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QUANTIFIED KANO MODELS COMBINING IPA SETS TO ASSESS FEATURES OF A NEW PRODUCT

Yun-Sheng Lin, Wei-Guang Tsaur, Hsiang-Chuan Liu and Mingchih Chen*

Graduate School of Business Administration
Fu Jen Catholic University
No. 510, Zhongzhen Road, Xinzhuang District, New Taipei City 24205, Taiwan
*Corresponding author: 081438@mail.fju.edu.tw

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Abstract. *This research adopted a multiproduct Kano questionnaire to fill the gap identified when investigating customer ratings of product features, and presented an integrated 3-ways validity index of different importance-performance analysis sets of quantified Kano models to assist in the quantitative comparison of product attributes between several brands. The proposed approach can simultaneously compare the degree of importance and, customer satisfaction as well as the performance of features between different products of the same type. Therefore, the new product under development can be rated in terms of its features to help in making correct decisions during product development. A real case is presented to demonstrate how the proposed approach was used to compare a newly developed product with two products of different brands in the market.*
Keywords: Kano model, Product development, Product performance, Customer satisfaction, Importance-performance analysis, Validity index

1. **Introduction.** New product development (NPD) covers the complete process of bringing a new product to market. Figure 1 details a generic product development process presented by Ulrich and Eppinger [1]. The number and content of phases may vary based on different definitions and depending on the NPD process employed. Nevertheless, in most cases the phase of testing cannot be eliminated from the NPD process because it is vital to completely validate the functionality and documentation of a new product. Avoiding this stage can often result in a failed product launch [2].

Thus, this research adopts a multiproduct Kano questionnaire to fill the gap identified when investigating customer ratings on product features, and proposes an integrated approach of a 3-ways validity index of different importance-performance analysis (IPA) sets of quantified Kano models, which can quantitatively compare the degree of importance, customer satisfaction, as well as the performance of product attributes between different brands [3]. The approach can be used at the testing phase to compare the prototype of the new product with those of its competitors in the market to help decide whether the company can begin mass production and start marketing immediately, or whether it would be better to spend more time modifying the design according to the comparison results. The approach not only can reduce the risk of considerable investment and failures, but also can increase the opportunity of success because it is capable of comparing the new product with different products of the same type to provide sufficient information to the company so that they make the correct decisions during the product development process.

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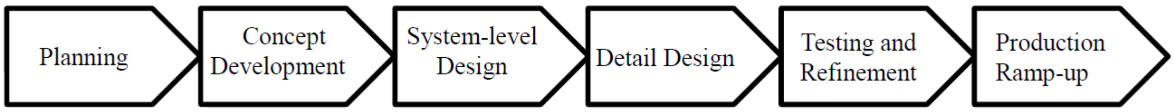

FIGURE 1. Generic product development process [1]

1.1. **IPA and Liu's 2-ways validity index.** The IPA was firstly proposed by Martilla, and James in 1977. It utilizes an I-P framework to analyze the relationship between the importance and performance of a product or service for customers [4]. Although the original IPA is a useful quality control technique for identifying the features of a specific product that should be improved, it cannot be used to compare the specific features and total accomplishments of different IPA models. To solve this problem, Liu et al. proposed a quantitative tool involving a 2-ways validity index as defined below [5,6], according to the effective value of the IPA matrix diagram shown in Figure 2.

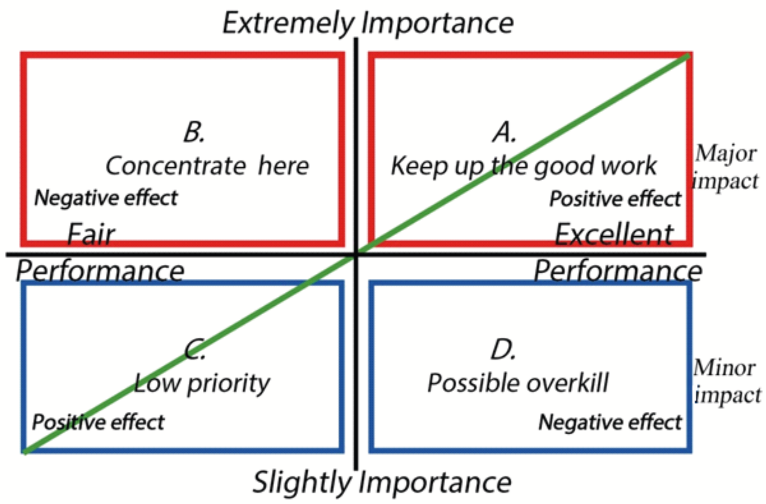

FIGURE 2. Effective value of the IPA matrix diagram [6]

