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Cooperative game study on Kano's model and quality function deployment

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***Abstract*—Cooperative game is incorporated in the quality function deployment (QFD) procedure in two major parts. The first part is to obtain the importance weights of customer requirements through the implementation of Kano's model and Shapley value. Subsequently, the second part is the formulation of a non-linear programming model to optimize the target levels of engineering characteristics in the new generation product, whose objective function reflects the bargaining between different fulfillment levels of customer requirements so as to maximize the overall customer satisfaction. Finally, the importance weight calculation is applied in an example of a personal computer design.**

***Index Terms*—Kano's model, Shapley value, QFD, Nash bargaining, non-linear programming**

I. Introduction

As the time changes, the evolution of manufacturing products has shifted from product-centric to customer-centric, even to the customer participation scenario. Correspondingly, humans have experienced the handicraft age to the mass production in manufacturing, and today's customization. It can be seen that customer requirements (CRs) played a significant role during these stages, which has made manufacturers continuously chase these needs and better satisfy their customers.

In regard to the widely applied customer-centric product design nowadays, quality function deployment (QFD) in [1] can be viewed as one of the effective and efficient tools to interpret CRs to engineering characteristics (ECs) in manufacturing aspect, to further enhance the performance of the new generation product. One critical problem before the implementation of QFD is how to identify and understand CRs in a systematic way. Kano's model has provided a solution to this challenge, which was proposed in [2] and was widely acknowledged afterwards. CRs are collected from the marketing department through paper or online questionnaires, and they are able to be categorized with the aid of Kano's model into different types, which makes CRs more visually and intuitively for manufacturers to capture.

Back to the QFD part, the importance weights of CRs should be determined before optimizing the current design. Traditionally, these weights are obtained directly from the questionnaire data by using the average function or the normalization method. Since the overall sum of the importance weights of CRs is 1, in this paper we take the marginal contribution of each CR into account by utilizing the quantitative Kano's model and Shapley value in cooperative games to derive the importance weight of individual CR. In addition, this importance weight vector is incorporated in a bargaining function, which is served as the objective function in a non-linear programming model in the QFD procedure.

The cooperative game in this paper contains two aspects, one is the determination of importance weights of CRs, and the other is the Nash bargaining among CRs to get the maximal overall customer satisfaction. There are commonality and differences between the game setup of these two aspects. Commonality: Players in these two aspects are both several specified customer requirements, which are indexed by i, $i = 1, 2, \cdots, n$. Differences: The strategy set for the first aspect is whether to cooperate or not to cooperate in a coalition, and the strategy set for the second aspect is $(x_1, x_2, \cdots, x_n)$, which represents a situation that an agreement is reached between all players. Besides, in the first aspect, the value functions are the customer satisfaction values or dissatisfaction values gained from the Kano's model. Whereas, in the other aspect, the payoff functions are the quantitative functions between the fulfillment level of each CR and the fulfillment level of the corresponding customer satisfaction.

The rest of the article is organized as follows. Firstly, Section II introduces Kano's model and the calculation of Shapley value to attain the importance weights of CRs. Secondly, Section III integrates cooperative games and quantitative Kano's model into the QFD process, and proposes a non-linear programming model in obtaining the target levels of ECs in the new generation product. Afterwards, an illustrative example regarding the personal computer is conducted in Section IV to figure out the numerical results elaborated in the former two sections. Lastly, Section V demonstrates some conclusions and future directions of this study.

II. The Importance Weights of Customer Requirements

Observed as an advance preparation for QFD, the specific CRs of a target product along with their importance weights

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should be recognized and calculated accordingly. In this section, the notions of Kano's model is firstly introduced, which aims at classifying CRs in terms of their features. The customer satisfaction (CS) and dissatisfaction (DS) of individual CR are also derived, respectively. Next, the notions of Shapley value together with its formulations are brought in, and the relationship of each CR with CS or DS is then utilized as the value function during the calculation procedure in Shapley value. Then, the relative importance weights of CRs can be obtained through a transformation of Shapley value of each CR.

