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An Approach Integrating Kano Model and Fuzzy Logic into the Planning Matrix of Quality Function Deployment: An Application for the Design of a Baby Diaper

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Abstract

Determining the customer requirements accurately early in the product development process, particularly in highly competitive industries such as baby diapers, would help to prevent design repetitions and consequently wasting time and resources. Quality Function Deployment (QFD) has turned out to be a key methodology to design products by getting the voice of the customer in the first place, as well as converting the customer's voice into product engineering characteristics. In addition, Kano model emphasizes the degree to which a customer is satisfied when a particular customer need is met. In this study, an approach integrating the Kano model into the planning matrix of QFD using Fuzzy logic, was proposed. The importance weights of customer requirements of a baby diaper were calculated using both the proposed Adjusted Kano-Fuzzy-QFD (AKFQFD) and traditional Kano-QFD model. It was demonstrated that the AKFQFD could effectively prioritize the importance weights of customer requirements.

Keywords: Quality function deployment, Kano model, Fuzzy logic, baby diaper

1. INTRODUCTION

Competitive reactions and changing customer needs are applying an ever-increasing pressure on companies to offer innovative products to the market and to reduce product development cycle-times. Furthermore, according to the research conducted by the Product Development and Management Association (PDMA) in 2012, which included around 453 respondents that were mostly from North America and Asia, and were from several industries (e.g., chemicals and materials, health care), new products have accounted for approximately 31% of sales and profits over the past 5 years of companies [1, 2]. Thus, many quality improvement tools including Quality Function Deployment (QFD), Failure Mode and Effect Analysis (FMEA), and lean six sigma, have been introduced by researchers to help companies to analyze problems effectively and systematically making the development of new products more manageable and successful [3, 4].

QFD, a customer-driven product design approach, was first introduced by Dr. Yoji Akao in Japan in 1966, and became popular with the American Supplier Institute (ASI) in the late 1980s with the "four-phase model" including four matrixes [5, 6]. The first phase is often referred to as the "House of Quality (HOQ)", and translates customer needs (Whats) into engineering characteristics (Hows), which is the most used matrix globally [7, 8]. The second, third, and fourth phase transforms the voice of the customer (VOC) into component characteristics, key process operations, and production requirements, respectively [9]. Toyota, one of the first companies successfully applied QFD, reduced the new product development costs, and decreased the development time by one third [10, 11]. Furthermore, researchers have integrated ergonomic design criteria (e.g., easy to use) into engineering design with the help of QFD for many years. Zhang et al. [12] used the HOQ to design a ceiling hood and hob. Marsot [13] designed a kitchen knife applying the HOQ. Prasad et al. [14] evaluated the drawing tables for students suffering from musculoskeletal disorders using the HOQ. Demirbilek & Demirkan [15] designed an inner door knocker by using the HOQ. Ergonomics is a scientific discipline that aims to maximize the harmony between human beings, the environment in which they are doing their work and the objects they use by focusing on human health and performance [16, 17]. Therefore, a product or service design with which a person interacts is within the scope of ergonomics.

The Kano model introduced in 1984 by Noriaki Kano, which can be integrated with QFD to deeply understand the voice of the customer, classifies customer requirements into five categories, namely must-be quality, one-dimensional quality, attractive quality, indifferent quality, and reverse quality, based on a customer survey [18]. Kano model emphasizes the degree to which a customer is satisfied when a particular customer need is met. Kano model has been studied in various fields by researchers.

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Bayraktaroglu&Ozgen [19] analyzed the user requirements regarding the library services of a state university by applying Kano model. Ma et al. [20] used Kano model to classify the quality characteristics of steering wheels in vehicles. Xu et al. [21] followed an analytical Kano model by using Kano classifiers and a configuration index to measure customer satisfaction quantitatively in design of a car dashboard. He et al. [22] introduced importance-frequency Kano model, and integrated it into QFD using a multi-population adaptive genetic algorithm for designing a home elevator.

Furthermore, since customer interpretations about a product or service quality are typically imprecise and vague, it could make more sense to use Fuzzy set theory to clarify questionnaire results. Fuzzy set theory, first introduced in 1965 by Lotfi Zadeh, provides a quantitative approach to formulate fuzzy data [23]. Lee & Huang [24] presented fuzzy Kano's questionnaire by allowing participants to interpret multiple feeling to reduce the uncertainty of human thought and applied it to the service quality of a theme park. Yadav et al. [25] and Avikal et al. [26] applied fuzzy Kano's questionnaire to categorize aesthetic attributes of a car profile. Wang & Fong [27] analyzed customer preferences for airline services using fuzzy Kano model.

This paper proposes an adjusted Kano model which integrates the Kano model indices, first introduced by Tan & Shen [28], into the formula of satisfaction index (SI) and dissatisfaction index (DI), developed by Berger et al. [29], adding the frequency of reversal quality to the denominator. The present study has shown an approach for fuzzification of Kano model by assigning fuzzy numbers instead of crisp values of Kano model indices, 0.5, 1, and 1.5, for must-be, one-dimensional, and attractive attributes, respectively. Then, the Adjusted Kano-Fuzzy model is integrated into QFD by following the common steps in the planning matrix of HOQ to calculate the absolute and relative importance weights of customer requirements of a baby diaper. According to the literature, limited research [30, 31] has been done on the use of the Kano model to examine the quality characteristics of a textile product.

The baby diapers market size was globally approximately $52.6 billion in 2019, and is forecasted to be $68.3 billion by 2027 with a compound annual growth rate (CAGR) of 5% from 2021 to 2027 [32]. A baby diaper can be in the form of cloth (reusable) or disposable (single-use), and disposable diapers have dominated the market with more than 90% use [33]. Disposable diapers are included in healthcare and hygiene products in medical textiles, and are made up of nonwoven fabrics. The nonwoven fabrics accounted for 64.29% of global medical textiles market that was approximately $16.7 billion in 2018, and the whole market is expected to grow at a CAGR of 4.9% to $23.3 billion by 2025 [34].

However, disposable diapers may contain chemicals that can cause allergic reactions in infants. In addition, a well-designed baby diaper could be of importance in managing the increasing rate of waste diapers by protecting the environment. In this context, the overall goal of this research is to improve the design of a baby diaper by focusing on the most important customer requirements. In this study, an approach integrating the Kano model into the planning matrix of QFD using Fuzzy logic, was proposed to effectively prioritize the importance weights of customer requirements.

In the next section, some theoretical aspects of QFD, Kano model, Fuzzy logic, and the approaches for integrating Kano model and QFD are discussed. In Section 3, the proposed AKFQFD model is introduced. Applying the proposed model in the design of a baby diaper are presented in Section 4. Discussions and conclusions are presented in Section 5 and 6, respectively.

