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Integrating conjoint analysis with quality function deployment to carry out customer-driven concept development for ultrabooks

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ABSTRACT

A hybrid framework integrating conjoint analysis (CA) with quality function deployment (QFD) is presented to incorporate customer preferences into the process of product development. In particular, the proposed framework constitutes two sequential phases, namely, concept generation based on CA and prototype evaluation based on QFD. In addition, product features are characterized by customer requirements (CRs) and functional attributes (FAs). By means of DEMATEL (*Decision Making and Trial Laboratory*), the impacts of FAs on CRs are systematically identified to visualize their causalities. Instead of utilizing FAs, the TOPSIS (*Technique for Order Preference by Similarity to Ideal Solution*) is employed to assess potential prototypes in terms of CRs.

1. Introduction

In an era of global customization, owing to dynamically changing customer desires coupled with rapid advances in manufacturing technologies, today's marketplaces are full of various product offerings. Back to 2011, Ultrabooks are designed to feature reduced size (less than 2.1 cm thick) and weight (less than 1.5 kg) without compromising system performance and battery life. Thus, low-power Intel processors with integrated graphics and unibody chassis are used to fit larger batteries into smaller cases. Different from past products like netbooks and notebooks, ultrabooks would be very thin, quite slight, and could also accommodate tablet features such as a touch screen and long battery life [29,30]. Obviously, the Ultrabook directly competes against Apple's MacBook Air, which has similar product specifications, but runs the kernels of Apple OS (and is capable of running Microsoft Windows). In order to avoid fatal mistakes before implementing practical product strategies, companies need to deliberately understand what customers want and desire for capturing customer preferences or customer perceptions.

In practice, new product development defined as a process of transforming an identified market opportunity into profitable product(s) for sale [4,26], usually consists of a sequence of steps in which an enterprise could employ it to accomplish the goal of commercialization. Typically, the NPD process consists of the following six phases, such as initial planning, concept development, system-level design, detail design, testing and refinement, and production ramp-up [24]. Among them, the phase of concept development is of critical importance because it does not only impact on downstream activities of the whole process, but also influence NPD's overall success, significantly. In particular, the process of concept development includes a couple of representative activities: (1) identifying customer needs, (2) concept generation, (3) concept selection, (4) cost analysis, (5) prototype testing, and (6) benchmarking analysis [14,15]. In this paper, we particularly focus on two critical activities, namely, concept generation and concept selection. Needless to say, product development without incorporating customer involvement into the process of concept development is doomed to failure since huge gaps might exist between perceived customer requirements (CRs) and configured functional attributes (FAs).

Specifically, five main schemes are commonly adopted for concept evaluation, including utility theory, analytical hierarchy/network process (AHP/ANP), graphical methods, fuzzy logic approaches, and QFD matrices [2,3]. Apparently, most of the above methods are fully reliant on subjective human assessment or experts' domain knowledge. For instance, a pairwise comparison among two alternatives is often applied to a respondent by asking the following question: *How much degree is concept A preferred to concept B with respect to a specific dimension*? Apparently, due to lack of concrete product features, the AHP [21] seems to be quite ambiguous in practice. Suppose there are n criteria at a hierarchy, we need to complete $\frac{n(n-1)}{2}$ times of pairwise comparisons for deriving their importance [20]. Obviously, when the number of criteria or competitive alternatives is over seven, its feasibility is highly doubtful for respondents to reach a consistent result. Thus, instead of using the AHP/ANP based schemes, this study integrates the conventional QFD

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with conjoint analysis (CA) to incorporate customer preference and utility into the decision-making process of concept development. In addition, artificial neural networks (ANNs) and clustering techniques have been sorely utilized or fused together to help firms achieve product conceptualization, product definition and product customization [7,28].

For clarity, Table 1 briefly compares our proposed approach with other past studies. Unfortunately, most of the previous studies rarely explore the impacts of FAs on CRs and hence it is quite challenging for them to assess product alternatives in a customer-driven way. Followed by [5,10,14,15,22,23,25], a market-oriented approach is presented and several crucial issues are addressed below:

- Based on the QFD platform, product features are characterized by perceived customer requirements (CRs) and configurable functional attributes (FAs) and a systematic approach is offered to identify the causal impacts of FAs on CRs,
- With respect to distinct segments, CA is employed to extract customer utilities of FAs for generating design concepts in a customer-driven way,
- With consideration of manufacturing costs, prototype alternatives are prioritized in terms of market-oriented CRs for offering managerial implications.

In particular, two fundamental design phases are emphasized in this study: phase 1 for concept generation and phase 2 for prototype evaluation. The rest of this paper is structured as follows. Section 2 briefly overviews conjoint analysis and quality function deployment. Section 3 presents the proposed framework. An industrial example regarding configuring varieties of ultrabooks is illustrated in Section 4. Concluding remarks are finally drawn in Section 5.