A. Quantitative Kano's model

According to Kano *et al.* [2], Kano's model is generated to get a better understanding of CRs as well as the influence on customer satisfaction. They defined three different types of CRs in accordance with different fulfillment levels to CS, i.e., Attractive, One-dimensional, and Must-be, which are demonstrated in Fig. 1. The horizontal axis represents the fulfillment level of CR, and the vertical axis is the fulfillment level of CS.

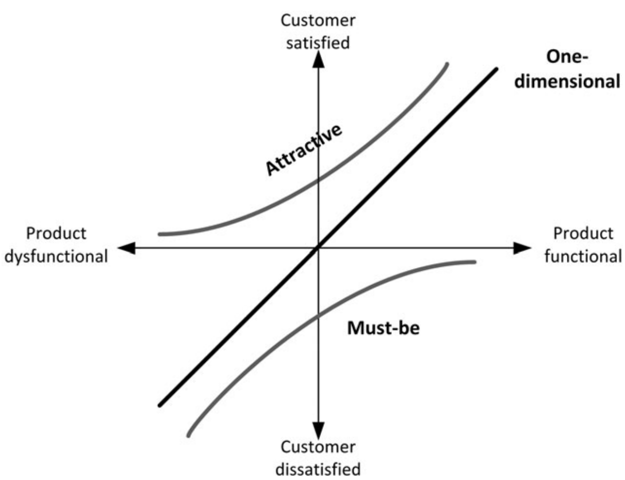

Fig. 1. The Kano diagram in [2].

As we can see from Fig. 1, the fulfillment of a One-dimensional attribute (O) is positively related to the CS fulfillment level in a linear way, such as the camera function of a smart phone. And the fulfillment of an Attractive attribute (A) leads to higher level of satisfaction proportionally, but since they are not expected by customers, the lack of this attribute will not result in high DS, such as the appearance design of a phone. Lastly, as to a Must-be attribute (M), if not satisfied, the customers will be very displeased, such as the calling function of a phone.

Regardless of the aforementioned three types, there also exist three other types, Indifferent (I), Reverse (R), and Questionable (Q), which can tell from their names. I, R and Q indicate those attributes that customers do not care at all, they dislike the requirements or there may cause a contradiction with the customers' expectations, respectively.

The above classification process is qualitative in determining a specific CR to see which category it may belong to. On this basis, some further quantitative study can be done, which was first suggested by Berger *et al.* [3]. In this paper, CS and DS values proposed by Ji *et al.* [4] are taken into consideration by calculating the proportion of consumers who feel pleased or displeased with one certain CR, which are shown in (1)-(2).

$$CS_i = \frac{f_A + f_O}{f_A + f_O + f_M + f_I} \tag{1}$$

$$DS_i = -\frac{f_O + f_M}{f_A + f_O + f_M + f_I}, \tag{2}$$

where i denotes the ith customer requirement extracted from the questionnaires or feedback from the marketing department, and f_A, f_O, f_M, and f_I indicate the total numbers of customers' attitudes towards the ith CR, to view it as A, O, M, or I types of attributes.

B. Shapley value in CR importance weights

Assuming that several specific CRs, their categories, and CS and DS values have already been acquired, we need to ascertain the importance weights of them for better updating the new product. One easier solution is to figure out the average values of customers' preference scores to each CR appeared in the questionnaire and get the final importance weights through normalization. However, what about considering each CR's marginal contribution to the whole customer satisfaction. Since all these selected CRs are of great importance as customers' voices against the product, any one of them joing in the cooperation will help enhance the overall CS definitely. Certainly, their contributions are different from each other, which can be reflected from Shapley value.

