Design of Worth for Consumer Product Development

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Abstract

Worth is assessed throughout the Life Cycle. Then we consider a trade-off between Worth, Cost, and Time. This methodology is a concerning selection of design solutions from thousands of combinations of design parameters. The current Design for X (DfX) is considered to be extended, and so the methodology is called Extended DfX. Here, this methodology is applied to consumer product development. Worth of consumer products is especially important, but Worth is not always equivalent to performances, whereas it usually is in the case of other products. Therefore, a novel approach is required for assessing Worth in consumer product development. The design for product sound quality is also introduced as the another approach for the design of worth.

Keywords

DfX ; worth ; cost ; time ; customer ; function ; structure ; PC ; trade-off ; method ; tool ; optimization ; Sound ; Sound quality ; SQ metrics ; Noise ; Multiple classification analysis ; Psychoacoustic

1. Introduction

The process of product development varies greatly depending on the product field. Fig.1. shows an example of classification of the product development pattern. The axis of abscissas indicates the size of the product development in proportion to the development cost. The vertical axis indicates whether the objective is mass production for an unspecified client or production ordered by a specific client. Power plant and space equipment correspond to the lower right region. This region is a product field in which development cost is high and the performance can be investigated thoroughly over a long period of time. The consumer product that is the target of this paper is antithetical to power plant and space equipment. This region is a product field in which investment in product development is relatively small and development time is short. The product of this region is customer-driven. Fig.2. shows various methods/tools for the product development [1, 2]. These methods/tools can be extensively used for the above-mentioned plant and space equipment. On the other hand, it is necessary to apply them selectively and efficiently in the case of consumer product development.

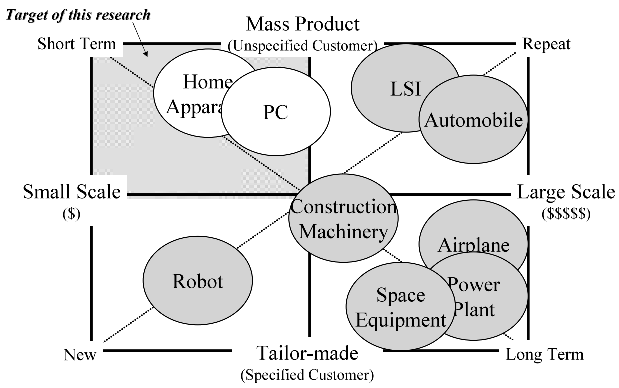

Fig.1. Product classification

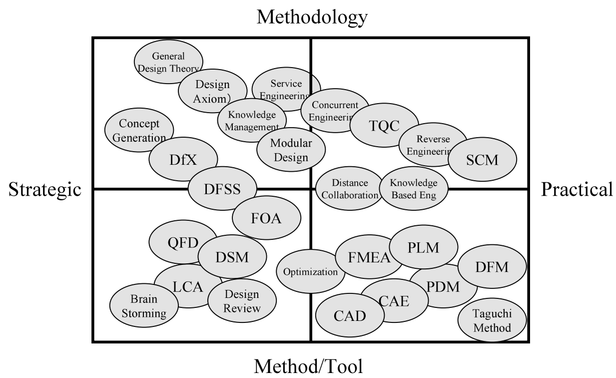

Fig.2. Design Method/Tool

In this paper, we propose a design concept for consumer product development. In the case of consumer product development, a customer has the ability to decide the product price in many cases. This causes a manufacturer to make a product that has less variety. As a result, a manufacture endeavors to reduce costs by improving efficiency and becomes caught up in price-driven competition. In order to break this cycle, it is necessary to assess Worth from the manufacturer's point of view and to reflect the result in product development. Many studies have attempted to evaluate worth/value from the customer's point of view [3, 4]. That is, a potential customer requirement is analyzed, and quantified as absolute worth (we define this as Worth) independent of cost. Then, we estimate Cost to realize the above-mentioned Worth by using Worth/Function/Structure relation graph [5]. We define this concept as Extended DfX methodology, an extension of the current DfX [6] to Worth-based product development.