2. LITERATURE REVIEW

2.1. Quality function deployment (QFD)

Quality Function Deployment (QFD) is a valid method for designing new products, aiming at customer satisfaction by transforming customer needs into product characteristics, as well as diffusing quality into whole production [35].

A typical HOQ, the first phase of QFD, involves identifying customer needs, determining relative importance of customer needs, detecting major engineering characteristics, building the relationship matrix between customer needs and engineering characteristics, determining tradeoffs in design, obtaining technical performance data of competitors, and setting measurable design targets [7]. Figure 1 shows an example of HOQ including customer needs and engineering characteristics of an airbag.

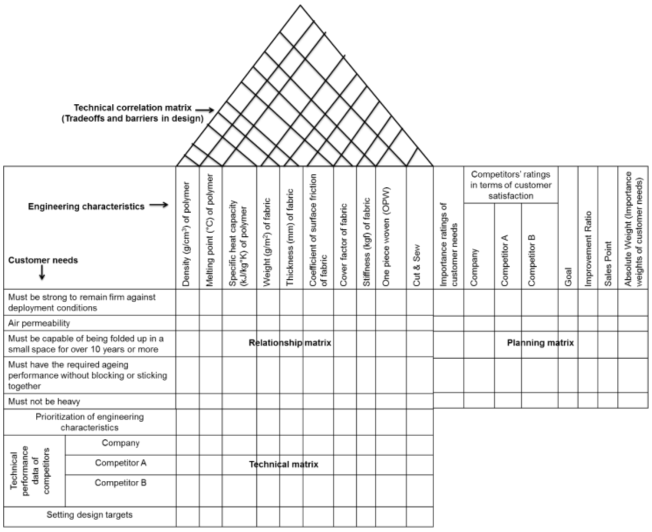

Figure 1. House of quality chart

In case of too many customer needs, understanding and prioritizing customer needs accurately may not be guaranteed by traditional HOQ due to complexity in calculations and long implementation times caused by increased matrix sizes. Therefore, integrating quantitative techniques into the HOQ planning matrix can help to diminish computational handicaps.

2.2. Kano model

Kano model emphasizes the degree to which a customer is satisfied when a particular customer need is met. The Kano model classifies customer requirements into five categories as follows (Figure 2) [18]:

(1) Must-be (M): While fulfilling must-be characteristics beyond the expectation does not increase customer satisfaction, the absence of them dissatisfies the customer. For example, a car owner would expect an airbag to deploy properly in case of an accident.

(2) One-dimensional (O): Customer satisfaction occurs in case of fulfillment of one-dimensional requirements, and dissatisfaction occurs in case of nonfulfillment of them. For example, the more the refrigerator saves energy the more satisfied the customer is.

(3) Attractive (A): While the presence of attractive characteristics can increase customer satisfaction, the absence of them does not cause any dissatisfaction. These characteristics are mostly not pronounced by customers, and can result in exciting products.

(4) Indifference (I): It does not matter for customers whether this type of quality is present or not. For instance, package design of a tooth paste may not be an important concern for tooth paste purchasers, which makes this quality as an indifferent characteristic.

(5) Reverse (R): Customers are satisfied when this type of requirement is nonfulfilled, and they are dissatisfied when it is fulfilled.

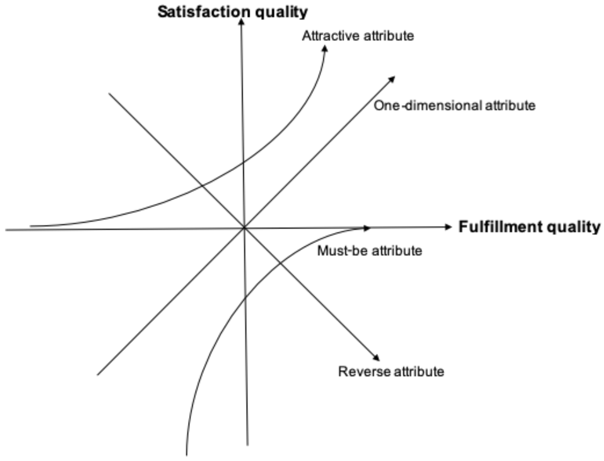

Figure 2. Kano model (adapted from [36])

To decide which customer needs are included in which Kano category, a survey should be conducted. To that end, a pair of question, functional and dysfunctional, in case of presence and absence of a particular need how a customer feels, respectively, should be asked. Then, the pair of responses are evaluated according to the Kano table as shown in Table 1. The attribute with the highest response frequency determines the category of the related customer requirement. When customers are either confused or misunderstand the pair of question of a particular need in the survey they do not give logic responses. This type of group is referred to as questionable characteristics (Q).

Table 1. Kano evaluation table (adapted from [29])

Customer Needs		Dysfunctional Question (e.g., if baby diaper is not soft, how do you feel?)				
		I like it that way	It must be that way	I am neutral	I can live it that way	I dislike it that way
Functional Question (e.g., if baby diaper is soft, how do you feel?)	I like it that way	Q	A	A	A	O
	It must be that way	R	I	I	I	M
	I am neutral	R	I	I	I	M
	I can live it that way	R	I	I	I	M
	I dislike it that way	R	R	R	R	Q

Note: A: attractive, O: one-dimensional, M: must-be, I: indifference, R: reverse, Q: questionable

2.3. Fuzzy Set Theory

Lotfi Zadeh who was a professor at the University of California, Berkeley, provided a quantitative approach to formulate vague data by Fuzzy set theory [23]. A fuzzy set is a set of objects in which there is no clear boundary between objects and each object is assigned a degree of membership ranging between zero and one by a membership function [24, 37]. Therefore, fuzzy sets are characterized by membership functions (MFs), where triangular, trapezoidal and Gaussian MFs are commonly used.
A triangular fuzzy number (TFN) $\tilde{A}$ = (a_1, a_2, a_3), in which $a_1 < a_2 < a_3$, and its membership function is defined as follows:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0 & x \leq a_1 \\ \frac{x-a_1}{a_2-a_1} & a_1 \leq a_2 \\ \frac{a_3-x}{a_3-a_2} & a_2 \leq x \leq a_3 \\ 0 & a_3 \leq x \end{cases} \quad (1)$$

To convert the fuzzy set into a numerical (crisp) number the process of defuzzification including center of area, maxima, and bisector methods are carried out. The center of area (gravity) (COA) can be calculated as follows:

$$F_{COA}^{-1} = \frac{\int \mu_{\tilde{A}}(x)xdx}{\int \mu_{\tilde{A}}(x)dx} \quad (2)$$

