The Journal of Management Accounting, Japan
Vol. 6,No.2 1998

Product Development Using Cost-Performance Curve

Yasuo Kusaka*

Abstract

Product development(PD) needs to consider such characteristics as multi-goals and qualitative evaluation, cost constraint and combinatorial structure of development alternatives. The term cost-performance used so far has been mainly emphasizing ex post facto the improvement in single function with respect to cost. The use of cost-performance curve (CPC), including multiple and qualitative criteria and under varied cost constraints, will be effective for better PD decision making.

This paper develops an extended model of CPC for selecting combinatorial alternative (CA) in PD so as to maximize total performance under cost constraint. The characteristics of this model lie in the following points: target sales quantity of product is newly introduced; the joint use of Analytic Hierarchy Process (AHP) and Enumeration Method (EM) is attempted throughout this study to treat with more general cases including dependent alternatives among functional units; some practical viewpoints, which are useful to other PD problems, are presented through the application of copying machine. The results of analyses show that the introduction of sales quantity has an important influence on CPC and thus on optimal selection of CA, and it is also considered to be important in developing further extended PD models.

Key Words

Product Development, Cost-Performance Curve, Target Sales Quantity
Combinatorial Alternative, Analytic Hierarchy Process, Enumeration Method
Application to Copying Machine

Submitted December 1997.
Accepted October 1998.
* Professor of Bisiness Management Division, Faculty of Economics, Dokkyo University

1. Introduction

In an environment of diversified values and intense competition, to meet clients' requirements from a total viewpoint, that is, to supply products with well-balanced functions at lower cost, is a key factor in product development (PD).

This paper develops an extended model of cost-performance curve (CPC) for selecting combinatorial alternative (CA) in PD so as to maximize total performance under total cost constraint (hereafter, we call it cost constraint) by jointly using Analytic Hierarchy Process (AHP) and Enumeration Method (EM). CPC represents change in optimal total performance when changing target cost.

It is important in PD to consider multigoal and qualitative evaluation items, cost constraint, and combinatorial characteristics of development alternatives.

With regard to multigoal and qualitative evaluation items, the term cost-performance ratio (price-performance ratio) has been often used so far. Here, the performance has been limited mainly to a single performance that can be evaluated quantitatively. However, the performance in PD should be understood as total performance which includes factors evaluated from multigoal and qualitative viewpoints, such as operability, reliability, maintainability, comfort, design, etc. Therefore, it is important to quantify this total performance and utilize it effectively in decision making for PD.

As for cost constraint, a product is developed under a certain concept by setting target product cost based on its price and target sales quantity which are determined according to the characteristics and market trend. This relationship is shown in Figure 1.

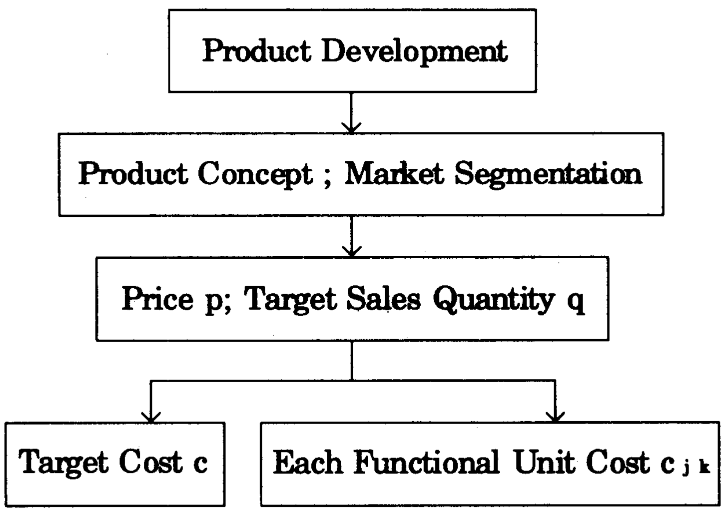

Figure 1 Cost Determination Mechanism in Product Development

For PD treated in this study, we suppose the case where target sales quantity is set (or predicted) for given product concept and market after its concept and market are determined, multiple criteria are introduced and all the functional units' alternatives are made. Here, target sales quantity plays a key role in PD, because it affects on cost estimation for all functional units' alternatives and thus optimal choice of CA in PD. In general, the more target sales quantity increases the more alternative cost decreases by the scale economy as explained in Step 2 of Section 2.3. Therefore, it's important to explicitly introduce target sales quantity into cost estimation mechanism for these alternatives. When target cost constraint is set at a certain value within a permitted range or multiple products are developed simultaneously in different grades, it is needed to make clear changes in optimal total performance with respect to changes in target cost (that is, CPC) for each combination of prices and target sales quantities of multiple products.

