Applications of Kansei Engineering

for Shape Design and Material Selection of Products

（商品の形状デザインと素材選択への感性工学の応用）

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Abstract

Nowadays, the product design and development has become more complexity and fast changes. Among these conditions, the product image shows the significant role in customer's preference and purchasing behavior. Kansei engineering (KE) is used to determine customer emotion on the shape design and material selection in Thailand. KE can find the feeling and emotion that causes purchasing behavior. Also, it finds the product attributes that affect the customer emotion. Box–Behnken response surface methodology and Taguchi based Grey relation analysis are integrated to seek the optimal product shape from continuous variables design. The study of food wrapping has proposed a base methodology to evaluate materials of food wrapping based on tactile sense. In more detail, it identified a set of Kansei words representing the tactile sense, made clear the relationships among them as well as their relationships with the attitude. This dissertation also succeeds to apply KE with Fuzzy Analytical Hierarchy Process (FAHP) and Analytic Network Process (ANP) in Thai ceramic manufacturing. Five applications are included in this dissertation.

First, the application of KE and Box–Behnken response surface methodology (RSM-BBD) for optimization of shape design parameters was proposed using a wine glass design as a case study. KE was used to evoke costumer feelings and emotions by evaluation of Kansei words. The RSM-BBD was successfully applied to estimate the optimal design parameters for the extraction of customer emotions. The result of this study provides useful understanding for shape product design and shows that these techniques can be applied to other products.

Second, the application of KE, Taguchi design and Grey relation analysis (GRA) for optimization of shape design parameters was illustrated using a wine glass design as a case study. KE was used to translate costumer feelings and emotions. Taguchi design and GRA were employed to identify the optimal shape parameters which optimize multi-objective customer emotions. This study has proved the feasibility of KE, Taguchi and GRA for solving multi-customer feelings in product design and development.

Third, the study of food wrapping has proposed a base methodology to evaluate materials of food wrapping based on tactile sense. The food wrapping materials included plastic bag, aluminum foil, plastic film, paper, plastic foam net, banana leaf, wax paper, plastic net and plastic air bubble. The evaluation based only on tactile sense meanwhile vision sense was blocked. A semantic differential measurement was used for the evaluation and the principal component analysis for the analysis.

Fourth, the application of KE and Quantification Theory Type 1 was employed to definition of mapping of Kansei word space to mug cup design space. And we also applied FAHP to identification of importance of design characteristics. These findings can support the designer to design ceramic products that satisfy the customer's perception.

Fifth, the application of KE and ANP for multi-criteria decision of the product attribute design was illustrated. KE was used to evoke costumer feelings and emotions. ANP was successfully applied to decide the most important customer emotions and the most important product attributes that extracting the customer emotions. In addition, it can be recommended to manufacturers to apply this procedure into widespread used in several cases of the product design and development.

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Chapter 1

Introduction

1-1 Introduction to Kansei engineering

Kansei engineering (KE) or Affective engineering was firstly introduced in 1970 by Prof. Mitsuo Nagamachi [1] and is known as “translating technology a consumer’s feeling and image for a product into design elements”. Nagamachi [2] proposed KE is performed by Kansei and the engineering field to evaluate human sensibility and produce the product that customers need and satisfy. The objectives of KE are understanding and creating the product attributes according to customer feelings and emotions. Kansei Engineering System (KES) is used in order to analyze the product attributes which affect the responses from consumer at psychological level as shown in Fig. 1-1 [2].

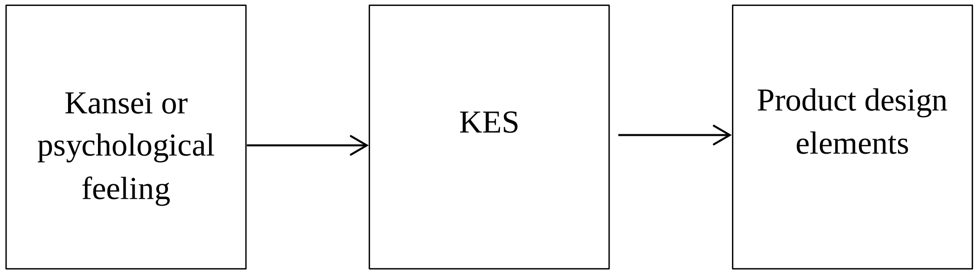

Fig. 1-1 Kansei Engineering System process. [2]

KE has been conducted in many kinds of industrial products such as running shoe [3], chocolate snacks [4] and sunglasses [5], in supporting product designers to perceive the consumer emotions and feelings toward product attributes. KE is obtained through experiments on customer emotions and feelings affected the physical product and finding the interaction between the customer affectives and the product elements. The eight techniques for the implementation of KE have been employed [6]. These techniques are different to conduct KE in various conditions such as information availability, complexity and required performance [7]. This dissertation employed KE Type 1 among them. Nagamachi [1] explained ‘‘Category Classification is a method in which a Kansei category of a product is broken down in the tree structure to determine the design element’’. To determine the design specification, physical product characteristics and Kansei words are created and translated into tangible product designs [8]. This procedure represents in Fig. 1-2.

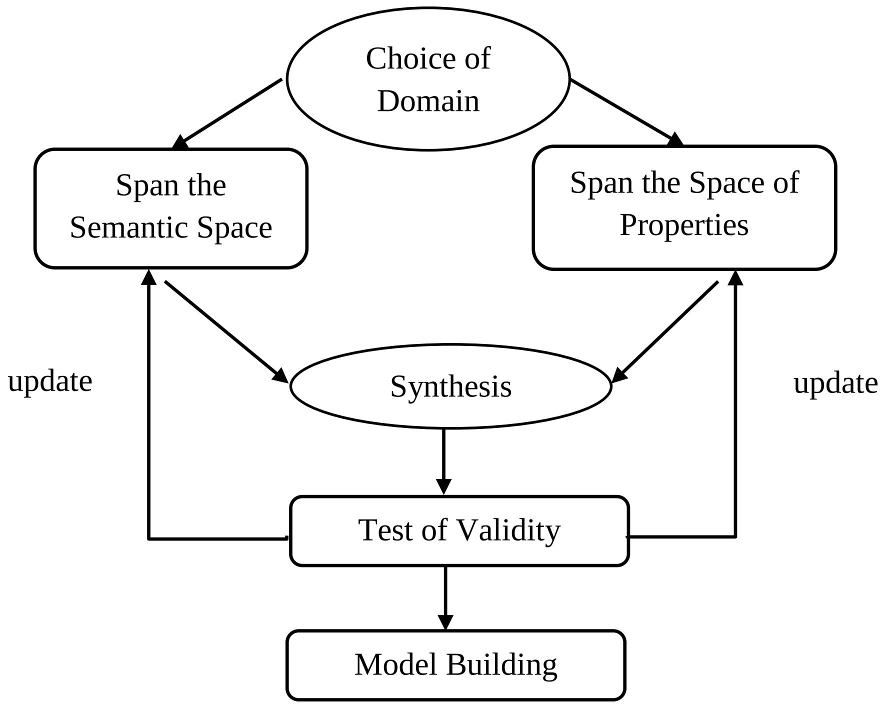

Fig. 1-2 A general model of KE. [9]

Figure 1-2 represents that product as the choice of domain is analyzed by both of the perspectives including a semantic perspective and a physical perspective [10]. Both of the perspectives are identified by themselves. Then, the synthesis step is conducted for finding the relationships between a semantic perspective and a physical perspective. Next, a validity test is conducted. The semantic and the physical perspective are reprocessing. The synthesis phase is also carried out again. If the findings are satisfactory, a relational model between the semantic space and the space of properties is modeled [10]. Each block of the general model in Fig. 1-2 will be explained below.

(1) Choice of domain

Choice of product domain is the ideal concept of a certain product. The domain cites to the existing product or the concept product and innovative design [8].

(2) Span the semantic space

Choice of product domain is explained by both of the semantic space and the product property space [11]. The product domain is also described by collecting relevant words. According to Schütte [10], the semantic space is spanned using three steps.

Step 1: Kansei word collection. Relative words are obtained using different sources such as websites, product reviews, advertisements, user interviews, experts, experienced users, ideas and visions [10].

Step 2: Reduce amount of Kansei words. Relative words are reduced depending on the existing data. This goal is to make the data management by using different methods such as factor analysis, affinity diagram, and brainstorming [10].

Step 3: Final selection of Kansei words. Kansei word is finally chosen as the representative word. Higher level of Kansei word is associated to the product properties in the synthesis step [10].

(3) Span the space of properties

The space of properties is the physical products which affecting customer feelings and emotions. This phase is conducted similar to the span semantic space [10].

Step 1: Physical product properties collection. The product properties are described using various resources for example, technical manual, interview with expert, literature and benchmarking [10].

Step 2: Important product properties identification. The experts or the professors identify the most important properties of product [10].

Step 3: Selected product properties and selected samples. The experts or the professors choose final product properties and representative products that describe the physical product perspective [10].

(4) Synthesis

The relationships between the semantic space and the product properties space are considered. Questionnaire is employed to make this connection for evaluating the customers emotions and feelings regarding the concepts of product selected [12].

(5) Test of validity

Data are compiled with a careful examination regarding validity [9]. Not only the validity testing of semantic differential is needed, but also the validity testing of concept should be conducted [10].

(6) Model building

The data acquired from the synthesis step are presented in a relational model. According to emotions and feelings may not be encoded with a mathematical model, the relational model can be a non-mathematical model corresponding to technique of the synthesis step [12].

1-2 Motivation and problem statement

Nowadays, the new production technology has made the global competitions [13]. The product design techniques have become more complexity and fast changes. Among these conditions, the product image shows the significant role in customer's preference and purchasing behavior [14]. Several new product design techniques have been employed to achieve consumer's perceptions. The most prominent study is KE [7]. Most of KE researches focus on proposing various methodologies to understand customer emotions and feeling that affected by the objective product design [15]. Several studies have conducted this methodology for the physical appearance of a product. For example, Shieh and Yeh [3] determined the correlation between the form of running shoes and consumer emotional responses. Schütte [16] mapped the affective impression of chocolate bars exterior. Yanagisawa and Fukuda [17] developed a design methodology for an automobile sideboard shape design. Lanzotti, et al. [18] determined the optimal seats design. Yadav, et al. [19] found the optimum level of the car shape parameters. Sutono, et al. [20] determined the optimal design parameters of the office chair. Widiyati and Aoyama [21] studied KE in PET bottle design. Nordgren [22] built a car model.

The above literature survey reveals that KE has carried out in order to translate customer emotions and feelings into concrete shape features. However, these studies did not focused on the geometries precisely because there are several problems that have to be overcome in order to determine a set of design parameters as the design parameters of a product shape should be optimized in all of significant customer emotions and feelings. One of the most useful tools for process optimization that has many factors and interactions influencing the response is Response Surface Methodology (RSM). RSM, first introduced by Box and Wilson [23], has become an important tool in process and product development. RSM consists of statistical techniques and mathematical optimization that are used to improve existing processes or develop new processes. Then, RSM can be used to obtain optimal condition that resulting in a better overall product. In addition, RSM combined with Box-Behnken design (BBD) would provide us with 1) ability to process multiple variables, 2) good evaluating the interactions between factors, 3) perform under extreme conditions and 4) less resource demand [24]. To understand customer emotions and feelings of product shape, this dissertation proposes a methodology incorporating RSM and BBD in KE. This is the first trial of this kind of study.

In addition, one of the most effective tools for optimization that has many factors influence on many desired responses is Taguchi design base on Grey Relation Analysis (GRA). Taguchi design is the effective technique for improving product quality and manufacture process using the statistical experimental design [20]. GRA approach enables assessing complicated relationships among multiple factors and variables using the minimum data [25]. Both methods have been employed quite successfully in engineering applications but the application in product design is not widely applied. There are only 2 researches that integrated Taguchi design and GRA for product design. Yadav et al. [19] used RSM, Kano model, Taguchi design and GRA to find the optimum car shape parameters. And, Chen and Chuang [26] combined GRA with the Taguchi method to optimize shape of mobile phone. This dissertation also demonstrates how to apply KE with Taguchi based GRA to parameterize design of shape product. Differ for their researches, the product form design variables ordinarily consist of discrete and continuous variables. This dissertation focuses on continuous design variables into consideration whereas their researches focused on discrete design variables. Therefore, this research can seek the optimal product shape from continuous design variables and the detail size of shape parameters determines accurately.

Consequently, the study of shape design has proposed a way to design precise geometric shapes in KE using the combination of BBD and RSM as well as a way to optimize the parameters using Taguchi design method and Gray relational analysis.

Furthermore, the studies on KE have been widely applied for design the product shape and characteristic. The investigation on material selection has not been emphasized [27]. Material selection is a step in product design and development, the objective is to minimize cost and succeed product performance goals [28]. According to the process of product design, material selection should be emphasized on the relationships between human sensation and material characteristic. Product designers should associate to identify what are the material properties that influence customer emotions, and select the proper material for their products. Lei, et al. [27] applied KE in the material selection of furniture. Yin and Gan [29] studied the consumer emotional needs of clothing material design. Nishino, et al. [30] developed project of car floor carpet including material. Nakada [31] conducted KE for car seat including outer layer material. Besides, Kansei is the psychological sense which includes all the human feelings and senses to see, hear, feel and smell. Generally, there are five human senses consisting of vision, hearing, smell, taste and tactile sensation which affecting human emotions, feelings and perceptions [32]. Certainly, customers generally evaluate products through more than one sense especially by vision as well as tactile. Of course, the tactile sense is also significant similarly to the other senses because many new modern products are designed based on the response of product touch [33]. Therefore, this sense would affect the customer's decision to purchase the product. It is important to investigate tactile sensation which users touch the exposed surface of products when this sense is separated from the other sensations [34]. Choi and Chun [33] studied the affective of tactile sense regarding the surface roughness of the polymer-based products. Chen, et al. [35] analyzed the relationships between feelings and sensory judgments by touching confectionery packaging.

Because of the signification of the KE using tactile sense in material selection described above, to reveal the relationship of customer emotion affect by the product material seem to be necessary. This dissertation puts forward the method of material selection of food wrapping, investigates the customer's sensory feelings by touch. The food wrapping is used to preserve and protect food that is on sell in the stores or to cover unpeeled or peeled fruit in home. According to the great advantage of food wrapping, it has been used very widely in Thai's market. It is the first time to apply this method to a product with the features of food wrapping. Consequently, the study of food wrapping has proposed a base methodology to evaluate materials of food wrapping based on tactile sense. In more detail, it identified a set of Kansei words representing the tactile sense (feelings), made clear the relationships among them as well as their relationships with the attitude (dislike-like), and evaluated some materials of food wrapping using them.

Finally, even though KE was firstly introduced in 1970 in Japan and many countries have conducted in many kinds of industry. However, KE is not well-known in Thailand because of lacking knowledge and limiting applied in only academic sector. Few of researches have employed KE. For example, Wattanutchariya and Royintarat [36] implemented quality function deployment and KE for GABA rice snack development. Pitaktiratham, et al. [37] applied KE and association rules mining in sofa design.

Pitaktiratham and Anantavoranich [38] used semantic questionnaire for KE in sofa design. Kawtummachai [39] conducted the concept of KE in packaging design. In Thailand, ceramic is one of products that play a vital role in product design and development. Many Thai ceramic companies have attempted to implement the user experience strategy to capture the consumer perceptions and to make their desired products. However, their design process often designs the product that unfit for the consumer perceptions and needs. Ceramic designers tend to use emotional or intuitive techniques in customer survey. Nevertheless, they have lacked the formal emotional techniques.

This dissertation determines user preferences and feelings related to the appearance of physical ceramic design in Thai manufacturing using KE with Quantification Theory Type 1. Moreover, the author extends product image studies on product form with Fuzzy Analytical Hierarchy Process (FAHP) and Analytic Network Process (ANP). FAHP and ANP techniques have been used to develop decision making tools for product design and development. For instance, Hsiao [40-41] conducted Fuzzy theory and AHP to finding the interrelated assessment of color schemes. Hsiao and Ko [42] studied consumers' emphasis on appearance of bicycle using FAHP. Hsiao, et al. [43] studied the optimal performance of bicycle model using ANP. Lan, et al. [44] selected an icon dish of food tourism and ordered the important of food features. Hence, FAHP and ANP are also applied to decide the most important customer emotion and the most important product attribute that customers satisfy. It is the first time to apply these methods to a product with the features of ceramics.

1-3 Objectives of research work

The dissertation proposes a set of new methodologies that can be applied to steps in KE from product attribute selection and material selection to shape design and its optimization. In addition, we show their effectiveness through some applications. This dissertation has expanded the application range of KE through the five methodologies proposed as following.

- To propose how to apply KE with Box–Behnken response surface methodology for shape parameter design. A wine glass design was selected as a case study.
- To illustrate how to apply KE with Taguchi based grey relation analysis for shape parameter design. A wine glass design was selected as a case study.
- To investigate tactile attributes of food wrapping materials based on KE.
- To illustrate how to apply KE with Quantification Theory Type 1 in the Thai ceramic. In addition, Fuzzy AHP was used to identification of importance of design characteristics.
- To illustrate how to apply KE with analytic network process in the Thai ceramic. A mug design was selected as a case study.

1-4 Outline of dissertation

This dissertation is divided into seven chapters. In each chapter, main contents are existed as follows:

Chapter 1 “Introduction” this chapter describes theoretical background of KE. The author also explains the motivation and problem statement of this research work. The objectives of the research are clarified.

Chapter 2 “Application of Kansei engineering and Box–Behnken response surface methodology for shape parameter design: A case study of wine glass” describes how to apply KE to obtain customer feelings and emotions on the shape of wine glasses and the optimal precise design. This study was performed using a four-factor and three-level Box-Behnken design with response surface methodology.

Chapter 3 “Application of Kansei engineering and Taguchi based Grey relation analysis for shape parameter design: A case study of wine glass”, the author describes how to optimize the shape parameter to get the customer satisfaction of a wine glass using the applications of KE, Taguchi design and grey relation analysis.

Chapter 4 “Application of Kansei engineering to tactile sense in the Thai food wrapping materials” investigates tactile attributes of food wrapping materials in Thailand based on KE. The highlight of this chapter is to evaluate customer emotions in Thailand by investigating the tactile sense.

Chapter 5 “Application of Affective engineering and Fuzzy analytical hierarchy process in Thai ceramic manufacturing” the author describes how to apply KE methodology to study consumer’s perception of ceramic product. Quantification Theory Type 1 was conducted to analyze the relationships between product elements and customer emotions. FAHP method was used to evaluate and to identify the most favorite product attributes.

Chapter 6 “Application of Kansei engineering and Analytic network process in the Thai ceramic design” the author describes how to applied KE technique that employs ANP to identify the most favorite product attributes and the important affective emotions. A mug design was selected as a case study.

Finally, Chapter 7 “Conclusions” is summarized all works in this dissertation.

Some parts of the dissertation have undergone publications in journals and conferences. Chapter 2 has been published in Journal of Advanced Mechanical Design, Systems, and Manufacturing. Chapter 3 has been published in International Conference on Innovative Design and Manufacturing 2016. Chapter 4 has been published in Journal of Applied Packaging Research. Chapter 5 has been published in International Journal of Affective Engineering and International Design and Concurrent Engineering Conference

2015. Chapter 6 has been published in Joint 8th International Conference on Soft Computing and Intelligent Systems and 17th International Symposium on Advanced Intelligent Systems 2016.

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Chapter 2

Application of Kansei engineering and Box–Behnken response surface methodology for shape parameter design: A case study of wine glass

2-1 Introduction

As mentioned in Chapter 1, there are several studies in KE for translating customer feelings and emotions into product design. However, the design parameters of a product shape should be optimized in all of significant customer feelings and emotions. One of the most useful tools for process optimization that has many factors and interactions influencing the responses is response surface methodology (RSM) using with Box–Behnken design (BBD) [1]. Several studies on the RSM-BBD have been conducted for the optimization of process parameters such as styrene recovery from waste polystyrene [2], the aqueous extraction of betalain from beetroot [3], catalysts of sodium silicate and cadmium oxide [4] and modeling of some Turkish coals [5]. According to a literature survey, it shows that the study on RSM-BBD approach in KE is not used to design shape of product. Therefore, it is the first time to apply these methods for design product and it can be the prototype of the various design cases. In this study, a wine glass design was selected as a case study to illustrate how applied KE and RSM-BBD used to parameterize design of shape product. A study on this product was one of samples that Petiot and Yannou [6] presented in a design of table glasses using PCA and semantic differential method. They rated and ranked the new prototypes according to the existing products. Differ from theirs study, results from RSM are high precision and accuracy which multi-optimize with multiple customer emotions. Furthermore, the cultural difference in nation differs significantly in terms of demand, purchasing behavior and product attributes [7]. Especially, glass industry is one of the high economic value added industries in Thailand [8].

2-2 Box-Behnken Design

In the optimization procedure, the optimum operating conditions are achieved by using complex experimental designs such as Doehlert Matrix, Central Composite Designs, and Box-Behnken Design (BBD). BBD is used for the experimental design based on three-level incomplete factorial design [9]. The number of experiments (*N*) is calculated from Eq. (2-1) as follow:

$$N = 2k(k-1) + C_0 \tag{2-1}$$

where N is number of experiments

k is number of factors

C_o is the number of central points

BBD does not consider the factors at highest or lowest levels, so that it is an advantage of this method. In addition, the eliminating experiment designs are performed under extreme conditions (the highest and lowest level) and the results which are undesired may not happen [10].

2-3 Response Surface Methodology

Response Surface Methodology (RSM) is a technique of statistic and mathematic which are conducted for improving, developing and optimizing process [11]. It has useful applications in design and developing of existing product design [12]. Most widespread applications of RSM are found in industrial sector, especially when there are several input variables potentially influence the key point performance or quality characteristic of product or process [11]. The response is the performance measurement or the quality characteristic [13]. The response is measured on a continuous rating, even though attribute responses, rank, and sensory measurements are not uncommon [14]. Generally, the response in most applications of RSM has more than one response. Either a linear (first-order) or a polynomial (second-order) expression is sufficient for RSM technique to model the observed responses [15].