According to Gao et al. [38] the calculation of scalar multiplication of a TFN and multiplication of two TFNs can be done as follows:
$\tilde{A}$ = (a_1, a_2, a_3), $a_1 < a_2 < a_3$; and $\tilde{B}$ = (b_1, b_2, b_3), $b_1 < b_2 < b_3$, are two TFNs

$$\lambda * [a_1; a_2; a_3] = [\lambda \text{ x } a_1; \lambda \text{ x } a_2; \lambda \text{ x } a_3] \; \lambda > 0 \quad (3)$$

$$[a_1; a_2; a_3] \text{ x } [b_1; b_2; b_3] = [a_1 \text{ x } b_1; a_2 \text{ x } b_2; a_3 \text{ x } b_3] \quad (4)$$

2.4. Integration of Kano model into QFD

Since Kano model is helpful for explaining the relationship between the degree of satisfaction and the fulfillment of customer requirements, integrating the Kano model into the planning matrix of HOQ would help deeply to understand the voice of the customer. In this direction, Berger et al. [29] introduced two terms that are satisfaction index (SI) and dissatisfaction index (DI). The SI symbolizes how much a customer satisfaction would be increased in case of fulfillment of a particular customer need, and the DI signifies how much a customer satisfaction would be decreased in case of nonfulfillment of that customer need, which are calculated as follows:

$$\text{Satisfaction index (SI)} = (f_A + f_O) / (f_A + f_O + f_M + f_I) \quad (5)$$

$$\text{Dissatisfaction index (DI)} = (-1)\,(f_O + f_M) / (f_A + f_O + f_M + f_I) \quad (6)$$

Here, f_A, f_O, f_M, $f_I$are frequency of attractive attribute, frequency of one-dimensional attribute, frequency of must-be attribute, and frequency of indifference attribute, respectively. Furthermore, Wang & Fong [27] and Avikal et al. [26] proposed methods by adding the frequency of reversal attribute (f_R) to the denominator to compute the SI and DI. In addition, Tontini [39] introduced the adjustment factor (m) for each customer need, which infuses the Kano result into the importance of a customer requirement, as follows:

$$m = \max\{SI, |DI|\} \quad (7)$$

m: adjustment factor

Tan & Shen [28] proposed a transformation function in which the Kano model indices, k values, are embedded into the original improvement ratio (IR_o) that is a component of the planning matrix of HOQ. Here, k values were chosen as 0.5, 1, and 2 for must-be, one-dimensional, and attractive qualities, respectively, to calculate the adjusted improvement ratio (IR_{adj}) as follows:

$$IR_{adj} = (IR_o)^{1/k} \quad (8)$$

Chaudha et al. [40] recommended another transformation function to adjust the IR_o using the adjustment factor (m), and Kano model indices, where the k values were 0, 0.5, 1, and 1.5 for indifferent, must-be, one-dimensional, and attractive attributes, respectively, as follows:

$$IR_{adj} = (1+m)^k \text{ x } IR_o \quad (9)$$

The original improvement ratio, IR_o, a factor determining the importance weights of customer needs, is calculated by dividing the goal by current company rating (Original Improvement Ratio (IR_o) = Goal / Current Company Rating). Strategic goals are determined on the basis of the values obtained in the competitive analysis. Furthermore, in most cases, to identify competitors' and company's current ratings whether they meet the customers' requirements, customers are asked how well they are satisfied with the competitors' and company's products utilizing a scale from 1 to 5 with 5 being the most important through mail/e-mail surveys [41, 42]. Similarly, to determine the importance of customer needs customers are usually asked to rank the needs according to a five-point scale through a survey [41, 42]. Then, for both the competitive analysis and the self-stated importance, the value of weighted average performance score for each customer need can be calculated as follows:

$$= \frac{\sum_i (\text{Number of respondents at performance value i}) * \text{i}}{\text{Total number of respondents}} \quad (10)$$

i = 1, 2, 3, 4, 5

The final importance weights of customer requirements (absolute weights) are generally determined by multiplying the improvement ratio, the self-stated importance, and the value of sales point [28, 29, 42]. The value of sales point for each customer need is generally determined by the marketing people, which indicates which customer needs, when met, would provide a competitive advantage to the company [6, 7, 42]. In general, three values, 1, 1.2, 1.5, are used for sales points, which are assigned to no competitive advantage or no sales, a slight competitive advantage or medium sales, and a strong competitive advantage or strong sales, respectively [6, 7, 42, 43]. In this study, to illustrate the proposed model efficiently sales point is not taken into account.

3. PROPOSED MODEL FOR INTEGRATING KANO MODEL AND FUZZY LOGIC INTO THE PLANNING MATRIX OF HOQ

In this paper, an approach, in which the Kano model indices that are assigned as 0.5, 1, and 1.5 for must-be, one-dimensional, and attractive attributes, respectively, are embedded into the formulae used to calculate the adjustment factor, is proposed by Equations (11-14):

$$w_j = f_j / (f_A + f_O + f_M + f_I + f_R) \qquad j = A, O, M \tag{11}$$

$$SI' = w_A * k_A + w_O * k_O \tag{12}$$

$$DI' = (-1)(w_O * k_O + w_M * k_M) \tag{13}$$

$$m' = \max\{SI', |DI'|\} \tag{14}$$

Here, k_A, k_O, and $k_M$represents Kano model indices of attractive, one-dimensional, and must-be qualities, respectively. The integration of Kano model indices to the model would increase the accuracy of understanding the relationship between customer requirements and customer satisfaction by considering the impact factors of each quality attribute. In previous studies it was stated that the quality attributes of Kano model were of different importance, and attractive attributes should be given higher weight since they create more value in terms of customer satisfaction and increase compatibility of products [28, 40, 44, 45]. Tan &Pawitra [44] applied the crisp values of 4, 2, and 1 for attractive, one-dimensional, and must be qualities, respectively as multiplier values for determining relative importance of customer needs. Calisoglu [45] used the Kano model indices 0, 0.5, 1, and 1.5 for indifferent, must-be, one-dimensional, and attractive attributes, respectively, as a multiplier for calculation of sales point. Furthermore, f_A, f_O, f_M, f_I, and f_R symbolizes frequencies of attractive, one-dimensional, must-be, indifference, and reversal qualities, respectively. Since reversal quality is included in the Kano model and reflects also customer expectations from a product or service, adding the frequency of reversal quality to the denominator, as shown in Wang & Fong [27] and Avikal et al. [26], would make sense for computing the adjustment factor, and finally the relative weights of customer needs. The proposed model is illustrated in Table 2.

In the proposed model, the triangular membership function (MF), and the center of area (gravity) (COA) method for the operation of defuzzification are chosen, where MATLAB is used for the calculations. However, other types of MFs (e.g., trapezoidal) could also be used for the proposed model. Figure 3 shows the triangular MF of the importance of customer need, where the fuzzy numbers are used instead of crisp values of 1, 2, 3, 4, and 5 for very low, low, medium, high, and very high significance, respectively. In addition, Figure 4 shows the triangular MF of the Kano model categories, where the Kano model indices that are assigned as 0, 0.5, 1, and 1.5 for indifferent, must-be, one-dimensional, and attractive attributes, respectively, are indicated by the fuzzy sets. Then, intersection areas are randomly selected as 0.3 for all categories.