2. Overview of quality function deployment and conjoint analysis

In response to customer desire and much shorter product life cycle than ever, launching attractive products faster than competitors can assist firms in not only acquiring larger market share but also reducing development lead time, significantly. In practice, however, manufacturing companies are often struggling with the dilemma of increasing product variety or controlling manufacturing complexity [15,25]. In other words, to survive in a wide range of market segments, companies are now more aware that seeking an optimal balance between enhancing product varieties and controlling manufacturing complexities is the key to staying ahead of competitors. In order to help an enterprise better optimize product varieties at the marketplace, typical schemes including product family architecture, product platform design, and product module mix have been widely presented [7,18].

In addition, two fundamental design phases are emphasized in product conceptualization, including product definition (aiming at establishing a product platform and relevant product family as well as design alternatives) and product customization (focusing on transferring specific customer desires into corresponding product design alternatives). Specifically, product conceptualization can be practically implemented by a set of customer requirements (CRs) and functional attributes (FAs). To effectively fulfill customer satisfaction, an enterprise needs to understand how product offerings are preferred and perceived in terms of market-oriented CRs. Meanwhile, to acquire new opportunities and to survive among distinct segments, an enterprise requires working out potential concepts or profitable prototypes through a series of decision-making processes [13,17,26].

In order to facilitate research gap between product configuration and concept development, a hybrid framework combining quality function deployment (QFD) with conjoint analysis (CA) is adopted in this study. As we know, the conventional QFD is good at interpreting intangible CRs in terms of measurable FAs for performing product definition, yet, it is deficient in realizing product customization, especially when incorporating customer preference or customer perception into the process of product development [5,10,22]. Furthermore, without considering the interrelationships between CRs and FAs, it might be problematic to give priorities to design alternatives. Thus, in this paper, CA is incorporated into the QFD and their details are briefly overviewed later. For convenience, an overall comparison between AHP, CA, and QFD is shown in Table 2 [14,16,24].

2.1. Quality function deployment (QFD)

Quality function deployment [1] originated in Japan has been widely applied to various industries for product development, service design, and competitor benchmarking. Basically, customers' desires on a specific product or service can be represented by a set of intangible customer requirements (CRs) and thus a series of functional attributes (FAs) that impact on CRs need to be realized for accomplishing successful product development or service design. Typically, the conventional QFD consists of the following four phases [6,25]: phase one translates customer requirements into functional attributes; phase two translates functional attributes into part characteristics; phase three translates part characteristics into manufacturing operation, and phase four translates manufacturing operations into production requirements. In particular, phase one — the QFD or the so-called HOQ (house of quality), provides a communication platform to fuse diverse opinions among cross-functional team members (see Fig. 1).

Table 1
A comparison between the proposed method and other existing studies.

	Market segmentation	Identifying the causalities between CRs and FAs[a]	Concept generation and prototype evaluation
Proposed method	Customers' affordable prices (pricing policies)	QFD and DEMATEL	Customer-driven by integrating CA with TOPSIS
Ayağ [2], Ayağ and Özdemir [3]	Not applicable	Not applicable	Reliant on domain experts
Chaudhuri and Bhattacharyya [5]	Not applicable	QFD	Integrating CA with integer programming
Chen et al. [7]	Respondents' ages, gender, and skill levels	Not applicable, only considering FAs	Customer-driven by fusing CA with Kohonen association
Fogliatto et al. [10]	Choice menus	Not applicable	Stated preferences
Işıklar and Büyüközkan [13]	Not applicable	Not applicable, but including product and interface features	Combining AHP with TOPSIS
Jiao and Zhang [15]	Not applicable, but considering manufacturing costs	Not applicable, only considering FAs	CA
Lin et al. [17]	Not applicable	Not applicable, only considering FAs	Combining AHP with TOPSIS
Liu and Hsiao [18]	Not applicable	ANP	Goal programming
Sereli et al. [22]	Not applicable	QFD	Not applicable
Yan et al. [28]	Not applicable	Not applicable, only considering FAs	General sorting and FCM clustering

[a] CRs stand for customer requirements and FAs represent functional attributes.

Table 2
An overall comparison between QFD, CA, and AHP.

	QFD	CA	AHP
Basic principle	Mapping customer requirements into functional attributes	Making trade-offs among simplified alternatives	Conducting pair-wise comparisons among alternatives
Handling multi-leveled product attributes	Limited	Good	Good
Source of gathering product information	Customers/experts	Customers	Most experts
Extracting customer preference for product features	Not applicable	Good	Good
Recognizing correlations between CRs and FAs	Good	Not applicable	Not applicable

In order to connect intangible CRs with measurable FAs, the weights of CRs and FAs could be modified and derived as follows [25,27]:

$$Wt_{CR_j} = \sum_{i=1}^{m} Wt_{FA_i} R_{ij}{}', 1 \le i \le m, \quad 1 \le j \le n, \tag{1}$$

$$R_{ij}{}' = \frac{\sum_{k=1}^{m} R_{jk} \times \gamma_{ki}}{\sum_{i=1}^{m}\sum_{k=1}^{m} R_{jk} \times \gamma_{ki}}, \tag{2}$$

where Wt_{CR_j} and Wt_{FA_i} represent the weight of CR_j and FA_i, respectively. Meanwhile, we assume that n customer requirements and m functional attributes exist in the QFD, R_{jk} means the dependences between FA_i and CR_j (R_{ij} ' is a normalized matrix), and γ_{ki} denotes the correlations among FAs. Once the weights of CRs are attained, they might be used to form a basis of market segmentation or incorporated into the evaluation system for prioritizing design alternatives.