The characteristics of CAs in PD manifest themselves in the following example: A product has multiple functions including basic function. To realize these functions, subsystems called functional units are developed. The functional units may be parts and/or modules developed already or to be developed in future. In general, plural development alternatives are considered for each functional unit. That is, in PD we have the problem of selecting a CA among a set of CAs for all functional units.

With respect to the study which is concerned with multigoal and qualitative aspects, cost constraint and combinatorial characteristics of alternatives, a prototype model [2] has been proposed for the choice of CA for PD using Analytic Hierarchy Process (AHP) [7] and the approximate solution (additional rate of return method for compound alternatives) [4]. The model deals with the problem of selecting a CA among a set of CAs for all functional units so as to maximize total performance under cost constraint, that is, the sum of development cost and manufacturing cost (hereinafter called "cost"). Though this study is characterized by jointly using AHP and combinatorial optimization technique, it has not clarified the property of optimal solution, namely, cost-performance behavior, because of using an approximate solution. In this context, another study proposes the concept of CPC and analyzes the behavior by jointly using AHP and dynamic programming (DP) [3]. However, the study should be extended in the following points: target sales quantity, which affects costing, should be explicitly introduced into the model, because alternative cost for developing every functional unit has been considered given so far; enumeration method, which enables us to easily treat with more general cases including technological or economic dependent alternatives among functional units, will be needed instead of DP; information obtained from a practical application should be utilized effectively in applying the model to other practical PD problems.

On the other hand, in the area of management accounting, Target Costing (TC) [1] which builds-in cost at PD phase, and Value Engineering (VE) [5],[6] as a concrete method for realizing TC, have been developed so far. VE method is characterized as one which analyzes product functions, creates alternatives and selects one alternative individually for each function. It is effective as a practical solution for avoiding selection from numerous number of CAs. However, where there are relatively small number of CAs and total judgement is required in product planning or method design, the proposed method (cost-performance curve method:CPCM) may also be effective in selecting a CA for all functional units. In this case, VE can be also used in analyzing functions and creating alternatives at CPCM. Therefore, CPCM may be interpreted as mutually complementary rather than an exclusive relationship with VE method. When total judgement is required at VE implementation phase, CPCM can be used by listing CAs for all functional units and tracing changes in performance by varied cost constraints.

The purpose of this study is

1. to formulate more general model by explicitly introducing target sales quantity and jointly using AHP and EM to easily treat with cases including dependent alternatives among functional units;
2. to examine the influence of target sales quantity on CPC and to clarify its role in decision making;
3. to apply the model to practical PD of copying machines and to present useful information for other PD problems.

The characteristics of this model lie in the points that target sales quantity of product is newly introduced, the joint use of AHP and EM is attempted throughout this study to treat with more general cases including dependent alternatives among functional units and a practical application is presented.

2. *Description of Product Development Model*

2.1 Choice of Alternative for Each Functional Unit

Suppose a certain concept of PD for predetermined planning periods. The product can be evaluated by such m types of criteria E_i $(i=1,...,m)$ as basic function, operability, reliability, maintainability, safety, comfort and so forth. The product consists of n types of functional units F_j $(j=1,...,n)$ which realize main functions. For each functional unit F_j, r_j types of possible development alternatives a_{jk} $(k=1,...,r_j)$ are considered and their costs c_{jk} can be evaluated. The problem is to choose a CA among a set of CAs for all functional units so as to maximize total performance under cost constraint c. These relations are shown in Figure 2.