Definition 1.1. *If the order pair (x_{ijk}, y_{ijk}) represents the performance and important score of feature j, product k of the respondent i, in a survey, where $i = 1, 2, \ldots, N$, $j = 1, 2, \ldots, n$, $k = 1, 2, \ldots, m$*

$$x_{ijk} \in \{1, 2, 3, 4, 5, 6\}, \quad x_{jk} = \frac{1}{N}\sum_{i=1}^{N} x_{ijk}, \quad \bar{x}_k = \frac{1}{n}\sum_{j=1}^{n} x_{jk} \tag{1}$$

then, $\{(x_{jk} - \bar{x}_k, y_{jk} - \bar{y}_k)\}_{j=1}^{n}$ is the set of the IPA of feature j of product k.

Definition 1.2. *The Liu's 2-ways validity index is defined as below.*

$$V_L^{(2)}(k) = \frac{1}{n}\sum_{j=1}^{n} \Delta_{jk}, \quad \Delta_{jk} = \left[a_j + b_j \frac{|(x_{jk} - \bar{x}_k) - (y_{jk} - \bar{y}_k)|}{\max_{1 \le j \le n} |(x_{jk} - \bar{x}_k) - (y_{jk} - \bar{y}_k)|}\right] \tag{2}$$

$$(a_j, b_j) = \begin{cases} \left(1, -\frac{1}{4}\right) & \text{if } j \in A : (I) \to (x_{jk} - \bar{x}_k) \ge 0, (y_{jk} - \bar{y}_k) \ge 0 \to \frac{3}{4} \le \Delta_{jk} \le 1 \\ \left(\frac{3}{4}, -\frac{1}{4}\right) & \text{if } j \in C : (III) \to (x_{jk} - \bar{x}_k) < 0, (y_{jk} - \bar{y}_k) < 0 \to \frac{1}{2} \le \Delta_{jk} \le \frac{3}{4} \\ \left(\frac{2}{4}, -\frac{1}{4}\right) & \text{if } j \in D : (IV) \to (x_{jk} - \bar{x}_k) \ge 0, (y_{jk} - \bar{y}_k) < 0 \to \frac{1}{4} \le \Delta_{jk} \le \frac{1}{2} \\ \left(\frac{1}{4}, -\frac{1}{4}\right) & \text{if } j \in B : (II) \to (x_{jk} - \bar{x}_k) < 0, (y_{jk} - \bar{y}_k) \ge 0 \to 0 \le \Delta_{jk} \le \frac{1}{4} \end{cases} \tag{3}$$

Definition 1.3. *If $V_L^{(2)}(s) > V_L^{(2)}(t)$, the total performance of product s is better than that of product t.*

Remark 1.1.

(i) The constant a_j of the first term indicates the quadrant each feature j belongs to.

(ii) The constant $b_j \frac{|(x_{jk}-\bar{x}_k)-(y_{jk}-\bar{y}_k)|}{\max_{1\le j\le n}|(x_{jk}-\bar{x}_k)-(y_{jk}-\bar{y}_k)|}$ of the second term indicates the distance between each feature j and the second diagonal line, the closer the better in quadrant I, but conversely in other quadrants.

1.2. **Kano model.** Kano et al. developed the Kano model which deals with product performance and customer satisfaction in 1984. Customer preferences are classified into three main types – "Must-be", "One-dimensional", and "Attractive", according to the priority of the attributes and how they affect customer satisfactions [7-9].

Despite the benefits in using Kano model, it is restricted by several limitations. The first is that the model classifies, but does not quantify either the numerical or the qualitative performance of the attributes. The second is that it does not provide an explanation of what drives customers' perceptions and, why particular attributes are more important to customers [10]. Kano model cannot precisely reflect the extent to which customers are satisfied, it is because the original Kano questionnaire consists of functional and dysfunctional questions for each attribute, and the Kano categories are determined by the highest response frequency [11].

2. **An Integrative Approach.** As discussed, an integrative approach of a multiproduct Kano questionnaire and 3-ways validity index of different importance-performance analysis (IPA) sets of quantified Kano models are proposed. To provide a systematic means of investigating customer ratings of product features, a process model is proposed as shown in Figure 3.