2.2. Conjoint analysis (CA)

Conjoint analysis [19] is one of the most popular techniques to measure diverse customers' preferences among multi-attributed products or services [7,10,15,23]. When a product is decomposed into independent multi-attributes, its overall utility could be obtained by aggregating part-worth utilities of the attributes with their associated levels. In brief, CA is in nature, a process of making trade-offs among limited alternatives that are characterized by various combinations of functional attributes. After gathering respondents' preference rankings among product alternatives, two critical measures could be obtained through CA: the importance degrees of functional attributes and the part-worth utilities of attributes associated with specific levels. Apparently, CA could be applied to analyzing customer individuals or previously-segmented groups for the purpose of target marketing. In this study, customer preference is defined by the perceived importance degrees of FAs and the extracted part-worth utilities are utilized to form a basis of concept generation.

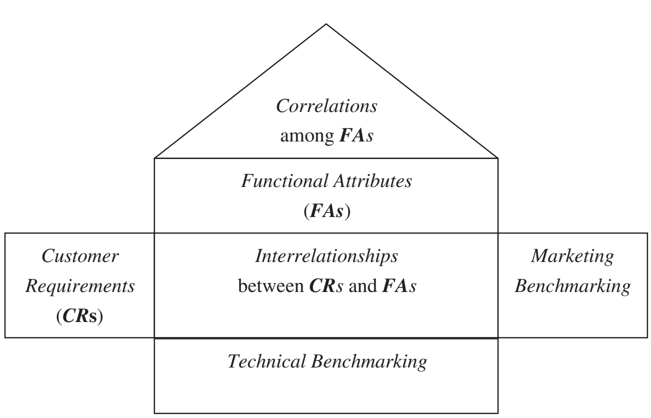

Fig. 1. A simple plot to illustrate the conventional QFD.

For simplification, let us illustrate a simple case to explain its applicability. Suppose that a product is characterized by six attributes (e.g., A1–A6) associated with specific levels (also see Fig. 2), intuitively, a maximal number of 144 (3 × 2 × 2 × 3 × 2 × 2) combinations may be possibly generated. When deriving their part-worth utilities among respondents, it is practically infeasible to ask an evaluator to prioritize 144 alternatives at a time. Hopefully, by means of fractional factorial design [11], the required alternatives for prioritizing can be significantly reduced to only 16 orthogonal samples. For convenience, a general form of CA for an alternative can be briefly modeled as follows:

$$U_k = \beta_0 + \sum_{i=1}^{m}\sum_{j=1}^{n} u_{ijk}, \tag{3}$$

where U_k is alternative k's overall utility, β_0 is a regularized constant, u_{ijk} is the part-worth of alternative k associated with attribute i and level j, m represents the number of attributes, and n denotes the number of corresponding levels. In order to derive the importance degree of functional attributes, it is commonly believed that attributes with a larger range of part-worth values should have a greater impact on the overall utility. Therefore, the relative weight (W_i) of attribute i can be obtained by normalizing its range (R_i) of part-worth utility:

$$W_i = \frac{R_i}{\sum_i R_i}, \text{where} \quad R_i = \underset{j}{Max}\left(u_{ij}\right) - \underset{j}{Min}\left(u_{ij}\right). \tag{4}$$

3. Proposed techniques

Referring to Fig. 3, several techniques including CA (conjoint analysis), DEMATEL (*decision making and trial laboratory*) and TOPSIS (*technique for order preference by similarity to ideal solution*) are well fused into the QFD to perform market-oriented concept generation and prototype evaluation. For convenience, their details are operated and described as follows:

- Initially, the QFD is employed to separate product features into either perceived CRs (customer requirements) or configurable FAs (functional attributes),
- Secondly, based on customers' affordable prices, the entire market is divided into two distinct segments, namely, the business segment and the home segment,
- With respect to two identified segments, CA is respectively applied to derive respondents' perceived importance weights of FAs and extract customer utilities of FAs for generating potential concepts,
- By virtue of the DEMATEL, the causal dependences of FAs on CRs are identified and thus the importance weights of CRs can be derived,
- Finally, with the aid of TOPSIS, the priorities of selected prototypes are systematically assessed and determined in a market-oriented manner.

