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ASSESSMENT METHOD OF VALUE DISTRIBUTION FOR PRODUCT FAMILY DEPLOYMENT

K Fujita, H Takagi and T Nakayama

Abstract

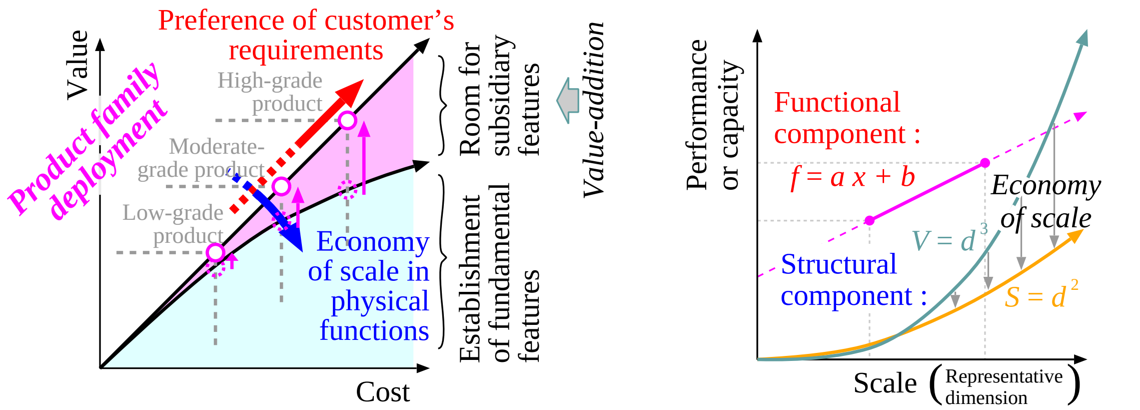
This paper proposes an assessment method for value distribution across a series of products within a product family. The maturation of society makes the life styles of individuals diverse. Such change demands the manufacturing firms the distributed integrity of a family of products from simple models to luxurious ones. The method aims to facilitate the establishment of product definitions over a product family. In the method, first the variety of customer's requirements is translated into a chained definition of required worth of respective modules and parts across products through value engineering techniques and quality function deployment, which are based on categorization of customer attributes, the standardized patterns of their distribution and switching mechanism in value propagation. Second the manufacturing cost is estimated on respective modules and parts across products through systematic utilization of design-for-X methodologies, in which the scale and cost of functional modules are assumed using the similarity laws of physical systems. Then the absolute levels of both worth and cost of all modules over different products are contrasted over the cost-worth graph. Tendency of their balances and expansion patterns reveals the controversial points of a chained product definition of a product family. The method is applied to the design analysis of three refrigerators with different capacities.

Keywords: *Product families, Quality function deployment, Value engineering, Customer satisfaction, Design-for-X.*

1 Introduction

As the society has been maturated, the customer's needs have become diversified over the variety of life styles, family structures, age groups, etc. This change is pushing product design from mass production to mass customization [1]. Such a trend is typical in home appliances, automotives, etc. Under those changes and trends, every manufacturing company requires offering a wide variety of products with different sizes, different features, etc. While each customer faces only a product, the overall image of a series of products generates its position and well-distributed products give each customer freedom of the best choice. Consequently it becomes an essential strategy for a manufacturing company to establish the chained product definition for a series of products. Since these changes require product planning wider scope on product development for compromising all associated issues, such as specifications, features, value and cost, beyond its conventional style, any sophisticated methodology is necessary for systematically compromising them.

This paper proposes an assessment method of value distribution for product family development under the above circumstance. It can be viewed as an expansion of integrated utilization of value engineering techniques, quality function deployment (QFD), and design for X methodologies on a single product to a series of products. In the following, the underlying



(a) Transition of product integrity over different grades

(b) Similarity law on primal features

Figure 1 Possibilities in value distribution of product family deployment

concepts are explained, the procedure of the assessment method is described, and then an application to the refrigerator design planning is demonstrated.

2 Form of Value Distribution in Product Family Deployment

The performance of a product is measured with equipped features, cost for implementing them and time for delivering it to the market. Although many features could be implemented if much cost were permitted, customer's budget and requirements must be moderate. Thus, the balance between features and cost is a key for a successful product. Diverse kinds of features are implemented into a consumer product, some of them define its fundamental values, and some others provide supplementary values. In the case of refrigerators, the capacity is the former, and separated compartments, an automatic icemaker, flexibility in use, low noise, etc. correspond to the latter. Furthermore, the former kinds of features are linked each other physically through system constraints. This means that different levels of fundamental values require the different sets of dimensions the relationship of which is physically governed.