The design for product sound quality is also introduced as the another approach for the design of worth. This methodology incorporates two evaluation methods. One is a sensory evaluation method employing the semantic differential (SD) technique, which determines psychological metrics to measure the level of pleasant sound. The other is a physical evaluation method to which Zwicker's sound quality metrics analysis can be applied, which determines physical metrics to measure the level of pleasant sound.

2. Trade-off between worth and cost

Here, for the sake of simplicity, we consider a product composed of three kinds of parts : a, b, and c. Each of these parts has two kinds of grades : 1 and 2. Then, eight kinds of products can be considered in accordance with the cube of two as shown in Tab.1. Roughly speaking, the cost is defined as the sum of the cost of each part for eight kinds of products. On the other hand, Worth at the component level increases if the grade is higher. However, unlike in the case of a CPU, Worth is not always proportional to price. There are some nonlinear factors. In addition, product Worth itself is not equal to the sum of component Worth. Harmonious balance as the product greatly affects Worth. In addition, Worth strongly depends on the user of the product, when it is used, and where it is used.

We assume that Worth of each of the eight kinds of products is obtained by some means. The result is plotted on the Worth/Cost map as shown in Fig.3. If the relation between Cost and Worth is linear, eight kinds of points are plotted on the straight line. However, since Worth is defined through a rather complex process, results will be scattered as shown in Fig.3. An actual product consists of dozens of parts and grades. Moreover, the style, the color, weight, size, etc. should be considered for evaluation of the relation between Cost and Worth. Therefore, thousands of product varieties exist. Once Cost and Worth for thousands of product varieties are plotted on the Worth/Cost map, a group of product varieties can be visualized. Then, the boundary of the lowest Cost limit and the highest Worth limit come into view. This boundary is called a Pareto optimal solution. Products B and F in Fig.3. correspond to this solution. That is, we can see a group of best solutions by mapping Cost and Worth on the Worth/Cost map like this. This is why we focus on Worth and compare Worth and Cost on an equal footing.

We consider a trade-off between Worth and Cost, but we may include Time (schedule) in addition to Worth and Cost. Product B and product F are optimal solutions in the current state. The optimal solution does not always satisfy the target solution. In this case, the reduction of Cost down and the increase of Worth will be needed in order to approach the target.

Tab.1. Product Varieties

Product	A	B	C	D	E	F	G	H
Part a	a1	a1	a1	a1	a2	a2	a2	a2
Part b	b1	b1	b2	b2	b1	b1	b2	b2
Part c	c1	c2	c1	c2	c1	c2	c1	c2
Worth	x1	x2	x3	x4	x5	x6	x7	x8
Cost	y1	y2	y3	y4	y5	y6	y7	y8