The proposed PD model is also applicable to other problems with more general hierarchical structures so long as the structure of CAs is held. For example, we can also consider a case of multi-layer evaluation items, where evaluation items specific to every functional unit can be set apart from those of product as a whole.

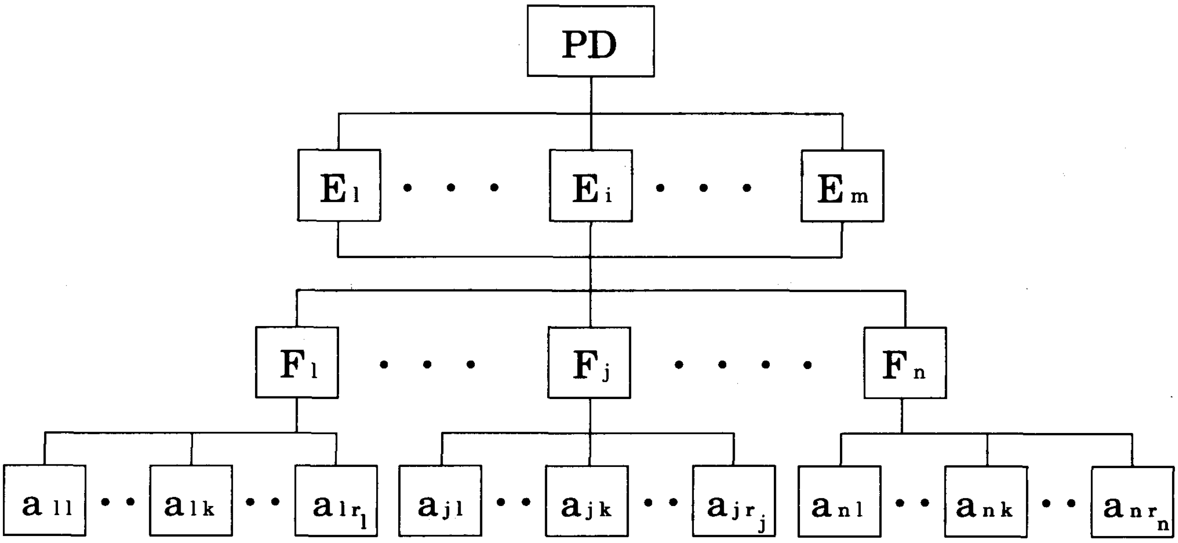

Figure 2 Hierarchical Structure of CAs Selection in Product Development

2.2 Assumptions and Notations

Assumptions and notations used in this study are as follows:

Assumptions

1. Target cost for the product can be set based on product price and target sales quantity.
2. Alternatives among different functional units are, technically and economically, mutually independent. The case where this assumption is removed is discussed in Chapter 5.
3. Cost of each alternative for any functional unit can be estimated based on target sales quantity.
4. Product cost becomes the sum of costs of alternatives selected in respective functional units.
5. Evaluation value for each alternative in any functional unit is the sum of values of all evaluation items assigned to the alternative.
6. Total performance of the product is the sum of evaluation values for alternatives selected in respective functional units.

Notations

E_i: the i-th evaluation item in PD (i=1,...,m)

F_j: the j-th functional unit in PD (j=1,...,n)

a_{jk}: the k-th alternative of functional unit F_j (j=1,...,n; k=1,..., r_j)

$A_j \equiv \{a_{j1},...,a_{jr_j}\}$: set of alternatives for F_j

In the case where we need to discriminate between alternatives listed originally and those arranged later, we mark the former notations with superscript "dash".

c_{jk}: cost for alternative a_{jk} (k=1,..., r_j)

c: product cost constraint, hereafter we call it cost constraint

w_i: weight of evaluation item E_i, which represents the degree of importance relative to other items

$(\sum_{i=1}^{m} w_i = 1)$

w_{ij}: weight of functional unit F_j for evaluation item E_i, which represents the degree of importance relative to other units

$(\sum_{j=1}^{n} w_{ij} = 1)$

u_{ijk}: evaluation value of alternative a_{jk} of functional unit F_j for evaluation item E_i, which represents the degree of importance among alternatives