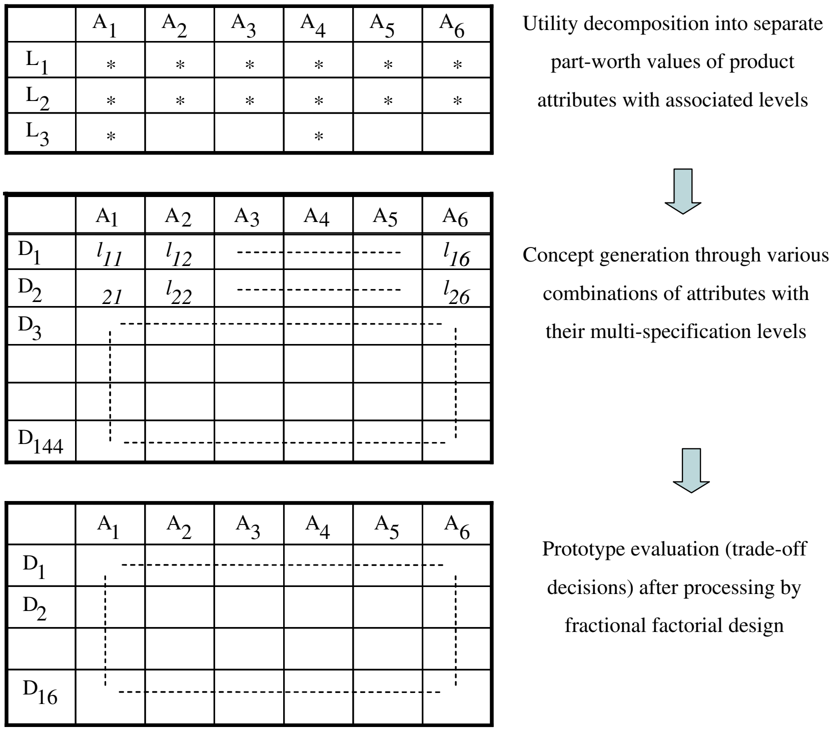

Fig. 2. Simplifying concept generation through conjoint analysis.

3.1. Use of DEMATEL to derive the interdependences between FAs and CRs

DEMATEL (*decision making and trial laboratory*), developed by the science and human affairs program of the Battelle Memorial Institute of Geneva Research Centre [9], is able to visualize the complex interrelationships among interdependent factors. Through converting their causal relationships of the whole system into an intelligible structure model, the DEMATEL could distinguish all factors into either the transmitter group which impacts on other factors or the receiver group which is influenced by other factors [25,26]. By using a 5-point rating scale (i.e. 1: *very low*, 2: *low*, 3: *moderate*, 4: *high*, 5: *very high*), domain experts are required to quantify their influential measures among factors and its details are described as:

- Generating the direct-relation matrix: Suppose there are m CRs and n FAs for the QFD framework, then, a $(m + n) \times (m + n)$ matrix A with elements of a_{ij} is filled to denote the impact of factor i exerted on factor j. Here, note that all diagonal elements of matrix A are initially set by zero.

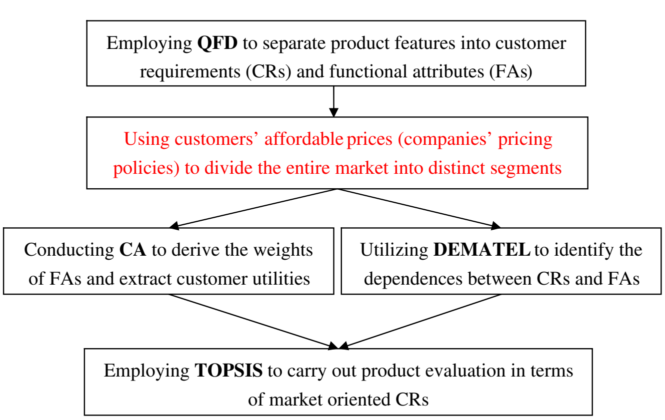

Fig. 3. The proposed research framework.

- Normalizing the direct-relation matrix: the normalized matrix B could be obtained through the above-mentioned matrix A (see Eqs. (5)–(6)), in which

$$B = k \times A \tag{5}$$

$$k = Min\left(\frac{1}{\max\limits_{j} \sum_{j=1}^{m+n} |a_{ij}|}, \frac{1}{\max\limits_{j} \sum_{i=1}^{m+n} |a_{ij}|}\right). \tag{6}$$

- Deriving the total-relation matrix: the total-relation matrix M can be derived via Eq. (7), where I denotes an identity matrix.

$$M = B + B^2 + B^3 + \cdots = B(I-B)^{-1} \tag{7}$$

Specifically, the interdependences between FAs and CRs could be extracted through the total-relation matrix.

- Displaying a causal diagram through distinguishing the transmitter group T from the receiver group R:

$$T_i = \sum_{j=1}^{n} M_{ij}, \tag{8}$$

$$R_j = \sum_{i=1}^{n} M_{ij}, \tag{9}$$

where T is the sum of rows of the total-relation matrix while R is the sum of columns.

A causal diagram is visualized by portraying the dataset comprising $(T + R, T - R)$, where the horizontal axis represents "$T + R$" and the vertical axis denotes "$T - R$". Intuitively, the "$T + R$" named "*prominence*" reveals how much important the factor is. On the other hand, the "$T - R$" named "*influence*" classifies the factor into either the cause group or the effect group. In simple words, the factors in the cause group are acting as a "*dispatcher*" since they impact on the others. By contrast, the factors in the effect group are playing as a "*receiver*" because they are affected by the others.