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k} \sum_{j=1, i<j}^{k} \beta_{ij} X_i X_j + \varepsilon \qquad (2\text{-}2)$$

where Y is the response variables used in the response surface design; k is number of factors; β_0 is the model constant; β_i (i = 1, 2,…, k) represents the linear coefficient; β_{ij} (i = 1, 2,…, k; j = 1, 2, …, k) represents the quadratic coefficient; X_i and X_j the coded independent variables and ε is the statistical error.

2-4 Methodology

This study applied KE and RSM based on model procedure presented by Schütte, et al. [16]. The procedure of this study is represented in Fig. 2-1. This procedure is presented as follows.

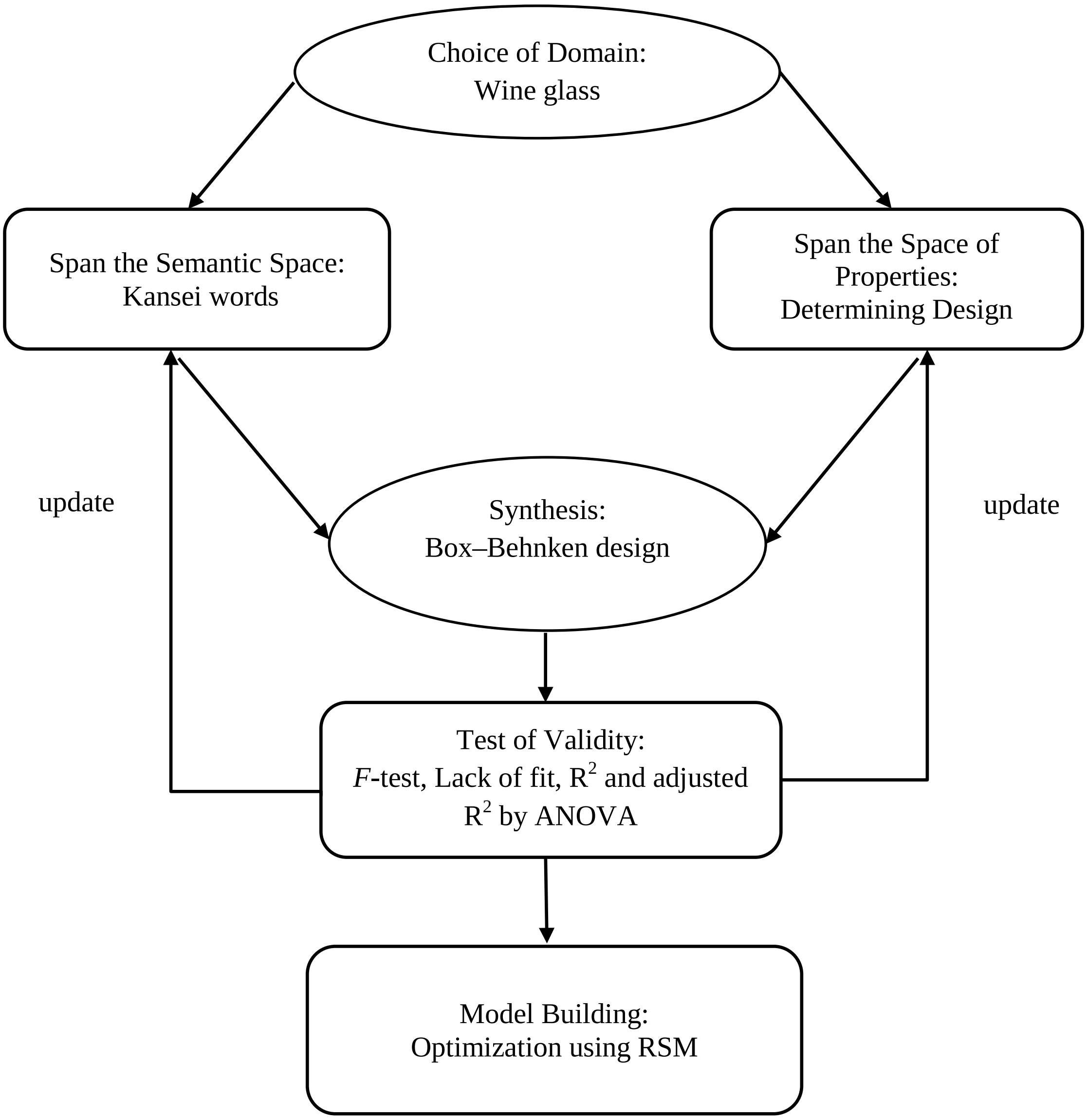


Fig. 2-1 Research methodology of KE and RSM-BBD

shape parameters design of wine glass. Adapted from [16].

(1) Choice of domain

A wine glass was selected as the product domain. The sample size of the study was 30 participants. The participants were wine drinkers who had been using wine glasses more than one year.

(2) Span the semantic space

Kansei words were collected from advertisements, internet, magazines and literature reviews. Some of the unclear words or the insignificant words were omitted in the screening step. After discussions with the professionals and experts in product design from Rajamangala University of Technology Lanna (Thailand), five highly relevant words were finally determined in the form of Kansei words to enhance customer emotions and feelings, namely: 1) modern, 2) quality, 3) durable, 4) ease of drinking and 5) ease of handle. These Kansei words were represented as the observed response (*Y*) for RSM technique as the output parameters in Fig.2-2.

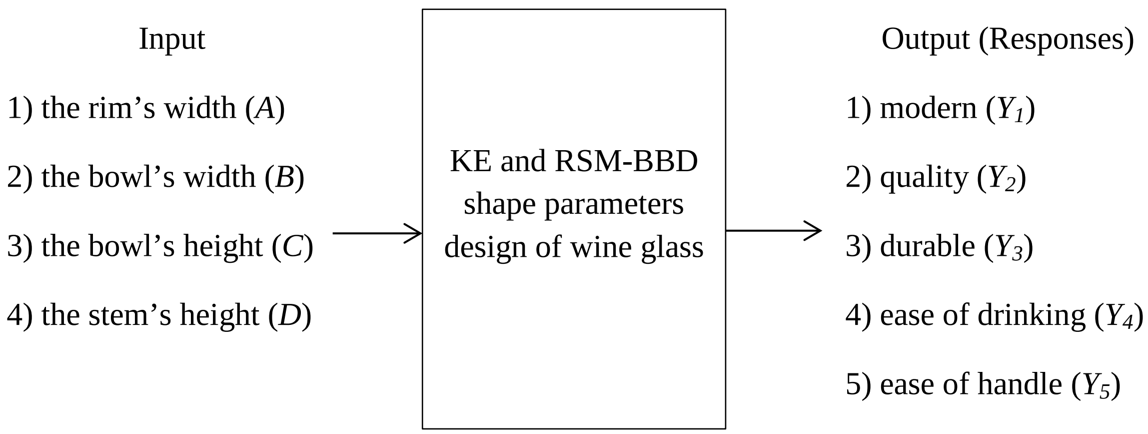


Fig. 2-2 Input-output parameters of KE and RSM-BBD shape parameters design of wine glass.

(3) Span the space of properties

The product shape parameters which can have an impact on the emotional response are identified as the control factors in the BBD experiments. Generally, there are four parts of a wine glass, namely: 1) the foot, 2) the stem, 3) the bowl and 4) the rim as shown in Fig. 2-3 [17]. The position of the identified shape features with respect to the overall wine glass design is described in Fig. 2-4. These design parameters were represented as the independent variables (X) as the input parameters in Fig. 2-2 The shape features that are insignificant factors for evaluation of customer feelings were kept fixed and excluded from the design parameter settings including the stem's width and the foot's width. In this study, a four-factor and three-level BBD design of experiment was used in conjunction with RSM of analysis. Each shape design parameter was chosen for three different levels as shown in Table 2-1. Here -1, 0, and +1 represent low, medium and high levels, respectively.

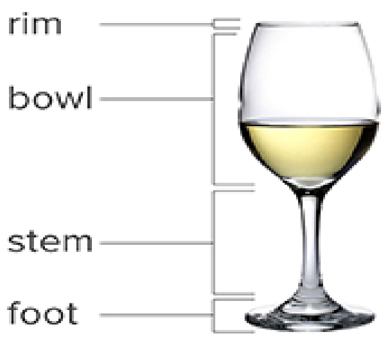


Fig. 2-3 Parts of wine glass. [17]

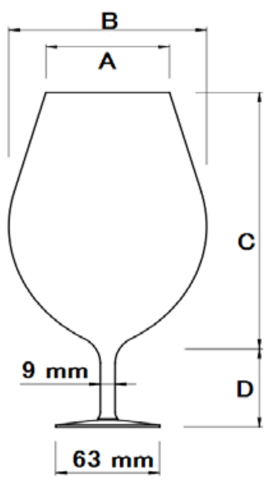


Fig. 2-4 Shape design parameters for wine glass design of KE and RSM-BBD shape parameters design of wine glass.

Table 1-1 Shape design parameters and their levels according to Box-Behnken design.

Shape design parameters	Symbol	Level		
		-1	0	+1
the rim's width (mm)	*A*	30	75	120
the bowl's width (mm)	*B*	30	75	120
the bowl's height (mm)	*C*	20	100	180
the stem's height (mm)	*D*	25	55	85

(4) Synthesis

(a) Experimental design

The BBD with two center point was performed. This design requires 26 experimental runs from Eq. (2-1) (N = 26; k = 4; C_o = 2). The experimental setup shown in Table 2-2 was obtained from a software package Minitab [18]. The shape design model generated based on BBD as shown in Fig. 2-5.

Table 2-2 RSM-BBD design matrix.

Run	Actual shape design parameters				Coded factors			
	the rim's width (mm)	the bowl's width (mm)	the bowl's height (mm)	the stem's height (mm)	*A*	*B*	*C*	*D*
1	75	120	180	55	0	1	1	0
2	120	120	100	55	1	1	0	0
3	30	75	20	55	-1	0	-1	0
4	75	75	100	55	0	0	0	0
5	75	120	20	55	0	1	-1	0
6	120	75	100	85	1	0	0	1
7	75	30	20	55	0	-1	-1	0
8	120	75	180	55	1	0	1	0
9	75	30	180	55	0	-1	1	0
10	75	30	100	85	0	-1	0	1
11	30	75	100	85	-1	0	0	1
12	75	120	100	25	0	1	0	-1
13	120	30	100	55	1	-1	0	0
14	30	75	180	55	-1	0	1	0
15	75	75	180	85	0	0	1	1
16	30	120	100	55	-1	1	0	0
17	120	75	100	25	1	0	0	-1
18	75	75	20	85	0	0	-1	1
19	75	75	100	55	0	0	0	0
20	30	30	100	55	-1	-1	0	0
21	75	30	100	25	0	-1	0	-1
22	120	75	20	55	1	0	-1	0
23	75	75	180	25	0	0	1	-1
24	75	120	100	85	0	1	0	1
25	75	75	20	25	0	0	-1	-1
26	30	75	100	25	-1	0	0	-1

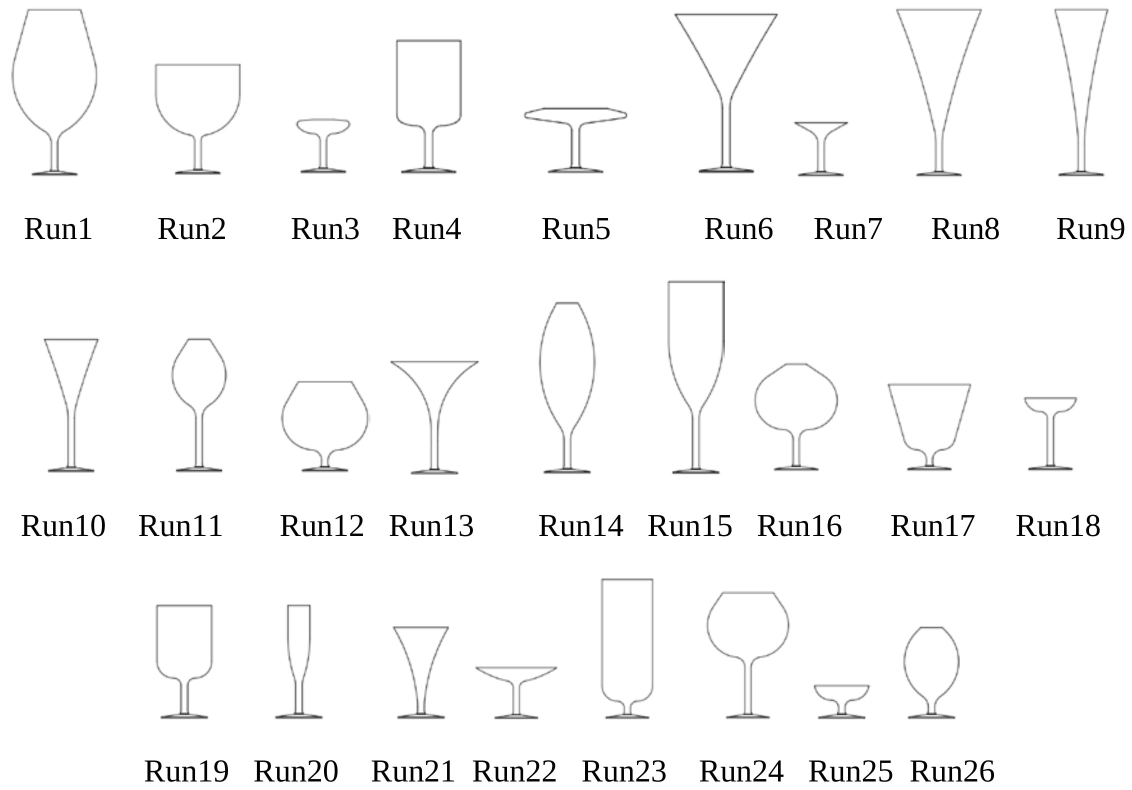


Fig. 2-5 Shape design models of wine glass generated based on BBD.

(b) Data collection process

The participants were requested to evaluate the 26 experimental runs for five Kansei words evaluation using a five level Likert scale (1 refers definitely disagree, 5 refers definitely agree). A questionnaire was distributed in order to classify the relationship between the shape design parameters and customer emotions. These surveys were conducted in Chiang Mai, Thailand.

(5) Test of validity

The statistical significance of Eq. (2-2) was checked by *F*-test. The analysis of variance (ANOVA) was used to test the adequacy and fitness of the models. The statistical technique that subdivides the total variation of a data set into components with sources of variation for testing hypotheses each of the parameters in model is ANOVA [19]. Fisher's test was conducted to analyze the significance of each independent variable or design parameter. According to Carnegie Mellon University [20], the *F* value is the ratio of two scaled by calculating the explained variance divided with the unexplained variance. It indicates the influence of each shape design parameter on the tested model. The high *F* value indicates that the variation in the responses can be interpreted by the regression equation [3]. The *p* values of model are greater than 0.05 indicate that the model terms are not significant whereas the values are less than 0.05 indicate that the model terms are significant. ‘‘Lack of fit’’ illustrates the lack of fit index of the fitted model. The fitted model is good if lack of fit is insignificant [21]. The coefficient of determination (R^2) and adjusted R^2 were computed to verify the sufficiency and fitness of the model. The high R^2 and adjusted-R^2 coefficient represent the good relationships between the experimental variables and predicted values of the response [22].

(6) Model building

RSM associates the optimal values of explanatory variables. Composite desirability (D) is computed for reveal how overall of the multi-response [18]. Desirability range is from zero to one. The value of zero means that one or more responses are outside the target limits whereas the value of one means the ideal target [18]. In this study, the shape design parameters of wine glass could be simulated with the multi objective optimization. The maximum predicted values for shape features as well as the maximum values of five Kansei words could be optimized from RSM.

2-5 Results and discussion

2-5-1 Box-Behnken design and analysis

RSM is an effective modeling technique used to analyze the relationship between the design parameters and the customer emotions that were evaluated by Kansei words. The results of the emotional evaluation are tabulated in Table 2-3.

Table 2-3 Experimental responses of shape design parameters.

Run	Modern (mean)	Quality (mean)	Durable (mean)	Ease of drinking (mean)	Ease of handle (mean)
1	1.87	4.83	3.63	3.70	4.33
2	3.16	3.67	2.47	3.63	3.97
3	3.47	2.33	2.63	2.43	2.57
4	2.33	3.53	4.57	4.67	4.53
5	3.10	4.03	2.33	3.67	4.30
6	3.47	3.73	2.47	3.47	3.73
7	2.63	3.20	2.13	4.53	4.23
8	3.67	3.93	2.37	3.77	4.23
9	3.47	3.33	2.37	3.43	4.67
10	3.77	3.43	3.33	3.47	3.47
11	3.47	2.53	4.40	2.77	2.77
12	2.33	4.06	3.10	3.10	2.47
13	4.53	3.13	2.63	3.47	4.33
14	3.20	2.43	3.97	2.77	2.63
15	2.57	4.33	4.03	3.73	3.47
16	3.23	2.83	3.13	2.90	2.50
17	3.73	2.63	2.33	3.23	3.23
18	2.53	3.67	2.13	3.43	3.67
19	2.43	3.43	4.50	4.67	4.23
20	4.13	2.13	3.63	2.63	3.57
21	3.23	3.47	2.97	4.13	2.33
22	3.63	3.13	2.13	3.47	4.23
23	2.23	3.43	4.13	4.33	2.33
24	2.13	4.67	3.07	3.43	3.67
25	2.43	3.43	2.23	3.67	2.43
26	3.50	2.47	4.37	2.67	1.77

The following five equations encoded form was established to explain the emotional Kansei words, namely modern, quality, durable, ease of drinking and ease of handle, respectively.

$$Y_1 = 2.385 - 0.10167A - 0.49333B - 0.06833C + 0.03333D + 1.06667A^2 + 0.35667B^2 + 0.00667C^2 + 0.09167D^2 - 0.1225AB + 0.07AC - 0.0675AD - 0.5125BC - 0.175BD + 0.0625CD \quad (2\text{-}3)$$

$$Y_2 = 3.49 + 0.465A + 0.45417B + 0.215C + 0.23917D - 0.74125A^2 + 0.235B^2 + 0.15375C^2 + 0.12D^2 - 0.0425\mathrm{AB} + 0.165AC + 0.2525AD + 0.1725BC + 0.1575BD + 0.1725CD \quad (2\text{-}4)$$

$$Y_3 = 4.525 - 0.64833A + 0.05417B + 0.5725C + 0.02333D - 0.69875A^2 - 0.905B^2 - 1.005C^2 - 0.44375D^2 + 0.0775AB - 0.265AC + 0.0175AD + 0.27BC - 0.105BD - 0.0025CD \quad (2\text{-}5)$$

$$Y_4 = 4.675 + 0.40833A - 0.10417B + 0.05167C - 0.06583D - 1.10042A^2 - 0.48417B^2 - 0.37792C^2 - 0.56667D^2 - 0.015AB - 0.02AC + 0.035AD + 0.29BC + 0.2525BD - 0.105CD \quad (2\text{-}6)$$

$$Y_5 = 4.39 + 0.660833A - 0.11167B + 0.02C + 0.5125D - 0.62333A^2 - 0.08958B^2 - 0.17708C^2 - 1.14583D^2 + 0.1775AB - 0.0175AC - 0.1175AD - 0.1BC + 0.0225BD - 0.0225CD \quad (2\text{-}7)$$

where Y_1, Y_2, Y_3, Y_4 and Y_5 are the emotional quality characteristics of modern, quality, durable, easy of drinking, easy of handle, respectively; *A*, *B*, *C* and *D* are the coded values of design parameters including the rim’s width, the bowl’s width, the bowl’s height and the stem’s height, respectively.

It could be observed from the coefficients in Eq. (2-3) – (2-7) that the emotion of quality, easy of drinking and easy of handle increased with the rim’s width (*A*) and the bowl’s height (*C*), whereas Kansei words ‘‘quality’’ and ‘‘durable’’ increased with the bowl’s width (*B*). The stem’s height (*D*) was affected the response of modern, quality, durable and ease of handle to increasing except ease of drinking. Also, these mathematical models could help to predict the overall shape feature of wine glass with different customer emotions.

Statistical significances of Eq. (2-3) – (2-7) were checked by F test, and the summaries of the analysis of variance (ANOVA) for response surface equations are shown in Tables 2-4. The model was further checked by F value, p value, Lack-of-Fit, R^2 and adjusted R^2. As shown in Table 2-4, the p values of all the linear and quadratic model were significant for all of five Kansei words at 5% ($p < 0.05$). The values of the response for lack of fit ($p > 0.05$) also confirmed the significance of the equation models. R^2 values that were close to 1 referred to the better correlations between the shape design parameters and Kansei words values. The determination coefficients (R^2) were calculated as 0.9643, 0.9689, 0.8700, 0.8732 and 0.9081, respectively. Therefore, the relations between the experimental and predicted values of the response were good. The values of adjusted R^2 were computed to be 91.89%, 92.92%, 70.46%, 71.18% and 79.12% for the five models. Only about 8.11%, 7.08%, 29.54%, 28.82% and 20.88% of the total variations could not be explained by the models.

Table 2-4 ANOVA test for response.