$(\sum_{k=1}^{rj} u_{ijk} = 1)$

u_{jk}: total evaluation value of alternative a_{jk} in functional unit F_j

$(u_{jk} = \sum_{i=1}^{m} w_i w_{ij} u_{ijk})$

$$c_{j*} \equiv \min_{a_{jk} \in A_j} c_{jk}$$

$$c_* \equiv \sum_{j=1}^{n} c_{j*}$$

$$c_j{}^* \equiv \max_{a_{jk} \in A_j} c_{jk}$$

$$c^* \equiv \sum_{j=1}^{n} c_j{}^*$$

U(c): optimal total performance when alternatives for all functional units F_j are chosen so as to maximize total performance under cost constraint c; hereafter we call function U(c) CPC;we denote it U(c ; q) instead of U(c) in case where we need to clarify optimal performance at sales quantity q.

w(c) $\uparrow$ c: function w(c) is non-decreasing in c

2.3 Preliminary Consideration

We are going to clarify the property of CPC and its role in PD decision making. For this purpose, the following steps are clarified for any original alternative a'_{jk} in each functional unit F_j:

Step 1: Method for calculating evaluation value u'_{jk} by using AHP.

Step 2: Basic method for estimating cost c'_{jk} on target sales quantity q.

Step 3: Method for preparing arranged alternative set $A_j \equiv \{a_{js}\}$ by excluding unqualified alternative from original alternative set $A'_j \equiv \{a'_{jk}\}$.

Step 1 : Method for calculating evaluation value u'_{jk} by AHP.

The details of evaluation method of alternatives for each functional unit in PD are omitted as they are described in Analytic Hierarchy Process (AHP) [7]. Here, we will give a minimum level of explanation for better understanding of our argument.

① Make such a hierarchical diagrsm of AHP as illustrated in Figure 2. Noticing that original alternative set $A'_j=\{a'_{jk}\}$ instead of alternative set $A_j=\{a_{js}\}$ in figure 2 should be described at first for F_j, evaluation items E_i, functional units F_j and alternatives a'_{jk} for F_j will be listed in the diagram.

② Determine weight w_i for evaluation item E_i, which represents the degree of importance among evalution items, by using the pairwise comparisons method of AHP.

③ Determine weight w_{ij} $(i=1, ..., m; j=1, ..., n)$ of functional unit F_j for evaluation item E_i which represents the degree of importance among functional units, by the pairwise comparisons method.

④ Determine evaluation value u'_{ijk} $(i=1, ..., m; j=1, ..., n; k=1, ..., r'_j)$ of alternative a'_{jk} in functional unti F_j for evaluation item E_i, by using the pairwise comparisons method among alternatives for functional unit F_j.

⑤ Calculate evaluation value u'_{jk} of alternative a'_{jk} for F_j $(j=1,...,n; k=1,...r'_j)$.

Step 2 : Basic method for estimating cost c'_{jk} at target sales quantity q

Cost per product $c'_{jk}(q)$ $(j=1,...,n; k=1,...r'_j)$ at sales quantity q of alternative a'_{jk} in functional unti F_j includes R&D cost such as personnel expenses, testing equipment, etc. and production cost such as production facilities, raw materials, etc. Production cost will be a function of target sales quantity q as the scale of production facilities may vary with target sales quantity q. Therefore, using cost $f'_{jk}(q)$ which includes R&D and production facility costs, and variable cost v'_{jk}, cost per product $c'_{jk}(q)$ is expressed as

$$c'_{jk}(q)=v'_{jk}+f'_{jk}(q)/q$$

where cost $f'_{jk}(q)$ is generally considered to vary with production scale. If it is considered as fixed within the range of variation in target sales quantity q under consideration, $f'_{jk}(q)$ becomes fixed cost f'_{jk}. In the conventional studies [2], [3], target sales quantity of product was supposed implicitly and thus cost c'_{jk} was considered as given.

Where there is an uncertainty in target sales quantity or we have a development case of multiple products series with different prices and target sales quantities, it is necessary to estimate costs of alternatives for each target sales quantity and prepare CPC separately. This study supposes a case where such cost estimation is possible.