According to the nature of technical systems, larger level of performance, which relates to fundamental features, can be accomplished with less cost than one proportional to its scale. On the other hand, a customer tends to require the values in a product that is proportional to or more than the cost that he or she pours onto. As a result, more subsidiary features must be introduced for enhancing the product integrity between features and cost as value addition for higher grades than lower grades. Figure 1(a) illustrates the mechanism governing such integrity.

Behind the above mechanism, the concept of similarity laws well explains such a relationship on how the room for subsidiary features is accrued. That is, for instance, a volume is the cube of a representative dimension, an area is the square of a representative dimension, and so forth as shown in Fig. 1(b). Thus, in the case of refrigerators, a double size of the capacity requires 1.260 times of original dimensions and 1.587 times of original surface area. Under this type of relationships, it is a case that a refrigerator with double capacity might cost less than two times of the original but some supplementary values must be introduced for attracting customers in proportion to its total cost. Similar scenarios are found in the design of audio-visual equipments, automotives, etc. under the aforementioned customer's mind.

While the above scenario relates to structural component, the relationship among performance, scale and cost of a functional component can be defined in any form, once the kind of devices is specified.

3 Assessment Method of Chained Product Definition

3.1 Assessment of product's value

This paper proposes an assessment method of value distribution over a series of products within a family based on the above consideration. For this purpose, quality function deployment (QFD) [2] and cost planning of value engineering [3] are introduced as its bases. QFD is a tool for assessing the correlation structure from customer attributes through engineering characteristics to manufacturing modules, and it deduces the relative worth of each manufacturing modules under customer's viewpoint. Cost planning is a tool for assessing the balance between such relative worth and relative cost of manufacturing modules for a certain product. Based on these functionalities, the authors have proposed a value-adds assessment method for product deployment across life stages [4]. Development of this method reveals that QFD and cost planning are useful for evaluating the consistency of product definition among different products that share underlying concepts. While it aims for a series of products across generations, it must be applicable for a series of products within a family.

3.2 Quality function deployment with switching mechanism

When applying QFD to a series of products, a unique set of QFD tables is applicable commonly for them because they share a underlying concept, but it is required that they can handle the difference in scale of fundamental features and implementation of subsidiary features among them.

A conventional procedure of QFD table operation is as follows: In the first phase, firstly, the items of customer characteristics are listed and their weights are assigned as u_i. Secondly, the correlation weight matrix from customer attributes to engineering characteristics is assumed as α_{ij}. Then the weight of respective engineering characteristics is calculated as $t_j = \sum_i \frac{\alpha_{ij}}{\sum_{\hat{j}} \alpha_{i\hat{j}}} u_i$, and their relative values is deduced as $t'_j = \frac{t_j}{\sum_{\hat{j}} t_{\hat{j}}}$. In the second phase, the importance weights, i.e., worths, of manufacturing modules are calculated as $m_k = \sum_j \frac{\beta_{jk}}{\sum_{\hat{k}} \beta_{j\hat{k}}} t'_j$ under the correlation weight matrix from engineering characteristics to manufacturing modules β_{jk} in a similar way to the first phase. Regarding the numerical value of weights and matrixes, any positive number, such as either of 1, 3 or 9, is assigned to u_i, and such a number or zero is assigned to α_{ij} and β_{jk}. Thus m_k is deduced as a non-zero positive number.

In applying it to a family of products, that is, sharing the unique correlation weight matrixes among them, some of u_i are zero when the corresponding feature is not required in lower grades, and then the associated manufacturing module should be eliminated, that is, it must be deduced that some of m_k are zero. In order to realize such a mechanism in the above QFD table operation, our method introduces the mechanism of '*switch*', which is a mark on the certain elements of correlation matrixes. In the mechanism, under $u_i = 0$, if α_{ij} is marked, $t_j = 0$ is deduced apart from the above equation. Under $t_j = 0$, if β_{jk} is marked, $m_k = 0$ is deduced apart from the above equation.

By combining the above switch with the conventional QFD operation, the relative worth of respective manufacturing modules and parts can be uniformly calculated for different products.