Y	Source	*DF*	Adjusted sums of squares	Adjusted Mean Square	*F* value	*p* value
Y_1 Modern	Regression	14	11.0258	0.78755	21.25	0.000
	Linear	4	3.1139	0.77848	21.00	0.000
	Square	4	6.6252	1.65631	44.68	0.000
	Interaction	6	1.2866	0.21443	5.78	0.006
	Lack-of-Fit	10	0.4037	0.04037	9.97	0.242
	R^2 = 96.43%	adjusted R^2 = 91.89%				
Y_2 Quality	Regression	14	12.0780	0.86271	24.44	0.000
	Linear	4	6.3110	1.57775	44.69	0.000
	Square	4	5.0586	1.26464	35.82	0.000
	Interaction	6	0.7084	0.11807	3.34	0.040
	Lack-of-Fit	10	0.3833	0.03833	7.67	0.275
	R^2 = 96.89%	adjusted R^2 = 92.92%				
Y_3 Durable	Regression	14	15.4394	1.10282	5.26	0.004
	Linear	4	9.0189	2.25471	10.75	0.001
	Square	4	5.7787	1.44468	6.89	0.005
	Interaction	6	0.6419	0.10698	0.51	0.789
	Lack-of-Fit	10	2.3037	0.23037	94.03	0.080
	R^2 = 87.00%	adjusted R^2 = 70.46%				
Y_4 Ease of drinking	Regression	14	8.29109	0.59222	5.41	0.004
	Linear	4	2.21508	0.55377	5.06	0.015
	Square	4	5.43308	1.35827	12.41	0.000
	Interaction	6	0.64292	0.10715	0.98	0.483
	Lack-of-Fit	10	1.20412	0.12041	2408.25	0.016
	R^2 = 87.32%	adjusted R^2 = 71.18%				
Y_5 Ease of handle	Regression	14	16.3238	1.16599	7.77	0.001
	Linear	4	8.5467	2.13668	14.24	0.000
	Square	4	7.5506	1.88764	12.58	0.000
	Interaction	6	0.2265	0.03775	0.25	0.949
	Lack-of-Fit	10	1.5999	0.15999	3.12	0.416
	R^2 = 90.81%	adjusted R^2 = 79.12%				

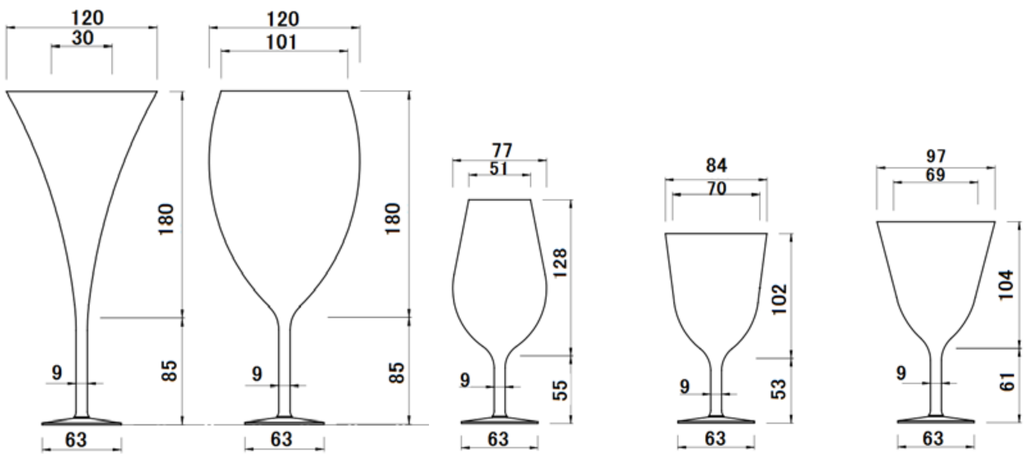
2-5-2 Response optimization

In order to consider shape design parameters of wine glass for the five emotions or Kansei words, the shape parameters were optimized by Minitab software. The optimum response level was defined to get maximum extraction. The analysis results can be summarized in Table 2-5.

Table 2-5 Response optimization of shape design parameters for each Kansei word.

Kansei word	Composite desirability (D)	*A*	*B*	*C*	*D*
		the rim's width (mm)	the bowl's width (mm)	the bowl's height (mm)	the stem's height (mm)
Modern (Y_1)	1.0000	120	30	180	85
Quality (Y_2)	1.0000	100.91	120	180	85
Durable (Y_3)	0.9505	50.91	77.27	128.28	55.30
Ease of drinking (Y_4)	0.9306	83.64	70	102.42	52.88
Ease of handle (Y_5)	0.9027	97.27	69.09	104.04	60.76

Figure 2-6 shows the shape parameter design models using KE and RSM approach. Control parameters for the optimization of customer impression variables are shown in Table 2-6. The goal was expected to be maximal, so the upper limit was not set. The lower limit of all responses was set at 1 whereas the target value was set at 5 regarding five level of Likert scale. The weight factors range between 0.1 and 10 with the larger ones relating to more significant responses. The importance of the goals is set for order the response according to increasing importance. In this study, the weight and importance value of each response were both set at 1 meaning all responses are equally important.



(a) (b) (c) (d) (e)

Fig. 2-6 Optimal models of wine glass for each Kansei word.

(a) modern (b) quality (c) durable (d) ease of drinking (e) ease of handle

Table 2-6 Parameters of the response optimization.

Response	Goal	Lower	Target	Upper	Weight	importance
Modern (Y_1)	Maximize	1	5	-	1	1
Quality (Y_2)	Maximize	1	5	-	1	1
Durable (Y_3)	Maximize	1	5	-	1	1
Ease of drinking (Y_4)	Maximize	1	5	-	1	1
Ease of handle (Y_5)	Maximize	1	5	-	1	1

Response optimization results are shown in Fig. 2-7. The values in the red line were the optimal value with an overall desirability value of 0.7752. When the rim's width, the bowl's width, the bowl's height and the stem's height were controlled at 90 mm., 61.82 mm., 126.67 mm. and 61.97 mm. respectively, the predicted emotion value of modern was at 2.78 (acceptability=55.69%), the predicted emotion value of quality was at 3.63

(acceptability=72.57%), the predicted emotion value of durable was at 4.14 (acceptability=82.87%), the predicted emotion value of ease of drinking was at 4.55 (acceptability=91.11%), and the predicted emotion value of ease of handle was at 4.59 (acceptability=91.77%).

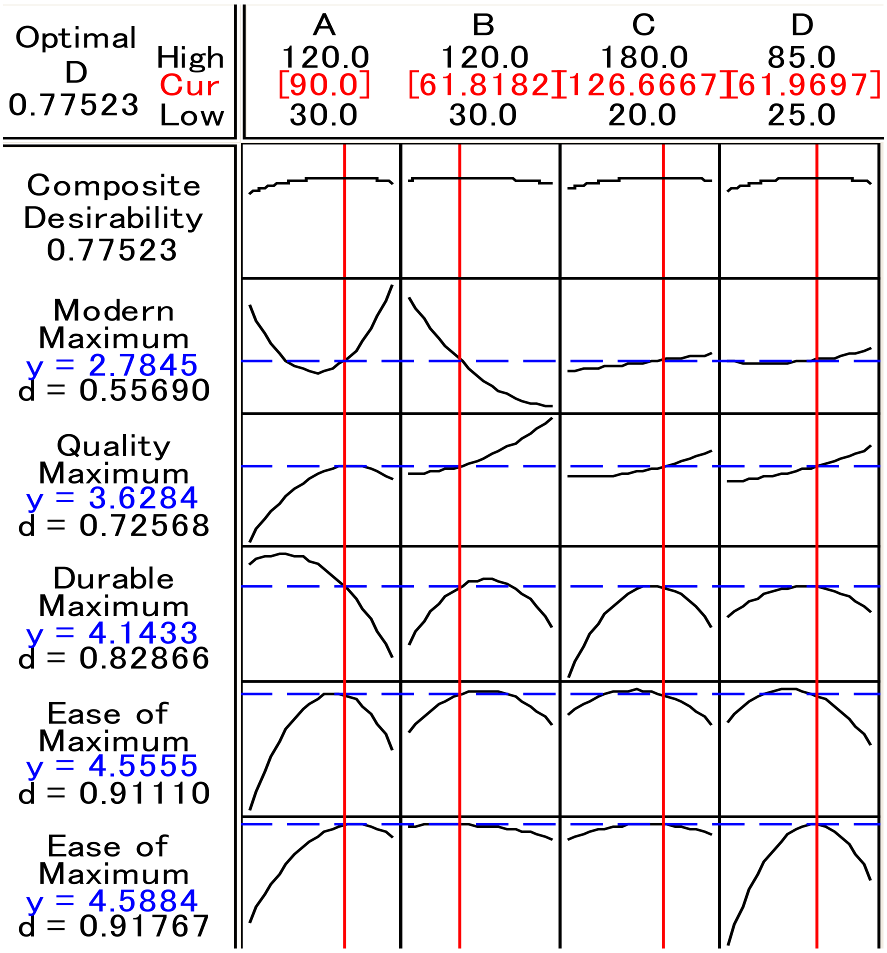


Fig. 2-7 Response optimization of all of five Kansei words.

In summary, the optimal model of wine glass design that could contains customer emotional values of modern, quality, durable, ease of drinking and ease of handle was shown in Fig. 2-8.

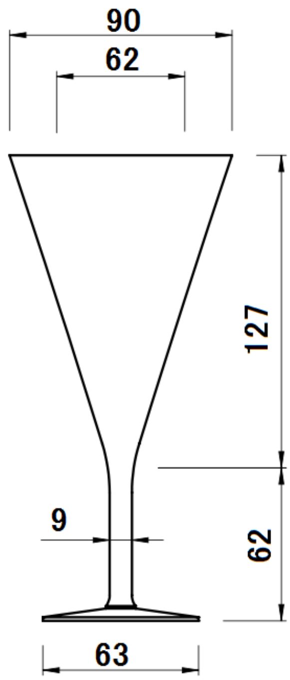


Fig. 2-8 Optimal model of wine glass for all Kansei words.

2-6 Summary

This study illustrates the application of KE and RSM-BBD for optimization of shape design parameters. This is the first trial of this kind of study. KE was used to evoke costumer feelings and emotions by evaluation of Kansei words. The RSM-BBD was successfully applied to estimate the optimal design parameters that extracting customer emotions and feelings. 4 shape parameters of wine glass (the rim's width, the bowl's width, the bowl's height, the stem's height) and 5 Kansei words (modern, quality, durable, ease of drinking, ease of handle) were examined. Afterward, based on all findings and results, the optimal model was designed. The result of this study provides useful understanding for shape product design and shows that these techniques can be applied to other products. Finally, the product designers can be utilized it to translate customer emotions and feelings into product attributes.

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Chapter 3

Application of Kansei engineering and Taguchi based Grey relation analysis for shape parameter design: A case study of wine glass

3-1 Introduction

Several studies of the Taguchi design and grey relation analysis (GRA) have been conducted for the optimization of process parameters. For example, Sarıkaya and Gullu [1] conducted Taguchi design and GRA to multi-optimize with multiple responses in turning of alloy Haynes. Sahu and Pal [2] employed Taguchi design and GRA to optimize the process parameters in friction stir welded. Both methods have been employed quite successfully in engineering applications but the application in product design is not widely applied. Few researchers used these methods for the physical appearance of products design. Sutono, et al. [3] applied KE and Taguchi design to determine the optimal design parameters of the office chair. Widiyati and Aoyama [4] studied KE in PET bottle using Taguchi methods and artificial neural network (ANN). Lai, et al. [5] applied the Taguchi design to optimize the car shape design. However, only Yadav, et al. [6] and Chen and Chuang [7] integrated Taguchi design and GRA for product design as described in Chapter 1. The study of this chapter applied KE, Taguchi design and GRA to parameterize design of shape product. A wine glass design was also selected as the previous chapter to illustrate how to apply. This dissertation focuses on continuous design variables into consideration whereas the previous researches focused on discrete design variables. Therefore, it can seek the optimal product shape from continuous design variables.

3-2 Taguchi Design

Taguchi Design is an important statistical technique for designs and analyzes the experiment for improving the product quality [8]. In order to evaluate the process factors, the original data are converted to signal-to-noise (S/N) ratio that is the ratio of the mean (signal) to the standard deviation (noise). The three types of S/N ratio are categories lower-the-better, higher-the-better and the nominal-the-better [9]. Accordingly, this study used the equation that described below:

For ‘‘Higher-the-better’’

$$\frac{S}{N}\,\text{ratio} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_{ij}^{2}}\right) \quad (3\text{-}1)$$

where, n number of replicates

y_{ij} observed response value at i_{th} replicate of j_{th} response

i = 1,2,..,n

j = 1,2,..,k

3-3 Gray relation analysis

According to the Taguchi design, it cannot optimize multi-objective optimization problems. GRA is conducted for the uncertainties in complex models, finding the relationships between variables and responses, and optimizing multi-objective problems [2]. GRA process is carried out in the following four steps.

Step 1. The S/N ratio values are converted to normalization as Z_{ij} (0<Z<1) by Eq. (3-2) in order to avoid the impact of various units and to decrease variability [10]. The experimental results are transformed into the form ''Higher-the-better'', the original experimental results can be normalized as:

For ''Higher-the-better''

$$Z_{ij} = \frac{Y_{ij} - min\left(Y_{ij}, i=1,2,\cdots,n\right)}{max\left(Y_{ij}, i=1,2,\cdots,n\right) - min\left(Y_{ij}, i=1,2,\cdots,n\right)} \quad (3\text{-}2)$$

where,	Z_{ij}	the value after normalization
	min y_{ij}	refers to the minimum value
	max y_{ij}	refers to the maximum value
		at i^{th} replicate of j^{th} response
	i	= 1,2,..,n
	j	= 1,2,..,k

Step 2. The deviation sequence is calculated using Eq.(3-3).

$$\Delta_{ij} = \left|y_0 - y_{ij}\right| \quad (3\text{-}3)$$

Step 3. The Grey relational coefficient is calculated from the deviation sequence using the following equation:

$$GC_{ij} = \frac{\Delta_{min} + \delta\Delta_{max}}{\Delta_{ij} + \delta\Delta_{max}} \quad (3\text{-}4)$$

where,	GC_{ij}	the grey relational coefficient for the i^{th} replicate of j^{th} response
	Y_{oj}	optimum performance value of the j^{th} response
	Δ_{ij}	the deviation sequence

Δ_{min} minimum value of delta

$\Delta_{\max}$ maximum value of delta

δ distinguishing coefficient which is defined in the range $0 \leq \delta \leq 1$,

$\delta = 0.5$ is generally used.

Step 4. After obtaining the results of previous step, the grey relational grade is calculated form the average of the grey relational coefficient using the following equation:

$$G_i = \frac{1}{k} \sum_{j=1}^{k} GC_{ij} \quad (3\text{-}5)$$

where, G_i grey relational grad for the i^{th} replicate

k the number of responses

3-4 Methodology

This study applied KE, Taguchi design and GRA based on model procedure presented by Schütte and Eklund [11]. The procedure of this study is represented as shown in Fig. 3-1. Each block of the research model in Fig. 3-1 will be explained below.

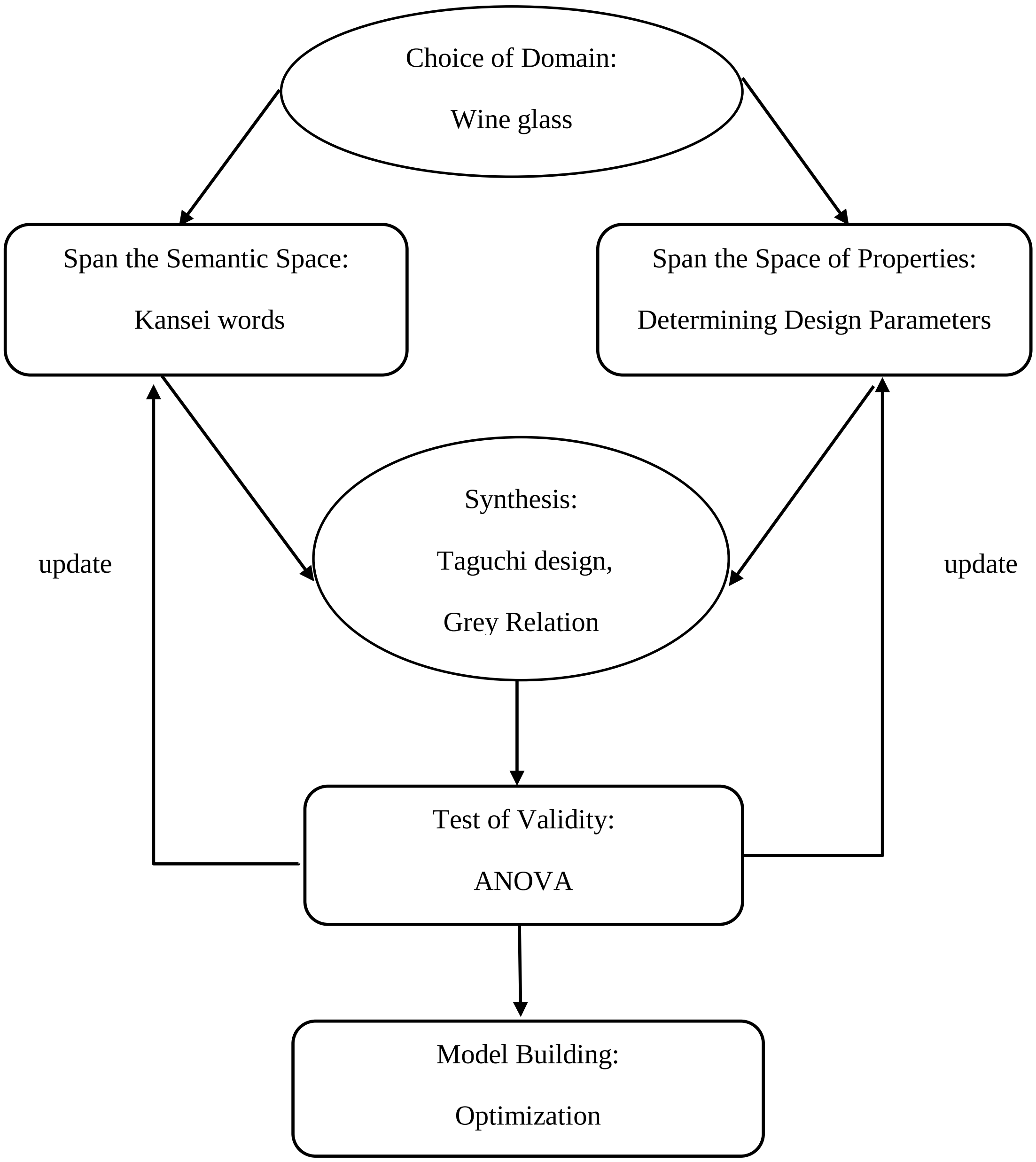

Fig. 3-1 Research methodology of KE and Taguchi base GRA shape parameters design of wine glass. Adapted from [11].

(1) Choice of domain

A wine glass was selected as the product domain. The sample size of the study was 30 participants. The participants were Thai people who have used wine glasses more than one year.

(2) Span the semantic space

Kansei words describe the wine glass selected through various sources such as magazines, internet, brochures, journals, advertisements and interview with experts. After discussions with the professionals and experts in product design from Rajamangala University of Technology Lanna (Thailand), five highly relevant words were finally determined in the form of Kansei words to enhance the customer feelings and emotions, namely, 1) modern, 2) quality, 3) durable, 4) ease of drinking and 5) ease of handing. These Kansei words were represented as the observed responses for Taguchi technique as the output parameters in Fig. 3-2.

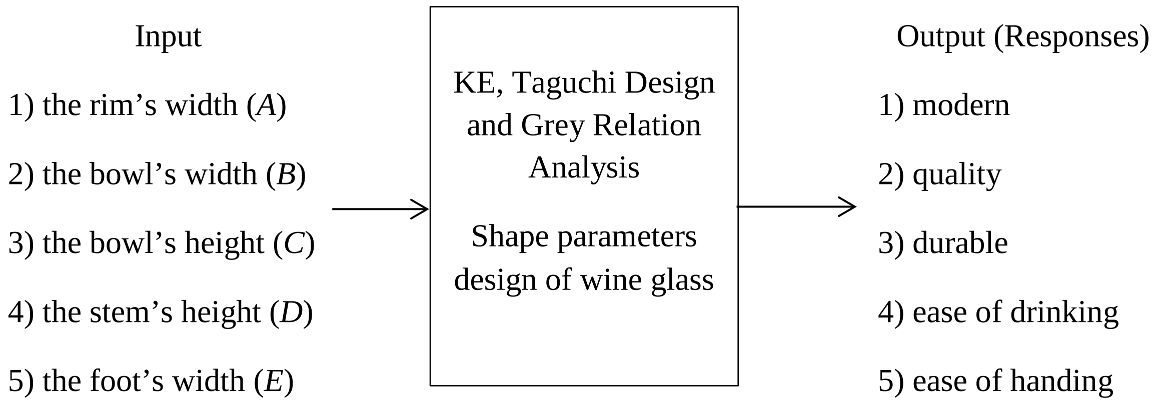

Fig. 3-2 Input-output parameters of KE and Taguchi base GRA shape parameters design of wine glass.

(3) Span the space of properties

The wine glass shape parameters which affect the customer emotions are identified as the input factors in Taguchi experiments as shown in Fig. 3-2. Basically, there are four parts of a wine glass including 1) the foot, 2) the stem, 3) the bowl and 4) the rim as shown in Fig. 2-3. The position of the identified shape features were represented as shown in Fig. 3-3. The stem's width was only kept fixed and excluded from the design parameter settings after the expert reviewed the experiment in Chapter 2. In this study, a five-factor and three-level Taguchi design of experiment was used in conjunction with GRA. Each of the shape design parameters was chosen for three different levels as shown in Table 3-1. Here 1, 2 and 3 represent low, medium and high levels, respectively.

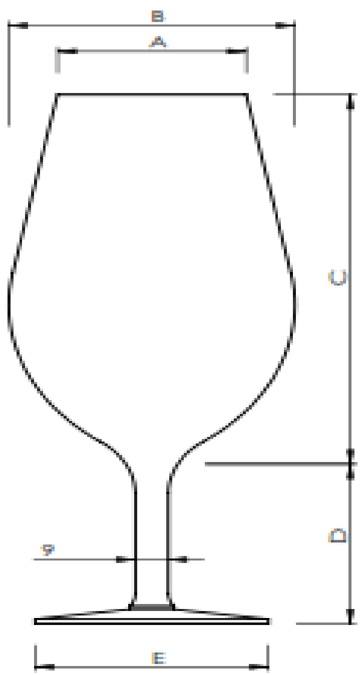

Fig. 3-3 Shape design parameters of the wine glass design

Table 3-1 The shape design parameters and their levels according to Taguchi design.

Shape design parameters	Symbol	Level		
		1	2	3
the rim's width (mm)	*A*	30	75	120
the bowl's width (mm)	*B*	30	75	120
the bowl's height (mm)	*C*	20	100	180
the stem's height (mm)	*D*	25	55	85
the foot's width (mm)	*E*	30	70	110

(4) Synthesis

(a) Experimental design

According to the shape design parameters and levels, Taguchi's L_{27} orthogonal array was employed from a software package Minitab [12] as shown in Table 3-2 for design of experiment. The rows represent the number of experiments whereas the columns represent the shape design parameters with three levels. The shape design models were generated as shown in Fig. 3-4.