This effective tool which handle arbitration among a bunch of players' coalitions was set forth by Shapley in [5], which is defined as the kth participant joining in a coalition M,

$$S_k = \sum_{all\ M} \gamma_n(M)[v(M \cup \{k\}) - v(M)], \tag{3}$$

where the weights $\gamma_n(M)$ of entering a coalition M is formulated as

$$\gamma_n(M) = \frac{m!(n-m-1)!}{n!}. \tag{4}$$

In (3)-(4), n represents the number of all participants in this game, m is the number of participants in the coalition M, and $v(.)$ is the value function for estimating the utility of each coalition. $M \cup \{k\}$ denotes that the kth participant is included in the coalition, while M is displayed without the kth participant. As we can see, the participants in our case are those specified customer requirements.

It is known that Shapley value computes a unique solution satisfying the basic requirements of the Nash Equilibrium, including the following three desirable properties.

- Axiom 1 (*Efficiency*). The total Shapley value of all participants is equal to the value of the coalition of all the participants together,

$$\sum_{k=1}^{n} S_k = v(all). \tag{5}$$

- Axiom 2 (*Symmetry*). All participants are primarily equally considered in regard to the impact on the outcome. And the value function of a null participant in a game is 0, i.e., $v(0) = 0$.
- Axiom 3 (*Linearity*). When two independent games are combined, their values should be added player by player.

In this paper, we take the CS or DS value of each CR illustrated in (1)-(2) as the value function of each participants in this cooperative game, which means $v(k) = CS_k$ or DS_k towards the kth participant. Although the formula of Shapley value in (3) is quite straightforward, the computational complexity will appear when the number of participants n is a large number. Conklin *et al.* [6] and Conklin and Lipovetsky [7] came up with a solution to this problem by calculating the mean values of combinations with or without the attribute k, which is described and adopted as follows,

$$S_k = \frac{1}{n-1}(k-\bar{1}) + \frac{1}{n-2}(\overline{k*}-\bar{2}) + \frac{1}{n-3}(\overline{k**}-\bar{3}) + \cdots + \frac{1}{n-(n-1)}\left(\overline{k*\cdots*}-\overline{(n-1)}\right) + \frac{1}{n}(all). \tag{6}$$

In (6), it can be seen that Shapley value towards the kth participant is aggregated as a sum of mean values of several parts. The mean value of the first level coalitions containing one element among all participants is denoted by $\bar{1}$, while at this time k is the mean value of itself. Then, $\overline{k*}$ stands for the mean value of those second level coalitions that include k, and $\bar{2}$ represents the mean value of all the second level coalitions. This averaging procedure continues to the combinations with $(n-1)$ elements, and the last one distributes the maximum coalitions equally into each Shapley value of all participants.

Generally, (6) can be further written equivalently as a simple version like

$$S_k = \frac{1}{n}v(M_{all}) + \sum_{j=1}^{n-1}\frac{1}{n-j}(\bar{v}(M_{kj}) - \bar{v}(M_j)). \tag{7}$$

As we may face bunches of customer needs regarding the target product (over 10 or even more), the analytical transformation in (7) is effective and efficient in decreasing the computational time and complexity, which is able to be modeled by incorporating random sampling algorithms.

III. Integration of Cooperative Games and Quantitative Kano's Model to QFD

Quality function deployment (QFD) is a systematic and effective tool in translating multiple CRs into ECs in manufacturing and help appropriately allocate the resources. In order to make the model more realistic, a Nash bargaining based non-linear programming model is put forward to attain the target levels of ECs, which aims at maximizing the overall customer satisfaction under the constraint of a limited budget. The notation used in this paper is summarized in Table I.