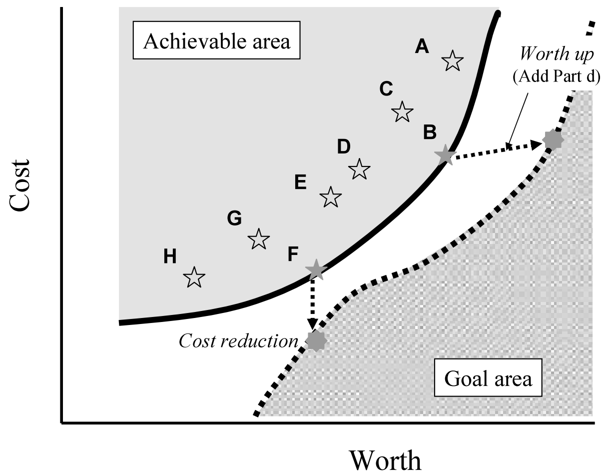

Fig.3. Worth/Cost Map for Eight Products

3. Extended DFX methodology

We propose Extended DfX methodology that enhances the DfX design procedure for digital consumer product development. DfX is a philosophy and practice advocated by Gatenby of Bell Laboratories, of AT&T, in 1990 [6] that ensure quality products and services, reduce the time to market for a product, and minimize life-cycle costs. That is, it is a way of evaluating various problems throughout the life cycle at an early stage of product development as much as possible, and decreasing the redesign in the latter half of the product development as much as possible. In practice, the design method/tool shown in Fig.2. is systematically applied according to the DfX methodology. It is comparatively easy to apply the DfX methodology to large-scale product development, but for consumer products a more concrete way of focusing on Worth is required. So, the DfX methodology is expanded to include the design of Worth as shown in Fig.4. Worth is set first, and Cost is derived through functional design and structural design. Worth becomes the target for the customer and Cost becomes the target for the manufacturer, that is, this is a trade-off between Worth and Cost.

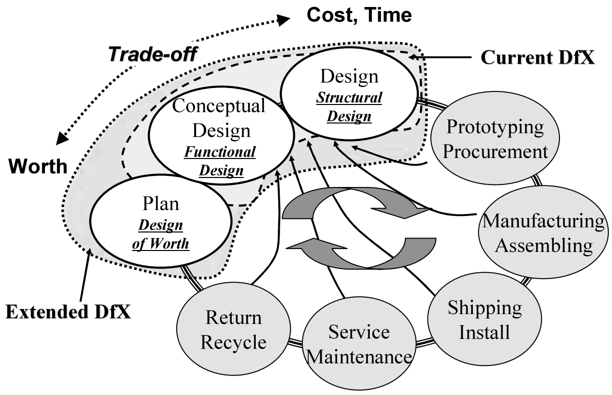

Fig.4. Concept of Extended DfX Methodology

In general, the relation between Worth and Cost is mapped on the Worth/Cost graph as shown in Fig.5. An achievable area is obtained by trade-off analysis, but generally neither an achievable area nor a goal area corresponds. This is a kind of trade-off. A trade-off analysis method that uses GA has recently been established and can be applied. Thus, the problem becomes clear by plotting current design on the Worth/Cost graph. For instance, the cooling method becomes a problem when the generated heat grows by advancing CPU performance as shown in Fig.6. in notebook PC design. If we introduce a large fan system to remove the generated heat from notebook PC with high-performance CPU, the entire PC becomes large, and Worth for customer decreases overall. Therefore, a technical breakthrough for heat rejection is required.

