directly operate the product. The overall mean perceived satisfaction score was 4.42 out of 5.00, indicating a high level of satisfaction with the observed design and demonstrated functions. The five product attributes that received the highest satisfaction ratings were lighting installed in the overhead storage compartments (4.62), operational safety (4.57), ease of maintenance (4.56), product structural strength (4.54), and price appropriateness (4.54). The findings of this study provide practical guidelines for the design of kitchen counter furniture for elderly users and demonstrate that the application of the QFD approach enables the systematic translation of customer needs into technical design specifications. Consequently, the findings provide preliminary evidence that the developed product concept is perceived as being aligned with consumer requirements. Nevertheless, because the participants evaluated the prototype through observation of a demonstration rather than direct hands-on use, further task-based usability testing involving elderly users is necessary to confirm its usability, safety, and effectiveness under actual use conditions. Future work will involve long-term reliability testing of the system and sensors under real usage conditions to verify their accuracy and stability over extended deployment.

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