TABLE I
NOTATION IN THIS PAPER

l_j	the target level of EC_j, $j = 1, 2, \cdots, q$
x_j	the fulfillment level of EC_j, $j = 1, 2, \cdots, q$
d_i	the customer satisfaction degree of CR_i, $i = 1, 2, \cdots, n$
y_i	the fulfillment level of CR_i, $i = 1, 2, \cdots, n$
p_i^t	the performance of CR_i in company t, $t = 1, 2, \cdots, s$
w_i	the relative importance weight of CR_i, $i = 1, 2, \cdots, n$
r_{ij}	the relationship between CR_i and EC_j
c_j	the unit improvement cost for EC_j, $j = 1, 2, \cdots, q$
B	the budget during the whole product design procedure

A. Quality function deployment

The house of quality (HoQ) in [8] is the core of QFD, which is a diagram that resembles a house, including several matrices, i.e., CRs and their relative importance weights w_i are listed in the left wall, ECs together with their correlations are enumerated in the ceiling and roof separately. The room of the HoQ displays the relationships r_{ij} between CRs and ECs, and the data of the rivals p_i^t are listed in the strategic planning room. From Table I, there are n CRs, q ECs in the design, and s competitor companies in the current market.

From former literatures, the overall customer satisfaction (OCS) of a certain product was gained as a linearly additive operator of the fulfillment degrees (y_i) towards all CRs in [9] like

$$OCS = \sum_{i=1}^{n} w_i y_i.$$

Following this concept, Ji *et al.* [4] formed the overall customer satisfaction as the weighted sum of the degree of CS for individual CR d_i as

$$OCS(y_1, y_2, \cdots, y_n) = \sum_{i=1}^{n} w_i d_i. \tag{8}$$

On the basis of the CS and DS values described detailedly in Section II-A, we can further compute the analytical expressions of the curves of different attributes d_i approximately with the aid of exponential functions and linear functions, which can refer to [4] for more details. According to the the Kano diagram in Fig. 1, the relationships between the horizontal axis and vertical axis of A, O, M attributes are derived in Table II.

Generally, the target levels of ECs are measured in units, which usually fall into wide ranges. To eliminate the impact of different measurements, we apply a normalization formula in [10] to the target levels of ECs and convert them into the corresponding fulfillment levels. Firstly, ECs are grouped into

TABLE II
d_i-y_i RELATIONSHIP FUNCTIONS IN [4]

KC[a]	$f(y_i)$	$d_i = a_i f(y_i) + b_i$
A	e^{y_i}	$d_i = \frac{CS_i - DS_i}{e-1} e^{y_i} - \frac{CS_i - eDS_i}{e-1}$
O	y_i	$d_i = (CS_i - DS_i)y_i + DS_i$
M	$-e^{-y_i}$	$d_i = -\frac{e(CS_i - DS_i)}{e-1} e^{-y_i} + \frac{eCS_i - DS_i}{e-1}$

[a]KC is short for Kano classification, which is selected by the type of most responses.

two categories, 'cost' type (*C-type*) and 'benefit' type (*B-type*). Then, standardize l_j to each x_j as follows,

$$x_j = \begin{cases} \dfrac{l_j^{max} - l_j}{l_j^{max} - l_j^{min}} & (C\text{-}type) \\ \dfrac{l_j - l_j^{min}}{l_j^{max} - l_j^{min}} & (B\text{-}type) \end{cases} \tag{9}$$

where $0 \le x_j \le 1$. For those *C-type* ECs, $l_j^{\max}$ is the maximal target level that fits for the capability of rivals while $l_j^{\min}$ denotes the minimal limit. When it comes to *B-type* ECs, $l_j^{\min}$ represents the minimal target level that fits for the capability of the rivals whereas $l_j^{\max}$ is the maximal limit.

B. Bargaining function

If we switch the angle looking into this maximizing overall customer satisfaction problem, it can be regarded as a cooperative game, and there exists bargaining among all the fulfillment degrees of CRs. At first, the basic concept of cooperative game and Nash bargaining are recalled.

Suppose that the payoff function of individual player i is $f_i(x)$, and the players bargain with each other, hoping that there is a deal that their payoff functions are maximized, and the bargaining function $B(.)$ should satisfy that

$$\min(f_1, \cdots, f_n) < B(f_1, \cdots, f_n) < \max(f_1, \cdots, f_n).$$

The generalized bargaining function is established as

$$B(x) = \prod_{i=1}^{n} (f_i(x) - f_i(x_w))^{w_i}, \tag{10}$$

where $f_i(x_w)$ is the worst value of the payoff function $f_i(x)$ that the ith player is willing to pay, and w_i represents the weights of the payoff functions such that $\sum_{i=1}^{n} w_i = 1$, $0 \le w_i \le 1$, $i = 1, 2, \cdots, n$, which can refer to [11].