3.3 Cost estimation in the early phase of design process

Cost estimation is essential for the assessment of product integrity. Manufacturing modules and parts are categorized into functional components and structural components. In the case of refrigerators, compressor, evaporator, etc. correspond to the former, and door, tray, inner shell, frame, etc. correspond to the latter.

Cost estimation methods for the early phase of design process are applicable for structural components. Under the assumption that cost is composed of material cost, fabrication cost and assembly cost for simplicity, the following methods are used for respective cost categories. Material cost of a module is estimated based on material kind and volume. Fabrication cost of a module is estimated by combining the point method [5] and the revision method based on relative comparison [6] under the assumed fabrication method and rough geometry. Assembly cost is estimated by the Westinghouse method [7] and it is distributed to assembly operations for respective modules.

Regarding functional components, since each is composed of several kinds of materials and fabrication process is rather complicated, the above procedure is not applicable. However, it can be expected that enough samples have been accumulated for maturated products, and that new models are mostly fit within the past tendency. Thus, linear regression over their scale is used for cost estimation.

3.4 Similarity laws for estimating relationship among performance, scale and cost

Regarding the scale of respective components, the performance grade of respective subsystems can be deduced so as to accomplish the totally assigned requirements under the simultaneous system of balance equations on the functional behavior. Once such grades of respective subsystems are assumed, their scale can be deduced with the similarity laws in the sense shown in Fig. 1(b). Furthermore, their cost level can be estimated in the similar way under the past tendency.

3.5 Simultaneous cost planning of a family of products with different cost levels

As aforementioned, cost planning is effective for examining the balance between cost and worth across various manufacturing modules and parts. Their relativized values are used in it for eliminating any bias and regularizing plan assessment. However, in the case of value distribution over product family, assessment of distributed integrity requires any common base across plural models, the total cost of which must be different each other due to different level of value addition as shown in Fig. 1(a). The assessment method of this paper uses the absolute values of cost and worth as such a base. That is, the relative worth of respective manufacturing modules and parts are translated into the absolute worth by multiplying the estimated total cost of each product, and then individual modules and parts are plotted on the cost-worth graph by such values and their estimated raw cost.

This absolutization of cost planning is expected to facilitate the understanding and criticizing of value distribution among a product family. That is, the obtained shape of worth and cost distribution of respective modules across different products tells designers its scape. All plots are expected to be on the orthogonally upward-sloping line or within its closer area as the original nature of cost planning [3]. Further the shift of certain modules from a lower grade to a upper grade is from left-lower position to right-upper position on the graph as an effect of absolutization toward superior product definitions and their chain.

3.6 Assessment procedure

Based on the individual means discussed in the above, the procedure of our assessment method is configured as shown in Fig. 2. It is enumerated as follows step by step.

(i) The items that index customer's attributes are listed through exploring value graph, a tool of value engineering.