(b) Data collection process

The participants were requested to evaluate the 27 experimental runs for five Kansei words evaluation using a five-level Likert scale (from 1 refers definitely disagree to 5 refers definitely agree). A questionnaire was distributed in order to classify the relationship between the shape design parameters and the customer emotions and feelings. These surveys were conducted in Chiang Mai, Thailand.

Table 3-2 Taguchi experimental design.

Run	Actual shape design parameters					Coded factors				
	the rim's width (mm.)	the bowl's width (mm.)	the bowl's height (mm.)	the stem's height (mm.)	the foot's width (mm.)	*A*	*B*	*C*	*D*	*E*
1	30	30	20	25	30	1	1	1	1	1
2	30	30	20	25	70	1	1	1	1	2
3	30	30	20	25	110	1	1	1	1	3
4	30	75	100	55	30	1	2	2	2	1
5	30	75	100	55	70	1	2	2	2	2
6	30	75	100	55	110	1	2	2	2	3
7	30	120	180	85	30	1	3	3	3	1
8	30	120	180	85	70	1	3	3	3	2
9	30	120	180	85	110	1	3	3	3	3
10	75	30	100	85	30	2	1	2	3	1
11	75	30	100	85	70	2	1	2	3	2
12	75	30	100	85	110	2	1	2	3	3
13	75	75	180	25	30	2	2	3	1	1
14	75	75	180	25	70	2	2	3	1	2
15	75	75	180	25	110	2	2	3	1	3
16	75	120	20	55	30	2	3	1	2	1
17	75	120	20	55	70	2	3	1	2	2
18	75	120	20	55	110	2	3	1	2	3
19	120	30	180	55	30	3	1	3	2	1
20	120	30	180	55	70	3	1	3	2	2
21	120	30	180	55	110	3	1	3	2	3
22	120	75	20	85	30	3	2	1	3	1
23	120	75	20	85	70	3	2	1	3	2
24	120	75	20	85	110	3	2	1	3	3
25	120	120	100	25	30	3	3	2	1	1
26	120	120	100	25	70	3	3	2	1	2
27	120	120	100	25	110	3	3	2	1	3

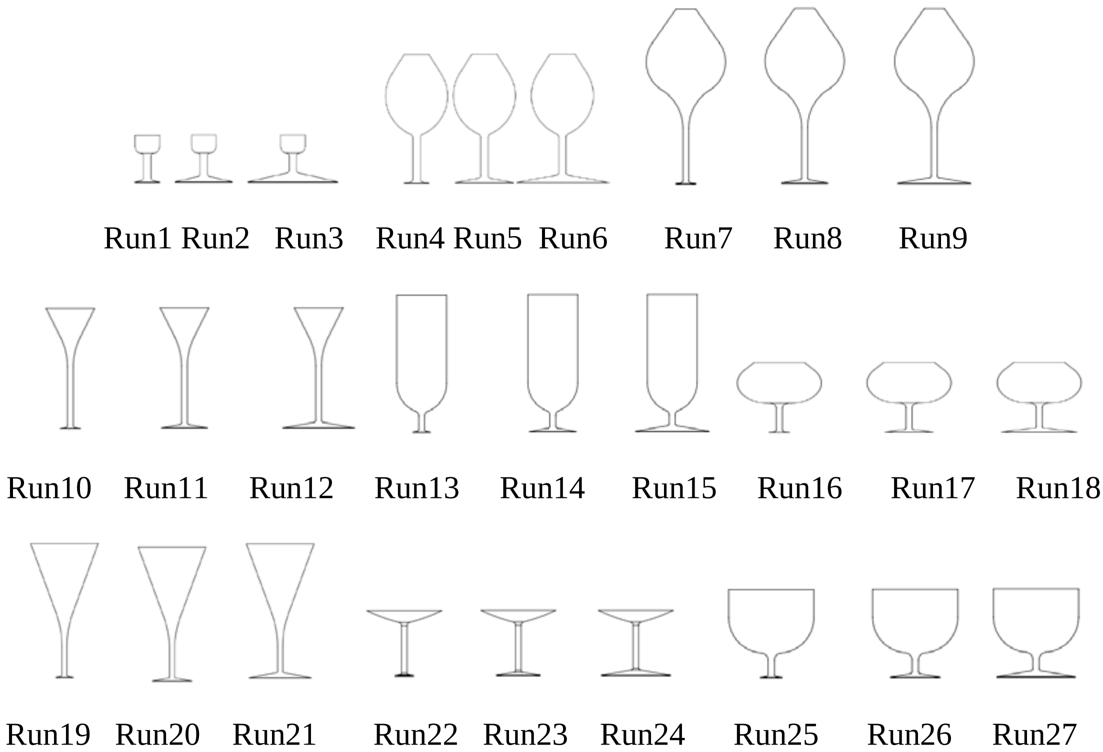

Fig. 3-4 Shape design models of wine glass generated based on Taguchi design.

(5) Test of validity

The analysis of variance (ANOVA) is conducted to check the significant product attributes and the percentage contribution of each product parameter on the responses. The statistical technique that subdivides the total variation of a data set into components with sources of variation for testing hypotheses each of the parameters in model is ANOVA [13].

(6) Model building

With GRA and ANOVA, the optimum shape parameters of the wine glass could be predicted with the multi-objective optimization or the customer emotions and feelings.

3-5 Results and discussion

3-5-1 Taguchi design result

Taguchi design technique was used to evaluate the relationship between the shape parameters and the customer emotions/feelings or Kansei words. The average of the emotional evaluation results were obtained in accordance with orthogonal array and are also shown in Table 3-3. The S/N ratios were calculated for each of the customer emotions/feelings in condition of ‘‘Higher-the-better’’ using Eq. (3-1).

Table 3-3 Experimental response and S/N ratio values.

Run	Modern (mean)	Quality (mean)	Durable (mean)	Ease of drinking (mean)	Ease of handing (mean)	S/N ratio Modern	S/N ratio Quality	S/N ratio Durable	S/N ratio Ease of drinking	S/N ratio Ease of handing
1	2.47	2.77	2.33	2.43	2.50	7.854	8.850	7.347	7.712	7.959
2	2.63	2.47	2.47	2.33	2.63	8.399	7.854	7.854	7.347	8.399
3	2.33	2.33	2.63	2.43	2.57	7.347	7.347	8.399	7.712	8.199
4	2.33	3.53	4.57	4.67	4.53	7.347	10.955	13.198	13.386	13.122
5	3.30	4.23	2.33	3.67	4.30	10.370	12.527	7.347	11.293	12.669
6	3.47	3.73	2.47	3.47	3.73	10.807	11.434	7.854	10.807	11.434
7	2.63	3.20	2.33	3.67	3.47	8.399	10.103	7.347	11.293	10.807
8	3.67	3.93	2.37	3.77	4.23	11.293	11.888	7.495	11.527	12.527
9	2.63	2.47	2.37	2.77	2.63	8.399	7.854	7.495	8.850	8.399
10	3.77	3.43	3.33	3.47	3.47	11.527	10.706	10.449	10.807	10.807
11	3.47	2.53	4.40	2.77	2.77	10.807	8.062	12.869	8.850	8.850
12	2.33	4.26	3.30	3.30	2.47	7.347	12.588	10.370	10.370	7.854
13	3.47	3.33	3.70	3.47	3.93	10.807	10.449	11.364	10.807	11.888
14	4.53	4.33	3.97	3.77	2.63	13.122	12.730	11.976	11.527	8.399
15	3.77	3.63	4.23	3.73	3.47	11.527	11.198	12.527	11.434	10.807
16	2.67	3.23	2.33	2.90	2.50	8.530	10.184	7.347	9.248	7.959
17	3.73	2.63	2.33	3.23	3.23	11.434	8.399	7.347	10.184	10.184
18	4.33	3.67	2.33	3.43	3.67	12.730	11.293	7.347	10.706	11.293
19	2.43	3.43	2.47	2.63	2.67	7.712	10.706	7.854	8.399	8.530
20	4.33	2.33	3.63	2.63	3.57	12.730	7.347	11.198	8.399	11.053
21	3.23	3.47	2.97	3.43	2.33	10.184	10.807	9.455	10.706	7.347
22	2.77	3.33	2.33	2.63	2.33	8.850	10.449	7.347	8.399	7.347
23	2.23	3.43	4.33	4.33	2.33	6.966	10.706	12.730	12.730	7.347
24	2.33	4.67	3.27	3.43	3.67	7.347	13.386	10.291	10.706	11.293
25	2.43	3.43	2.23	3.67	2.43	7.712	10.706	6.966	11.293	7.712
26	3.50	2.47	4.37	2.67	3.77	10.881	7.854	12.810	8.530	11.527
27	3.73	3.43	4.23	3.30	4.23	11.434	10.706	12.527	10.370	12.527

3-5-2 Gray relation analysis result

All the original S/N ratio data were considered as ‘‘Higher-the-better’’ and normalized using Eq. (3-2) and the deviation sequence value was calculated using Eq. (3-3) as shown in Table 3-4.

Table 3-4 The normalized S/N ratio values and the deviation sequence values.

Run	Z_{modern}	Z_{quality}	Z_{durable}	$Z_{\text{ease of drinking}}$	$Z_{\text{ease of handing}}$	Δ_{modern}	Δ_{quality}	Δ_{durable}	$\Delta_{\text{ease of drinking}}$	$\Delta_{\text{ease of handing}}$
1	0.144	0.249	0.061	0.060	0.106	0.856	0.751	0.939	0.940	0.894
2	0.233	0.084	0.142	0.000	0.182	0.767	0.916	0.858	1.000	0.818
3	0.062	0.000	0.230	0.060	0.147	0.938	1.000	0.770	0.940	0.853
4	0.062	0.597	1.000	1.000	1.000	0.938	0.403	0.000	0.000	0.000
5	0.553	0.858	0.061	0.653	0.922	0.447	0.142	0.939	0.347	0.078
6	0.624	0.677	0.142	0.573	0.708	0.376	0.323	0.858	0.427	0.292
7	0.233	0.456	0.061	0.653	0.599	0.767	0.544	0.939	0.347	0.401
8	0.703	0.752	0.085	0.692	0.897	0.297	0.248	0.915	0.308	0.103
9	0.233	0.084	0.085	0.249	0.182	0.767	0.916	0.915	0.751	0.818
10	0.741	0.556	0.559	0.573	0.599	0.259	0.444	0.441	0.427	0.401
11	0.624	0.118	0.947	0.249	0.260	0.376	0.882	0.053	0.751	0.740
12	0.062	0.868	0.546	0.501	0.088	0.938	0.132	0.454	0.499	0.912
13	0.624	0.514	0.706	0.573	0.786	0.376	0.486	0.294	0.427	0.214
14	1.000	0.891	0.804	0.692	0.182	0.000	0.109	0.196	0.308	0.818
15	0.741	0.638	0.892	0.677	0.599	0.259	0.362	0.108	0.323	0.401
16	0.254	0.470	0.061	0.315	0.106	0.746	0.530	0.939	0.685	0.894
17	0.726	0.174	0.061	0.470	0.491	0.274	0.826	0.939	0.530	0.509
18	0.936	0.653	0.061	0.556	0.683	0.064	0.347	0.939	0.444	0.317
19	0.121	0.556	0.142	0.174	0.205	0.879	0.444	0.858	0.826	0.795
20	0.936	0.000	0.679	0.174	0.642	0.064	1.000	0.321	0.826	0.358
21	0.523	0.573	0.399	0.556	0.000	0.477	0.427	0.601	0.444	1.000
22	0.306	0.514	0.061	0.174	0.000	0.694	0.486	0.939	0.826	1.000
23	0.000	0.556	0.925	0.891	0.000	1.000	0.444	0.075	0.109	1.000
24	0.062	1.000	0.533	0.556	0.683	0.938	0.000	0.467	0.444	0.317
25	0.121	0.556	0.000	0.653	0.063	0.879	0.444	1.000	0.347	0.937
26	0.636	0.084	0.938	0.196	0.724	0.364	0.916	0.062	0.804	0.276
27	0.726	0.556	0.892	0.501	0.897	0.274	0.444	0.108	0.499	0.103

Table 3-5 shows the grey relational coefficient that was calculated as using Eq. (3-4). The average of the grey relational coefficient using Eq. (3-5) is also shown in the same table.

Table 3-5 The grey relational coefficient and the grey grade values.

Run	GC_{modern}	GC_{quality}	GC_{durable}	$GC_{\text{ease of drinking}}$	$GC_{\text{ease of handing}}$	G_{i}	Order
1	0.369	0.400	0.347	0.347	0.359	0.364	26
2	0.395	0.353	0.368	0.333	0.379	0.366	25
3	0.348	0.333	0.394	0.347	0.370	0.358	27
4	0.348	0.554	1.000	1.000	1.000	0.780	1
5	0.528	0.778	0.347	0.591	0.864	0.622	5
6	0.571	0.607	0.368	0.539	0.631	0.543	14
7	0.395	0.479	0.347	0.591	0.555	0.473	18
8	0.627	0.668	0.353	0.619	0.829	0.619	6
9	0.395	0.353	0.353	0.400	0.379	0.376	24
10	0.659	0.530	0.531	0.539	0.555	0.563	12
11	0.571	0.362	0.904	0.400	0.403	0.528	15
12	0.348	0.791	0.524	0.500	0.354	0.503	16
13	0.571	0.507	0.629	0.539	0.701	0.589	9
14	1.000	0.821	0.718	0.619	0.379	0.708	2
15	0.659	0.580	0.823	0.607	0.555	0.645	4
16	0.401	0.485	0.347	0.422	0.359	0.403	22
17	0.646	0.377	0.347	0.485	0.496	0.470	19
18	0.887	0.591	0.347	0.530	0.612	0.593	8
19	0.363	0.530	0.368	0.377	0.386	0.405	21
20	0.887	0.333	0.609	0.377	0.583	0.558	13
21	0.512	0.539	0.454	0.530	0.333	0.474	17
22	0.419	0.507	0.347	0.377	0.333	0.397	23
23	0.333	0.530	0.869	0.821	0.333	0.577	10
24	0.348	1.000	0.517	0.530	0.612	0.601	7
25	0.363	0.530	0.333	0.591	0.348	0.433	20
26	0.579	0.353	0.889	0.383	0.644	0.570	11
27	0.646	0.530	0.823	0.500	0.829	0.666	3

Table 3-6 shows the best levels of the shape design parameters by calculating the average of the grey relational grade corresponding to each level of parameters.

Table 3-6 The average of the grey relational grade corresponding to each level of parameters.

Level	*A*	*B*	*C*	*D*	*E*
1	0.500	0.458	0.459	0.522	0.490
2	**0.556**	**0.607**	**0.579**	**0.539**	**0.558**
3	0.520	0.512	0.539	0.515	0.529
Delta	0.056	0.149	0.120	0.024	0.068
Rank	4	1	2	5	3

From Table 3-6, the optimal model of wine glass design that could contains values of customer emotions and feelings were the rim's width (75 mm.) at level 2, the bowl's width (75 mm.) at level 2, the bowl's height (100 mm.) at level 2, the stem's height (55 mm.) at level 2 and the foot's width (70 mm.) at level 2 as shown in Fig.3-5.

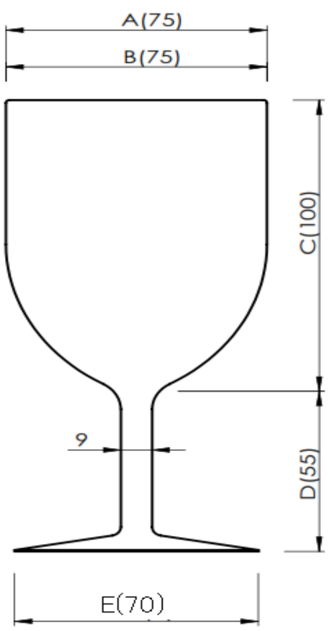

Fig. 3-5 Optimal model of wine glass.

3-5-3 ANOVA for the grey relational grade

ANOVA is conducted to determine which of the shape parameters are significant and influence the customer emotions and feelings, and the percentage contribution of each the shape parameters in the response variable is attributed. The percentage contribution of each shape parameters is shown in Table 3-7. From this table, only the bowl's width (*B*) and the bowl's height (*C*) were significant and influenced the grey relational grade values with 30.50% and 19.80% on the total variability respectively. Therefore, the bowl's width (*B*) was the highest significant parameter affecting the customer emotions and feelings. Remaining the rim's width (*A*), the stem's height (*D*) and the foot's width (*E*) were found insignificant and the contributions were low.

Table 3-7 ANOVA analysis for the grey relational grade.

Shape parameters	Degree of freedom	Sum of squares	Adjust mean of square	*F* ratio	*p*	Contribution (%)
A	2	0.0143	0.0071	0.88	0.434	4.24
B	2	0.1029	0.0515	6.34	0.009	30.50
C	2	0.0668	0.0334	4.11	0.036	19.80
D	2	0.0026	0.0013	0.16	0.853	0.77
E	2	0.0209	0.0104	1.28	0.304	6.19
Error	16	0.1299	0.0081			38.50
Total	26	0.3374				100.00

3-6 Summary

This study represents the application of KE, Taguchi design and GRA for optimization of shape design parameters. KE was used to translate customer feelings and emotions by Kansei words. Taguchi design and GRA were employed to identify the optimal shape parameters which optimize multi-objective customer emotions. A wine glass was selected as the product domain. The experimental results show that the rim's width of 75 mm., the bowl's width of 75 mm., the bowl's height of 100 mm., the stem's height of 55 mm. and the foot's width of 70 mm. provide the optimal results of five emotions including modern, quality, durable, ease of drinking and ease of handing. From the ANOVA results demonstrate that the bowl's width and the bowl's height are the significant shape parameter contributing by 30.50% and 19.80%, respectively. This study has proved the feasibility of KE, Taguchi and GRA for solving multi-customer feelings in product design and development.

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Chapter 4

Application of Kansei engineering to tactile sense in the Thai food wrapping materials

4-1 Introduction

Because of the signification of the KE using tactile sense in material selection as described in Chapter 1, this chapter puts forward the method of material selection of food wrapping, investigates the customer's sensory feelings by touch. In addition, it is the first time to apply this method to a product with the features of food wrapping. According to Waste Management Act cited in Schou, et al. [1], the term packaging means ‘‘any material, container or wrapping used for or in connection with the containment, transport, handling, protection, promotion, marketing or sale of any product or substance’’.

4-2 Semantic Differential

The most widespread used measurement method for user centered design techniques which can analyze the customer emotions and feelings is Semantic Differential (SD) [2]. SD has been conducted in KE to analyze the relationships between customer feelings and products in product design such as perfume bottle [3], wheel hub and car [4] and beverage bottle [5]. The reasons of the popular use of SD in the research might be: 1) easy-to-use and low-cost, 2) high confidentiality and validity and 3) capability method to assess human thinking psychology such as emotions and feelings

[6]. It determines human interactions between stimulus words and product by rating stimulus words on bipolar scales that each of end scale is contrasting adjective [6]. In order to study product semantics, the customer perception of product images with styles, color and other attributes is quantified on a Likert scale [7].

4-3 Methodology

According to Nagamachi [8], the process to translate human emotions to design attributes is summarized as follows: ‘‘1) select the design object, 2) collect adjectives to represent emotions about the object, 3) understand meanings of the adjectives, 4) prepare samples of the object, 5) evaluate emotions for the samples, 6) analyze them statistically and 7) build an expert system’’. Figure 4-1 shows our procedures that applied from his process. Firstly, the food wrapping samples in this experiment were selected as well as the definition of the product samples and Kansei words for the SD evaluation. Then, in the assessment step we used questionnaire which the main point is to evaluate all of the semantic attributes. Each of Kansei words was evaluated with a 7-level Likert scale, from +3 level to -3 level, where the respondents checked a mark in the level scale according to how they feel the word effect to the sample. For example, in the case of ‘‘Rough – Smooth’’, the respondents would check mark in +3 for extreme agreement, which means the sample was the most smooth, in +2 for strong agreement, in +1 for moderate agreement and in 0 for equal agreement. In contrast, to -3 for extreme agreement that the sample was the most rough. During the tactile evaluation, the respondents’ vision was blocked by a blindfold and could touch the samples as much as they wanted (Fig. 4-2). The procedures were explained to all participants in detail about how to fill in the questionnaire and meaning of Kansei words. All the stimuli materials were prepared in box and randomly presented to the respondents. Therefore, the respondents do not see and know them. Finally, Principal Component Analysis (PCA) was conducted to identify the relative correlations between the Kansei word variables and product samples.

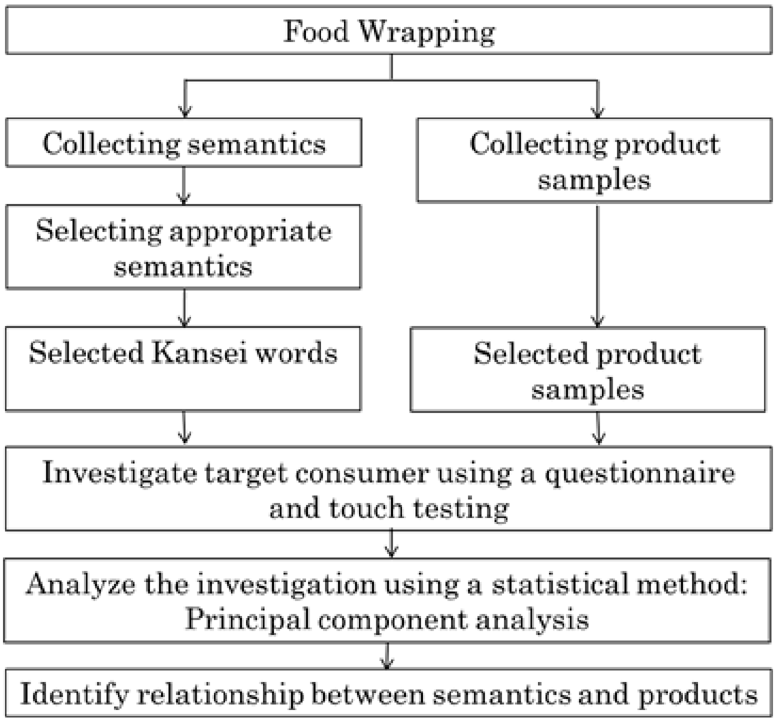

Fig. 4-1 Research methodology of tactile sense test. Adapted from [8].

Fig. 4-2 Test situation during the tactile study.