In our study, the relative importance weight w_i of CR_i is obtained through Shapley value, and the d_i-y_i relationship functions can be viewed as payoff functions of each CR. Therefore, (8) can be reconsidered to be a cooperative game version via the application of (10) as

$$B(y_i) = \prod_{i=1}^{n} (d_i(y_i) - DS_i)^{w_i}, \tag{11}$$

in which DS_i is the dissatisfaction degree value of each CR figured out from the questionnaire.

C. A novel modelling approach

In terms of the former two sections, we are able to build up a non-linear programming model so as to maximize the payoff functions of each CR through an optimal trade, which is expressed as

$$\begin{cases} \max \prod_{i=1}^{n} (d_i(y_i) - DS_i)^{w_i} \\ \text{subject to:} \\ \quad \sum_{j=1}^{q} c_j x_j \le B \\ \quad y_i = \sum_{j=1}^{q} r_{ij} x_j, i = 1, 2, \cdots, n \\ \quad y_i > \dfrac{\sum_{t=1}^{s} p_i^t}{s}, i = 1, 2, \cdots, n \\ \quad 0 \le x_j \le 1, \quad j = 1, 2, \cdots, q, \end{cases} \tag{12}$$

where $d_i(y_i)$ can refer to Table II. The first constraint demonstrates the budget limit in the product design, and the second constraint targets on transforming the fulfillment levels of ECs into those of CRs by taking advantage of the relationship between CRs and ECs. The average value of the rival companies are set as a benchmark for the fulfillment level of CS for each CR in the third constraint. Finally, since x_j is a standardized value from target levels l_j, it is defined from 0 to 1.

Let us look into a simple example, suppose that there are two players (two CRs) in this bargaining now, $i = 1, 2.$, and CR_1 is an Attractive attribute while CR_2 is a One-dimensional attribute. Then, we can formulate the non-linear programming model with respect to (12) as

$$\begin{cases} \max\ (d_1(y_1) - DS_1)^{w_1} (d_2(y_2) - DS_2)^{w_2} \\ \quad d_1(y_1) = \dfrac{CS_1 - DS_1}{e-1} e^{y_1} - \dfrac{CS_1 - eDS_1}{e-1} \\ \quad d_1(y_2) = (CS_2 - DS_2)y_2 + DS_2 \\ \text{subject to:} \\ \quad c_1 x_1 + c_2 x_2 + \cdots + c_q x_q \le B \\ \quad y_1 = r_{11} x_1 + r_{12} x_2 + \cdots + r_{1q} x_q \\ \quad y_2 = r_{21} x_1 + r_{22} x_2 + \cdots + r_{2q} x_q \\ \quad y_1 > \dfrac{\sum_{t=1}^{s} p_1^t}{s},\ y_2 > \dfrac{\sum_{t=1}^{s} p_2^t}{s} \\ \quad 0 \le x_j \le 1, \quad j = 1, 2, \cdots, q, \end{cases} \tag{13}$$

where x_j are decision variables of the fulfillment levels of q ECs. The unit improvement cost c_j is positive as well as the relationship r_{ij} between CR_i and EC_j. After plugging in the expressions of $d_i(y_i)$ into the objective function in (13), we can get

$$f(y_1, y_2) = \Big(\frac{CS_1 - DS_1}{e-1}(e^{y_1} - 1)\Big)^{w_1} \Big((CS_2 - DS_2)y_2\Big)^{w_2}. \tag{14}$$

For the purpose of better analyzing the above equation, we let $E = (CS_1 - DS_1)/(e-1)$ and $F = CS_2 - DS_2$. Since CS_i is positive and DS_i is negative, the values of E and F are both positive. After taking the first order derivative of (14) with respect to y_1, we can get

$$\frac{\partial f}{\partial y_1} = w_1 E(e^{y_1}-1)^{(w_1-1)} e^{y_1} \cdot (Fy_2)^{w_2}. \quad (15)$$