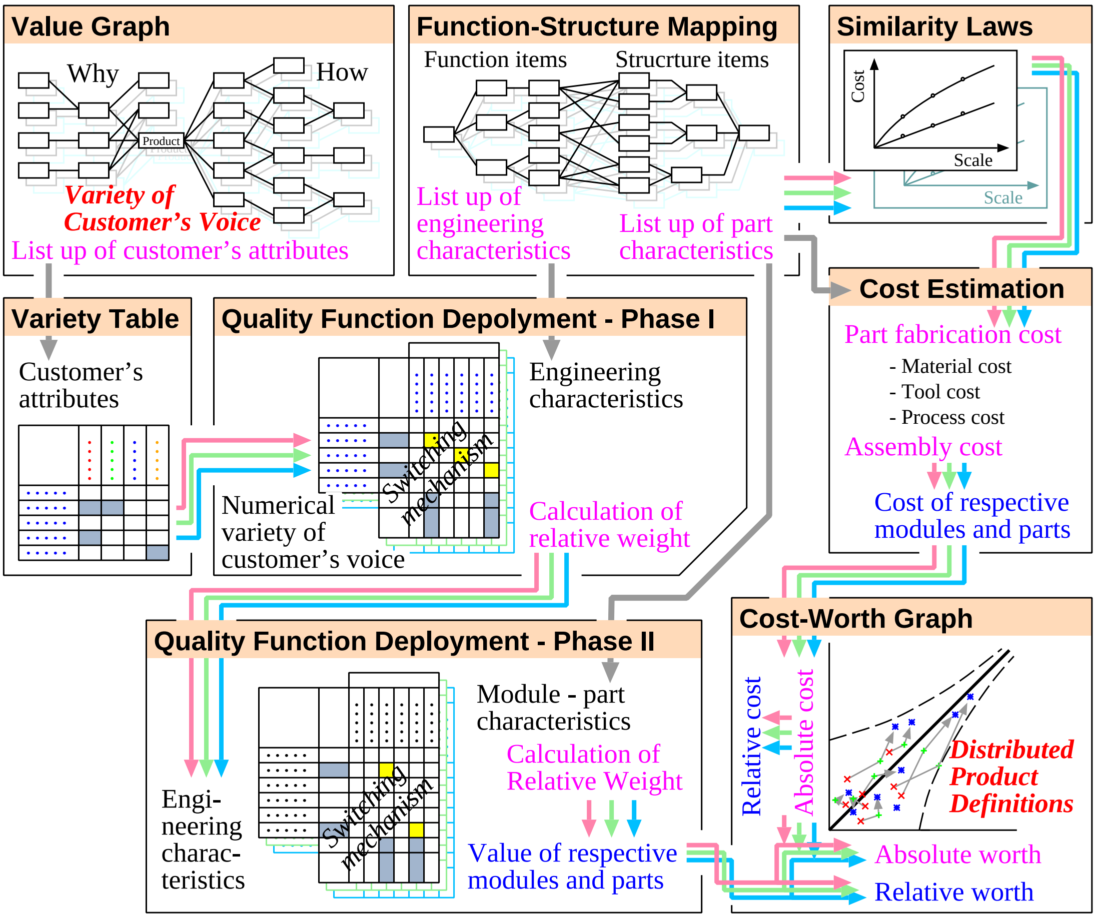


Figure 2 Assessment procedure for chained product definition

(ii) The items that index engineering characteristics and manufacturing modules are hierarchically established through exploring function-structure mapping graph, a tool of value engineering.

(iii) The items of customer's attributes are imported into 'variety table' from the result of (i), and then their weights are assigned for respective products. This weighting is guided by their classification into predefined categories [4].

(iv) The items used in QFD analysis are imported from the result of (iii) and (ii).

(v) QFD correlation matrixes are arranged generally apart from any specific grade.

(vi) A series of products to be assessed are defined with their sizes, and the degree of value-addition is assumed for respective products onto their categorized customer's attributes. The dimensions of functional modules are defined under the similarity laws governing system-level physical behaviors.

(vii) Following the weights of customer's attributes assigned in (vi), the relative worth of respective manufacturing modules is calculated by QFD table operation over common correlation matrixes, defined in (v), with the switching mechanism.

(viii) The raw (absolute) cost of each manufacturing module is estimated with design-for-manufacturing methodologies, etc. from their forms and dimensions. These operations result in overall cost structure.

(ix) By reflecting the difference of total cost, numerical values of relative worth gotten in (vii) are translated into absolute values by multiplying with total cost of each product.

(x) Finally absolute worth and absolute cost of respective manufacturing modules gotten in (ix) and (viii) are plotted as a graph.

Table 1 Three models in refrigerator family and their specifications

			Small model	Medium model	Large model
Specifications	compartment capacity	overall capacity [L]	137	255	415
		refrigeration comp. [L]	94	162	226
		vegetables comp. [L]	—	48	94
		freezing comp. [L]	—	45	67
		multi-purpose comp. [L]	—	—	24
		ice comp. [L]	—	—	14
	dimen-sions	width [mm]	476	596	650
		height [mm]	1200	1400	1798
		depth [mm]	553	656	698
					

Since the finally obtained cost-worth graph is based on rather vague assumptions and operations, it is important to iteratively refine all issues in the above procedure through the discussion in the design team.

4 An Application to Refrigerators' Design

4.1 A product family of refrigerators

In order to demonstrate the effectiveness of our method, it is applied to product definition of a set of three refrigerators, the capacities of which are 140L, 260L and 420L respectively. They are typical models in the Japanese market, while their cost information shown in the following is regularly biased with keeping overall tendency for confidentiality. Table 1 shows their specifications and shapes. The first is designed for a single and has two chambers, the second is designed for a couple and have three chambers, and the third is designed for a family with children and has five chambers.