3.2. Use of TOPSIS to prioritize design concepts and product prototypes

Originated from Hwang and Yoon [12], TOPSIS (*technique for order preference by similarity to ideal solution*) was proposed to seek an optimal solution which is the most closest to the "*PIS*" (positive ideal solution) but the farthest from the "*NIS*" (negative ideal solution). Suppose there are m alternatives and n attributes (criteria), the TOPSIS are operated by the following procedures [13,17]:

- Generating a decision matrix. A $m \times n$ decision matrix (i.e. m represents the number of alternatives and n denotes the number of attributes), X, consists of the elements of x_{ij} representing the performance rating of the ith alternative with respect to the jth attribute.
- Construing a normalized decision matrix. To reduce the scale effect among various dimensions, the normalized matrix Y is obtained as:

$$y_{ij} = \frac{x_{ij}}{\underset{i}{Max}\, x_{ij}}, \text{for} \quad \forall x_{ij} \in \text{ the set of “benefit” attributes}, \tag{10}$$

$$y_{ij} = \frac{\underset{i}{Min}\, x_{ij}}{x_{ij}}, \text{for} \quad \forall x_{ij} \in \text{ the set of “cost” attributes}. \tag{11}$$

Here, the "benefit" attributes possess the property of "the-larger-the-better" while the "cost" attributes own the characteristic of "the-smaller-the-better".

- Searching for the elements of "*PIS*" (S^+) and "*NIS*" (S^-) by using:

$$S_j^+ = \left\{ \underset{i}{Max} \quad y_{ij} \,|\, j = 1, 2, \ldots. n \right\}, \tag{13}$$

$$S_j^- = \left\{ \left(\underset{i}{Min} \quad y_{ij} \,|\, j = 1, 2, \ldots. n \right\}, \tag{14}$$

where S_j^+/S_j^- denotes the jth element of S^+/S^-, respectively.

- Measuring a weighted distance from alternative i to the "*PIS*" and the "*NIS*":

$$D_i^+ = \sqrt{\sum_{j=1}^{n} w_j * \left(y_{ij} - S_j^+ \right)^2}, i = 1, 2, \ldots. m \tag{15}$$

$$D_i^- = \sqrt{\sum_{j=1}^{n} w_j * \left(y_{ij} - S_j^- \right)^2}, i = 1, 2, \ldots. m, \tag{16}$$

where w_j represents the weight of attribute j.

- Conducting a ranking index (RI) for competing alternatives (prototypes):

$$RI_i = \frac{D_i^-}{D_i^+ + D_i^-}, i = 1, 2, \ldots. m. \tag{17}$$

In terms of market-oriented CRs, the weights of CRs derived through the DEMATEL are incorporated into the TOPSIS for evaluating competing prototypes.

4. An illustrative example of assessing various prototypes of ultrabooks

At the Intel Developer Forum in 2011, four Taiwan ODMs showed prototype ultrabooks that used Intel's Ivy Bridge processors which only consume 17 W default thermal power. Meanwhile, Intel tries to enhance the slumping PC markets against rising competition from tablet computers such as the iPad, which are typically powered by the ARM-based architectures [29,30]. Originally, for fast stimulating market sales, Intel plans to set a "below $1000" price for ultrabooks. However, the presidents of Acer and Compal think that this goal could be difficultly achieved if Intel did not lower the price of its CPU chips. In 2011, an Intel manager stated that market analysis should be carefully carried out to investigate customer preference for screen size since it might influence some of the reluctance to switch to ultrabooks. Actually, 11–12 inch ultrabooks might replace/substitute the markets of smart pads and netbooks to some degree while 13–14 inch ultrabooks currently dominate at least 50% models for the high-end segment.

A large-scale Taiwanese OEM/ODM company planned to precisely relate customer requirements (CRs) to functional attributes (FAs) prior to launching its next-generation ultrabooks. After looking at the specifications of current products and consulting experienced experts, six representative CRs and FAs associated with multi-levels and component costs are shown in Table 3. In addition to six critical FAs, it is noted that other common components like mother board, graphics card, Wi-Fi chip, front camera, keyboard, and the pre-installed operating system, are configured in an ultrabook and their entire cost is roughly estimated around 7100 in $TWD. More specifically, the questionnaires as well as relevant supporting commercial packages are illustrated in Table 4. Based on customers' affordable prices (companies' pricing policies), the target market is partitioned into two segments, namely, the business segment (pricing around $30,000 in TWD) and the home segment (pricing around $24,000 in TWD), respectively. For differentiating launched ultrabooks from Apple's products, the above pricing policies are set with consideration of MacBookAir's high-end prices (between $36,000 and $40,000 in TWD).