Next, take the second order partial derivative towards y_2, we attain that

$$\frac{\partial^2 f}{\partial y_1 \partial y_2} = w_1 E(e^{y_1}-1)^{(w_1-1)} e^{y_1} \cdot w_2 (Fy_2)^{(w_2-1)} F. \quad (16)$$

In (16), since y_1 and y_2 are both positive, the second order partial derivative is larger than 0, which means (14) is a convex function.

On the other hand, in (14), $\Big(\frac{CS_1 - DS_1}{e-1}(e^{y_1}-1)\Big)^{w_1}$ is increasing with respect to $y_1 \in (0, +\infty)$ and $\Big((CS_2 - DS_2)y_2\Big)^{w_2}$ is increasing with respect to $y_2 \in (0, +\infty)$ as well. This indicates that the objective function $f(y_1, y_2)$ in (13) is increasing both to y_1 and y_2 in the positive horizontal axis. If we are intended to maximize the value of $f(y_1, y_2)$, the larger the values of y_1 and y_2 the larger that of $f(y_1, y_2)$. As a consequence, the cost constraint in (13) should be equal to the budget to get the largest y_i, i.e., $c_1x_1 + c_2x_2 + \cdots + c_qx_q = B$.

There are some limitations of the proposed model (12), mainly focused on its objective. Firstly, since the objective is a product, with the increasing of number i, the remarkably smaller the product will be. Secondly, the index wi will add some difficulty to solve the model. Regarding the mentioned two circumstances, a mathematical transformation is needed.

IV. Case Analysis: A Personal Computer Development

The importance weight determination and modelling are applied to a notebook computer design so as to demonstrate the feasibility and effectiveness of the proposed approach. The original questionnaire data and Kano's model analysis are adopted from [4]. Primarily, the survey regarding a notebook computer is conducted, and 125 effective pieces of responses are received and confirmed in Table III.

Seven major CRs are figured out in this survey, i.e., 'Stylish design' (a), 'Mobility' (b), 'High computing speed' (c), 'Powerful graphics solution' (d), 'Solid audio capability' (e), 'Large storage' (f), 'High network performance' (g).

The values of CS and DS in Table III are obtained with respect to (1)-(2). Take the CR 'Stylish design' (a) as an example, we can get

$$CS_1 = \frac{70+25}{70+24+14+15} = \frac{95}{124} = 0.7661,$$
$$DS_1 = -\frac{25+14}{70+24+14+15} = -\frac{39}{124} = -0.3145.$$

Similarly, the satisfaction and dissatisfaction values of other customer requirements can be attained, which are adopted as value functions in Shapley value calculations later. Besides, from Table III, the KC of the last CR 'High network performance' is I, which means customers feel indifferent with this function. Therefore, this CR will be removed from the CR set in the subsequent QFD process, which indicates that we only need to allocate the importance weights among the remaining six CRs (a-f) and the sum of weights is 1.

TABLE III
Kano questionnaire results in [4]

	A	O	M	I	R	Q	Total	KC	CS	DS
a	**70**	25	14	15	0	1	125	A	0.7661	–0.3145
b	15	**75**	27	7	1	0	125	O	0.7258	–0.8226
c	24	**64**	23	11	2	1	125	O	0.7213	–0.7131
d	**69**	31	15	9	1	0	125	A	0.8065	–0.3710
e	**76**	25	12	10	2	0	125	A	0.8211	–0.3008
f	24	20	**70**	9	2	0	125	M	0.3577	–0.7317
g	16	27	22	**57**	1	2	125	**I**	0.3525	–0.4016