For functional unit F_j in PD, evaluation value set $\{u'_{jk}\}$ and cost set $\{c'_{jk}\}$ corresponding to development alternative set $\{a'_{jk}\}$ are obtained. For simplicity of description, $\{c'_{jk}\}$ is used as a substitute of $\{c'_{jk}(q)\}$, except the special case where it is needed to show target sales quantity q.

Step 3 : Method for preparing A_j by excluding unqualified alternatives from A'_j

Using cost c'_{jk} and evaluation value u'_{jk} of alternative a'_{jk} for functional unit F_j, monotonic subsequence A_j is composed from alternative set A'_j for functional unit F_j, in the following way. Here, denote the cost and evaluation value of alternative a_{js} be c_{js} and u_{js}, respectively.

Definition 1: For any j with j=1,...,n, let a'_{jk} satisfying

$$\min_{a'_{jk} \in A'_j} c'_{jk}$$

be a_{j1} and corresponding c'_{jk} and u'_{jk} be c_{j1} and u_{j1}, respectively. Here, if we have plural minimum values c'_{jk}, we choose alternative a'_{jk} which maximizes u'_{jk}. Then for s=2, 3, ..., we let a'_{jk} satisfying

$$\min_{a'_{jk} \in \{ a'_{jk} \mid c_{j(s-1)} < c'_{jk},\ u_{j(s-1)} < u'_{jk} \}} c'_{jk} \qquad \text{for one } a_{j(s-1)} \in A'_j \tag{1}$$

be a_{js}, recursively. If we have plural minimum values c'_{jk}, we choose alternative a'_{jk} which maximizes u'_{jk}. Then denote the arranged alternative set $\{a_{js}\}$ be A_j.

This subsequence is shown in Figure 3, which plots costs of alternatives as the abscissa and evaluation values as the ordinate for each functional unit F_j.

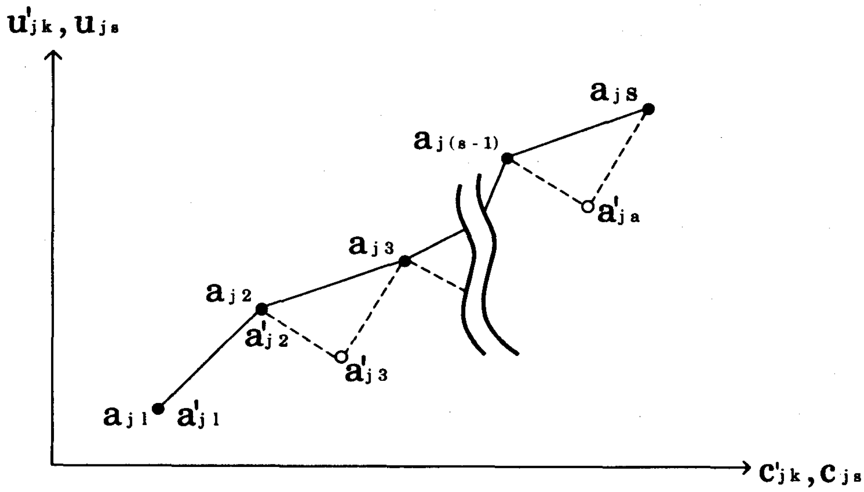

Figure 3 Relation of A'_j and A_j for functional unit F_j

Proposition 1

It is sufficient to consider A_j ($A_j \subseteq A'_j$) in place of A'_j as a set of alternatives in making optimal choice of alternative for functional unit F_j.

This is easily understandable by the following reason:
Suppose that alternative a'_{jk} such that

$$a'_{jk} \in \{ a'_{jk} \mid c_{j(s-1)} < c'_{jk},\ u_{j(s-1)} \geqq u'_{jk} \}$$

,which should be excluded as unqualified in equation (1) of Definition 1, is selected as optimal alternative. If we select $a_{j(s-1)}$ in place of a'_{jk}, the alternative with lower cost and higher evaluation value can be attained. This contradicts the assumption that a'_{jk} is optimal selection. By this reason, it is obvious that a'_{jk} cannot be optimal alternative, that is, a'_{jk} is an unqualified alternative in optimal selection.