4.1. Concept generation based on customer utilities of FAs

Initially, a total number of 160 respondents are invited to complete marketing surveys on ultrabooks. Specifically, 54% of the respondents consist of high-tech engineers (aged between 26 and 40) in the Hsinchu Science Park. And the remaining 46% is composed of graduate students in our university (aged between 22 and 30). All of the invited respondents are pre-screened to assure having experiences in using ultrabooks. After taking the multi-levels of FAs into account, intuitively, there are 144 ($3 \times 2 \times 2 \times 3 \times 2 \times 2$) design concepts which might be possibly generated. In particular, fractional factorial design originated from the concept of design of experiments [11] is employed to reduce 144 possible concepts to 16 representative samples, as indicated by Table 5. Moreover, to reduce the serial position effect like primacy and recency biases in psychological decision making [8], we suggest evaluators to focus on three key FAs when making the trade-offs among various FAs. Furthermore, to speed up the ranking process, they need to first

Table 3
Critical CRs and FAs for characterizing an ultrabook.

CR (customer requirement)		FA (functional attribute)		Associated levels ($TWD)
R1	System performance (benchmarking test)	A1	CPU (type)	A11—i7 series ($5800) A12—i5 series ($4400) A13—i3 series ($3500)
R2	Booting response time (s)	A2	RAM capacity (GB)	A21—8GB ($1800) A22—4GB ($1000)
R3	Operation duration (h)	A3	Hard disk (type)	A31—SSD (3600) A32—SATA (2400)
R4	Weight (kg)	A4	Body material (type)	A41—Carbon fiber ($3900) A42—Mg/Al alloy ($2400) A43—Common ($1500)
R5	Thickness (cm)	A5	Screen size (in.)	A51—13–14 in. ($3800) A52—11–12 in. ($2800)
R6	Manufacturing cost (in $TWD)	A6	Battery capacity (mAH)	A61—8000 mAH ($3000) A62—4000 mAH ($2000)

Table 4
Illustration of simplified questionnaires.

Schemes	Associated questions	Respondents	Software
Market segmentation	● How much is your maximally accepted price when purchasing an ultrabook ($30,000 or $24,000 in TWD)?	Consumers	Not applicable
CA	● What are your most preferred 5 alternatives (ranking from 1 to 5)? ● What are your most disgusting 5 alternatives (ranking from 12 to 16)? ● What are the intermediate 6 alternatives (ranking from 6 to 11)?	Consumers	SPSS
DEMATEL	● How much influence does FA_i impact on CR_j (ranging from 1 to 5)?	Experts	MATLAB
TOPSIS	● Not Applicable (N/A), through performing prototype testing.	N/A	MATLAB

determine their most preferred five alternatives, then select their most disgusting five ones, and leave the remaining six to the last.

After distinguishing the business segment from the home segment, conjoint analysis is applied to these two groups to extract their perceived importance weights of FAs and associated part-worth utilities for the purpose of concept generation. By observing customers' perceived importance weights (similar to customer preferences), Table 6 displays a diverse pattern for the priorities of FAs: $A1 \succ A4 \succ A3$ is favored by the business segment while $A1 \succ A5 \succ A2$ is preferred by the home segment. Apparently, the business group concerns more on CPU (A1), hard disk (A3), and body material (A4) than the remaining FAs. In contrast, the home group pays more attention to CPU (A1), RAM capacity (A2), and screen size (A5). Meanwhile, customer utilities of FAs (corresponding to associated levels) are further processed and extracted in Table 7. Very interestingly, the business segment favors smaller screen size (11″–12″) while the home segment prefers larger screen size (13″–14″). Finally, through prioritizing overall customer preference (OCP), the top five design concepts are selected and shown in Table 8 (see Eq. (18)).

$$OCP = \sum_{i=1,4} \sum_{j=1}^{3} x_{ij} u_{ij} + \sum_{i=2,3,5,6} \sum_{j=1}^{2} x_{ij} u_{ij}, \tag{18}$$

$$s.t. \sum_{j=1}^{3} x_{ij} = 1, \quad i \in \{1,4\}, (\text{three-level FAs}),$$

$$\sum_{j=1}^{2} x_{ij} = 1, \quad i \in \{2,3,5,6\}, (\text{two-level FAs}).$$

Table 5
Orthogonal questionnaire design characterized by functional attributes.

	CPU type	Memory capacity	Hard disk	Body material	Screen size	Battery capacity
1	i5	8 GB	SATA	Common	13–14 in.	4000 mAH
2	i7	4 GB	SATA	Common	11–12 in.	4000 mAH
3	i7	4 GB	SATA	Carbon fiber	11–12 in.	8000 mAH
4	i7	8 GB	SATA	Mg/Al alloy	11–12 in.	8000 mAH
5	i5	4 GB	SSD	Mg/Al alloy	11–12 in.	4000 mAH
6	i5	4 GB	SSD	Mg/Al alloy	11–12 in.	8000 mAH
7	i7	8 GB	SSD	Mg/Al alloy	13–14 in.	4000 mAH
8	i3	4 GB	SATA	Mg/Al alloy	13–14 in.	4000 mAH
9	i3	8 GB	SSD	Common	11–12 in.	8000 mAH
10	i7	4 GB	SSD	Common	13–14 in.	8000 mAH
11	i7	8 GB	SATA	Mg/Al alloy	13–14 in.	4000 mAH
12	i7	4 GB	SSD	Carbon fiber	13–14 in.	4000 mAH
13	i3	8 GB	SSD	Carbon fiber	11–12 in.	4000 mAH
14	i7	8 GB	SSD	Mg/Al alloy	13–14 in.	8000 mAH
15	i3	4 GB	SATA	Mg/Al alloy	13–14 in.	8000 mAH
16	i5	8 GB	SATA	Carbon fiber	13–14 in.	8000 mAH

Table 6
Extracted importance weights of FAs for two distinct segments.