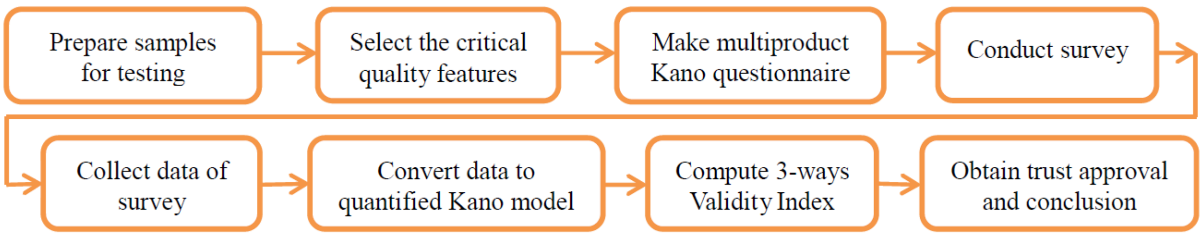

FIGURE 3. Process model for investigating customers' comments during NPD

2.1. **Multiproduct Kano questionnaire.** The prototypes of the new product are compared with products of leading brands to confirm whether the new product is as competitive as its opponents or requires further refinement. Because all respondents can experience the quality of products, we can obtain their specific answers to questions on product performance, attributes of product, as well as perceived satisfaction. A multiproduct Kano questionnaire, as shown in Figure 4, is employed for survey in the testing phase.

2.2. **Quantified Kano models and 3-ways validity index.** We integrated Liu's 2-way validity index with the quantified Kano model, and composed a 3-ways validity index. The formulas and definitions are explicated in detail as follows. First, we transform the 3-dimensions performances vector in the conventional Kano model into a one-dimension performance scale by using weighting regression. Second, we estimated the degree of importance of each attribute by its contribution, which is the simple regression of all scores of this attribute and total scores of all attributes. At this stage, the conventional

Product feature	What do you think of the performance of product feature to respective brand, and which attribute that it may be classified under?			
	Brand K			
a. The blade is sharp	Its performance is excellent	Its attribute of One-dimensional	Its attribute of Must-be	Its attribute of Attractive
Strongly agree	☐	☐	☐	☐
Agree	☐	☐	☐	☐
Slightly agree	☐	☐	☐	☐
Slightly disagree	☐	☐	☐	☐
Disagree	☐	☐	☐	☐
Strongly disagree	☐	☐	☐	☐

FIGURE 4. Multiproduct Kano questionnaire employed in this study

Kano model has been transformed into a quantified Kano model, similar to an IPA model. Finally, a 3-ways validity index was constructed for the IPA set of quantified Kano models. This index is sufficiently sensitive to compare both the individual attributes and their total accomplishment.

2.2.1. *Transforming the performances of each attribute.*

Definition 2.1. $\vec{x}_{ijk} = \left(x_{ijk}^{(1)}, x_{ijk}^{(2)}, x_{ijk}^{(3)}\right)$ *is the performance vector with attribute components (One-dimensional, Must-be, Attractive) of feature j of product k by consumer i in a survey, where $x_{ijk}^{(s)} \in \{1,2,3,4,5,6\}$, $s = 1,2,3$, $i = 1,2,\ldots,N$, $j = 1,2,\ldots,n$, $k = 1,2,\ldots,m$. Transform the said vector by using weight regression into scale x_{ijk}, and get*

$$x_{jk} = \frac{1}{N}\sum_{i=1}^{N} x_{ijk}, \quad \bar{x}_k = \frac{1}{n}\sum_{j=1}^{n} x_{jk} \tag{4}$$

2.2.2. *Estimating the importance degree of each feature.*

Definition 2.2. *Let x_{ijk} be defined as the foregoing, and the importance degree of feature j of product k be defined as below.*

$$y_{ik} = \frac{1}{2}\left[1 + \textit{Correlation of } (x_{ijk})_{i=1}^{N} \textit{ and } \left(\left(\sum_{j=1}^{n} x_{ijk}\right)\right)_{i=1}^{N}\right] \tag{5}$$

$$0 \le y_{jk} \le 1, \quad \bar{y}_k = \frac{1}{n}\sum_{j=1}^{n} y_{jk} \tag{6}$$

Then, $\{(x_{jk} - \bar{x}_k, y_{jk} - \bar{y}_k)\}_{j=1}^{n}$ is the IPA set of the quantified Kano model of product k.