As introduced in Section II-B, Shapley value is used to distribute the importance weights of CRs owing to their marginal contributions. Firstly, the CS value of each CR is taken as corresponding value function, e.g., $v(a) = CS_1 = 0.7661$. Meanwhile, for other kth level coalitions, according to the linearity property of Shapley value, e.g.,

$$v(a \cup b) = v(a) + v(b) = CS_1 + CS_2.$$
$$= 0.7661 + 0.7258 = 1.4919.$$

After we have derived all the value functions of different coalitions, with respect to (7), the mean values with or without the kth CR in each combination can be obtained, and the results of which are summarized in Table IV. In our case, there are six levels of coalitions. The figure in parenthesis after each level represents the number of coalitions in this level. The crossing point of column $\bar{n}$ with a specific level denotes the average value of all coalitions inside this level $(\bar{1}, \bar{2}, \cdots, \overline{(n-1)}, \frac{1}{n}(all))$, and the intersection nodes of columns a-f with a picked level demonstrate the mean values of these combinations that contain the kth CR. For instance, for intersection points in column a, they represent $a, \overline{a*}, \cdots, \overline{a****}$, respectively.

TABLE IV
The calculation procedure of Shapley value in (7)

	$\bar{n}$	a	b	c	d	e	f
1^{st} (6)	0.6998	0.7661	0.7258	0.7213	0.8065	0.8211	0.3577
2^{nd} (15)	1.3995	1.4526	1.4203	1.4167	1.4849	1.4966	1.1259
3^{rd} (20)	2.0993	2.1391	2.1149	2.1122	2.1633	2.1721	1.8940
4^{th} (15)	2.7990	2.8255	2.8094	2.8076	2.8417	2.8475	2.6622
5^{th} (3)	3.5502	3.6091	3.5502	3.5502	3.5502	3.6366	3.4049
6^{th} (1)	4.1985						

Based upon the primary results in Table IV and (6)-(7), we are able to figure out the Shapley value of each customer requirement as follows,

$$S_1 = \frac{1}{5} * (0.7661 - 0.6998) + \frac{1}{4} * (1.4526 - 1.3995) + \frac{1}{3} * (2.1391 - 2.0993) + \frac{1}{2} * (2.8255 - 2.7990) + \frac{1}{1} * (3.6091 - 3.5502) + \frac{1}{6} * 4.1985 = 0.8117. \quad (17)$$

Analogous to (17), S_2-S_6 are easily obtained and listed in Table V. The CR with the largest marginal contribution is the 'Solid audio capability' (e), which is an Attractive attribute, while the CR with the least contribution is the 'Large storage' (f), which is a Must-be attribute. The total amount of all Shapley values is 4.1985, which is equal to the value of the coalition of participants altogether, which further confirmed the first property of Shapley value in (5). Meanwhile, from Table III we can see that CS_5 (0.8211) is more than twice larger than CS_6 (0.3577), and DS_6 (–0.7317) is more than twice larger than DS_5 (–0.3008). Therefore, it makes sense that Shapley value of the 5th CR S_5 is more than three times greater than S_6.

TABLE V
SHAPLEY VALUES AND RELATIVE IMPORTANCE WEIGHTS OF CRS BASED ON CS VALUES

Shapley value	S_1	S_2	S_3	S_4	S_5	S_6
	0.8117	0.7206	0.7110	0.7852	0.8832	0.2808
Importance weight (%)	w_1	w_2	w_3	w_4	w_5	w_6
	19.3338	17.1630	17.0773	18.7007	21.0368	6.6883

In regard to the above Shapley value analysis, we can further generate the relative importance weight w_i of each CR by the following formula as

$$w_i = \frac{S_i}{\sum_{i=1}^{n} S_i} * 100\%. \quad (18)$$

For example, the relative importance weight of the first CR is

$$w_1 = (0.8117/4.1985) * 100\% = 19.3338\%. \quad (19)$$

And the remaining relative importance weights are calculated and displayed in Table V, which are in consistency with their corresponding Shapley values, and the 5th CR scores the highest, while the 6th CR is of the lowest significance.