4-4 Results and discussion

4-4-1 Collected and selected Kansei words

After food wrapping was chosen as the object, adjectives whose meaning and information relate to the food wrapping products were collected from various sources such as literature review, advertisements, brochures, journals, interview with experts and product reviews [9]. The total number of adjective words collected was 93. Three professional members from Rajamangala University of Technology Lanna (RMUTL) in Thailand were selected as the expert team in this experiment. After brainstorming and discussion by the expert team, 6 pairs of words highly relevant were finally determined in the form of SD Kansei words to enhance the subjects' feelings, namely: 1) dislike – like, 2) rough – smooth, 3) stable – flexible, 4) tight – wrinkled, 5) fine - fiber and 6) refined - natural.

4-4-2 Selected product samples

Fuji apples were used as the food for wrapping in this experiment because they have strong surface and do not change the shape when the participants touch them in the experiment. After collecting product samples, the expert team selected 9 types of food wrapping samples which are usually used in Thailand, namely: plastic bag, aluminum foil, plastic film, paper, plastic foam, banana leaf, wax paper, plastic net and plastic air bubble as shown in Fig. 4-3.

Fig. 4-3 Food wrapping samples.

Top row from left: banana leaf, wax paper, plastic net and plastic air bubble.

Bottom row from the left: plastic bag, aluminum foil, plastic film, paper and plastic foam.

4-4-3 Investigation and evaluation

36 participants took part in the experiment. The participants were randomly recruited at RMUTL. Their ages ranged between 18 and 30 years, and 16 participants were male. Fig. 4-4 shows the results of the evaluation which are the average values of the food wrapping samples for all the semantics. For the overall average mean, the participants agree that the highest favorite food wrapping is plastic foam whereas the lowest favorite food wrapping is paper. Moreover, the plastic foam is the most flexible while the aluminum foil is the most stable. Only food wrapping made from natural in this study is banana leaf and it has the highest score in ‘‘Natural’’ and the second highest in ‘‘Like’’, ‘‘Smooth’’ and ‘‘Wrinkled’’. Another interest result is the plastic net which is the highest in both wrinkled and fiber. Tukey’s significance tests for check to confirm the significant differences were used.

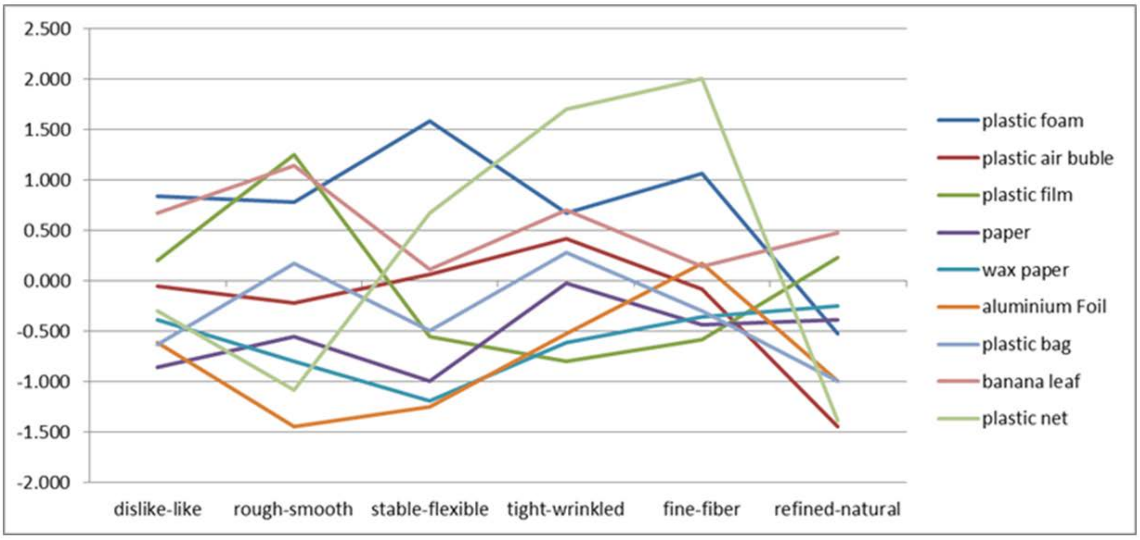

Fig. 4-4 The mean of Kansei words.

The results present that there were significant difference (*p* > 0.05) in all Kansei words. Pearson's correlations between Kansei words are shown in Table 4-1. Values in bold were different from 0 with 95% of the confidence level. Three correlations were greater than |0.4|: smooth - like, wrinkled - flexible and fiber - wrinkled. All most value close to zero that means the two variables are no relationship. Therefore, these Kansei words are not strong correlation relationships.

Table 4-1 Correlations.

Variables	like	smooth	flexible	wrinkled	fiber	natural
like	**1**	**0.4928**	**0.2720**	**0.2058**	**0.1676**	**0.3501**
smooth	**0.4928**	**1**	**0.2948**	0.0959	-0.0443	**0.3398**
flexible	**0.2720**	**0.2948**	**1**	**0.4947**	**0.3987**	0.0850
wrinkled	**0.2058**	0.0959	**0.4947**	**1**	**0.4575**	0.0958
fiber	**0.1676**	-0.0443	**0.3987**	**0.4575**	**1**	0.0241
natural	**0.3501**	**0.3398**	0.0850	0.0958	0.0241	**1**

4-4-4 Identify relationship between semantics and products

Principal Component Analysis (PCA) has used the covariance matrix instead of the correlation matrix. This statistical method was conducted to reveal the dimensionality and the interpretation of sample products [10]. From PCA, the food wrapping Kansei dimensions were divided into 2 factors which could explain 88.19 % of the total variance. The factor loadings and the percentage of communalities are shown in Table 4-2. The factor loadings that exceeding more than |0.4| were bolded. The first dimension has a contribution of 48.66% and the second dimension has a contribution of 39.54%. Meanwhile, the rest of the factors are insignificant.

Table 4-2 The factor loadings.

Kansei words	F1	F2
dislike-like	0.3933	**0.4382**
rough-smooth	0.1740	**0.5836**
stable-flexible	**0.5676**	0.0696
tight-wrinkled	**0.4990**	-0.2302
fine-fiber	**0.4833**	-0.2907
refined-natural	-0.1018	**0.5701**
Eigenvalue	2.9195	2.3721
Variability (%)	48.6580	39.5357
Cumulative %	48.6580	88.1937

Figure 4-5 represents Kansei words vectors which reveal direction and strength. In this figure, the sample positions are shown as dots and explain the relation between Kansei words and products. The attributes (we used only positive Kansei words) positively correlated with dimension 1 were ‘‘Flexible’’, ‘‘Wrinkled’’ and ‘‘Fiber’’. The attributes most related to dimension 2 were ‘‘Like’’, “Smooth” and ‘‘Natural’’. The plastic foam and banana leaf were most preferred with “Like’’. Negatively correlated with this Kansei words were aluminum foil, paper and wax paper that are shown in ‘‘Rough’’, ‘‘Stable’’, ‘‘Refined’’ and ‘‘Fine’’. Similarly, the banana leaf was represented as ‘‘Smooth’’ and the plastic film was illustrated as ‘‘Natural’’, whereas plastic net and aluminum foil had negative scores on the same factor. The plastic foam was mapped as ‘‘Flexible’’. The plastic bag and plastic air bubble were unclear to identify because they were near the origin. These results will be the significant decision of selecting the food wrapping to achieve the customer’s emotion.

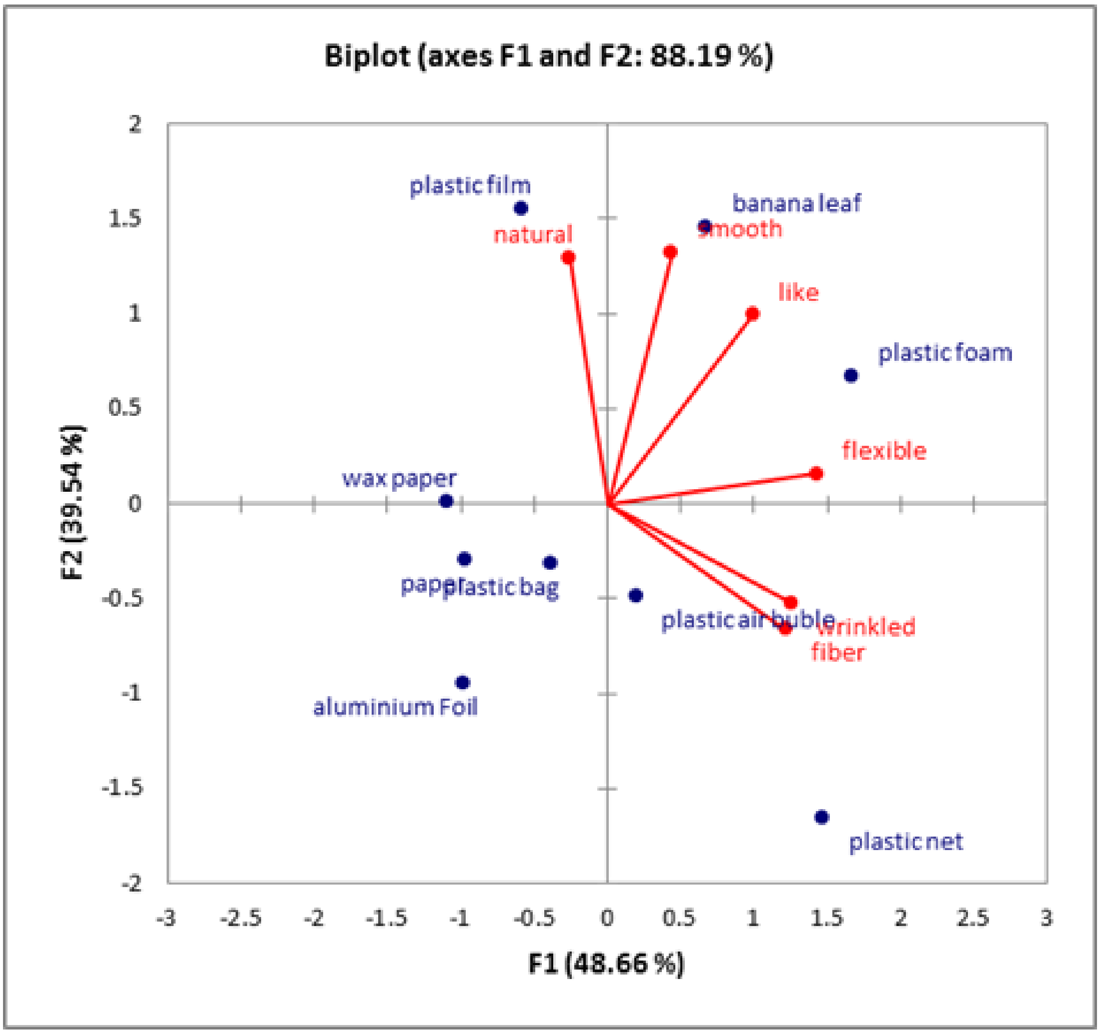

Fig. 4-5 Position of 9 the food wrapping relate to 6 Kansei words.

4-4-5 Discussion

The objective of this research was to represent the results from a tactile experiment of the food wrapping samples using KE. The proposed method provides support product designers to understand the desirable attributes of food wrapping products affected by the customer emotion using tactile sense. From the overall means, the highest favorite food wrapping is plastic foam which is usually used in Thai's supermarket. In our view, this wrapping is very soft and we feel familiar with fruits wrapped by plastic foam more than the other wrapping such as plastic air bubble or paper, which are used for rigid material such as mobile phone.

On the other hand, paper was the most disliked sample. The reason is that paper is thin layer material and we feel hard when we touch fruits covered by paper. In Thailand, we use the paper to cover fruits when we want to make fruits ripe for fertility but we do not use it into packaging. According to PCA, the plastic net and aluminum foil were evaluated to be refined and rough but the banana leaf and the plastic film were smooth and natural. Similar results were proposed by Childs, et al. [11] as they presented that glass, plastic and aluminum foil were considered as ‘‘Not genuine’’ while grapefruit skin film, leaf and cork were considered to ‘‘Genuine’’. The plastic foam was the optimum food material to wrap fruits from this study.

4-5 Summary

This research illustrated the tactile attributes of the food wrapping and interpreted semantically by applied KE in Thailand. The food wrapping samples included plastic bag, aluminum foil, plastic film, paper, plastic foam net, banana leaf, wax paper, plastic net and plastic air bubble. Only one sample that made from nature was banana leaf. The 36 participants evaluated the samples by the 6 SD Kansei words as dislike - like, rough -

smooth, stable - flexible, tight - wrinkled, fine - fiber and refined - natural. The evaluation based only on tactile sense meanwhile vision sense was blocked. PCA determined two main dimensions of perceived attributes and impressions. The banana leaf was perceived as particularly smooth, while plastic net and aluminum foil perceived as roughness. The plastic foam was the most favorite wrapping that customer like by tactile senses and was interpreted to be flexible, winkled and fiber. The study also reveals key concepts and process to obtain the affective product attributes through customer sensations for product design and development.

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Chapter 5

Application of Affective engineering and Fuzzy analytical hierarchy process in Thai ceramic manufacturing

5-1 Introduction

Multi-criteria decision-making (MCDM) is one of techniques for decision making in formal problems with multiple targets [1]. MCDM can help designers design the physical features of products that extracting the customer emotions and feelings. MCDM techniques have been widely used in many kinds of research. One of these popular techniques has been applied in many researches is Fuzzy Analytic Hierarchy Process (FAHP). This study advances our understating of the customer emotions and feelings related to appearance of physical ceramic design in Thai manufacturing by Affective engineering or Kansei engineering. Moreover, FAHP was conducted to rank the importance of product attributes. In addition, it is the first time to apply these methods to a product with the features of ceramics in Thailand.

5-2 Fuzzy Analytic Hierarchy Process (FAHP)

Analytic Hierarchy Process (AHP) was firstly introduced by Saaty [2]. This technique is a simple method to solve complex decision problems. The pairwise comparisons using a nine-point scale are conducted for evaluate each of level with regarding the alternative criteria. The principal benefit of AHP is its native ability to handle intangibles, which are outstanding in any decision making process. Buckley [3] applied the fuzzy theory into AHP and called it Fuzzy Analytic Hierarchy Process (FAHP). In the real life situations, human beings make decisions under uncertain environments. The vague of human beings is assessed using Fuzzy [4].

The seven steps of FAHP are listed in the following.

Step 1: Identify the complex decision problem and declare clearly the objectives.

Step 2: Analyze the complex decision problem and construct a hierarchical structure with evaluation elements (criteria, detailed criteria, and alternatives). Define the objectives at the top level of the hierarchical structure and set decision criteria at the second level [5]. The lowest level is alternative that approaching the objectives at the bottom.

Step 3: Create a fuzzy pairwise comparison matrix. Table 5-1 is the assessment and meaning of FAHP and shows the fuzzy number scale and membership functions of linguistic scales that were conducted in this experiment. Triangular fuzzy number is used to the best represent pairwise comparisons of evaluation process in order to capture the fuzziness.

Table 5-1 Triangular fuzzy number and meaning. [4]

Fuzzy number	Linguistic scales	TFN	Inverse TFN
$\tilde{1}$	Equally important	(1,1, 3)	(1/3, 1, 1)
$\tilde{3}$	Weakly important	(1,3, 5)	(1/5, 1/3, 1)
$\tilde{5}$	Essentially important	(3,5, 7)	(1/7,1/5,1/3)
$\tilde{7}$	Very strongly important	(5,7, 9)	(1/9, 1/7, 1/5)
$\tilde{9}$	Absolutely important	(7,9, 9)	(1/9, 1/9, 1/7)
$\tilde{2}$ $\tilde{4}$ $\tilde{6}$ $\tilde{8}$	Intermediate value between two adjacent judgments		

Step 4: Calculate the fuzzy geometric mean. The geometric mean of the fuzzy pairwise comparison is calculated using the geometric technique.

Step 5: Calculate the fuzzy weights by normalization.

Step 6: Check the consistency of the pairwise comparison to guarantee that the pairwise comparisons are consistent. The purpose of the Consistency Index (CI) is to measure the overall consistency for the hierarchy structure model and for each decision element. Furthermore, the Consistency Ratio (CR) is also calculated to explain the consistency of the pairwise comparisons. To decide the consistency of the pairwise outputs, if $CR \leq 0.1$, then the pairwise comparison is sufficiently consistent. In contrast, if $CR > 0.1$, then the pairwise comparison is inconsistent [2].

Step 7: Calculation of the priority weights for each alternative by considering the individual weights of all the relevant sub-criteria.

5-3 Methodology

According to Affective engineering, the ceramic products were identified from both of a semantic perspective and a product perspective. Each perspective spans its space as described in this section. Subsequently, the interaction between these two perspectives is analyzed in order to identify which Kansei words impact to product properties. We divided the overall appearance of mugs into six evaluation items, then the data are obtained by questionnaire, computed the overall prioritization weights for each alternatives by FAHP. Therefore, the results from these methods were compared and discussed.

5-4 Results and discussion

5-4-1 Results of Affective engineering

This research used Category Classification which makes clear the relationships between customer's perception in term of Kansei words and the physical product attributes. The study can be divided into 4 steps and will be explained below.

(1) Selection of Kansei words

In the initial collection from various sources including magazines and relevant advertisements, a total of around 170 different words were extracted. Some of the initial words that are unclear or have the same meaning were omitted. Finally, three professional members from Rajamangala University of Technology Lanna (RMUTL) in Thailand were selected to compose an expert team. After brainstorming and discussion by the expert team, 6 main groups of words were chosen: Attractive, Easy to drink, Easy to handle, Quality, Modern and Durable.

(2) Important properties and sample products

The input of Affective engineering is the physical product attribute, whereas the output is the response of consumer emotions and feelings. We conducted an interview with 3 ceramic manufacturing experts from RMUTL to obtain the relevant product properties of mug appearance. In the same way as the deduction of Kansei words, the product properties of mug design can be deconstructed as 6 important characteristics (items) namely, body, handle, foot, lip, color and pattern. Finally, 6 important items with 24 important categories were identified as shown in Table 5-2.

Table 5-2 Product properties identified.

Body	Handle	Foot	Lip	Color	Pattern
Cylinder	Loop	Non Foot	Non Lip	Pale Color	Non Pattern
Inward Curve	Square	Foot	Lip	Bright Color	Cartoon
Barrel	Geometric	Slot Foot		Dark Color	Image
Cone	Number 7				Alphabet
Curved Cone	Number 3				
Short					
Square					

Accordingly, the expert team who has experiences in ceramic manufacturing initial collected 30 mug sample images. After brainstorming, only final selected 10 mug sample images for assessing in questionnaires are shown in Fig. 5-1.

Fig. 5-1 Mug samples selected for evaluation.

Top row from left: Mug 1 to Mug 5.

Bottom row from left: Mug 6 to Mug 10.

(3) Investigation and evaluation

Firstly, the questionnaire is to constructed by using the 5-score Likert scale while ‘‘5’’ refers to the highest score (definitely agree), ‘‘4’’ refers to agree, ‘‘3’’ means fair, ‘‘2’’ means disagree and ‘‘1’’ means definitely disagree. The sample size of 37 people, who study in RMUTL and aged between 18-30 years old, is set to be the target group. Finally, a brief introduction about how to fill in the questionnaire and the definition of Kansei words were described to participants. The product sample images were ordered randomly.

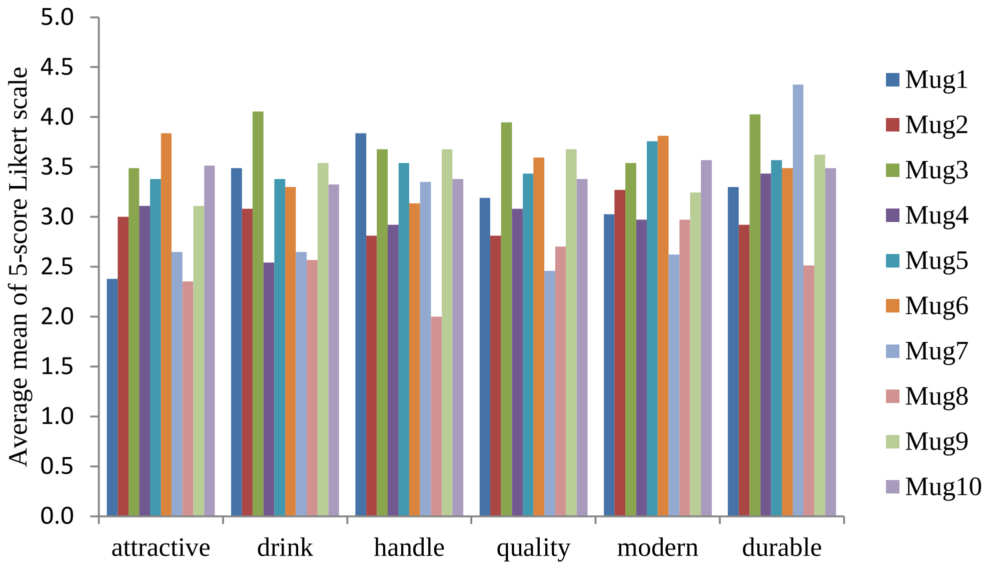


Fig. 5-2 The mean values of samples considering Kansei words.

Figure 5-2 shows results of the mean values corresponding to Kansei words. For example, Mug 6 receives a higher Kansei value of “Attractive” than the others. This mug has inward curve body, loop handle, non- foot, bright color and cartoon pattern. For Kansei value of “Easy to drink” the highest is Mug 3 that has both square body and handle, non- foot, lip bright color and alphabet pattern.

Table 5-3 represents to summarize the most preferred product in perception of customers regarding the mean values from Fig. 5-2. Consequently, Mug 3 was the highest preferred products in this evaluation and Mug 8 was the lowest preferred products.

Table 5-3 The highest and lowest preferred products.