2.2.3. *Constructing 3-ways validity index.*

Definition 2.3. *The 3-ways validity index is defined as below.*

$$V_L^{(3)}(k) = \frac{1}{n}\sum_{j=1}^{n} \Delta_{jk} \tag{7}$$

$$\begin{aligned}\Delta_{jk} = \Bigg[& a_j + b_j \frac{|(x_{jk} - \bar{x}_k) - (y_{jk} - \bar{y}_k)|}{\max_{1\le j\le n} |(x_{jk} - \bar{x}_k) - (y_{jk} - \bar{y}_k)|} \\ & + c_j \frac{\sqrt{(x_{jk} - \bar{x}_k)^2 + (y_{jk} - \bar{y}_k)^2}}{\max_{1\le j\le n}\sqrt{(x_{jk} - \bar{x}_k)^2 + (y_{jk} - \bar{y}_k)^2}} \Bigg]\end{aligned} \tag{8}$$

$$(a_j, b_j, c_j) = \begin{cases} \left(\frac{7}{8}, -\frac{1}{8}, \frac{1}{8}\right) & \textit{if } j \in I \to (x_{jk} - \bar{x}_k) \geq 0, (y_{jk} - \bar{y}_k) \geq 0 \to \frac{3}{4} \leq \Delta_{jk} \leq 1 \\ \left(\frac{6}{8}, -\frac{1}{8}, -\frac{1}{8}\right) & \textit{if } j \in III \to (x_{jk} - \bar{x}_k) < 0, (y_{jk} - \bar{y}_k) < 0 \to \frac{1}{2} \leq \Delta_{jk} \leq \frac{3}{4} \\ \left(\frac{4}{8}, -\frac{1}{8}, -\frac{1}{8}\right) & \textit{if } j \in IV \to (x_{jk} - \bar{x}_k) \geq 0, (y_{jk} - \bar{y}_k) < 0 \to \frac{1}{4} \leq \Delta_{jk} \leq \frac{1}{2} \\ \left(\frac{2}{8}, -\frac{1}{8}, -\frac{1}{8}\right) & \textit{if } j \in II \to (x_{jk} - \bar{x}_k) < 0, (y_{jk} - \bar{y}_k) \geq 0 \to 0 \leq \Delta_{jk} \leq \frac{1}{4} \end{cases} \tag{9}$$

Definition 2.4. *If $V_L^{(3)}(s) > V_L^{(3)}(t)$, the total performance of product s is better than that of product t.*

Remark 2.1.

(i) The constant a_j of the first term indicates the quadrant each attribute component of feature j belongs to.

(ii) The constant $b_j \dfrac{|(x_{jk} - \bar{x}_k) - (y_{jk} - \bar{y}_k)|}{\max_{1 \leq j \leq n} |(x_{jk} - \bar{x}_k) - (y_{jk} - \bar{y}_k)|}$ of the second term indicates the distance between each attribute component of feature j and the second diagonal line, the closer the better in quadrant I, but conversely in other quadrants.

(iii) The constant $c_j \dfrac{\sqrt{(x_{jk} - \bar{x}_k)^2 + (y_{jk} - \bar{y}_k)^2}}{\max_{1 \leq j \leq n} \sqrt{(x_{jk} - \bar{x}_k)^2 + (y_{jk} - \bar{y}_k)^2}}$ of the third term indicates the distance between each attribute component of feature j and the origin of the coordinates, the closer the better in quadrant I, but conversely in other quadrants.

3. **Case Study.** To ensure that the proposed approach is usable in practice for the comparison of the different Kano models of the same product type, we investigated a product of men's trimmer that was newly developed by a company located in Taiwan as well as two similar items already marketed by leading brands. Twelve main features of the products were included as items in the foregoing questionnaire. The survey was conducted by the company on 120 men aged from 21 to 65 years selected at random after they tested the three types of trimmers. A total of 103 respondents answered the questionnaire completely, and all the data were used for follow-up studies by statistics.

We first transformed the 3-dimensons performance vector to a one-dimension performance scale, and obtained the total performance and degree of importance of the attribute j of product k which was denoted respectively as follows:

$$x_{jk} = \frac{1}{103} \sum_{i=1}^{103} \left(\frac{w_{j1} x_{ijk}^{(1)} + w_{j2} x_{ijk}^{(2)} + w_{j3} x_{ijk}^{(3)}}{w_{j1} + w_{j2} + w_{j3}} \right), \quad \bar{x}_k = \frac{1}{12} \sum_{j=1}^{12} x_{jk}$$
$$j = 1, 2, \ldots, 12, \quad k = 1, 2, 3 \tag{10}$$

$$w_{js} = \text{Correlation of } \left(x_{ijk}^{(s)} \right)_{i=1}^{103} \text{ and } \left(\sum_{s=1}^{3} x_{ijk}^{(s)} \right)_{i=1}^{103} \tag{11}$$

Then, the importance degree of each attribute is estimated by:

$$y_{jk} = \frac{1}{2} \left[1 + \text{Correlation of } (x_{ijk})_{i=1}^{103} \text{ and } \left(\sum_{j=1}^{12} x_{ijk} \right)_{i=1}^{103} \right] \tag{12}$$

$$\bar{y}_k = \frac{1}{12} \sum_{j=1}^{12} y_{jk} \tag{13}$$

The IPA set of quantified Kano model of the product k is derived as:

$$\{(u_{jk}, v_{jk})\}_{j=1}^{12} = \{(x_{jk} - \bar{x}_k, y_{jk} - \bar{y}_k)\}_{j=1}^{12} \tag{14}$$

Finally, all the calculated results are listed in Table 1 for further comparison.