Table 2 Variety table — Customer's requirements of three refrigerators

			Small model	Medium model	Large model
Preferences of customer requirements	preserve food	··· ice	3	3	9
		··· vegetables	9	9	9
		··· freezer food	3	9	9
		··· beverages	3	9	9
		··· refrigerated food	9	9	9
	ice compartment		0	0	3
	vegetables compartment		0	9	9
	freezer compartment		9	9	9
	refrigerator compartment		9	9	9
	multi-purpose compartment		0	0	3
	automatic ice making		0	0	3
	cheap price		9	3	3
	low electricity consumption		3	3	9
	ease to take food out	··· ice	1	3	3
		··· vegetables	1	3	3
		··· frozen food	3	3	3
		··· beverages	3	3	9
		··· refrigerated food	3	9	9
	quick refrigeration		1	3	3
	ease to open and close		1	3	3
	quiet operation		1	3	3
	ease to move		1	1	3
	nice look		3	3	3
	storage on top		3	3	1
	deodorization		1	1	1

Table 2 is the variety table that lists the customer's requirements items and their weights assigned for three refrigerators. As shown in the table, the weights on the ice compartment, the vegetables compartment, the multi-purpose compartment and automatic ice making are assigned to zero on the small model, and ones on the ice compartment, the multi-purpose compartment and automatic ice making are assigned to zero on the medium model.

Table 3 QFD Phase I on small model

Customer's attributes	Customer's weights	Engineering characteristics				refrigerate food		cool air route					preserve food						take food in and out												
		transform electricity to kinetic energy	radiation of heat	absorption of heat	compression	natural convection	forced convection	to icemaker	to vegetables compartment	to freezer compartment	to refrigerator compartment	to multi-purpose compartment	··· ice	··· vegetables	··· freezer food	··· beverages	··· refrigerated food	··· miscellaneous things	··· ice	··· vegetables	··· frozen food	··· beverages	··· refrigerated food	··· miscellaneous things	heat insulation	low noise	automatic ice making	automatic defrosting	temperature control	heat-resistance of top table	move and settle	anti-germ and deodorization
preserve food ··· ice	3	1	1	1	1	1	3	9	0	3	0	1	9	0	0	0	0	1	1	0	0	0	0	1	3	0	3	1	3	0	0	1
preserve food ··· vegetables	9	1	1	1	1	1	3	0	9	0	0	1	0	9	0	0	0	1	0	1	0	0	0	1	3	0	0	1	3	0	0	1
preserve food ··· freezer food	3	1	1	1	1	1	3	1	0	9	0	1	0	0	9	0	0	1	0	0	1	0	0	1	3	0	0	1	3	0	0	1
preserve food ··· beverages	3	1	1	1	1	1	3	0	0	1	3	1	0	0	0	9	0	1	0	0	0	1	0	1	3	0	0	1	3	0	0	1
preserve food ··· refrigerated food	9	1	1	1	1	1	3	0	1	0	3	1	0	0	0	0	9	1	0	0	0	0	1	1	3	0	0	1	3	0	0	1
ice compartment	0	0	0	0	0	0	0	3	0	0	0	0	9	0	0	0	0	1	9	0	0	0	0	1	0	0	3	0	0	0	0	0
vegetables compartment	0	0	0	0	0	0	0	0	3	0	0	0	0	9	0	0	3	1	0	9	0	1	1	1	0	0	0	0	0	0	0	0
freezer compartment	9	0	0	0	0	0	0	0	0	3	0	0	3	0	9	0	0	1	3	0	9	0	0	1	0	0	0	0	0	0	0	0
refrigerator compartment	9	0	0	0	0	0	0	0	0	0	3	0	0	3	0	3	9	1	0	3	0	3	9	1	0	0	0	0	0	0	0	0
multi-purpose compartment	0	0	0	0	0	0	0	0	0	0	0	3	1	1	1	1	1	3	1	1	1	1	1	3	0	0	0	0	9	0	0	0
automatic ice making	0	0	0	0	0	0	1	3	0	3	0	0	3	0	0	0	0	0	1	0	0	0	0	1	0	3	9	0	0	0	0	0
cheap price	9	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0
low electricity consumption	3	3	3	3	3	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	9	3	1	0	3	0	0	0
ease to take food out ··· ice	1	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	1	9	0	0	0	0	1	0	0	3	0	0	0	0	0
ease to take food out ··· vegetables	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	1	0	9	0	0	0	1	0	0	0	0	0	0	0	0
ease to take food out ··· frozen food	3	0	0	0	0	0	0	0	0	0	0	0	1	0	3	0	0	1	0	0	9	0	0	1	0	0	0	0	0	0	0	0
ease to take food out ··· beverages	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	9	0	1	0	0	0	0	0	0	0	0
ease to take food out ··· refrigerated food	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	9	1	0	0	0	0	0	0	0	0
quick refrigeration	1	3	1	1	1	1	9	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	3	0	0	0
ease to open and close	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	3	3	3	3	3	3	0	1	0	3	0	0	0	0
quiet operation	1	3	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	3	0	0	0	0	0
ease to move	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0
nice look	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	1	0	1	3	0	1	1	1	0
storage on top	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	1	0
deodorization	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	9
Raw score		2.78	2.57	2.57	2.57	1.01	4.56	0	0	2.09	1.97	0	2.61	3.91	4.23	2.29	5.61	2.73	2.11	1.84	4.78	2.90	4.64	2.80	3.59	2.60	0	1.12	3.45	4.36	1.68	1.63
Relative weight [%]		3.5	3.3	3.3	3.3	1.3	5.8	0	0	2.6	2.5	0	3.3	5.0	5.3	2.9	7.1	3.5	2.7	2.3	6.1	3.7	5.9	3.5	4.5	3.3	0	1.4	4.4	5.5	2.1	2.1