2.4 Formulation

Formulation by DP is possible so long as Assumption 2 holds (case where no dependency exists among functional units). However, since Assumption 2 does not hold in the case where dependency exists among functional units, the principle of optimality cannot be applied and thus DP formulation is impossible. In this case, EM is needed in order to check the existence of dependency for all the CAs and select optimal CA among possible CAs. In this study, the formulation is made supposing more general case where Assumption 2 does not hold. A more detailed treatment of the case will be discussed in Chapter 5.

The problem of selecting an alternative for each functional unit, which maximizes total performance (total evaluation value) under cost constraint c, is formulated as a knapsack problem in 0-1 integer programming:

Suppose evaluation value u_{jk} is calculated for each alternative a_{jk}. Define variable x_{jk} with respect to adoption or rejection of alternative a_{jk}:

$$x_{jk}=\begin{cases}0 & \text{reject alternative } a_{jk}\\ 1 & \text{adopt alternative } a_{jk}\end{cases} \qquad \text{for } \forall j=1, \ldots, n;\ \forall k=1, \ldots, r_j$$

The condition, where only one alternative is selected and the other alternatives cannot be selected for each functional unit F_j, can be written by

$$\sum_{k=1}^{r_j} x_{jk}=1 \qquad \text{for } \forall j=1,\ldots,n.$$

The cost of adopting alternative a_{jk} is given by c_{jk}, so that total cost constraint in the case of adopting one alternative for each functional unit is expressed by

$$\sum_{j=1}^{n}\sum_{k=1}^{r_j} c_{jk}x_{jk} \leqq c.$$

Paying attention to the fact that evaluation value of alternative a_{jk} for functional unit F_j is expressed by u_{jk}, total performance (total evaluation value) is given by

$$\sum_{j=1}^{n}\sum_{k=1}^{r_j} u_{jk}x_{jk}.$$

Then, the problem of choosing alternative for each functional unit so as to maximize total performance under cost constraint is formulated as follows:

$$\begin{aligned}
&\underset{x_{jk}}{\text{Maximize}}\ \sum_{j=1}^{n}\sum_{k=1}^{r_j} u_{jk}x_{jk}\\
&\text{Subject to}\\
&\qquad \sum_{j=1}^{n}\sum_{k=1}^{r_j} c_{jk}x_{jk} \leqq c\\
&\qquad \sum_{k=1}^{r_j} x_{jk}=1 \quad \text{for } \forall j=1,\ldots,n\\
&\qquad x_{jk} \in \{0,1\} \quad \text{for } \forall j=1,\ldots,n; \forall k=1,\ldots,r_j.
\end{aligned} \tag{2}$$

3. Analyses

3.1 Optimization and CPCM

Optimal Choice of CA

Equation (2) implies that the problem is to select a CA among a set of CAs with the finite size $\prod_{j=1}^{n} r_j$ in number so as to maximize total performance under cost constraint.

Making use of spread sheets and macro functions of a certain application software, we can easily obtain the figure of CAs as illustrated in the application example of Figure 8, which plots cost as the abscissa and total performance as the ordinate. From the figure, we can select optimal CA for a given cost constraint.

Method for Making CPC

Usually we don't know an appropriate magnitude given to target cost constraint so the constraint will be set at a certain value within a permitted range. Therefore, it's important to make CPC which represents changes in optimal performance when changing target cost constraint.

Applying the same argument as the method for preparing A_j from A'_j in Step 3 of Section 2.3 (which uses Definition 1 and Proposition 1) to the figure of CAs, we can easily obtain CPC. Here, we briefly present this method.

Among all the CAs in the figure, select the CA with minimum cost and let it be CA $_{(1)}$. Here, if we have plural CAs with minimum cost, we choose the CA which maximizes total performance. In general, when CA $_{(s-1)}$ is selected for s=2,3,... , we choose the CA which attains minimum cost among CAs with larger costs and higher performances than those for CA $_{(s-1)}$ and let it CA $_{(s)}$. In order to clarify the sequence, the selected CA $_{(s)}$'s are successively connected by solid line. The remaining CAs under the curve are not relevant to optimal selection.