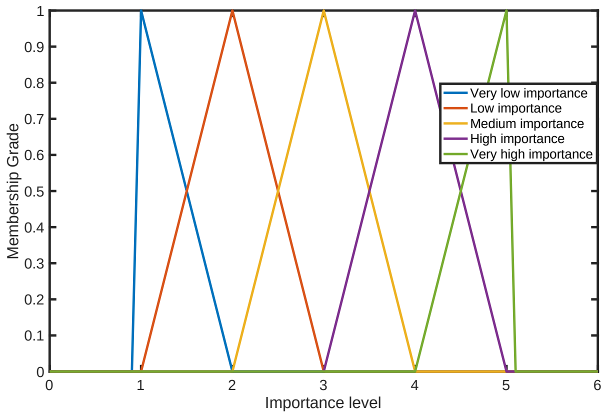

Figure 3. Triangular membership function of importance of customer need

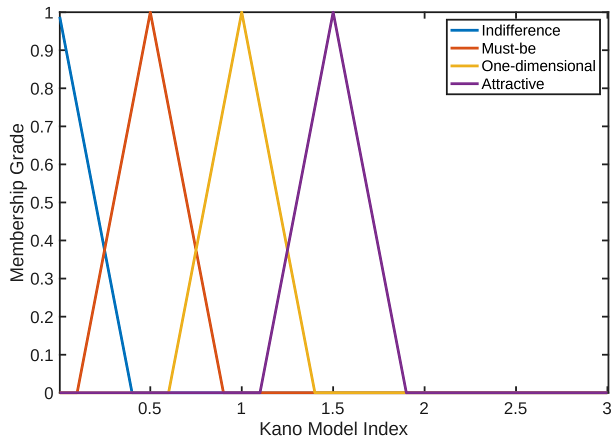

Figure 4. Triangular membership function of Kano model categories

Table2. Proposed Adjusted Kano-Fuzzy-QFD model

Steps	Proposed model: Adjusted Kano-Fuzzy-QFD
Step 1	Conducting the preliminary study to identify customer needs.
Step 2	Determining the importance of customer needs by market survey. Here, importance of customer needs are assigned by fuzzy numbers instead of crisp values of 1, 2, 3, 4, and 5 for very low, low, medium, high, and very high significance, respectively. Very Low: (1;1;2) Low: (1;2;3) Medium: (2;3;4) High: (3;4;5) Very High: (4;5;5)
Step 3	Making Kano questionnaire based on results of market survey.
Step 4	Evaluation of Kano survey according to Kano evaluation table. Attribute gauge chart is plotted to demonstrate how well the respondents agreed with each other for each question (item).
Step 5	Determining the adjustment factor (m′) for each customer need by using the proposed model. Here, Kano model indices are assigned by fuzzy numbers [45]. Indifference attributes: (0;0;0.4) Must-be attributes: (0.1;0.5;0.9) One-dimensional attributes: (0.6;1;1.4) Attractive attributes: (1.1;1.5;1.9) $w_j = f_j / (f_A + f_O + f_M + f_I + f_R)$ $j = A, O, M$ $SI' = w_A * k_A + w_O * k_O$ $DI' = (-1)(w_O * k_O + w_M * k_M)$ $m' = \max\{SI', \lvert DI' \rvert\}$
Step 6	Doing competitive analysis
Step 7	Setting goal and finding IR
Step 8	Calculation of absolute and relative weights of customer needs

4. APPLYING THE PROPOSED MODEL IN THE DESIGN OF A BABY DIAPER

4.1. Body Of A Disposable Baby Diaper

A typical modern disposable baby diaper consists of a topsheet directly contacting with the baby's skin transfering liquid to the underlying layers, a water vapor permeable backsheet forming the outer layer preventing liquid from leaking out of the diaper, and an absorbent core layer positioned between the topsheet and the backsheet [46]. In general, the topsheet consists of a nonwoven structure composed of polypropylene or polypropylene/polyethylene blend, the backsheet is made of polyethylene or polyurethane laminated film, and the core layer comprises superabsorbable polymers (e.g., sodium polyacrylate) and wood pulp covered by cellulose or polypropylene nonwoven fabric [46, 47]. Although the polymers used for diapers are chemically inert materials, the contamination of polymers with monomers, and other impurities (e.g., additives) during the polymerization or manufacturing process can cause allergic reactions in infants [47].

The elastic bands consisting of spandex or synthetic rubber, and the fastening system including adhesives, in the waist and inguinal folds are the other design components for preventing leakage and guaranteeing a good fit to the diaper [47, 48]. However, reports demonstrated that rubber chemicals such as mercaptobenzothiazole, cyclohexylthiophthalimide, and adhesives (e.g., p-tertiary-butylphenol formaldehyde resin) induced contact allergy particulary in case of preceding diaper rash [48–50]. Diaper rash, in other words diaper dermatitis, is a common skin disorder in infants, which occurs mostly in a warm and humid environment with prolonged exposure to urine and feces in the diaper area, making the skin more susceptible to friction and irritation and consequently penetration by substances due to overhydration of skin and maceration [51, 52].

Additionally, diapers could contain dyes (e.g., pigment) for aesthetics purposes, fragrances (e.g. perfume) to mask fecal odor, and lotion, in other words emollients (e.g., zinc oxide, petrolatum) in the topsheet aiming at protecting the skin from overhydration [47, 53]. On the other hand, fragrances (e.g., myroxylonpereirae), disperse dyes, and lotions (e.g., sorbitansesquioleate, lanolin) have been reported as potential allergens in diapers [48, 54].

Since the disclosure of all ingredients of disposable diapers for infants is under no obligation for the manufacturers in the USA and Europe it cannot be possible to trace back all possible chemicals developing allergic reactions [55, 56]. Although it is announced by manufacturers that disposable diapers are approved by dermatologists or pediatricians there is no standardization in this regard [47].

Furthermore, waste absorbent hygiene products including baby diapers account for 1.5%-6.3% of municipal solid waste in Europe [57]. Waste baby diapers that may partially contain also biodegradable materials, have been subject to either incineration or landfilling, causing environmental problems such as greenhouse gas emissions (e.g., methane), and water pollution since the 1970s [58, 59]. Costly, and limited end product quality solutions of current recycling and composting methods of waste diapers pose other handicaps for diapers [58, 60].