Correspondingly, the weights on 'ease to take food out' are differentiated among models. Conversely, the weights on 'cheap price' and 'storage on top' are assigned higher for lower grade models.

4.2 Quality function deployment

Tables 3 and 4 are the result of QFD table operation on the small model. In both tables, the correlation weight matrixes are commonly defined across three refrigerators. The yellow-colored elements of the matrixes are the switches for eliminating items that are not implemented in the lower grades of models. For instance, in Table 3, the element from 'ice compartment' to 'cool air route to ice compartment', one from 'vegetables compartment' to 'cool air route to vegetables compartment' and so forth are marked as switches. According to their mechanism over the commonly defined correlation, the raw score of the latter items of the pairs on

Table 4 QFD Phase II on small model

Engineering characteristics	Phase I Relative weight [%]	compressor	radiation pipe	evaporator	ice compartment door	ice compartment tray	vegetables compartment door	vegetables compartment tray	freezer compartment door	freezer compartment tray	refrigerator compartment door	refrigerator compartment tray	multi-purpose compartment door	multi-purpose compartment tray	icemaker	body: inner shell	body: frame	body: back plate	body: inner partition	body: top table	base legs	hinge joints	circuit board	urethane foam	power cable	evaporating dish
transform electricity to kinetic energy	3.5	9	1	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
radiation of heat	3.3	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
absorption of heat	3.3	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
compression	3.3	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
refrigerate food: natural convection	1.3	0	0	0	1	1	1	1	1	1	1	1	1	1	0	1	0	0	3	0	0	0	0	1	0	0
refrigerate food: forced convection	5.8	3	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	3	1	1	0
refrigerate food: cool air route: to icemaker	0	1	0	1	3	1	0	0	0	0	0	0	0	0	1	1	0	0	3	0	0	0	1	1	1	0
refrigerate food: cool air route: to vegetables compartment	0	1	0	1	0	0	3	1	0	0	0	0	0	0	0	1	0	0	3	0	0	0	1	1	1	0
refrigerate food: cool air route: to freezer compartment	2.6	1	0	1	0	0	0	0	3	1	0	0	0	0	0	1	0	0	3	0	0	0	1	1	1	0
refrigerate food: cool air route: to refrigerator compartment	2.5	1	0	1	0	0	0	0	0	0	3	1	0	0	0	1	0	0	3	0	0	0	1	1	1	0
refrigerate food: cool air route: to multi-purpose compartment	0	1	0	1	0	0	0	0	0	0	0	0	3	1	0	1	0	0	3	0	0	0	3	1	1	0
preserve food: · · · ice	3.3	0	0	0	3	3	0	0	1	1	0	0	0	1	1	3	3	1	1	0	0	0	0	0	0	0