Monotonicity of CPC

From the procedure for making CPC, it is easily seen that the monotonicity of CPC holds. This property holds in more general situation described in Chapter 5 where Assumption 2 does not hold. Here we present the result only. With respect to optimal total performance U(c) which satisfies equation (2), we have

$$U(c) \uparrow c \quad \text{for } c_* \leqq c < c^*. \tag{3}$$

Relation (3) shows that performance U(c), namely, CPC is non-decreasing with respect to an increase in cost constraint c. Noticing optimal CA which attains maximum total performance under cost constraint is realized at a CA among these selected CA $_{(s)}$'s, it can be easily understood that U(c) becomes a step function illustrated as dotted line in Figure 4. However, from now on, we conveniently call the curve connected by solid line CPC instead of step function.

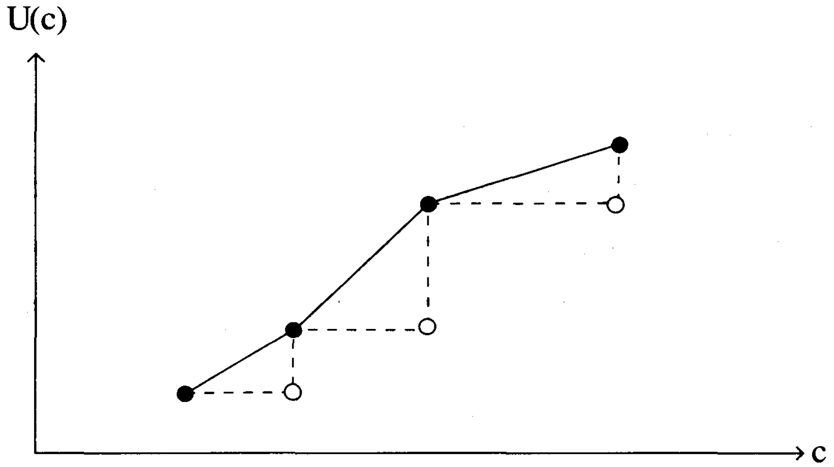

Figure 4 Change in U(c) by c

<u>Comparison between CPCM and IDM</u>

In alternative choice of VE, an approach is used to narrow down to one single alternative for each functional unit. This approach is considered as a practical method to avoid the evaluation of enormous number of CAs in the case of detailed design where design alternatives go into details. In fact, it had been used at plural companies which we visited. We call the method, which individually selects one alternative for each functional unit considering technological and economic factors, "individual design method (IDM)". However, at initial phase of PD such as concept or method design, it is required to form basic product concepts. Here, it is important to select a few set of well-balanced CAs which may attain an excellent total cost-performance and meet all the evaluation items. Especially in development of new product with limited experience, we often have little specific information on cost-performance of product to be adopted, permissible range for target cost constraint, etc. Also, in developing a series of products, it may be needed to define two or more CAs with different grades. In such cases, it will be effective to consider CPC, that is, changes in optimal performance when changing cost constraint as target value. Taking into consideration the fact that IDM has been used in practice so far, now we will clarify the difference between CPCM and IDM.

Suppose a CPC is obtained as shown in Figure 5 by CPCM. Let cost and evaluation value of preferable alternative $a_{j\star}$ for functional unit F_j $(j=1,\ldots,n)$ by IDM be $c_{j\star}$ and $u_{j\star}$, respectively, and the CA be $A_\star=\{a_{1\star},\ldots,a_{n\star}\}$. Also define $C_\star$ and $U_\star$ as follows:

$$C_\star \equiv \sum_{j=1}^{n} c_{j\star}, \quad U_\star \equiv \sum_{j=1}^{n} u_j$$

Then any alternative which belongs to the area $u>U_\star$ and $c<C_\star$ (diagonally shaded area in the figure) becomes superior to alternative $A_\star$ (marked with ◎ in the figure). The fact shows that CPCM is equal to or better than IDM. We should notice that CPCM can present a practical and convenient method for selecting optimal CA from a total viewpoint in PD.