Kansei words	Mean	Best scores
Attractive	3.486	Mug 3
Easy to drink	4.054	
Easy to handle	3.676	
Quality	3.946	
Modern	3.541	
Durable	4.027	
Kansei words	**Mean**	**Worst scores**
Attractive	2.351	Mug 8
Easy to drink	2.568	
Easy to handle	2.000	
Quality	2.703	
Modern	2.973	
Durable	2.514	

(4) Analysis by Quantification Theory Type1 (QT1)

QT1 is a technique of multiple regression analysis for deducing a quantitative variable (a dependent variable) from some qualitative variables (independent variables) [6]. The results of linear regression are presented by the multiple correlation coefficient (MCC) and square multiple correlation coefficient (MCC^2) of each Kansei word. According to Schütte and Eklund [7], this study accepts MCC^2 value greater than 0.5 to be satisfactory for evaluation. Another important value is the partial correlations coefficient (PCC) that represents the relation of significant item. Similarly, the category score (CS) also represents the significant product category. QTT1 results are shown in Table 5-4.

The results of regression analysis for Kansei words can be written in equations as follows:

$$\text{Attractive} = 2.425+1.064(\text{Barrel})+0.818(\text{Loop})-0.390(\text{Foot})-1.354(\text{Lip})+0.327(\text{Bright Color})-0.151(\text{Dark Color})+0.440(\text{Non Pattern}) \quad (5\text{-}1)$$

$$\text{Easy to drink} = 2.958 - 0.085(\text{Square Body}) +0.982(\text{Square Handle})-0.352(\text{Non Foot})+0.87(\text{Lip})+1.169(\text{Bright Color})+1.169(\text{Alphabet}) \quad (5\text{-}2)$$

$$\text{Easy to handle} = 2.944+0.639(\text{Cylinder})+1.028(\text{Loop})-0.944(\text{Non Foot})+0.055(\text{Non Lip})-1.263(\text{Pale Color}) \quad (5\text{-}3)$$

$$\text{Quality} = 2.586+1.685(\text{Square Body})+0.223(\text{Square Handle})+0.483(\text{Non Foot})+0.504(\text{Lip})+0.021(\text{Bright Color})+1.081(\text{Dark Color})-0.777(\text{Alphabet}) \quad (5\text{-}4)$$

Modern = 2.713+0.344(Inward Curve)+0.314(Loop)-

0.344(Non Foot)-0.713(Non Lip)+0.688(Bright Color)+

1.597(Cartoon) (5-5)

Durable = 3.254+1.034(Short)+0.508(Loop)+0.254(Foot)-

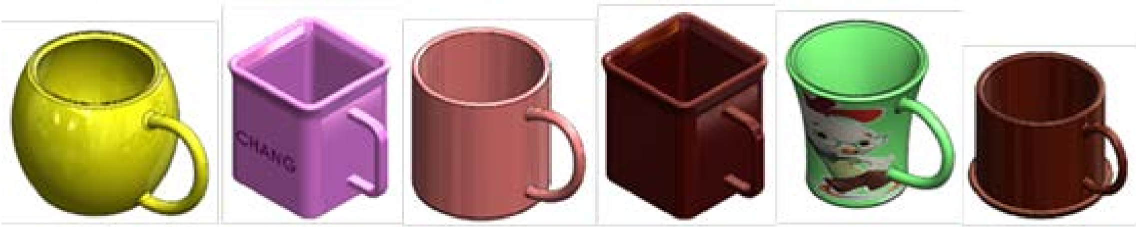
0.254(Non Lip)-0.289(Dark Color)-

0.526(Non Pattern) (5-6)

Table 5-4 QT1 results.

Attractive(mcc = 0.73 mcc^2 = 0.54)	PCC	Product properties	CS
body	0.856	Barrel	1.065
handle	0.955	Loop	0.819
foot	-0.601	Foot	-0.390
lip	-1.008	lip	-1.355
color	-0.258	Bright Color	0.328
		Dark Color	-0.152
pattern	0.153	Non Pattern	0.440
Easy to drink (mcc = 0.76 mcc^2 = 0.58)	PCC	Product properties	CS
body	-0.085	Square Body	-0.085
handle	0.982	Square Handle	0.982
foot	-0.352	Non Foot	-0.352
lip	0.872	lip	0.872
color	1.169	Bright Color	1.169
pattern	1.169	Alphabet	1.169
Easy to handle (mcc = 0.72 mcc^2 = 0.52)	PCC	Product properties	CS
body	0.640	Cylinder	0.640
handle	1.029	Loop	1.029
foot	-0.944	Non Foot	-0.944
lip	0.056	Non Lip	0.056
color	-1.264	Pale Color	-1.264
Quality (mcc = 0.74 mcc^2 = 0.55)	PCC	Product properties	CS
body	1.673	Square Body	1.686
handle	0.102	Square Handle	0.223
foot	0.204	Non Foot	0.483
lip	0.650	Lip	0.505
color	0.446	Bright Color	0.021
		Dark Color	1.082
pattern	-0.322	Alphabet	-0.777
Modern (mcc = 0.72 mcc^2 = 0.51)	PCC	Product properties	CS
body	0.345	Inward Curve	0.345
handle	0.315	Loop	0.315
foot	-0.345	Non Foot	-0.345
lip	-0.714	Non Lip	-0.714
color	0.688	Bright Color	0.688
pattern	1.598	Cartoon	1.598
durable (mcc = 0.77 mcc^2 = 0.59)	PCC	Product properties	CS
body	1.035	Short	1.035
handle	0.508	Loop	0.508
foot	0.254	Foot	0.254
lip	-0.254	Non Lip	-0.254
color	-0.289	Dark Color	-0.289
pattern	-0.526	Non Pattern	-0.526

Table 5-4 presents the values of partial correlation coefficient (PCC) and category score (CS). PCC is computed the relative importance of a concept for a certain emotion/feeling while CS shows the property affects to emotion and feeling. For instance, results of Kansei word of “Attractive”, PCC value of the handle is 0.955 which means this property item is the most important attribute that customers have attractive feeling. The body is the second important. The CS values indicate that the barrel body, the loop handle, non-lip, and non-pattern are considered to be the most attractive. As does the attractive feeling, the CS values of “Easy to drink” indicate that the square handle, lip, bright color and alphabet pattern give the subjective impression of this feeling. Examples of mug design that extracting the customer emotion and feeling are shown in the Fig. 5-3.



(a) (b) (c) (d) (e) (f)

Fig. 5-3 Proposed mugs that based on Affective Engineering.

(a) attractive (b) easy to drink (c) easy to handle (d) quality (e) modern (f) durable

5-4-2 Results of Fuzzy Analytic Hierarchy Process

In the ceramic industry, product characteristics or requirements are measured regarding the product properties such as feature, color, pattern and packaging. The important product properties are classified into ‘‘must-be’’ attributes. The proposed FAHP methodology provides a framework for order attributes. This methodology can be divided into 5 steps as described in the following paragraphs.

(1) Selected product properties as evaluation items

Similarly, the product items and categories from the span product properties in Affective engineering were used in this step. The evaluation items of mugs were divided to different visual into major evaluation items, namely: body, handle, foot, lip, color and pattern.

(2) Establish evaluation items as Hierarchical structure

The objective of the hierarchical structure is to determine the favorite appearance of mugs as the top level structure. On the second level, the decision criteria of product items (W_i) were setting as the major evaluation criteria such as body, handle and foot. At the next lower level, we consider 24 attributes for sub-criteria which are represented as W_{ij} that significantly influence the identified criteria. On the bottom level, 4 alternative mug design ideas were constructed which approaching the objectives as shown in Fig. 5-4.

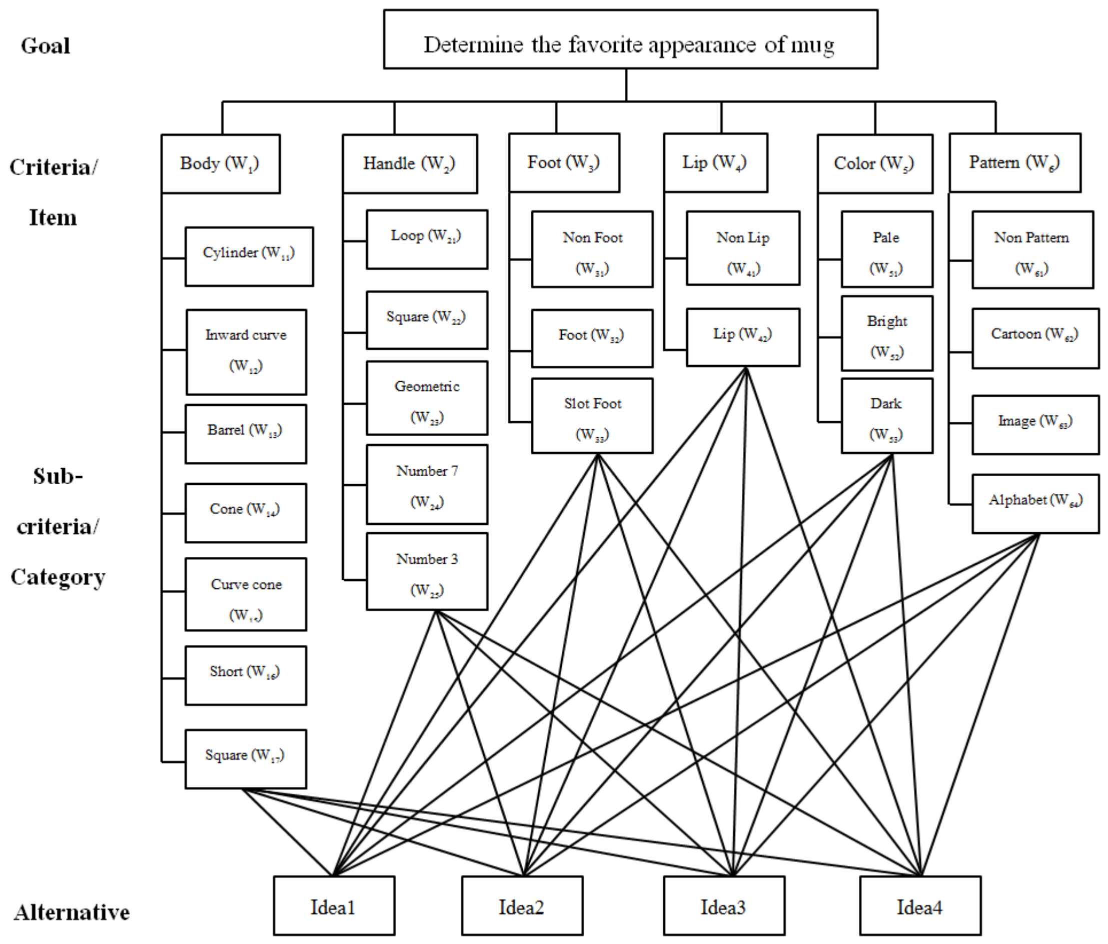


Fig. 5-4 Analytic hierarchy structure for mug element.

(3) Create a fuzzy pairwise comparison matrix

Pairwise comparison questionnaire was designed based on the analytic hierarchy structure. The product items and categories were drawn with a grayscale diagram in order to avoid the effects of color in this questionnaire. Next, the mug element diagram was constructed as shown in Fig. 5-5.

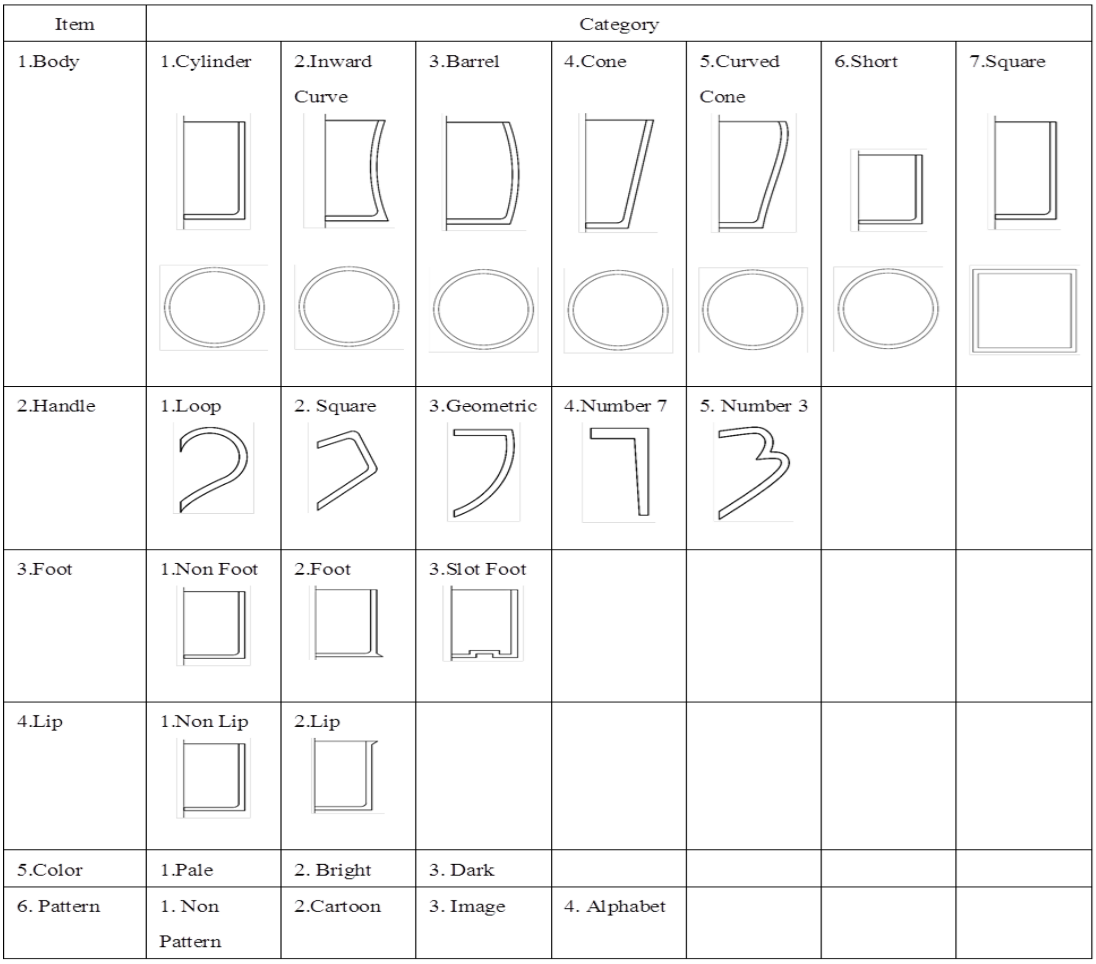


Fig. 5-5 The mug element diagram.

(4) Constructing the weight of evaluation criteria and check the consistency

37 participants from RMUTL students and expert team took part in this experiment. Table 5-5 represents the weight of each product items and also shows the geometric mean. From Table 5-5, the importance of the evaluation items is represented as Body>Handle>Color>Pattern>Lip>Foot.

If consumers want to purchase a mug, they first consider body shape (the highest weight of 0.363) more than the others. Secondly, the handle indicated by a weight of 0.175. Next, the feature of color, pattern and lip whose weights are 0.095, 0.107 and

0.152 respectively. The appearance of foot is the last item to be considered. The lowest weight is 0.095 among all of the evaluation items.

Table 5-5 A pairwise comparison matrix.

	Body	Handle	Foot	Lip	Color	Pattern	Geometric Mean	Item Weight
Body	1	3.387	5.169	3.519	2.331	2.070	2.180	0.363
Handle	0.295	1	4.224	2.108	1.008	1.010	1.051	0.175
Foot	0.193	0.237	1	1.209	1.016	1.034	0.570	0.095
Lip	0.284	0.474	0.827	1	1.171	1.166	0.640	0.107
Color	0.429	0.992	0.985	0.854	1	2.731	0.912	0.152
Pattern	0.483	0.990	0.967	0.857	0.366	1	0.647	0.108

Similarly, Table 5-6 illustrates the weight of sub-criteria or category after the fuzzy statistical analysis. It represents the priority for favorite characteristics of each category as follows.

Body: Cylinder > Inward Curve > Barrel > Cone > Curve Cone > Square > Short

Handle: Loop > Square > Geometric > Number 7 > Number 3

Foot: Non-foot > Foot > Slot-foot

Lip: Non-lip > Lip

Color: Pale color > Bright color > Dark color

Pattern: Non-pattern > Cartoon pattern > Image pattern > Alphabet pattern

Table 5-6 The weight of category.

	Category 1	Category 2	Category 3	Category 4	Category 5	Category 6	Category 7
Body	0.293	0.184	0.148	0.143	0.122	0.052	0.058
Handle	0.427	0.227	0.172	0.103	0.070		
Foot	0.625	0.224	0.152				
Lip	0.793	0.207					
Color	0.551	0.313	0.136				
Pattern	0.417	0.282	0.174	0.127			

Consequently, we computed the values of the Consistency Index (CI) and Consistency Ratio (CR) to check the consistency of the pairwise comparison matrices. CR values in this study have been found to be less than 0.1. Table 5-7 illustrates the largest eigenvalue (λ_{max}), CI and CR validating the pairwise comparison.

Table 5-7 The largest eigenvalue (λ_{max}), Consistency Index (CI) and Consistency Ratio (CR).

	Item level	Body category level	Handle category level	Foot category level	Lip category level	Color category level	Pattern category level
λ_{max}	1.084	1.122	1.103	1.048	1.000	1.040	1.079
CI	0.091	0.124	0.101	0.052	0.000	0.048	0.089
CR	0.073	0.094	0.091	0.089	0.000	0.083	0.099

(5) Establish evaluation model

In order to establish evaluation model, we chose the top two categories with the highest weight of the pairwise comparison matrices and two categories with the lowest weight of the pairwise comparison matrices to establish four mug design alternatives.

Idea 1: Assembled from category weight of the highest values. Hence this idea is composite from cylinder body, loop handle, non-foot, non-lip, pale color and non-pattern.

Idea 2: Assembled from category weight of the second highest values. Because there are only two categories of the lip item, so we selected the highest values in this category in this idea. Hence this idea is composite from inward curve body, square handle, foot, non-lip, bright color and cartoon pattern.

Idea 3: Assembled from category weight of the lowest values. Hence this idea is composite from short body, number 3 handle, slot-foot, lip, dark color and alphabet pattern.

Idea 4: Assembled from category weight of the second lowest values. Because there are only two categories of the lip item, so we selected the lowest values in this category in this idea. Hence this idea is square body, number 7 handle, foot, lip, bright color and image pattern.

The resulting appearances of these ideas are shown in Fig. 5-6. We calculated the overall prioritization weights for each alternative by considering the item weights and the category weight. The most favorite mug designs can be order as Mug idea 1, Mug idea 2, Mug idea 4 and Mug idea 3, respectively, as shown in Table 5-8.

Fig. 5-6 The appearances of ideas. From left: Mug idea1 to Mug idea 4.

Table 5-8 The overall prioritization weights of ideas.

Item	Item weight (w_i)	Idea1		Idea2		Idea3		Idea4	
		Category weight (w_{ij})	Importance weight (w_i) x (w_{ij})	Category weight (w_{ij})	Importance weight (w_i) x (w_{ij})	Category weight (w_{ij})	Importance weight (w_i) x (w_{ij})	Category weight (w_{ij})	Importance weight (w_i) x (w_{ij})
Body	0.363	0.293	0.106	0.184	0.067	0.052	0.019	0.058	0.021
Handle	0.175	0.427	0.075	0.227	0.040	0.070	0.012	0.103	0.018
Foot	0.950	0.625	0.594	0.224	0.213	0.152	0.144	0.224	0.213
Lip	0.107	0.793	0.085	0.793	0.085	0.207	0.022	0.207	0.022
Color	0.152	0.551	0.084	0.313	0.048	0.136	0.021	0.313	0.048
Pattern	0.108	0.417	0.045	0.282	0.030	0.127	0.014	0.174	0.019
Overall prioritization weights			0.988		0.482		0.232		0.340

After computing the overall prioritization weights of alternative ideas, the highest favorite mug is the composite from cylinder body, loop handle, non-foot, non-lip, pale color and non-pattern. On the other hand, the lowest favorite mug is the composite from short body, number 3 handle, slot-foot, lip, dark color and alphabet pattern.

5-4-3 Discussion

From the results, the body and handle are actually the most importance items in the overall appearance of mugs, as are the results of Kansei word "Attractive", "Easy to handle", "Quality" and "Durable". But the most favorite category of body from FAHP is cylinder as same only "Easy to handle", besides, the barrel , square and short body are the influences of customer's feeling "Attractive", "Quality" and "Durable", respectively. In contrast, the highest preference category of handle from FAHP is loop handle that is the most effective in three Kansei words likewise, "Attractive", "Easy to drink" and "Durable". Otherwise, the square handle is only one of efficiency in "Easy to handle". From FAHP results, the overall physical shape such as body and handle are significant more than the detail elements such as lip or foot. From Affective engineering results, the color and pattern of mugs are considered in term of 'Modern" that the bright color and the cartoon pattern are significant. However, most customers prefer to the pain color and non-pattern greater than the dark color or patterned mugs in term of 'Attractive". The appearance of lip and foot are the last items to be considered by the consumers from FAHP. Solely Kansei word "Easy to drink", has dominated by lip. Therefore, consumers are insensitive to its existence because it is not main parts for purchase selecting.

5-5 Summary

Even though several popular techniques in product design and development are conducted for knowing the customer needs and producing the suitable design attributes, but some of techniques are hard to employ in the real manufacturing. This research conducted Affective engineering and FAHP for designing product in Thailand. Affective engineering with Quantification Theory Type 1 analyze the relationships between customer emotions and product elements. And we also applied FAHP to identify the importance of product characteristics. Afterward, based on all findings, some candidate samples were designed. The result of this study shows that these techniques can be applied to ceramic design in Thai manufacturing. For further research, we suggest increasing the number of category of each product items or the other factors such as weight, size and thickness into considering in order to certainly approaching the customer satisfaction.

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Chapter 6

Application of Kansei engineering and Analytic network process in the Thai ceramic design

6-1 Introduction

Analytic Network Process (ANP) is employed in our study to analyze and rank the significant product attributes that affect the customer emotions and feelings. ANP is an enlarger from AHP and capability to link the interdependencies among different evaluation criteria, and have realistic thinking when criteria have inner dependency and feedback [1]. However, the study on ANP approach in emotion design is not widely applied. Only Hsiao, et al. [2] and Lan, et al. [3] employed ANP for product design as described in Chapter 1. Our most important contribution is to determine customer emotions and feelings interact with the appearance of mug design in Thai ceramic manufacturing by integrated KE and ANP. Differ from the previous studies, this dissertation focuses on the large number of components in complicated designs and our results classify detail of product elements which response with the significant customer emotions. In addition, our study is novel approach in the framework of the ceramic design since previous studies have not applied KE and ANP for ceramic product in Thailand.