4.2. Ethical Approval

Ethical approval was obtained from the Social and Human Sciences Ethics Committee of Erciyes University (project number: 222) to conduct surveys for the study. Participation in the study was voluntary.

4.3. Applying The Proposed Adjusted Kano-Fuzzy-QFD Model For Determining Of Importance Weights Of Customer Requirements Of A Baby Diaper

4.3.1. Step 1 & Step 2: Conducting The Preliminary Study To Identify Customer Needs And Determining The Importance Of Customer Needs

In the preliminary study, to collect customer needs (CNs), and subsequently enhance the accuracy of data for the Kano customer survey, literature review, market research through commercial websites (e.g., amazon.com), and social networks, one-to-one and face-to-face interviews were conducted. Then, a list of 18 CNs (Table 5) were obtained; however, to find out if there is any missing need a market survey was also carried out.

The market survey had four parts: the first part: informed consent form of the survey; the second part: demographic questions; the third part: a few questions listed in Table 3; the fourth part: respondents were asked to rate the 18 CNs using a five-point scale from 1 to 5, where 1, 2, 3, 4, and 5 signify for very low, low, medium, high and very high importance, respectively.

Table 3. Questions of preliminary market survey

(i)	What kind of baby diaper do you choose for your baby (i.e., disposable, cloth)?
(ii)	What kinds of features did you get from your current baby diaper?
(iii)	Which brand do you prefer when you compare the products of different companies?
(iv)	What kinds of complaints do you have from your current baby diaper?
(v)	What kinds of features do you expect from a baby diaper?

The survey was deployed to all people in Turkey, where the participation was voluntary. In total, 554 valid responses were received. The results of the third part of the market survey are given in Table 4; all of the respondents were women, and approximately 76% of them had 1 child, 21% of them had two children, and 3% of them had three children.

Table 4. Market survey results (N= 554)

Baby Diaper Type	Response (%)	Diaper Change Frequency Per Day	Response (%)	Brand Preference	Response (%)
Disposable	99.46	1-3	13.18	Company A	40.79
Cloth	0.54	4-6	65.70	Company B	28.88
		7-9	16.61	Company C	15.52
		>9	4.51	Others	14.80

The majority of the respondents indicated that they have used disposable diapers, and they have changed an average of 4-6 diapers per day, where the results are parallel to those reported in Odio& Friedlander [61] and the UK Environment Agency[62]. In addition, according to the survey the market has been dominated by three companies. Due to confidentiality reasons the company names cannot be declared.

Furthermore, based on the results of the survey it was emphasized that "Baby diaper should not smell of petroleum-based polymers" with the S4 in the list of CNs. The 18 CNs were classified into four categories: aesthetics, performance, safety, and comfort, by considering ergonomic design criteria based on ergonomics literature [12, 17, 63], which is shown in Table 5.

To deal with the last part of the market survey, first, the value of weighted average importance score for each customer need was calculated; second, the corresponding values of the importance that were developed by fuzzy set members were determined and shown in Table 6. The fuzzy numbers used instead of crisp values of 1, 2, 3, 4, and 5, are listed in Table 2 and are shown in Figure 3 for the proposed model.

In order to verify the reliability of the questionnaire, the coefficient of Cronbach's alpha(α) was calculated as 0.76. Here, a questionnaire with an alpha coefficient of greater than or equal to 0.7 is generally accepted to be reliable in terms of the internal consistency of the items [20, 64].

4.3.2. Step 3:Making Kano Survey

The Kano survey had four parts: the first part included the informed consent form of the survey, the second part consisted of 36 questions on 18 baby diaper quality attributes (Table 5), the third part was related to the demographic questions, and the fourth part included the section of competitive analysis for rating the three major brands in the market determined by the market survey, for each quality attribute by using a five point scale from 1 to 5, where the higher the score the higher the perceived satisfaction was.

The second part of the Kano survey was conducted based on the Kano questionnaire including functional and dysfunctional questions as shown in Table 1, which were

The survey was deployed to all people in Turkey, where the participation was voluntary. In total, 344 valid responses were received, where all of the respondents were women, and approximately 77 % of them had 1 child, 21% of them had two children, and 2% of them had three children.

The percent agreement which demonstrates how well the respondents agreed with each other for each question (item) was plotted as shown in Figure 5. The formula of the percent agreement is as follows [65]:

$$\% \text{ Agreement for item i} = \frac{\sum_{l=1}^{k} \binom{\text{number of responses for level } l}{2}}{\binom{N_i}{2}} \quad (15)$$

k = number of levels
N_i = Number of ratings on item i (i = 1,……,n)
n = number of items

The trial version of JMP® 15.1 statistical software was used for the attribute gauge chart shown in Figure 5.

Table 5. CNs for a baby diaper

Primary customer requirements	Item number	Item code	Whats / Customer needs
Aesthetics	1	A1	The package should be well designed
	2	A2	The aesthetic appearance (e.g., color, pattern) of the outer surface of baby diaper should be great
Performance	3	P1	Baby diaper should not leak pee
	4	P2	The waist band of baby diaper should not become deformed when used
	5	P3	Baby diaper should have substantially absorptive property
	6	P4	Baby diaper should have a good water vapor permeable outer layer
	7	P5	Baby diaper leg wraps in the inguinal folds should not be too tight
	8	P6	The waist band of baby diaper should exhibit elasticity sufficiently
	9	P7	Baby diaper should consist of bio-based (organic) materials
Safety	10	S1	Baby diaper should be approved by dermatologists/pediatricians (Baby diaper should be dermatologically tested)
	11	S2	Baby diaper should not cause an allergic reaction (Baby diaper should not contain allergenic ingredients)
	12	S3	Baby diaper should not cause diaper rash
	13	S4	Baby diaper should not smell of chemicals (e.g., petroleum-based polymers)
Comfort	14	C1	Baby diaper should contain lotion
	15	C2	Baby diaper should be thin
	16	C3	Baby diaper should include wetness indicator
	17	C4	The smell of pee should not get out of baby diaper
	18	C5	Baby diaper should be soft