	Entire	Business	Home
A1 CPU type	0.292	0.326	0.266
A2 RAM capacity	0.129	0.076	0.171
A3 Hard disk type	0.161	0.192	0.137
A4 Body material	0.162	0.202	0.131
A5 Screen size	0.113	0.045	0.166
A6 Battery capacity	0.142	0.158	0.129
Count	160	48	62

4.2. Prototype evaluation in terms of market-oriented CRs

In order to derive the weights of CRs, the interdependences between FAs and CRs need to be systematically identified. Referring to Fig. 4, the DEMATEL is applied to invited experts to consult their judgments on the interdependences between CRs and FAs. For instance, a simple question is usually performed as follows: *How much influence does FA_i $(1 \le i \le m)$ impact on CR_j $(1 \le j \le n)$ in a 5-point rating scale*? As shown in Table 9, the interdependences between FAs and CRs are utilized to derive the weights of CRs and they are consecutively incorporated into the TOPSIS ranking. In order to visualize the complicated interrelationships among all factors, Table 10 lists the four main scores of CRs and FAs: active score, passive score, prominence score, and influence score. Hence, a structural diagram could be accordingly portrayed in Fig. 5. Apparently, all FAs (denoted by the symbol of "square") are categorized into the "cause" group because of having "positive" influence. Conversely, all CRs (denoted by the symbol of "diamond") are classified into the "effect" group due to having "negative" influence.

At the phase of concept generation, recall that only the top five priorities of potential concepts are screened out for speeding up the entire process. Now, at the phase of prototype evaluation, they are configured into potential prototypes and passed to the testing center for measuring their performances of CRs. By means of the TOPSIS, a market-oriented approach is adopted to assess selected prototypes with respect to the business segment (see Table 11) and the home segment (see Table 12), respectively. At a first glance of the weights of CRs, it is found that an order of $R6 \succ R2 \succ R3$ presents a pattern for the significant CRs and that means, three CRs including "manufacturing cost", "response time", and "operation duration" are mostly concerned in the minds of customers. Thereafter, rather than merely considering engineering-oriented FAs, selected prototype are systematically assessed and reprioritized in terms of market-oriented CRs.

Table 7
Mean customer utility of FAs with associated levels.

Attributes	Specifications	Entire	Business	Home
CPU type	i7 series	1.387	1.853	1.026
	i5 series	−0.207	−0.346	−0.099
	i3 series	−1.181	−1.507	−0.928
RAM capacity	8GB	0.525	0.391	0.628
	4GB	−0.525	−0.391	−0.628
Hard disk	SSD	0.717	0.991	0.504
	SATA	−0.717	−0.991	−0.504
Body material	Carbon fiber	0.558	0.741	0.417
	Mg/Al alloy	0.334	0.596	0.131
	Common	−0.893	−1.338	−0.548
Screen size	13–14 in.	0.244	−0.231	0.611
	11–12 in.	−0.244	0.231	−0.611
Battery capacity	6000 mAH	0.624	0.816	0.476
	3500 mAH	−0.624	−0.816	−0.476

Table 8
Suggested potential prototypes by means of CA.

	Business (cost < 30,000 in $TWD)					Home (cost < 24,000 in $TWD)				
	*P*1	*P*2	*P*3	*P*4	*P*5	*P*1	*P*2	*P*3	*P*4	*P*5
A1	A11	A11	A11	A11	A11	A12	A12	A13	A13	A12
A2	A21	A21	A21	A21	A22	A21	A21	A21	A21	A21
A3	A31	A31	A31	A31	A31	A32	A32	A31	A32	A32
A4	A41	A42	A41	A42	A41	A42	A42	A43	A43	A43
A5	A52	A52	A51	A51	A52	A51	A52	A51	A51	A51
A6	A61	A61	A61	A61	A61	A62	A61	A62	A61	A62

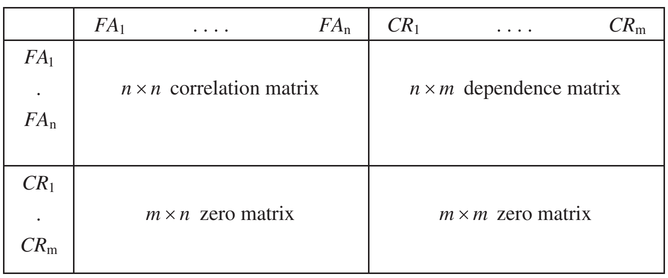

Fig. 4. Input of the direct-relation matrix for the DEMATEL.