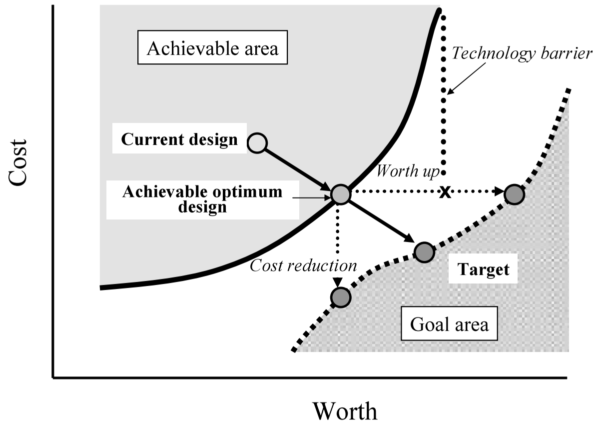

Fig.5. Worth/Cost Map

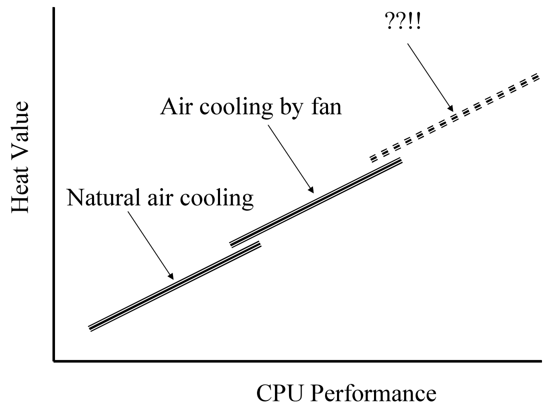

Fig.6. Need for Break-through Technology

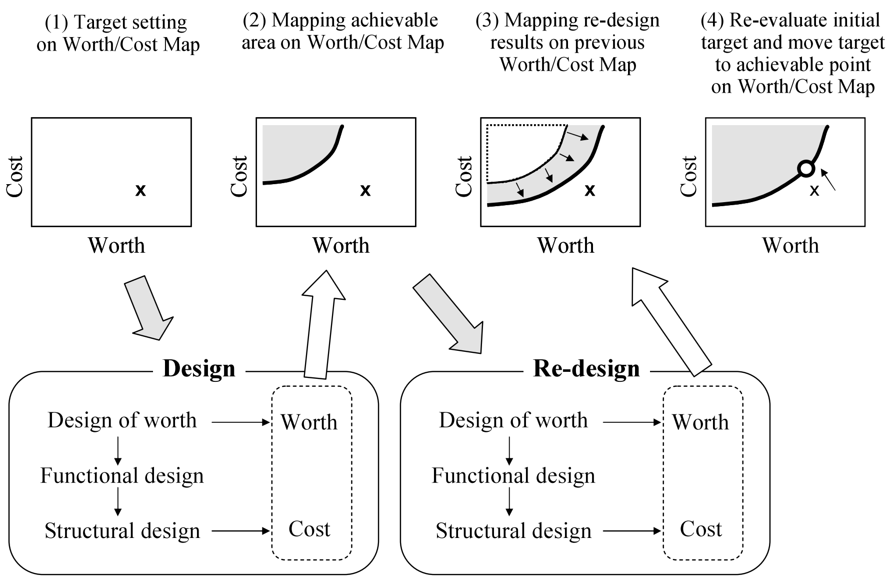

Fig.7. Procedure of Extended DfX

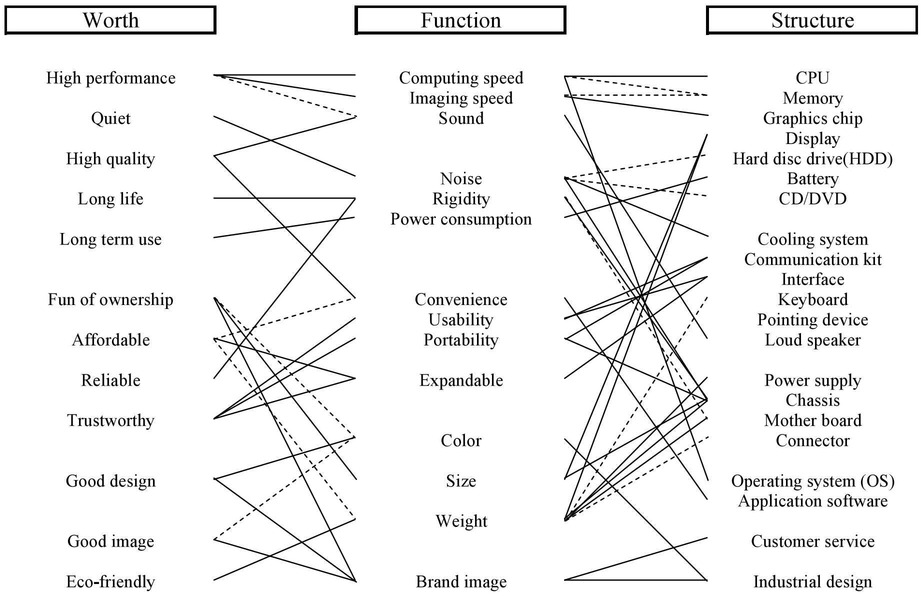

Fig.8. Worth/Function/Structure Relation

We explain the procedure of the extended DfX by referring to Fig.7. First of all, the target is set on the Worth/Cost map. This is at the planning stage. For example, PC with Worth equivalent to $4000 is developed at a Cost of $2000 for the power PC user. Next, “Design of Worth”, “Functional design”, and “Structural design” are executed in accordance with the DfX methodology. Worth is obtained from “Design of Worth”, Cost is assessed from “Design of the structure”, and, as a result, Worth and Cost are plotted on the Worth/Cost map. In general, because the design achievable area doesn’t satisfy the target at this stage, we need to redesign to obtain new Worth and Cost close to the target by controlling design parameters and design restrictions. New Worth and Cost are plotted on the Worth/Cost map again. This procedure enables us to approach the target. An initial target is re-evaluated when we judge that the achievement of an initial target is difficult, and the agreement point of the design feasible region and the design target is set. In practice, this design process is executed by using the Worth/Function/Structure relation graph shown in Fig.8.