Surely, the DS value can also be regarded as the value functions for CRs, and the relevant results of Shapley value S'_1-S'_6 are carried out as well, which are listed in Table VI.

TABLE VI
SHAPLEY VALUES BASED ON DS VALUES

Shapley value	S'_1	S'_2	S'_3	S'_4	S'_5	S'_6
	–0.2928	–0.7665	–0.6789	–0.4053	–0.2750	–0.8352

It can be seen that the order of this DS-type Shapley value is the same as the CS-type, but there are slight differences with the deviations among S'_2-S'_4 in Table VI compared with S_2-S_4 in Table V. Intuitively, we adopt the relative importance weights in Table V in the next QFD procedure.

The remaining part in this section is about the implementation of the proposed non-linear programming models based on Nash bargaining in Section III, but the data of the subsequent research have not been prepared thoroughly yet.

V. Conclusion

This paper combined the cooperative games into product design process in two aspects. One aspect was ascertaining the importance weights of customer requirements in terms of Shapley value considering each CR's marginal contribution to the whole customer satisfaction. During this course, the quantitative results of Kano's model help provide the value functions for calculation. The other aspect was establishing a non-linear programming model to determine the target levels of ECs in the new generation product so as to maximize the overall customer satisfaction. The objective of this model was a Nash bargaining function among the fulfillment levels of CRs, which was different from the objectives in the former literature. Although both of the applications of game theory in Kano's model and QFD are rare, we can switch our angles of thinking to conduct some interesting and meaningful researches regarding them. For instance, the Δ Shapley value with the variation of the CS or DS values in Kano's models can be further studied.

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References

[1] Y. Akao, Quality Function Deployment: Integrating Customer Requirements into Product Design, Cambridge, MA: Product Press, 1990.
[2] N. Kano, N. Seraku, F. Takahashi, and S. Tsuji, "Attractive quality and must-be quality, Hinshitsu," J. Jpn. Soc. Qual. Contr., Vol. 14, pp. 39–48, April 1984.
[3] C. Berger, R. Blauth, D. Boger, C. Bolster, G. Burchill, W. DuMouchel, et al., "Kano's methods for understanding customer-defined quality," Cent. Qual. Manage. J., pp. 3–35, Fall 1993.
[4] P. Ji, J. Jin, T. Wang, Y. Chen, "Quantification and integration of Kano's model into QFD for optimising product design," Int. J. Prod. Res., Vol. 52, No. 21, pp. 6335–6348, July 2014.
[5] L. S. Shapley, "A value for n-person games," in Contribution to the Theory of Games, Vol. II, H. W. Kuhn and A. W. Tucker, Eds. Princeton, NJ: Princeton University Press, 1953, pp. 307–317.
[6] M. Conklin, K. Powaga, S. Lipovetsky, "Customer satisfaction analysis: Identification of key drivers," Eur. J. Oper. Res., Vol. 154, No. 3, pp. 819–827, May 2004.
[7] M. Conklin, S. Lipovetsky, "Marketing design analysis by TURF and shapley value," Int. J. Inf. Tech. Dec. Mak., Vol. 4, No. 1, pp. 5–19, March 2005.
[8] J. R. Hauser, D. Clausing, "The house of quality," Harvard Bus. Rev., Vol. 66, No. 3, pp. 63–73, May 1988.
[9] I. Poel, "Methodological problems in QFD and directions for future development," Res. Eng. Des., Vol. 18, No. 1, pp. 21–36, may 2007.
[10] Y. Chen, J. Tang, R. Y. K. Fung, Z. Ren, "Fuzzy regression-based mathematical programming model for quality function deployment," Int. J. Prod. Res., Vol. 42, No. 5, pp. 1009–1027, March 2004.
[11] Z. Yang, Y. Chen, Y. Yin, "Cooperative fuzzy games approach to setting target levels of ECs in quality function deployment," The Scientific World J., Vol. 2014, Article ID 673563, pp. 1–9, July 2014, Available: http://dx.doi.org/10.1155/2014/673563.