preserve food: · · · vegetables	5.0	0	0	0	0	0	3	3	0	0	1	3	0	1	0	3	3	1	1	0	0	0	0	0	0	0
preserve food: · · · freezer food	5.3	0	0	0	0	0	0	0	3	3	0	0	0	1	0	3	3	1	1	0	0	0	0	0	0	0
preserve food: · · · beverages	2.9	0	0	0	0	0	0	1	0	1	3	3	1	1	0	3	3	1	1	0	0	0	0	0	0	0
preserve food: · · · refrigerated food	7.1	0	0	0	0	0	1	3	0	0	3	3	1	1	0	3	3	1	1	0	0	0	0	0	0	0
preserve food: · · · miscellaneous things	3.5	0	0	0	0	0	0	1	0	1	0	3	3	3	0	3	3	1	1	0	0	0	0	0	0	0
take food in and out: · · · ice	2.7	0	0	0	9	3	0	0	3	3	0	0	1	0	1	1	1	1	1	0	0	3	0	1	0	0
take food in and out: · · · vegetables	2.3	0	0	0	0	0	9	3	0	0	3	1	1	0	0	1	1	1	1	0	0	3	0	1	0	0
take food in and out: · · · frozen food	6.1	0	0	0	0	0	0	0	9	3	0	0	1	0	0	1	1	1	1	0	0	3	0	1	0	0
take food in and out: · · · beverages	3.7	0	0	0	0	0	1	1	1	1	9	3	1	0	0	1	1	1	1	0	0	3	0	1	0	0
take food in and out: · · · refrigerated food	5.9	0	0	0	0	0	1	0	0	0	9	3	1	0	0	1	1	1	1	0	0	3	0	1	0	0
take food in and out: · · · miscellaneous things	3.5	0	0	0	1	0	1	0	1	0	1	0	9	3	0	1	1	1	1	0	0	3	0	1	0	0
heat insulation	4.5	0	0	0	3	0	3	0	3	0	3	0	3	0	0	1	1	1	1	1	0	0	0	9	0	0
low noise	3.3	9	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0
automatic ice making	0	0	0	0	1	3	0	0	0	1	0	0	0	0	9	0	0	0	0	0	0	0	1	0	0	0
automatic defrosting	1.4	0	3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	9
temperature control	4.4	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	1	0	0
heat-resistance of top table	5.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	9	0	0	0	1	0	0
move and settle	2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9	3	1	0	9	0	0	0	0	0
anti-germ and deodorization	2.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	3	0	0	0	0	0	0	0
Relative weight (worth) [%]		9.5	3.8	7.0	0	0	0	0	6.7	4.0	9.0	6.1	0	0	0	10.3	9.5	4.1	7.0	4.7	0.8	4.8	5.0	5.6	1.1	0.9
Absolute worth [Yen] under the assumed total cost 11,358.		1,082.	433.	795.	0	0	0	0	764.	449.	1,022.	694.	0	0	0	1,167.	1,079.	468.	798.	539.	94.	944.	568.	638.	124.	103.

engineering characteristics are canceled in the case of the small model, as marked with gray color. Further, the items on manufacturing modules and parts, such as ice compartment door and tray, multi-purpose compartment door and tray and so forth are eliminated. These operations are executed for medium and large models over the same weight matrixes and switches as well.

4.3 Cost-worth analysis

Figure 3 shows the cost-worth graphs, which describe how product definition is transferred among three refrigerators from the small model to the large model. The left-side graphs are conventional relative analysis with relative cost and relative worth. The right-side graphs are