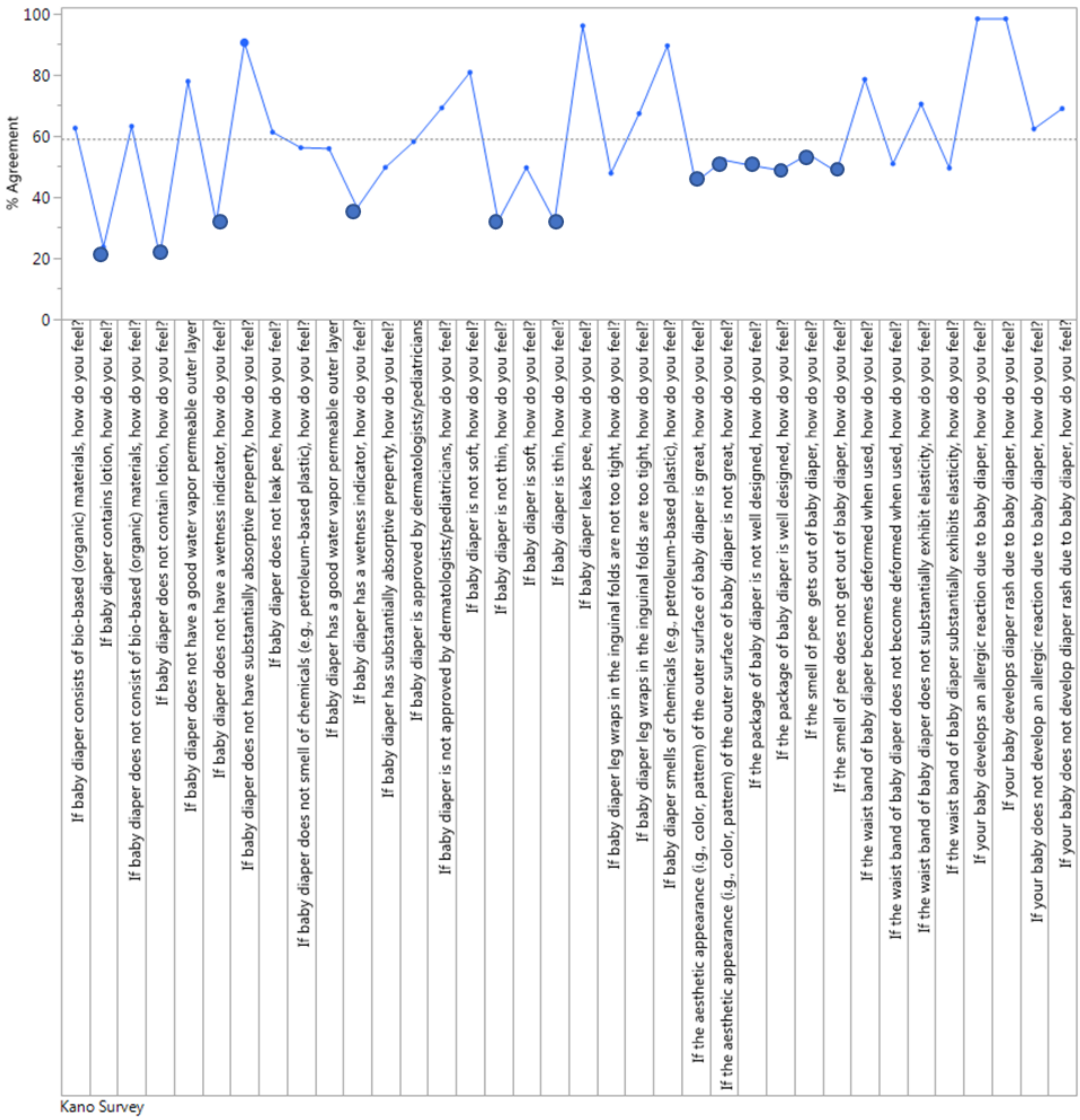

Figure 5. Attribute gauge chart of the Kano survey

The points marked with the blue filled circles indicate the six attributes that have lower agreement for their related both functional and dysfunctional questions when compared with those of other attributes. Out of six attributes, two of them belong to the category of aesthetics (A1, A2) and four of them (C1, C2, C3, C4) belong to the category of comfort. Although the lower agreement of the perceptions of aesthetics and comfort could potentially be a consequence of their subjective nature, it increases the variability, and subsequently decreases the internal consistency of the questionnaire.

4.3.3. Step 4 And Step 5: Evaluation Of Kano Survey According To Kano Evaluation Table And Determining The Adjustment Factors For Each Customer Need

Table 7 shows the results of the Kano questionnaire, which includes the adjustment factors calculated according to both traditional and proposed method.

The scatter plot of satisfaction index and dissatisfaction index of both methods is shown in Figure 6.

Table 6. Importance of customer need and corresponding Fuzzy set members

Customer needs	Rate of importance	Rate of importance - Fuzzy set members		
		Lower bound	Core	Upper bound
A1	2	1	2	3
A2	3	2	3	4
P1	5	4	5	5
P2	5	4	5	5
P3	5	4	5	5
P4	5	4	5	5
P5	5	4	5	5
P6	5	4	5	5
P7	5	4	5	5
S1	5	4	5	5
S2	5	4	5	5
S3	5	4	5	5
S4	5	4	5	5
C1	3	2	3	4
C2	4	3	4	5
C3	4	3	4	5
C4	4	3	4	5
C5	5	4	5	5

Equations (5-7) were used for the calculations of the traditional method; whereas Equations (11-14) were used for the calculations of the proposed method. Overall questionable (Q)-rate is not higher than 1%.

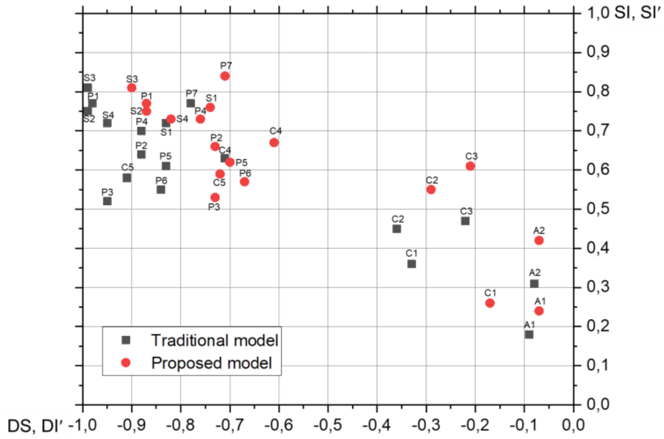

Figure 6. Matrix of satisfaction index and dissatisfaction index

4.3.4. Step 6 & Step 7: Doing competitive analysis, setting goal and finding IR

The three major brands (competitors) determined by the market survey were rated for each quality attribute, using a five point scale from 1 to 5, with 5 being the highest perceived satisfaction, through the Kano survey. However, since the C1 was found out to be a reverse requirement based on the results of the Kano survey, it was rated as 1. Furthermore, the number of raters for each competitor changed depending on the related brand experienceof the raters.

The value of weighted average performance score for each quality attribute per competitor was calculated; goals were set by the QFD team (here, they are the authors of this paper); and, improvement ratios were found as shown in Table 8.