6-2 Analytic Network Process (ANP)

ANP is a multi-problem decision technique approach developed by Saaty that procedures are similar to AHP [4]. AHP generates a multi-problem decision using a hierarchical structure of criteria which are independence of each other [5]. ANP extends AHP by replacing the hierarchy with the network structure which related to the complex interdependences between the decision levels and components [6]. According to ANP technique, an inner dependence refers to the interaction and feedback within clusters of elements. An outer dependence refers to the interaction between criteria [7]. Figure 6-1 shows the structure of AHP and Fig. 6-2 shows the structure of ANP.

A hierarchy is the simple as shown in Fig. 6-1. Arcs reveal interactions between nodes or components of the system as shown in Fig. 6-2. The meaning of arrow Goal to Criterion 1 is that the element of a component Criterion 1 depends on component Goal. A two-way arrow reveals the interrelationships between criteria that related to the feedback networks [8]. A loop arc represents inner dependency within criteria.

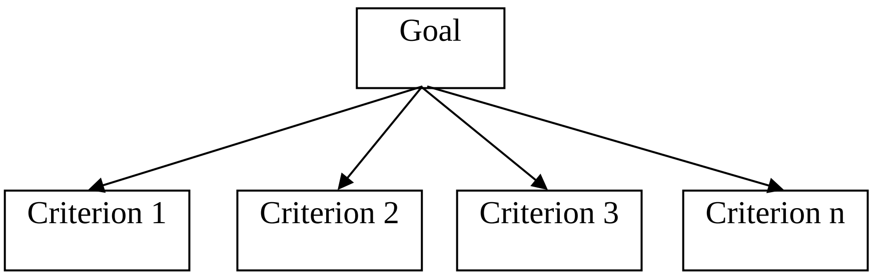

Fig. 6-1 Structure of AHP. [5]

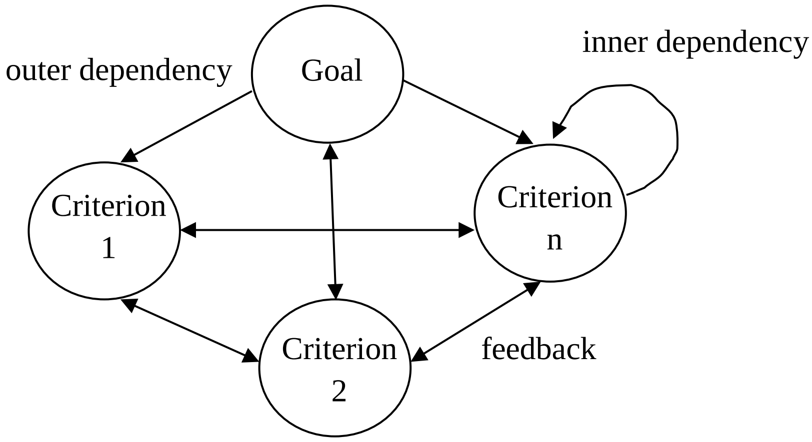

Fig. 6-2 Structure of ANP. [7]

The implementation of the ANP can be divided into 4 steps as explained in the following paragraphs.

Step 1: Model construction

The decision problem was clearly defined and structured into a network in the first step. The elements within cluster have an effect on some or all of elements in cluster as also shown in Fig. 6-2. The structure can be obtained from the discussion by the experts [9].

Step 2: Pairwise comparisons matrices and priority weights

Pairwise comparisons matrices are compared one by one in terms of their importance regarding the control criteria. The interrelationships between elements in cluster need to be determined where an eigenvector is the impact of each element on other elements [9]. ANP uses a nine-point scale measurement based on pairwise comparisons to compare elements with one by one similar to AHP as Table 6-1 [10]. Some problems about the consistency in the evaluation process may be happen. Saaty [11] suggested tool for checking using the consistency index (CI) and the consistency ratio (CR). Pairwise comparisons are consistent if CR < 0.1.

Table 6-1 Nine-point rating scale for pairwise comparisons. [10]

Number	Definition
1	Equal importance
3	Moderate importance
5	Strong Importance
7	Very strong importance
9	Extreme importance
2, 4, 6, 8	Used to represent compromise between the priorities listed above

Step 3: Forming the supermatrix

The value priorities are filled in columns of the supermatrix to find out the the geometric means that concern with interdependent networks. The supermatrix must be stochastic in order to obtain the important limiting priorities. The weighted supermatrix is computed by multiplying all of elements in the unweighted supermatrix usiing the innerdependency weights. After, the final weight of significant of each factor in the network model is represented by the limit matrix [9].

Step 4: Ranking alternatives

We can order alternatives using the weights of the limit matrix and select alternatives which have the highest values for achieving the goal [9].

6-3 Methodology

The procedures of this study can be represented in Fig. 6-3 that is adapted from Schütte and Eklund [12]. Ceramic products were identified from both of a semantic perspective and a product perspective. Each perspective spans its space as described in this section. Consequently, the interaction between two perspectives is analyzed in order to identify which Kansei words impact to product attributes. Each block of the research model in Fig. 6-3 will be explained below.

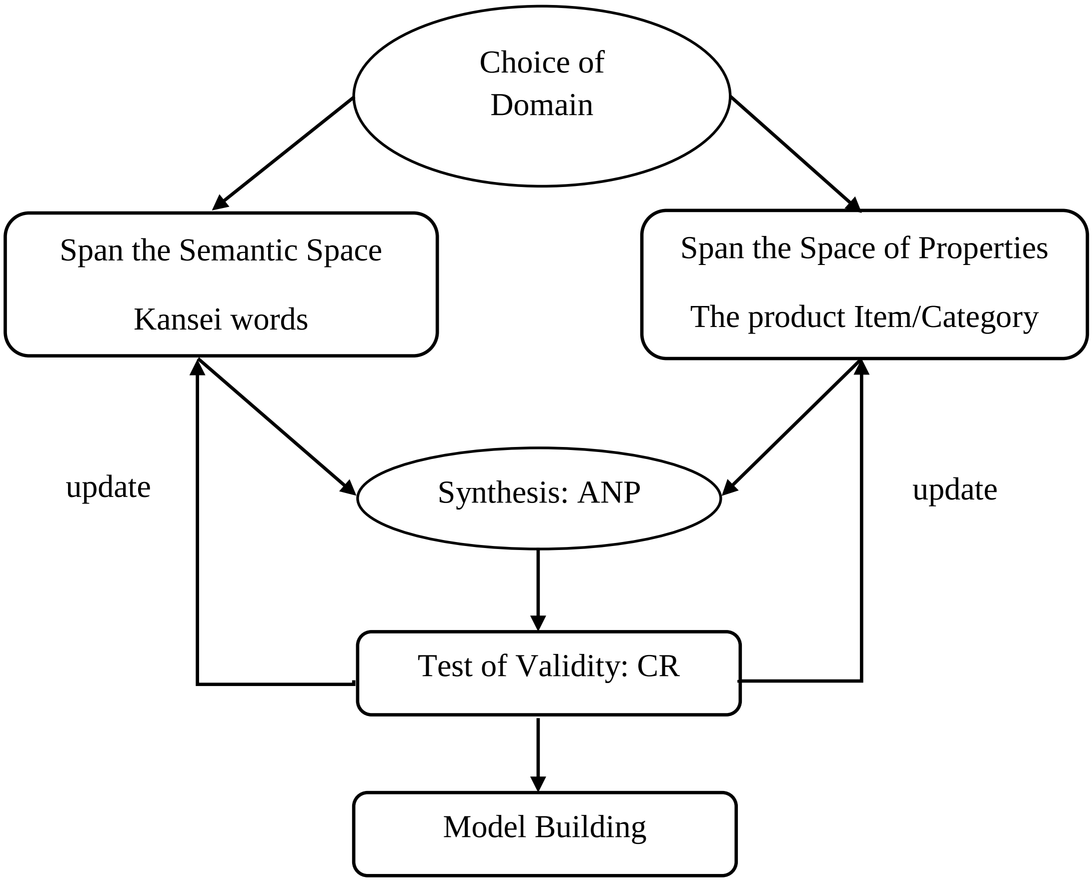

Fig. 6-3 Research methodology of KE-ANP study. Adapted from [12]

(1) Choice of domain

In this research, a mug was selected as the domain of ceramic product design. The sample size of the study was 30 participants. The participants were Thai people who aged 18-30 years old.

(2) Span the semantic space

All words describing the mug design were collected. Kansei words which related to mug were selected through different sources such as magazines, internet, journals, experts, literature and newspapers. After brainstorming with experts from Rajamangala University of Technology Lanna (Thailand), 5 Kansei words were finally chosen, namely: attractiveness, ease of drinking, ease of handing, product quality and durability.

(3) Span the space of product properties

Different mugs were chosen in this step for deconstructing the mug features such as shapes, color and detailing. To obtain complete data of the product properties, a brainstorming were employed with 3 experts in ceramic design from Rajamangala University of Technology Lanna (Thailand). After discussions with experts, the main items as important were body, handle, foot, lip, color and pattern. The product categories or the varying properties within each of product items which attract consumer attention and influence purchasing behavior were identified as shown in Table 5-5.

(4) Synthesis

The questionnaire is constructed by using the pairwise comparisons (nine-point rating scale) to obtain the weight of priorities for the product properties and the emotions in a network model. This study constructed the ANP model to evaluate the product attributes that affect customer emotions and feelings. Super Decision software [13] has been used for the ANP computations.

(5) Test of validity

The consistency test results confirm that the CR below 0.1, indicating that the results of the evaluation process are consistent and reliable [11].

(6) Model building

The weighted supermatrix multiplies by itself until all the columns in the same row are equal that called the limit supermatrix. Each column of the limit matrix is the priority weights of Kansei words and the product attributes. The priority weight of the product items is equal to sum of its categories weights. The priority weights of the product categories within their clusters or items are calculated by normalizing their priority weights in the related product item.

6-4 Results and discussion

6-4-1 Model construction

The proposed decision model of mug design was implemented for 24 categories under 6 main items and 5 Kansei words alternative as shown in Fig. 6-3. Outer dependencies (feedback) are represented by arrows among the clusters. For example, six items of the mug property are all influenced by the Kansei word alternatives and all the Kansei words also influences by all the mug items.

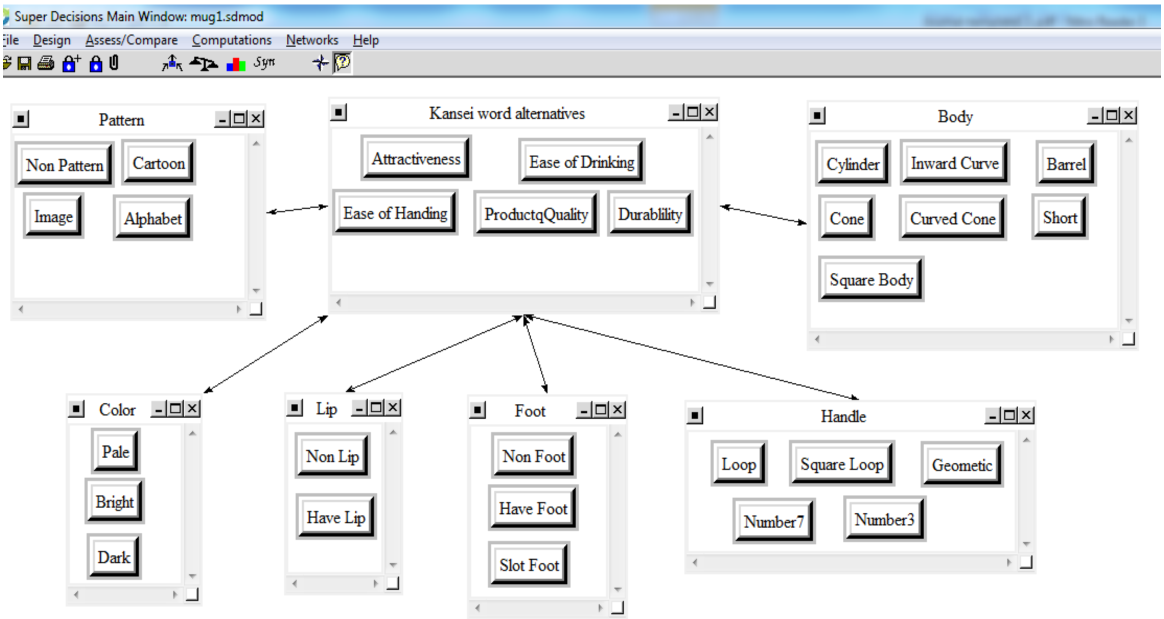

Fig. 6-4 The ANP network of the decision problem.

6-4-2 Pairwise comparisons matrices and priority vectors

A questionnaire was designed using a pairwise comparison based on the ANP network described above. After all participants finished their assessments, the geometric mean of the pairwise comparison matrix is calculated using the geometric technique. A total of 55 pairwise comparison matrices were constructed for the interdependence relationships among the product items/categories and Kansei word alternatives.

Table 6-2 shows the example of the outer dependence (feedback) relationships among the product category (barrel) and Kansei word alternatives (attractiveness, durability,…, product quality).

Table 6-2 Pairwise comparison matrix for the product category (Barrel) and Kansei word alternatives.

Barrel	Attractiveness	Durability	Ease of Drinking	Ease of Handing	Product quality	Weights
Attractiveness	1.00	0.15	2.10	1.10	1.00	0.120
Durability	6.50	1.00	4.20	6.40	6.40	0.586
Ease of Drinking	0.48	0.24	1.00	1.40	0.83	0.099
Ease of Handing	0.91	0.16	0.71	1.00	1.30	0.096
Product quality	1.00	0.16	1.20	0.77	1.00	0.097
						CR = 0.035

Table 6-3 shows the example of the outer dependence relationships among the Kansei word alternative (attractiveness) and the product category (barrel, cone,…, square) of the product item (body).

Table 6-3 Pairwise comparison matrix for the Kansei word alternative (Attractive) and the product category of the product item (Body).

Attractive	Barrel	Cone	Curve cone	Cylinder	Inward Curve	Short	Square	Weights
Barrel	1.00	0.25	0.22	0.25	0.40	1.10	0.25	0.047
Cone	4.00	1.00	0.31	1.30	0.38	5.40	0.29	0.108
Curve cone	4.60	3.20	1.00	2.30	1.50	6.40	1.40	0.255
Cylinder	4.00	0.77	0.43	1.00	0.28	4.60	0.63	0.106
Inward Curve	2.50	2.60	0.67	3.60	1.00	4.60	3.80	0.272
Short	0.91	0.19	0.16	0.22	0.22	1.00	0.15	0.032
Square	4.00	3.40	0.71	1.60	0.26	6.80	1.00	0.179
								CR = 0.070

Table 6-4 shows the weight of the product item. Consequently, we computed the values of Consistency Ratio (CR) to check the consistency of the pairwise comparison matrices. CR values in this study have been found to be less than 0.1, so that all of the pairwise comparison matrices were consistent.

Table 6-4 Pairwise comparison matrix for the product item.

Kansei word	Body	Color	Foot	Handle	Lip	Pattern	Weights
Body	1.00	1.00	4.60	2.50	2.80	0.83	0.230
Color	1.00	1.00	3.50	4.00	4.20	0.67	0.253
Foot	0.22	0.29	1.00	0.30	0.53	0.28	0.053
Handle	0.40	0.25	3.30	1.00	1.00	0.28	0.094
Lip	0.36	0.24	1.90	1.00	1.00	0.24	0.078
Pattern	1.20	1.50	3.60	3.60	4.20	1.00	0.292
							CR= 0.03

6-4-3 Forming the supermatrix

The unweighted, weighted and limit supermatrices were calculated using the Super Decisions software. Table 6-5 presents the unweighted supermatrix (see full Table in Appendix B). The weighted and limit supermatrices are shown in Table 6-6 and Table 6-7 (see full Table in Appendix B). The limit matrix represents the final eigenvector or the priority weights of the product categories and Kansei words.

Table 6-5 The unweighted supermatrix.

		kansei words alternatives				
		Attractive	Durable	Ease of Drinking	Ease of Handing	Quality
kansei words alternatives	Attractive	0.000	0.000	0.000	0.000	0.000
	Durable	0.000	0.000	0.000	0.000	0.000
	Ease of Drinking	0.000	0.000	0.000	0.000	0.000
	Ease of Handing	0.000	0.000	0.000	0.000	0.000
	Quality	0.000	0.000	0.000	0.000	0.000
Body	Barrel	0.047	0.303	0.037	0.077	0.044
	Cone	0.108	0.075	0.216	0.112	0.089
	Curved Cone	0.255	0.048	0.154	0.054	0.320
	Cylinder	0.107	0.221	0.307	0.216	0.119
	Inward Curve	0.271	0.048	0.122	0.074	0.168
	Short	0.032	0.135	0.061	0.276	0.035
	Square Body	0.180	0.170	0.102	0.192	0.224
Color	Bright	0.656	0.157	0.586	0.453	0.560
	Dark	0.085	0.670	0.109	0.196	0.129
	Pale	0.259	0.173	0.305	0.351	0.312
Foot	Have Foot	0.112	0.224	0.341	0.261	0.550
	Non Foot	0.235	0.657	0.432	0.560	0.210
	Slot Foot	0.653	0.119	0.227	0.179	0.240
Handle	Geometric	0.117	0.148	0.088	0.091	0.063
	Loop	0.083	0.380	0.213	0.227	0.205
	Number3	0.448	0.060	0.054	0.054	0.421
	Number7	0.285	0.089	0.482	0.491	0.105
	Square Loop	0.066	0.323	0.163	0.138	0.207
Lip	Have Lip	0.500	0.303	0.841	0.303	0.500
	Non Lip	0.500	0.697	0.159	0.697	0.500
Pattern	Alphabet	0.174	0.141	0.225	0.262	0.169
	Cartoon	0.401	0.105	0.514	0.134	0.440
	Image	0.370	0.197	0.096	0.130	0.314
	Non Pattern	0.054	0.557	0.165	0.474	0.077

Table 6-6 The weighted supermatrix.

		kansei words alternatives				
		Attractive	Durable	Ease of Drinking	Ease of Handing	Quality
Body	Barrel	0.011	0.070	0.009	0.018	0.010
	Cone	0.025	0.017	0.050	0.026	0.021
	Curved Cone	0.059	0.011	0.035	0.012	0.074
	Cylinder	0.025	0.051	0.071	0.050	0.027
	Inward Curve	0.062	0.011	0.028	0.017	0.039
	Short	0.007	0.031	0.014	0.063	0.008
	Square Body	0.041	0.039	0.024	0.044	0.052
Color	Bright	0.166	0.040	0.148	0.115	0.142
	Dark	0.022	0.170	0.028	0.050	0.033
	Pale	0.066	0.044	0.077	0.089	0.079
Foot	Have Foot	0.006	0.012	0.018	0.014	0.029
	Non Foot	0.012	0.035	0.023	0.029	0.011
	Slot Foot	0.034	0.006	0.012	0.009	0.013
Handle	Geometric	0.011	0.014	0.008	0.009	0.006
	Loop	0.008	0.036	0.020	0.021	0.019
	Number3	0.042	0.006	0.005	0.005	0.040
	Number7	0.027	0.008	0.045	0.046	0.010
	Square Loop	0.006	0.030	0.015	0.013	0.019
Lip	Have Lip	0.039	0.024	0.066	0.024	0.039
	Non Lip	0.039	0.055	0.012	0.055	0.039
Pattern	Alphabet	0.051	0.041	0.066	0.076	0.049
	Cartoon	0.117	0.031	0.150	0.039	0.128
	Image	0.108	0.057	0.028	0.038	0.091
	Non Pattern	0.016	0.162	0.048	0.138	0.022

Table 6-7 The limit supermatrix.

		kansei words alternatives				
		Attractive	Durable	Ease of Drinking	Ease of Handing	Quality
kansei words alternatives	Attractive	0.182	0.182	0.182	0.182	0.182
	Durable	0.078	0.078	0.078	0.078	0.078
	Ease of Drinking	0.077	0.077	0.077	0.077	0.077
	Ease of Handing	0.057	0.057	0.057	0.057	0.057
	Quality	0.106	0.106	0.106	0.106	0.106
Body	Barrel	0.010	0.010	0.010	0.010	0.010
	Cone	0.013	0.013	0.013	0.013	0.013
	Curved Cone	0.023	0.023	0.023	0.023	0.023
	Cylinder	0.020	0.020	0.020	0.020	0.020
	Inward Curve	0.019	0.019	0.019	0.019	0.019
	Short	0.009	0.009	0.009	0.009	0.009
	Square Body	0.020	0.020	0.020	0.020	0.020
Color	Bright	0.066	0.066	0.066	0.066	0.066
	Dark	0.026	0.026	0.026	0.026	0.026
	Pale	0.035	0.035	0.035	0.035	0.035
Foot	Have Foot	0.007	0.007	0.007	0.007	0.007
	Non Foot	0.010	0.010	0.010	0.010	0.010
	Slot Foot	0.010	0.010	0.010	0.010	0.010
Handle	Geometric	0.005	0.005	0.005	0.005	0.005
	Loop	0.009	0.009	0.009	0.009	0.009
	Number3	0.013	0.013	0.013	0.013	0.013
	Number7	0.013	0.013	0.013	0.013	0.013
	Square Loop	0.007	0.007	0.007	0.007	0.007
Lip	Have Lip	0.020	0.020	0.020	0.020	0.020
	Non Lip	0.020	0.020	0.020	0.020	0.020
Pattern	Alphabet	0.027	0.027	0.027	0.027	0.027
	Cartoon	0.051	0.051	0.051	0.051	0.051
	Image	0.038	0.038	0.038	0.038	0.038
	Non Pattern	0.029	0.029	0.029	0.029	0.029

6-4-4 Ranking alternatives

This study utilized ANP to solve multi-criteria decision making problems in which the product attributes affect customer emotions and feelings. The final weights for the Kansei words were shown in Table 6-8. The mug design may need to be attractiveness (0.183) and product quality (0.106) that is the two most important emotion affecting customer selecting, followed by durability (0.078), ease of drinking (0.077) and ease of handing (0.057). The product category of curved cone (0.197), bright color (0.520), non-foot or slot foot (0.363), number 3 handle (0.276), non-lip (0.501) and cartoon (0.350) reveal the significant priority corresponding to each the product item in the order of body, color, foot, handle, lip and pattern, respectively as shown in Table 6-9. Among the product item, the pattern was the most important of the product item and the color was weighted the second. In addition, the lip and foot were the two least weight in decision-making regarding mug selecting. Therefore, the sequential weights of the product item were pattern > color > body > handle > lip > foot and the sequential weights of the product category were bright color > cartoon pattern > image pattern > ….> geometric handle.