4. Design for product sound quality

All the sounds generated by an operating product have been considered to be noise so far. Therefore, both users and manufacturers have tended to view a product with a lower noise level as a better product. However, sound is a key factor in Kansei/emotional information, whereas noise reduction is subject to a limitation. The product sound should not be considered as a negative direction of noise but treated as one sound. Product worth can be enhanced by improving the product sound. That is, the targeted product sound is appropriate or not for the customer, if not, how to realize the appropriate product sound. This approach is important because it enables the manufacturer to add worth to the product.

The performance and the sound (noise) of the product are closely related in the case of home appliances. For example, “collecting garbage” and “sound” cannot be considered separately in the case of a vacuum cleaner. In product sound design, noise reduction techniques have been executed mainly from the viewpoint of “noise”. Moreover, noise reduction techniques have been applied to products that are already completed to some degree.

Fig.9. shows the design methodology for product sound by comparing the “as-is” and the “to-be” product sound definition. In the traditional approach to noise reduction, product sound is treated as noise that should be minimized as much as possible. Moreover, because performance is the first priority and noise reduction is a secondary issue, countermeasures to reduce noise are usually implemented after prototyping. Thus, the product worth generated is determined by the decrease of a negative impression.

On the other hand, in the design for product sound quality, the product sound is treated as sound that adds worth to the product. Therefore, the customer’s preference in terms of sound is defined and a strategy to realize this is required. The worth realized by this approach can endow the product with an attribute that gives a positive impression to the user. However, for this purpose, it is necessary to embrace the view that "the product sound is not a noise" and the metrics for designing the sound at the product design stage should be defined.

The conventional product development process is shown in Fig.10. The new idea for the next product is decided by analyzing the sensory evaluation and the evaluation of sound quality metrics. In this case, the sensory evaluation and the evaluation of sound quality metrics are performed separately. For the next product embodying the new idea, the sound evaluation can be performed after prototyping. When the sound after prototyping is unsatisfactory, countermeasures should be implemented within the time and cost constraints.

On the other hand, the design for product sound quality determines the metrics for product sound, considering both the sensory evaluation and the evaluation of sound quality metrics. The target sound for the next product is determined according to the metrics for product sound. As the target sound is defined physically, this can be produced virtually by a digital sound tool. Therefore, the sound evaluation for the next product can be performed before prototyping. Next, the product sound design is performed to realize the target sound, considering performance etc. Finally, a product with excellent performance and sound can be realized.

Fig.11. shows the procedure of the design for product sound quality. It is necessary to define two metrics to perform the product sound design. First, an impression evaluation is performed by sensory analysis to evaluate the customer's impression of the targeted product sound. In the impression evaluation, target customers listen to the targeted sound. Then,