4.3.5. Step 8: Calculation Of Absolute And Relative Weigths Of Customer Requirements

The formula of absolute weight and relative weight are as follows [7, 35]:

Absolute $weight_i$ = m_i x (Importance to customer) x IR_i (16)

m_i: the adjustment factor of customer need i

IR_i: improvement ratio of customer need i

Relative weight= (absolute $weight_i$)/(maximum absolute weight) (17)

Table 7. Results of the Kano questionnaire

Item code	A	O	M	I	R	Q	Total	Kano category	SI	DI	m	SI′	DI′	m′
A1	43	18	12	270		1	344	I	0.18	-0.09	0.18	0.24	-0.07	0.24
A2	80	24	3	232	4	1	344	I	0.31	-0.08	0.31	0.42	-0.07	0.42
P1	2	256	74	5		7	344	O	0.77	-0.98	0.98	0.77	-0.87	0.87
P2	18	199	101	21	1	4	344	O	0.64	-0.88	0.88	0.66	-0.73	0.73
P3	4	175	152	12	1		344	O	0.52	-0.95	0.95	0.53	-0.73	0.73
P4	22	214	84	19		5	344	O	0.70	-0.88	0.88	0.73	-0.76	0.76
P5	8	197	83	48	3	5	344	O	0.61	-0.83	0.83	0.62	-0.70	0.70
P6	15	173	111	40	2	3	344	O	0.55	-0.84	0.84	0.57	-0.67	0.67
P7	44	217	45	32		6	344	O	0.77	-0.78	0.78	0.84	-0.71	0.84
S1	26	218	65	30		5	344	O	0.72	-0.83	0.83	0.76	-0.74	0.76
S2	1	256	84	1		2	344	O	0.75	-0.99	0.99	0.75	-0.87	0.87
S3	1	277	64	2			344	O	0.81	-0.99	0.99	0.81	-0.90	0.9
S4	8	235	86	10	1	4	344	O	0.72	-0.95	0.95	0.73	-0.82	0.82
C1	27	49	19	114	130	5	344	R	0.36	-0.33	0.36	0.26	-0.17	0.26
C2	71	78	41	141	6	7	344	I	0.45	-0.36	0.45	0.55	-0.29	0.55
C3	95	65	11	168	3	2	344	I	0.47	-0.22	0.47	0.61	-0.21	0.61
C4	32	180	59	64	6	3	344	O	0.63	-0.71	0.71	0.67	-0.61	0.67
C5	11	186	122	21	3	1	344	O	0.58	-0.91	0.91	0.59	-0.72	0.72

Note: A: attractive attribute, O: one-dimensional attribute, M: must-be attribute, I: indifference attribute, R: reversal attribute, Q: questionable attribute, SI: satisfaction index according to the traditional method, DI: dissatisfaction index according to the traditional method, SI′: satisfaction index according to the proposed method, DI′: dissatisfaction index according to the proposed method, m: adjustment factor according to the traditional method, m′: adjustment factor according to the proposed method

The absolute and relative weight results of customer needs according to both proposed and traditional models are shown in Table 9. The lower bound, core, and upper bond of the absolute weight for each CN for the proposed model was calculated taking into account SI′ or $|DI'|$whichever had the higher score. The fuzzy numbers shown in Table 2, and the center of area (gravity) (COA) method for the operation of defuzzification were applied through MATLAB.

Table 8. Competitive analysis, setting goal and finding IR

Customer needs	Company A (N = 255)	Company B (N=231)	Company C (N= 207)	Our Product	Goal	Improvement Ratio (IR)
A1	4.2	4.1	3.9	1	4	4
A2	4.2	4.1	3.9	1	4	4
P1	4.1	3.6	3.4	1	5	4
P2	4.3	4.1	3.9	1	4	4
P3	4.3	3.7	3.5	1	4	4
P4	4.1	3.9	3.6	1	4	4
P5	4.2	3.9	3.8	1	4	4
P6	4.3	4.0	3.9	1	4	4
P7	3.2	4.3	3.4	1	5	5
S1	4.1	4.3	4.1	1	4	4
S2	4.2	4.1	3.9	1	5	5
S3	4.3	3.9	3.7	1	5	5
S4	3.2	4.3	3.6	1	5	5
C1	1	1	1	1	1	1
C2	4.3	3.7	3.3	1	4	4
C3	4.3	4.2	4.0	1	4	4
C4	3.8	3.4	3.4	1	4	4
C5	4.3	3.9	3.6	1	4	4

5. RESULTS AND DISCUSSION

Based on the results of the Kano questionnaire evaluation (Table 7), among the 18 customer needs, 13 were classified as one-dimensional, 4 were classified as indifferent, and 1 was classified as reverse. Here, the most frequent responses were categorized as one-dimensional or indifferent. It can be argued that this could be slightly different. For example, P3, having a baby diaper that should have substantially absorptive property, was classified as a one-dimensional attribute. On the other hand, P3 is considered as a primary function of a baby diaper and, it is expected to be a must-be attribute. However, commenting on the subject to the participants may cause subjective bias.

Figure 7 and 8 show the graphs of relative importance of customer requirements according to the proposed and traditional model, respectively.

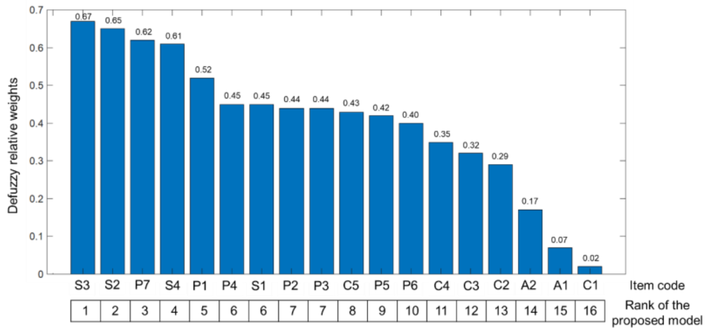

Figure 7. Defuzzy relative weights of the proposed model

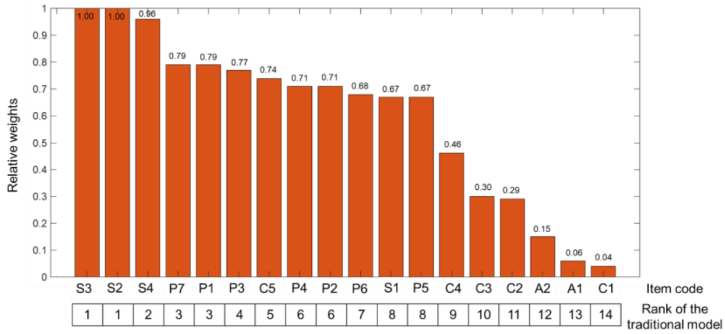

Figure 8. Relative weights of the traditional model

According to the relative weights of both models, the safety and performance design criteria have the highest priority which are followed by the comfort criteria, and the aesthetic design criteria are of the least importance. However, the comfort and aesthetic design criteria could be the future attractive attributes [40, 66]. Since C1 was found out to be a reverse attribute it is ranked at the end of the list. Although the frequency of reverse attribute for the requirements other than C1 are negligible, it cannot be ignored for CN1 due to the allergic ingredients potentially included in lotions. In addition, leading diaper manufacturers differ in whether to add lotion to the top sheet.