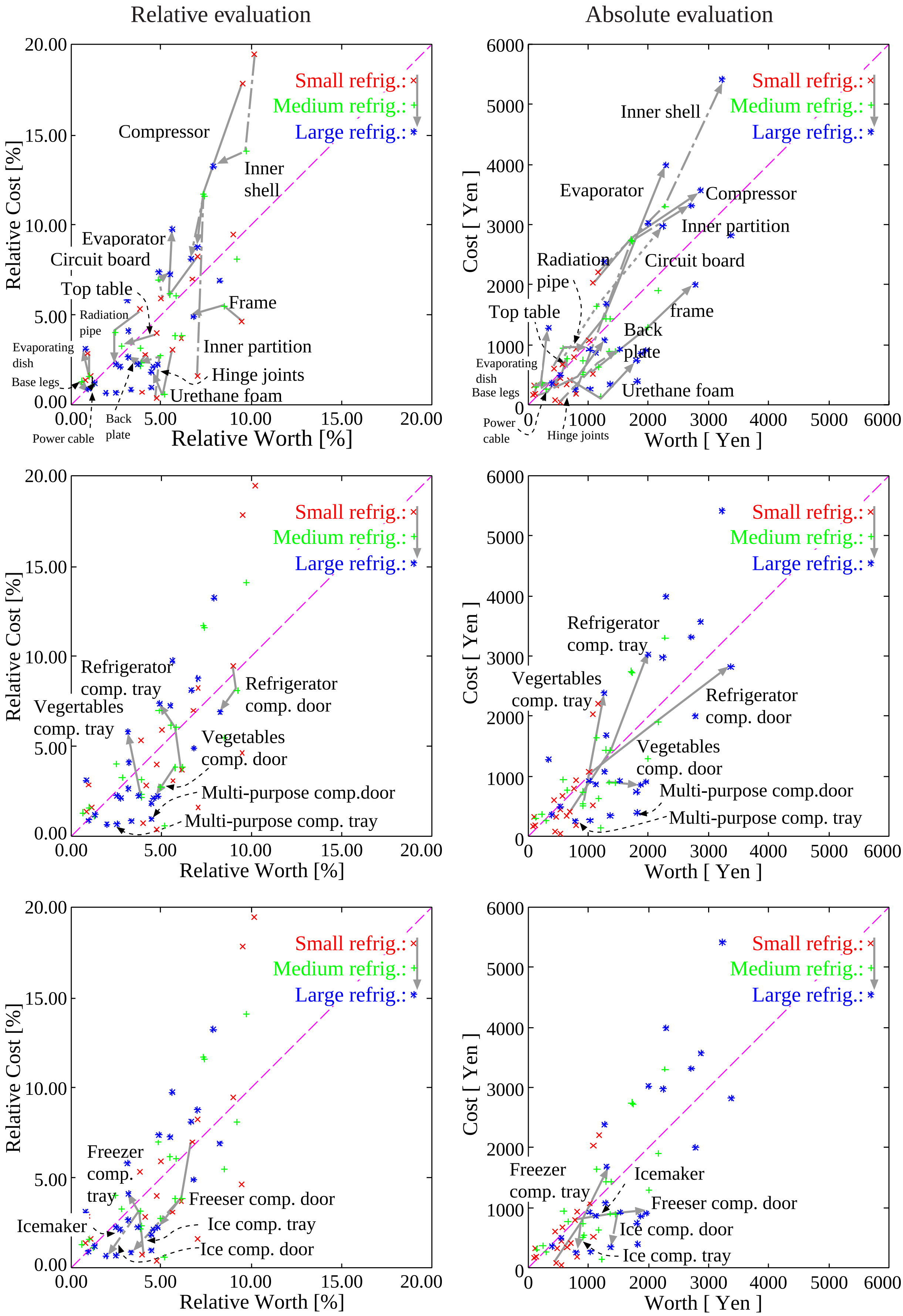


Figure 3 Comparison of cost-worth graphs over product family

absolute analysis with absolute cost and absolute worth, which is expected to be effective for value distribution analysis in product family design. As shown in the figure, most of modules, except inner shell of the all models and compressor of the small model, are plotted along with diagonal zone shown as magenta-colored diagonal broken line. This means that each product definition is individually well integrated between cost and worth. However, relative evaluation is rather confusing. That is, some plots shift from lower-left to upper-right, some others shift from upper-right to lower-left, while for instance it can be confirmed that the importance of circuit board is almost constant in percentage across all models. Beyond these, in the absolute evaluation, plots of most modules, except ice compartment door and tray, shift from lower-left to upper-right, and their magnitude becomes larger on major structural components such as inner shell, refrigerator component door and tray, and primally functional component such as evaporator, compressor. This tendency makes the cost planning framework expand from value distribution on respective modules to value distribution over a product family. It facilitates designers' defining the appropriate value levels of respective products.

5 Concluding Remarks

This paper proposed an assessment method for value distribution for a product family by extending the cost planning framework with QFD from a single product to a series of products. Through its application of design analysis of a refrigerator family, it is confirmed that the introduction of similarity laws for cost estimation, the switching mechanism in QFD table operation, absolutization of cost-worth graph makes the application of cost planning with QFD for a series of products significantly sound and consistent.

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Corresponding author:
Kikuo Fujita, Professor
Department of Computer-Controlled Mechanical Systems
Graduate School of Engineering, Osaka University
2-1 Yamadaoka, Suita, Osaka 565-0871, JAPAN.

Telephone: +81-6-6879-7323
Facsimile: +81-6-6879-7325
E-mail: fujita@mech.eng.osaka-u.ac.jp
URL: http://syd.mech.eng.osaka-u.ac.jp