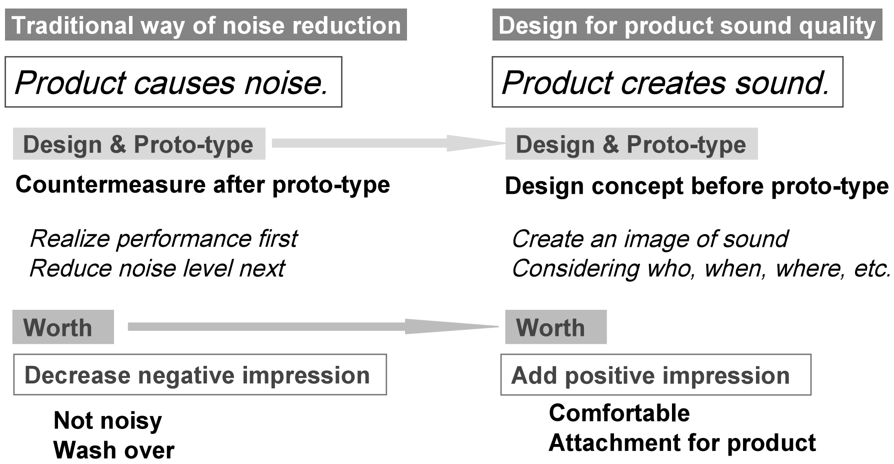

Fig.9. Design methodology for product sound

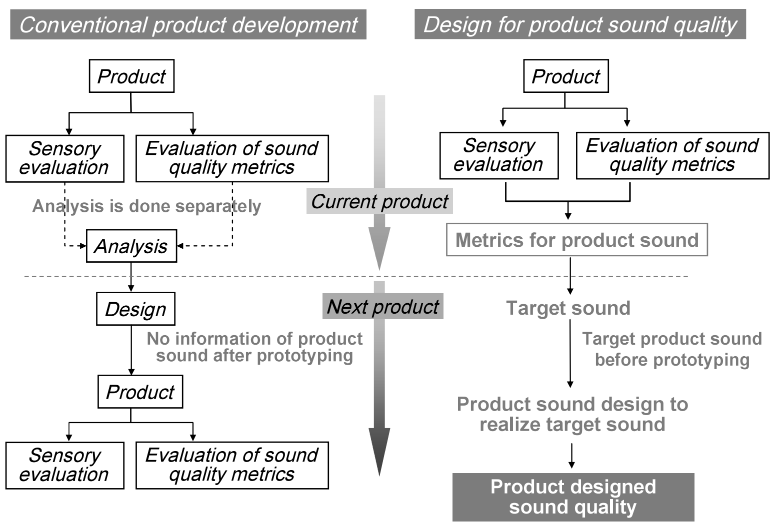

Fig.10. Design for product sound quality

the VoC (Voice of Customer) revealing potential needs concerning the sound is analyzed by the SD (semantic differential) method and/or the method of paired comparison, etc. The results are transformed into the metrics for product sound by multiple classification analysis. The metrics obtained by the impression evaluation is defined as the psychological metrics here.

The psychological metrics is important for quantifying how the customer's impression of the targeted sound. However, it is difficult to combine the targeted sound with the sound design only on the basis of the psychological metrics. It is also necessary to express the targeted sound physically by means of an objective evaluation. As measurable design parameters of the product sound, we use four basic SQ (Sound Quality) metrics [7] : loudness, sharpness, roughness, and fluctuation strength. These are widely used and well defined.

These basic metrics are not always defined physically but derived through many sensory evaluations. These SQ metrics can be applied directly to the objective evaluation, but as the number of SQ metrics is rather big, it is necessary to define a new metrics using these SQ metrics. Moreover, it is notable that some product sounds cannot be defined by these SQ metrics. In this case, we should define the new metrics for the principle of the physical meaning. The metrics obtained by the physical evaluation is defined as the physical metrics here.

Generally, the psychological metrics is used for sound design. However, because the target sound is not expressed numerically (physical metrics), it is difficult to design product sound directly from the psychological metrics. So, the psychological metrics should be reflected in the design of product sound through the physical metrics. For this purpose, the relation between the psychological metrics and the physical metrics should be defined. This relation is the metrics for product sound. After defining the metrics for product sound, the target product sound is set. The target sound set in the psychological domain is mapped into the physical domain. The target sound mapped in the physical domain is not unique. Finally, the target sound is determined, considering the easiness of realization etc. This target sound becomes a specification of the design for product sound quality that achieves the worthy sound.

5. Application of design for product sound quality

The application of the design for product sound quality to a vacuum cleaner is introduced. A vacuum cleaner makes a continuous sound during operation. The product sound is classified into continuous sounds, discontinuous sounds, unexpected sounds, etc. Continuous sounds are common and fundamental to the product sound. In the case of vacuum cleaner sound design, we would pursue "sounds like vacuum cleaner", "feeling of luxury", and "sounds heard softly". Our target for vacuum cleaner sound is the inclusion of these ambiguous requirements in the product development. This paper presents the first step toward realizing that target.