TABLE 1. IPA sets of quantified Kano models of 3 trimmers

	Product U			**Product M**			**Product L**		
Product features	***Relative P.***	***Relative I.***	***Q.***	***Relative P.***	***Relative I.***	***Q.***	***Relative P.***	***Relative I.***	***Q.***
a	−0.031	−0.322	3	0.037	0.358	1	−0.065	−0.239	3
b	−0.012	−0.323	3	0.037	0.385	1	−0.025	−0.320	3
c	0.005	−0.266	4	0.043	0.370	1	0.061	0.380	1
d	0.005	−0.291	4	0.032	0.324	1	0.070	0.378	1
e	0.009	−0.420	4	−0.009	−0.538	3	0.063	−0.388	4
f	−0.003	−0.206	3	−0.008	−0.237	3	0.088	0.472	1
g	0.016	0.267	1	0.042	0.263	1	0.021	−0.246	4
h	0.000	−0.237	3	−0.027	−0.218	3	0.101	0.500	1
i	0.002	0.544	1	−0.038	−0.191	3	−0.095	−0.177	3
j	0.009	0.406	1	0.003	−0.233	4	0.015	−0.168	4
k	0.000	0.516	1	−0.050	−0.060	3	−0.137	−0.090	3
l	0.001	0.332	1	−0.061	−0.222	3	−0.097	−0.102	3

P. = Performance *I.* = Importance *Q.* = Quadrant

Table 1 shows the scale of relative performance and relative importance of IPA sets of three products, which was composed and transformed from their original Kano models. A comparison of the figures listed in Table 1 demonstrates that the product with the comparative advantage in terms of features can be easily observed. For example, product U has features g, i, j, k, and l in quadrant I, and in the IPA model this means that these features in product U are of high relative importance with excellent relative performance; therefore, company should "keep up the good work". Similarly, features a, b, c, d and g in product M, and features c, d, f, and h in product L are of high relative importance with excellent relative performance. Every product has its own strengths based on different features and users have different preferences for each product. A pertinent concern is how the individual comprehensive strength can be determined based on their comparisons with others. We employed the proposed 3-ways validity index to compare these three IPA sets of quantified Kano models. The results show that among the three brands product M is the best, product U is ranked second and product L is ranked third.

$$V_L^{(3)}(\text{U}) = 0.5307, \quad V_L^{(3)}(\text{M}) = 0.5697, \quad V_L^{(3)}(\text{L}) = 0.4767 \tag{15}$$

The new product U should be as competitive as those of leading brands. The next question is whether we can analyze the above data to decide which features of product U can be refined or improved to increase customer preference. This may increase the ranking of such a product. A comparison of the figures in Table 1 reveals that products M and L both have strengths in terms of features c and d whose coordinates fall in quadrant I. Conversely, product U is in a weak position regarding these two features as their coordinates are in quadrant IV. As previously mentioned, feature c refers to "smooth operating" and feature d refers to "low noise". According to our survey, these two features belong to either "Must-be" or "One-dimensional" attributes in the Kano model depending on the preference of different users. If the company can upgrade features c and d of their product U, product U will become more acceptable by those users who prefer products M and L because of their satisfaction with the aforementioned features. Feature f refers to "low current consumption" which belongs to either "One-dimensional" or "Must-be" attribute in the survey for the Kano model. The coordinate of feature f of product U falls in quadrant III. However, the coordinate of feature f of product L is in quadrant I. Thus, the company may consider making efforts to increase the power efficiency of feature f of their product U to increase performance and satisfy more customers.

The case study proved that the integrative approach we proposed is useful for developing new and competitive products. When proceeding with any improvement on a product, we must also consider the cost that may arise, so that we can develop a product with the highest popularity and best value.

4. **Conclusions.** By employing the multiproduct Kano questionnaire we designed for the survey, we can obtain actual customer opinions on different products of the same type. According to the actual case illustrated as per our proposed integrative approach, a comparison of different Kano models of the same product type was conducted. Nevertheless, no absolute standard exists as yet, future studies should attempt to research this further.

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