Table 6-8 Weights and ranking of Kansei word.

Kansei words alternatives	Weights (Ranking)
Attractiveness	0.183 (1)
Durability	0.078 (3)
Ease of Drinking	0.077 (4)
Ease of Handing	0.057 (5)
Product quality	0.106 (2)

Table 6-9 Weights and ranking of the product item and the product category.

The product item	The product category	(1) Weights of the product category (Ranking)	(2) Weights of the product item (Ranking)	(3) = (1)/(2) Normal weight of the product category (Ranking)
Body	Barrel	0.010 (17)	0.115 (3)	0.088 (6)
	Cone	0.013 (14)		0.116 (5)
	Curved Cone	0.022 (8)		0.197 (1)
	Cylinder	0.019 (11)		0.170 (3)
	Inward Curve	0.019 (13)		0.169 (4)
	Short	0.009 (20)		0.081 (7)
	Square Body	0.020 (9)		0.177 (2)
Color	Bright	0.066 (1)	0.126 (2)	0.520 (1)
	Dark	0.025 (7)		0.202 (3)
	Pale	0.034 (4)		0.274 (2)
Foot	Have Foot	0.007 (23)	0.026 (6)	0.274 (3)
	Non Foot	0.009 (19)		0.363 (1)
	Slot Foot	0.009 (18)		0.363 (1)
Handle	Geometric	0.004 (24)	0.047 (4)	0.103 (5)
	Loop	0.009 (21)		0.191 (3)
	Number3	0.013 (15)		0.276 (1)
	Number7	0.012 (16)		0.270 (2)
	Square Loop	0.007 (22)		0.159 (4)
Lip	Have Lip	0.019 (12)	0.039 (5)	0.499 (2)
	Non Lip	0.019 (10)		0.501 (1)
Pattern	Alphabet	0.027 (6)	0.145 (1)	0.186 (4)
	Cartoon	0.051 (2)		0.350 (1)
	Image	0.038 (3)		0.262 (2)
	Non Pattern	0.029 (5)		0.202 (3)

The propose model would be curved cone body, bright color, non-foot or slot foot, number 3 handle, non-lip and cartoon pattern. Thus, the findings from the research of KE and ANP represented that most important emotion to select the mug is attractiveness and the pattern is the most important product attribute.

6-4-5 Discussion

We analyzed and ranked the most important customer emotions and the most important product elements related to mug design using KE with ANP. According to literature review, the most important product attributes were analyzed using various techniques such as Quantification Theory Type 1 [12], [14], factor analysis [15], [16], artificial neural network [17], linear regression analysis [18], [19] and AHP [20]-[24]. They have taken this approach only outer relationships between product elements and Kansei words, whereas, ANP allows for more complex inter relationships and feedback within clusters of Kansei words, which differs from their approach. For instance, each of Kansei word was evaluated by the product categories in pairwise comparison matrix, whereas the product category was evaluated without the consideration of Kansei words in AHP (no feedback). This method is one of the best tools for finding the relationships between product elements and customer emotions. Nevertheless, the disadvantage of questionnaire is that the results are sometimes unreliable and respondents give wrong data without actual emotional conditions [25]. If questionnaire has many questions and takes a long time to complete, respondents will answer roughly and the results will be incorrect [26].

Our results are also different and similar from the previous works that use ANP in product design. For difference, the foremost food features were shape, color, material, and savory but authors did not analysis in detail such as type of shape [3]. Whereas, we attempt to identify product components in the large number of components in complicated designs. For similarity, ANP was employed to compute the optimal important of modules as well as to obtain the optimal model of mug design [3].

Based on the finding, to make the new mug model more affective, the mug model may need to be attractive and/or quality emotions with designers concentrate on the design of pattern, color and body than another element. In our opinion, general consumers are very sensitive to overall physical shape more than small elements such as lip or foot. Finally, this study can be prototype of the product design and development for various design cases.

6-5 Summary

This chapter presents a method applying a combination of KE and ANP for multi-criteria decision of the product attribute design that are affecting customer emotions. KE was used to evoke costumer feelings and emotions by Kansei words. ANP was successfully applied to decide the most important customer emotion and the most important product attribute that extracting the customer emotions. The application of these methods involved the supermatrix that specifies the relationships between the product attributes and the customer emotions. The limit supermatrix prioritized the priority weights of customer emotions and product attributes. This study differs from previous works, result from our study is high precision and classifies detail of product elements which response with the significant customer emotions. Super Decisions software was conducted for calculating the results. The most important emotion that affecting the mug design was ‘‘attractiveness’’ and the most significant product attributes was the pattern. Finally, it can be recommended to the manufacturers to apply this procedure into widespread use in several cases of the product design and development.

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Chapter 7

Conclusions

7-1 Conclusions

In this research work, the author aims to purpose the applications of Kansei engineering for shape design and material selection. Firstly, the author proposes the application of KE for shape parameter design. Secondly, the author also proposes the application of KE using tactile sense for material selection. Finally, the author proposes the application of KE in the Thai product design. The most important conclusions obtained in this dissertation were summarized below.

In Chapter 2, KE utilizes a product design methodology which translates a customers' perception regarding feelings and emotions on appearance of a product into a product design parameters. This study applied KE methodology to determine customer emotions and feelings on the shape of wine glasses. This study was performed using a four-factor and three-level BBD-RSM. 4 parameters of wine glass consist of the rim's width (A), the bowl's width (B), the bowl's height (C) and the stem's height (D) were examined with 5 Kansei words (modern, quality, durable, ease of drinking and ease of handle). The data obtained from the experiments were analyzed by ANOVA. Furthermore, a second-order polynomial equation of customer emotion using multiple regression analysis was shown. The optimal model of wine glass design was controlled at A=90 mm., B=61.82 mm., C=126.67 mm. and D=61.97 mm., respectively. These results reveal that our proposed method can be effective for translate all of customer emotions and feelings into define product attributes. Finally, this study provides useful understanding for shape parameter design and this method can be applied to a variety of design cases.

In Chapter 3, most manufacturers have to increase competition by satisfying customer emotions. The purpose of this study is to optimize the shape parameter to get the customer satisfaction of a wine glass using the applications of KE, Taguchi design and grey relation analysis. The considered shape parameters were the rim's width (*A*), the bowl's width (*B*), the bowl's height (*C)*, the stem's height (*D*) and the foot's width (*E*). The multi-responses were modern, quality, durable, ease of drinking and ease of handing. The optimal set of the shape parameters were *A* = 75 mm., *B* = 75 mm., *C* = 100 mm., *D* = 55 mm., and *E* = 70 mm., respectively. The bowl's width was the most significant factor affecting the grey grade values with the multiple responses. This research also demonstrates how to apply KE with Taguchi based Grey relation analysis to parameterize design of shape product and can be applied to a variety of design cases.

In Chapter 4, this study investigates tactile attributes of food wrapping materials in Thailand based on KE and finds that 1) there are two major Kansei dimensions in tactile sense of food wrapping materials, 2) the emotion of ‘‘like’’ constitutes one of the two dimensions both with ‘‘smooth’’ and ‘‘natural’’ and 3) the most favorable wrapping material for Thai is ‘‘plastic foam’’ among nine different wrapping materials; plastic bag, aluminum foil, plastic film, paper, banana leaf, wax paper, plastic net, plastic air bubble and plastic foam. The study was conducted through a questionnaire that asked 6 pairs of emotions about samples; dislike - like, rough - smooth, stable - flexible, tight - wrinkled, fine - fiber and refined - natural. A semantic differential measurement was used for the evaluation and the principal component analysis for the analysis.

In Chapter 5, ceramic is one of Thai products that are always changing to meet customer's requirements. Knowing customer's need is the target of designers as well as developing a product that must satisfy customers. This research applies Affective engineering and Fuzzy Analytic Hierarchy Process (FAHP) approach into the product design and development process. Affective engineering analyze the relationships between customer perceptions and product attributes. Six factors were retrieved: attractive, easy to drink, easy to handle, quality, modern and durable. Quantification Theory Type 1 was applied to map the relationships between product attributes and customer emotions. FAHP was conducted to identify the most importance of product attributes. Afterward, based on all findings, some candidate samples were designed. The result of this study shows that these techniques can be applied to ceramic design in Thai manufacturing.

In Chapter 6, ceramic is one of Thailand products that are in a highly competitive industry. To know customer needs is the target of designers and to develop a product that must satisfy customers. This is a study to apply KE and Analytic Network Process (ANP) to the customer driven product design process. KE has been widely used for new product development in many kinds of industries. ANP was conducted to determine the relationship between customer emotions and product attributes. The incorporation of interdependent relationships between elements is an advantage of ANP. The objective of this study is to propose a KE technique that employs ANP to 1) to find the feeling and emotion that cause purchasing behavior of products and 2) to find the product attributes that affect the customer emotion. A mug was selected as the product domain. The results showed that the most important perspective is ‘‘attractiveness’’, the most significant product attribute of the 6 product items is ‘‘pattern’’ and the best design is ‘‘curved cone body, bright color, non-foot or slot foot, number 3 handle, non-lip and cartoon pattern’’. This research also shows that ANP is powerful to employ with complex decision-making problem. Finally, the findings of the study are expected to help designers design a product that satisfies the consumer’s perceptions and requirements.

In conclusion, the application of KE for shape design and material selection is suitable for the product design and development. KE can find the customer feelings and emotions that cause purchasing behavior of products. Also, it finds the product attributes that affect the customer emotion. Box–Behnken response surface methodology and Taguchi based Grey relation analysis are integrated to seek the optimal product shape from continuous variables design and the detail size of shape parameters are accurately. The methodology incorporating RSM base BBD in KE is also the first trial of this kind of study. The results show that the proposed methods would be worth studying in KE field.

According to the process of product design, material selection should be emphasized on the relationships between human sensation and material characteristic. Results of KE using tactile sense for material selection reveal that this method did not only help product designers take into account the desirable materials of products affected the customer emotions and feelings using tactile sense, but also could be applied to the design of all the other senses. In addition, it is the first time to apply this method to a product with the features of food wrapping.

Although, KE is not well-known in Thailand but this dissertation succeeds to determine customer preferences and feelings related to product shape in Thai manufacturing using KE with Quantification Theory Type 1. Moreover, Fuzzy Analytical Hierarchy Process (FAHP) and Analytic Network Process (ANP) were used to decide the most important customer emotion and the most important product attribute that extracting the customer emotions. Furthermore, it is the first time to apply these methods to a product with the features of ceramics in Thailand.

Finally, the proposed methods can be utilized to capture and analyze consumer feelings and emotions as well as a scientific method of incorporating human sensibilities into applied shape design and material selection.

7-2 Limitation and future work

There are some limitations in this dissertation. Age, income, region, customs, gender and other factors can greatly influence on the results. Only the 18 - 30 years old Thai students from Rajamangala University of Technology Lanna (Thailand) were selected as the participants in our experiments. This dissertation does not consider seriously for grouping which influences certainly on the results. In addition, this dissertation focuses on the shape parameters but the functions of wine glasses (a case study) are not taken into account in the study. For example, we do not consider type of wine for wine glasses (red wine/white wine/sparkling wine/dessert wine), thickness (thick/thin) and weight (light/heavy).

Besides, the applications of KE not only focus on the product design, but also can be applied in service design. Future research will bring the concept of KE to associate the relationships between service qualities and customer's emotional perceptions in service design such as health care service, travel service and education service.

Appendix

Appendix A

Publications

List of Publications

Chapter 2

[1] **Applicationof Kansei engineering and Box–Behnken response surface methodology for shape parameter design: A case study of wine glass**
Chaiwat Kittidecha and Ashuboda Chandrajith Marasunghe
Journal of Advanced Mechanical Design, Systems, and Manufacturing, Vol.9, No.5, 2015
DOI: http://dx.doi.org/10.1299/jamdsm.2015jamdsm0059

Chapter 4

[2] **Application of Kansei engineering to tactile sense in the Thai food wrapping materials**
Chaiwat Kittidecha, Ashuboda Chandrajith Marasunghe and Koichi Yamada
Journal of Applied Packaging Research, Vol.8, No.2, Article 2, 2016
http://scholarworks.rit.edu/japr/vol8/iss2/2/

Chapter 5

[3] **Application of Affective engineering and Fuzzy analytical hierarchy process in Thai ceramic manufacturing**
Chaiwat Kittidecha, Ashuboda Chandrajith Marasunghe and Koichi Yamada
International Journal of Affective Engineering, Vol.15, No.3, 2016, pp. 325-334
DOI:10.5057/ijae.IJAE-D-15-00022

List of International Conferences

Chapter 5

[1] **Application of Kansei engineering in Thai ceramic manufacturing**

Chaiwat Kittidecha and Ashuboda Chandrajith Marasunghe

International Design and Concurrent Engineering Conference 2015, September 6th –7th, Tokushima, Japan (2015).

Chapter 3

[2] **Application of Kansei engineering and Taguchi based Grey relation analysis for shape parameter design: A case study of wine glass**

Chaiwat Kittidecha, Ashuboda Chandrajith Marasunghe and Koichi Yamada

International Conference on Innovative Design and Manufacturing 2016, January 24th –26th, Auckland, New Zealand (2016).

Chapter 6

[3] **Application of Kansei engineering and Analytic network process in the Thai ceramic design**

Chaiwat Kittidecha and Koichi Yamada

Joint 8th International Conference on Soft Computing and Intelligent Systems and 17th International Symposium on Advanced Intelligent Systems2016, August 25th –28th, Hokkaido, Japan (2016).

Appendix B

Table of the unweighted, weighted and limit supermatrices

Table A-1 The unweighted supermatrix.

		kansei words alternatives					Body							Color			Foot			Handle					Lip		Pattern			
		Attractive	Durable	Ease of Drinking	Ease of Handing	Quality	Barrel	Cone	Curved Cone	Cylinder	Inward Curve	Short	Square Body	Bright	Dark	Pale	Have Foot	Non Foot	Slot Foot	Geometric	Loop	Number3	Number7	Square Loop	Have Lip	Non Lip	Alphabet	Cartoon	Image	Non Pattern
kansei words alternatives	Attractive	0.000	0.000	0.000	0.000	0.000	0.121	0.458	0.403	0.463	0.385	0.118	0.388	0.396	0.219	0.312	0.332	0.165	0.444	0.139	0.074	0.249	0.159	0.176	0.166	0.134	0.525	0.514	0.523	0.513
	Durable	0.000	0.000	0.000	0.000	0.000	0.587	0.048	0.067	0.184	0.085	0.422	0.114	0.265	0.398	0.097	0.145	0.396	0.112	0.047	0.058	0.042	0.038	0.048	0.052	0.194	0.078	0.097	0.103	0.106
	Ease of Drinking	0.000	0.000	0.000	0.000	0.000	0.099	0.288	0.100	0.081	0.118	0.223	0.078	0.170	0.089	0.127	0.188	0.113	0.074	0.230	0.276	0.149	0.224	0.183	0.546	0.536	0.075	0.063	0.062	0.077
	Ease of Handing	0.000	0.000	0.000	0.000	0.000	0.096	0.092	0.090	0.065	0.085	0.095	0.069	0.088	0.082	0.112	0.141	0.090	0.072	0.485	0.420	0.478	0.470	0.493	0.086	0.058	0.064	0.052	0.050	0.073
	Quality	0.000	0.000	0.000	0.000	0.000	0.097	0.115	0.340	0.206	0.327	0.143	0.351	0.080	0.212	0.352	0.194	0.237	0.297	0.100	0.171	0.082	0.109	0.101	0.150	0.079	0.258	0.273	0.263	0.231
Body	Barrel	0.047	0.303	0.037	0.077	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cone	0.108	0.075	0.216	0.112	0.089	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Curved Cone	0.255	0.048	0.154	0.054	0.320	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cylinder	0.107	0.221	0.307	0.216	0.119	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Inward Curve	0.271	0.048	0.122	0.074	0.168	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Short	0.032	0.135	0.061	0.276	0.035	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Square Body	0.180	0.170	0.102	0.192	0.224	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Color	Bright	0.656	0.157	0.586	0.453	0.560	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Dark	0.085	0.670	0.109	0.196	0.129	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Pale	0.259	0.173	0.305	0.351	0.312	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Foot	Have Foot	0.112	0.224	0.341	0.261	0.550	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Non Foot	0.235	0.657	0.432	0.560	0.210	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Slot Foot	0.653	0.119	0.227	0.179	0.240	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Handle	Geometric	0.117	0.148	0.088	0.091	0.063	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Loop	0.083	0.380	0.213	0.227	0.205	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Number3	0.448	0.060	0.054	0.054	0.421	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Number7	0.285	0.089	0.482	0.491	0.105	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Square Loop	0.066	0.323	0.163	0.138	0.207	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lip	Have Lip	0.500	0.303	0.841	0.303	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Non Lip	0.500	0.697	0.159	0.697	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pattern	Alphabet	0.174	0.141	0.225	0.262	0.169	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cartoon	0.401	0.105	0.514	0.134	0.440	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Image	0.370	0.197	0.096	0.130	0.314	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Non Pattern	0.054	0.557	0.165	0.474	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A-2 The weighted supermatrix.

		kansei words alternatives					Body							Color			Foot			Handle					Lip		Pattern			
		Attractive	Durable	Ease of Drinking	Ease of Handing	Quality	Barrel	Cone	Curved Cone	Cylinder	Inward Curve	Short	Square Body	Bright	Dark	Pale	Have Foot	Non Foot	Slot Foot	Geometric	Loop	Number3	Number7	Square Loop	Have Lip	Non Lip	Alphabet	Cartoon	Image	Non Pattern
kansei words alternatives	Attractive	0.000	0.000	0.000	0.000	0.000	0.121	0.458	0.403	0.463	0.385	0.118	0.388	0.396	0.219	0.312	0.332	0.165	0.444	0.139	0.074	0.249	0.159	0.176	0.166	0.134	0.525	0.514	0.523	0.513
	Durable	0.000	0.000	0.000	0.000	0.000	0.587	0.048	0.067	0.184	0.085	0.422	0.114	0.265	0.398	0.097	0.145	0.396	0.112	0.047	0.058	0.042	0.038	0.048	0.052	0.194	0.078	0.097	0.103	0.106
	Ease of Drinking	0.000	0.000	0.000	0.000	0.000	0.099	0.288	0.100	0.081	0.118	0.223	0.078	0.170	0.089	0.127	0.188	0.113	0.074	0.230	0.276	0.149	0.224	0.183	0.546	0.536	0.075	0.063	0.062	0.077
	Ease of Handing	0.000	0.000	0.000	0.000	0.000	0.096	0.092	0.090	0.065	0.085	0.095	0.069	0.088	0.082	0.112	0.141	0.090	0.072	0.485	0.420	0.478	0.470	0.493	0.086	0.058	0.064	0.052	0.050	0.073
	Quality	0.000	0.000	0.000	0.000	0.000	0.097	0.115	0.340	0.206	0.327	0.143	0.351	0.080	0.212	0.352	0.194	0.237	0.297	0.100	0.171	0.082	0.109	0.101	0.150	0.079	0.258	0.273	0.263	0.231
Body	Barrel	0.011	0.070	0.009	0.018	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cone	0.025	0.017	0.050	0.026	0.021	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Curved Cone	0.059	0.011	0.035	0.012	0.074	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cylinder	0.025	0.051	0.071	0.050	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Inward Curve	0.062	0.011	0.028	0.017	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Short	0.007	0.031	0.014	0.063	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Square Body	0.041	0.039	0.024	0.044	0.052	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Color	Bright	0.166	0.040	0.148	0.115	0.142	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Dark	0.022	0.170	0.028	0.050	0.033	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Pale	0.066	0.044	0.077	0.089	0.079	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Foot	Have Foot	0.006	0.012	0.018	0.014	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Non Foot	0.012	0.035	0.023	0.029	0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Slot Foot	0.034	0.006	0.012	0.009	0.013	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Handle	Geometric	0.011	0.014	0.008	0.009	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Loop	0.008	0.036	0.020	0.021	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Number3	0.042	0.006	0.005	0.005	0.040	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Number7	0.027	0.008	0.045	0.046	0.010	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Square Loop	0.006	0.030	0.015	0.013	0.019	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lip	Have Lip	0.039	0.024	0.066	0.024	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Non Lip	0.039	0.055	0.012	0.055	0.039	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Pattern	Alphabet	0.051	0.041	0.066	0.076	0.049	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Cartoon	0.117	0.031	0.150	0.039	0.128	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Image	0.108	0.057	0.028	0.038	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Non Pattern	0.016	0.162	0.048	0.138	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table A-3 The limit supermatrix.

		kansei words alternatives					Body							Color			Foot			Handle					Lip		Pattern			
		Attractive	Durable	Ease of Drinking	Ease of Handing	Quality	Barrel	Cone	Curved Cone	Cylinder	Inward Curve	Short	Square Body	Bright	Dark	Pale	Have Foot	Non Foot	Slot Foot	Geometric	Loop	Number3	Number7	Square Loop	Have Lip	Non Lip	Alphabet	Cartoon	Image	Non Pattern
kansei words alternatives	Attractive	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182	0.182
	Durable	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078
	Ease of Drinking	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
	Ease of Handing	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057
	Quality	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106
Body	Barrel	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Cone	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
	Curved Cone	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023	0.023
	Cylinder	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
	Inward Curve	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
	Short	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
	Square Body	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Color	Bright	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066
	Dark	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026	0.026
	Pale	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035	0.035
Foot	Have Foot	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	Non Foot	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
	Slot Foot	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010
Handle	Geometric	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	Loop	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
	Number3	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
	Number7	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
	Square Loop	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
Lip	Have Lip	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
	Non Lip	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Pattern	Alphabet	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
	Cartoon	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051	0.051
	Image	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038
	Non Pattern	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029