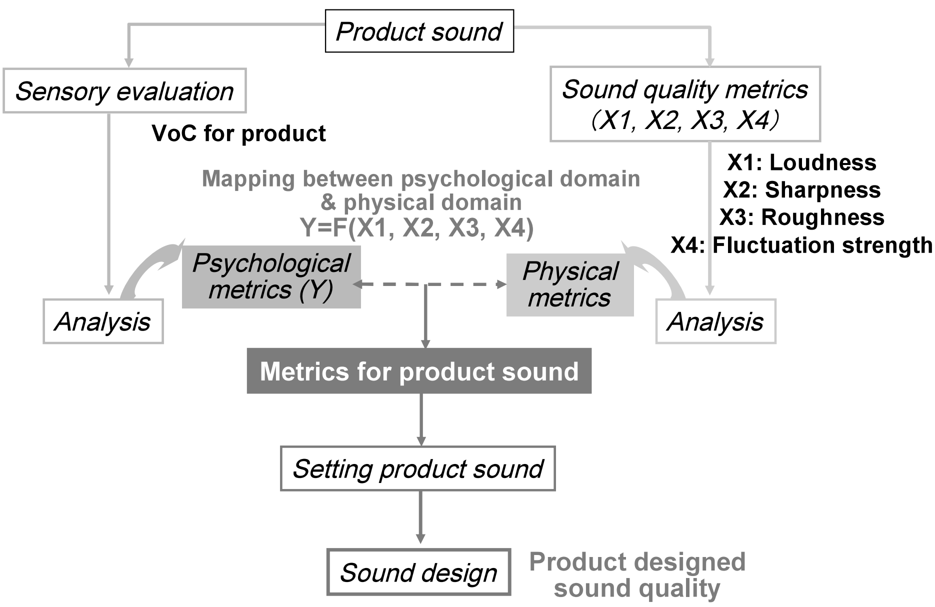

Fig.11. Procedure of design for product sound quality

Here, the sensory evaluation, the physical evaluation, and the mapping between sensory evaluation and sound quality metrics are performed for the sounds of 10 models.

Fig.12. shows the application of the design for product sound quality to a vacuum cleaner. The design process is divided into two parts : “sensory evaluation” and “physical evaluation”. The stationary sounds from 10 selected models of different manufacturers are recorded in an anechoic chamber and used as evaluation samples.

In the sensory evaluation, 22 examinees listen to the sounds of the 10 models. The SD (semantic differential) method is applied to responses consisting of 25 pairs of adjectives (16 pairs of general adjectives and 9 pairs of product-specific adjectives). When the SD method is applied to the sensory evaluation, it is important to select a pair of adjectives carefully. First, the target was clarified and then a pair of adjectives to be extracted is selected.

The 22 examinees are divided into four groups and seated in front of a speaker. Each sound is played for five seconds and the examinees give their impressions of the sound by completing a questionnaire consisting of adjective pairs. Two trials of the same experiment are conducted to test the reliability of the data. To avoid the influence of the learning curve, the examinees practice responding before the experiment is performed.

The multiple classification analysis is applied to the value of 25 pairs of adjectives (mean value of 22 examinees) for the sounds from 10 models. As a result, the principal components shown on the left in Fig.12. are obtained. Here, the primary principal component is defined as the psychological metrics.

Fig.13. shows the relation between the physical and psychological metrics based on Fig.12. We call this relation “sound measure for vacuum cleaner”. This figure means that the smaller the psychological metrics, the better the sound quality by the sensory evaluation of 22 examinees. The physical metrics for the sounds from 10 models are widely scattered. The sounds that exist in the vicinity on this figure have similar sound quality. The physical metrics is related directly to the sound design.