When the two models are compared, there are some changes in the ranking lists. While in the traditional model, 8 customer needs share 4 ranks: S3 and S2 = rank#1, P7 and P1= rank#3, P2 and P4= rank#6, P5 and S1= rank#8; in the proposed model just 4 customer needs share 2 ranks: P4 and S1= rank#6, P2 and P3= rank#7. Unlike the traditional model, in the proposed model, P7, having a baby diaper that should consist of bio-based materials, is the third significant customer need ranked before S4, having a baby diaper that should not smell of chemicals. Here, the result of the proposed model seems to be logical. On the contrary to the traditional model, in the proposed model, P4, having a baby diaper with a good water vapor permeable outer layer is ranked before P3, having a baby diaper with substantially

Table 9. Absolute and relative weight results of both proposed model and traditional model

Customer needs	Absolute weights			Relative weights			Defuzzy relative weights of the proposed model	Absolute weights of the traditional model	Relative weights of the traditional model
	Lower bound	Core	Upper bound	Lower bound	Core	Upper bound			
A1	0.68	1.92	3.74	0.02	0.06	0.12	0.07	1.44	0.06
A2	2.39	5.04	8.66	0.07	0.16	0.27	0.17	3.72	0.15
P1	7.64	17.39	25.22	0.24	0.54	0.78	0.52	19.6	0.79
P2	6.09	14.68	21.74	0.19	0.45	0.67	0.44	17.6	0.71
P3	5.59	14.59	22.20	0.17	0.45	0.69	0.44	19	0.77
P4	6.46	15.10	22.14	0.20	0.47	0.68	0.45	17.6	0.71
P5	5.97	14.07	20.68	0.18	0.43	0.64	0.42	16.6	0.67
P6	5.39	13.40	20.06	0.17	0.41	0.62	0.40	16.8	0.68
P7	10.57	20.93	28.65	0.33	0.65	0.89	0.62	19.5	0.79
S1	7.52	15.16	20.92	0.23	0.47	0.65	0.45	16.6	0.67
S2	9.47	21.78	31.73	0.29	0.67	0.98	0.65	24.75	1.00
S3	10.03	22.46	32.37	0.31	0.69	1.00	0.67	24.75	1.00
S4	8.80	20.44	29.88	0.27	0.63	0.92	0.61	23.75	0.96
C1	0.35	0.79	1.41	0.01	0.02	0.04	0.02	1.08	0.04
C2	4.45	8.76	14.49	0.14	0.27	0.45	0.29	7.2	0.29
C3	5.04	9.71	15.88	0.16	0.30	0.49	0.32	7.52	0.30
C4	5.04	10.70	18.35	0.16	0.33	0.57	0.35	11.36	0.46
C5	5.77	14.40	21.59	0.18	0.44	0.67	0.43	18.2	0.74

absorptive property. Here, to obtain a baby diaper with substantially absorptive property leading diaper manufacturers use superabsorbable polymers that reduce the leakage values below 2% [67]. Furthermore, a baby diaper with a good water vapor permeable outer layer is critical in terms of not developing diaper rash. Such being the case, P4 involves more design challenges than P3, which makes the results of the proposed model valid. In addition, S1, having a baby diaper with the approval of dermatologists/pediatricians, is ranked before C5, having a soft baby diaper, in the proposed model unlike the traditional model. Here, S1 is included in the safety design criteria, and is related to baby health; thus, S1 is not expected to be less important than C5.

As the quality attributes used to calculate customer SI and customer DI are not equal as stated in the current literature [28, 40] the integration of the Kano model indice of k to the computation of the adjustment factor (m) would finally adjust the original improvement ratio, and consequently final importance of customer requirements. Furthermore, reversal attribute sometimes can alert unrecognized things related to a requirement as shown in C1. Therefore, adding the frequency of reversal quality to the denominator of the customer SI and customer DI formula would be meaningful while obtaining final importance values. Since customer interpretations about a product or service are typically vague, it could make more sense to use fuzzy membership functions instead of crisp numbers to clarify questionnaire results.

In recent years, fuzzy Kano's questionnaire (FKQ) has been introduced, which deals with multiple answers rather than a single answer, unlike the traditional Kano's questionnaire (TKQ) [24]. However, like the TKQ, the FKQ is still conducted with functional and dysfunctional question pair for each CN, in which the Kano evaluation table is used for every participant's answer pair for each CN. Therefore, FKQ can be said to take more time than TKQ, and still to maintain uncertainties regarding human judgements.

However, since this study focused on just one product, further research is required to investigate the proposed model by taking into account the plausible values of the attribute-driven Kano model indices for designing of different products. In addition, the integration of the proposed model with other methodologies including Artificial Neural Networks (ANNs), Analytical Hierarchy Process (AHP) should be studied to evaluate its performance in prioritizing customer requirements.

6. CONCLUSION

In this study, the Adjusted Kano-Fuzzy-Quality Function Deployment (QFD) (AKFQFD) approach is presented in order to better understand the relationship between customer requirements and customer satisfaction, and consequently to increase the accuracy of determining the importance weights of customer requirements in product design. It is aimed to improve the existing Kano-QFD approaches by considering the impact factor of each quality attribute, that is Kano model indices, while calculating the adjustment factor (m) which is embedded into the QFD. Furthermore, fuzzy logic has been proposed by assigning fuzzy numbers instead of crisp values of Kano model indices, 0.5, 1, and 1.5, for must-be, one-dimensional, and attractive attributes, respectively, to manage the vagueness of customer interpretations about a product. In addition, since the reverse quality also reflects customer expectations in product or service design it makes sense to add its frequency to the denominator of the satisfaction index and dissatisfaction index.

The proposed AKFQFD model was applied for determining the importance weights of CNs of a baby diaper, in which the CNs were divided into four categories: aesthetics, performance, safety, and comfort. It has been shown that the proposed model helps to distinguish the CNs within the same category, and to prioritize the CNs of a baby diaper effectively. Hence, considering the impact factor of each Kano quality category while determining customer satisfaction or customer dissatisfaction, would facilitate decisions of companies in product design by effectively prioritizing customer needs.

However, it is generally accepted that dealing with the subjectivity is complex, and this paper develops an approximate method for the adjustment factor. Further study is needed to examine the potential values of the attribute-driven Kano model indices. Furthermore, future work should focus on studying the integration of the proposed approach with other methodologies such as Analytical Hierarchy Process (AHP) to improve the model.

Conflicts of interest

The authors declare that there are no conflicts of interest

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