Finally, let us illustrate the optimal combination of FAs (A1–A6) for the identified two segments. Referring to both Tables 3 and 8 again, the top winner *P*1 for the business segment is characterized by "*i7-CPU* (*A11*), *8G-RAM* (*A21*), *SSD-HD* (*A31*), *carbon fiber-body material* (*A41*), *11–12 inch screen* (*A52*), *and 8000 mAh battery* (*A61*)". While for the home segment, the top winner becomes *P*2 which corresponds to "*i5-CPU* (*A12*), *8G-RAM* (*A21*), *SATA-HD* (*A32*), *Mg/Al alloy-body material* (*A42*), *13–14 inch screen* (*A51*), *and 8000 mAh battery* (*A61*)". For each segment, similar explanations can be generalized to all selected prototypes (P1–P5) to characterize their configurations. Apparently, owing to diverse customer desires and different pricing policies, two distinct segments display their own preference structures through differentiating the priorities of pre-selected prototypes.

5. Concluding remarks and future research

Today, manufacturing companies are inevitably to face the trade-offs between enhancing product varieties and controlling manufacturing costs. Despite that many studies have been presented to address this issue, however, most of them are fully reliant on experts' assessments without tacking customer preferences or customer utilities into account. In order to overcome the above-mentioned shortcoming, this paper presents a hybrid framework which integrates QFD (quality function deployment) with CA (conjoint analysis). In particular, without incurring tedious pairwise comparisons between product features or among prototype alternatives, this study contributes to this domain by demonstrating the following merits: (1) concept generation is conducted in a customer-driven way (through CA), (2) the complicated interdependences between FAs and CRs are systematically identified (through DEMATEL), and (3) prototype evaluation is carried out in a market-oriented manner (through TOPSIS). Furthermore, an industrial example regarding configuration varieties of ultrabooks for different segments is demonstrated to justify the validity of our proposed framework. In future studies, Kano model, Kansei engineering, or artificial neural networks could be considered and integrated with our framework for accommodating other product features (i.e. dichotomous functional attributes or esthetic factors) or for predicting customers' dynamic desires.

Table 9
Identified interdependences between FAs and CRs through DEMATEL.

	R1	R2	R3	R4	R5	R6
A1	0.290	0.258	0.129			0.258
A2	0.194	0.194				0.065
A3		0.161	0.065	0.065		0.129
A4				0.258	0.194	0.226
A5			0.194	0.161		0.194
A6			0.323	0.194	0.065	0.129

Table 10
Visualizing a causal diagram between CRs and FAs via DEMATEL.

	Active score T_i	Passive score R_j	Prominence score $T_i + R_j$	Influence score $T_i - R_j$
A1	0.935		0.935	0.935
A2	0.452		0.452	0.452
A3	0.419		0.419	0.419
A4	0.677		0.677	0.677
A5	0.548		0.548	0.548
A6	0.710		0.710	0.710
R1		0.484	0.484	−0.484
R2		0.613	0.613	−0.613
R3		0.710	0.710	−0.710
R4		0.677	0.677	−0.677
R5		0.258	0.258	−0.258
R6		1.000	1.000	−1.000

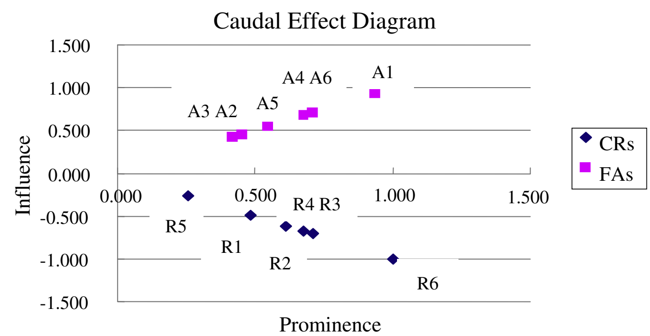

Fig. 5. The cause and effect diagram between CRs and FAs.

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Table 11
Prototype evaluation for the business segment.

CRs (weights)	Business				
	*P*1	*P*2	*P*3	*P*4	*P*5
R1 (0.158)	3000	3000	3000	3000	2700
R2 (0.187)	2.50	2.50	2.50	2.50	3.00
R3 (0.165)	6.00	6.00	5.00	5.00	6.00
R4 (0.148)	1.20	1.35	1.30	1.50	1.20
R5 (0.071)	1.50	2.00	1.50	2.00	1.50
R6 (0.272)	28,000	26,500	29,000	27,500	27,200
Similarity	0.963	0.924	0.908	0.880	0.918
Priorities	1	2	4	5	3

Table 12
Prototype evaluation for the home segment.

CRs (weights)	Home				
	P1	*P2*	*P3*	*P4*	*P5*
R1 (0.168)	2500	2500	2300	2100	2500
R2 (0.189)	4.0	4.0	3.5	5.0	4.0
R3 (0.179)	5.0	6.8	6.5	7.0	5.0
R4 (0.144)	1.6	1.5	1.8	1.8	1.8
R5 (0.051)	2.0	2.0	2.2	2.2	2.2
R6 (0.268)	23,900	23,900	23,300	23,100	23,000
Similarity	0.868	0.939	0.921	0.848	0.859
Priorities	3	1	2	5	4

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