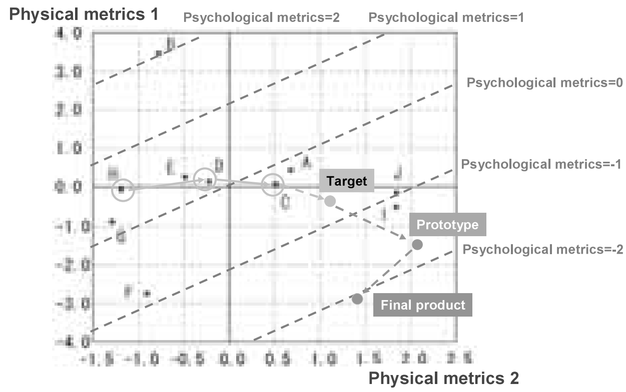

Fig.13. Relation between physical & psychological metrics for setting of target sound & final product sound

Next, the target sound is set in terms of the physical metrics. Fig.13. also shows the procedure of the target sound setting. Models H, D, and C are by the same manufacturer and the design has been improved in this order. The conventional product development results in the improvement of the product sound. The target sound is set based on the current model C as

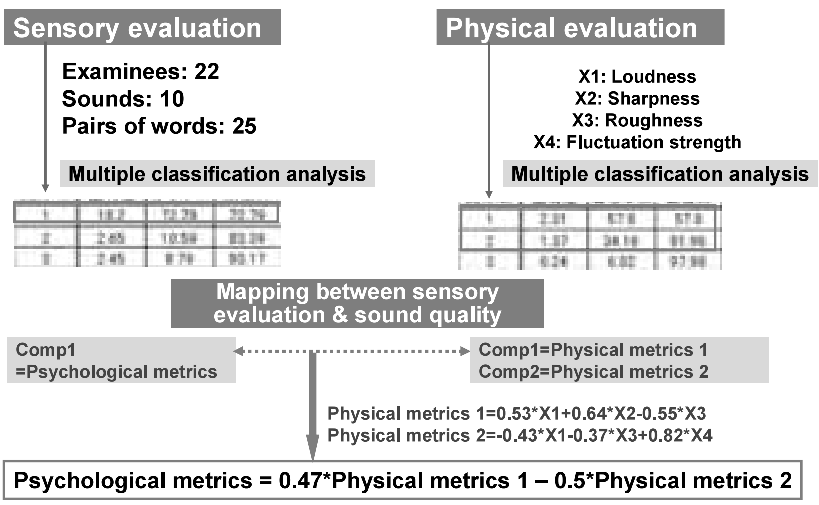

Fig.12. Application of design for product sound quality to vacuum cleaner

shown in Fig.13. This figure also shows the results for the prototype and the final product. The sound for the prototype satisfies the target sound, but the sound for the final product is set based on a consideration of the auditory evaluation of the prototype. In order to realize the target sound, the newly developed supporting system and the absorbing procedure are applied.

6. Future prospects for design for product sound quality

Design is an important element of product development [8]. On the other hand, the design greatly depends on the designer's abilities and standardization is insufficient. It is therefore necessary to clarify what the requirements are at the design stage in order to develop a product strategically and efficiently. The design for product sound quality is one of the best examples of top-down design. Lyon mentions the importance of the design for product sound quality [9], and also refers the difficulty of realizing that. The difficulty comes from the quantification of the ambiguous customer's needs. The physical evaluation can be done by four basic SQ (Sound Quality) metrics, but these metrics cannot be applied to discontinuous sounds such as a copier sound. The physical metrics to define discontinuous sounds should be developed to extend applicable products for the design for product sound quality. A lot of technical issues exist for realizing the design for product sound quality, but the most serious problem is innovations of the product development environment. It is important how to change the design philosophy to lead innovations [10].

7. Conclusion

In this paper, features of consumer product design were first described from the perspective of the design of Worth. Next, we introduced the Extended DfX methodology to enhance DfX (Design for X) that was already established for consumer products. We also introduced a practical example of trade-off analysis and the satisfying design that is the key technology when Extended DfX is applied. Moreover, the design for product sound quality is also introduced as the another approach for the design of worth.

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