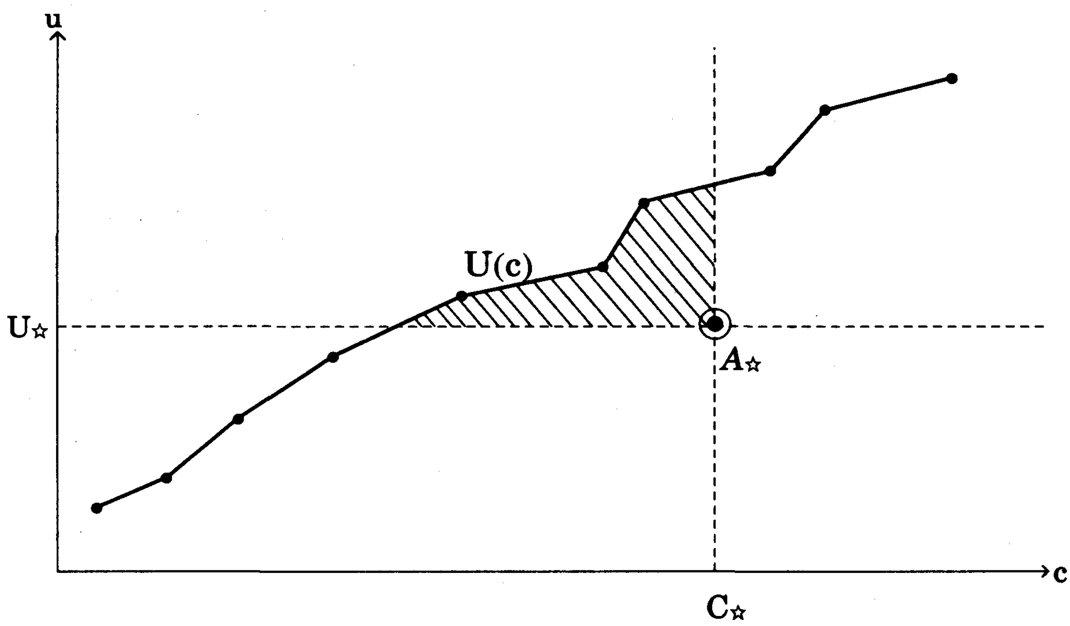

Figure 5 Cost-Performance Curve for CAs

3.2 CPC Taking Target Sales Quantity into Account

We will consider the effect on PD when target sales quantity of product at sales price p is changed from q_1 to q_2 $(q_1<q_2)$. Here, we suppose the case, where alternatives for any functional unit are same for both cases since target sales quantity is set under

predetermined circumstances with respect to product concept, multiple criteria and alternatives as explained in Chapter 1 and the scale economy exists in cost $c_{jk}(q)$ for any functional unit F_j at target sales quantity q, that is, the relation

$$c_{jk}(q_1) > c_{jk}(q_2) \quad \text{for } \forall j=1, \ldots, n \,;\ \forall k=1, \ldots, r_j$$

holds.

Evaluation values u_{jk} of any alternatives $a_{jk}(q_1)$ and $a_{jk}(q_2)$ at two target sales quantities q_1 and q_2 are same but only costs are different. Excluding unqualified alternatives from all the CAs and drawing CPC according to the method of Definition 1, the curves of solid and chain lines in Figure 6(a) are obtained. All the CAs for each functional unit at target sales quantity q_2 locate above those for $q=q_1$. Letting target cost when $q=q_2$ be $c_{2\bigstar}$ that realizes performance $u=u_1$ at $q=q_1$ and $c=c_1$, then the relation $c_{2\bigstar}<c_1$, and thus it becomes possible to reduce target cost by the scale economy.

Next, as a special case in Figure 6(a), we will consider a case where product 2 (popular product) with price p_2 and target sales quantity q_2 and product 1 (high-quality product) with price p_1 and target sales quantity q_1 are lined up simultaneously. Here, it is natural to suppose

$$p_2<p_1, \quad q_2>q_1.$$

According to the above consideration, the relation between the CPCs for two products can be expressed as shown in Figure 6 (b) for the same cost constraint by the difference in scale economy.

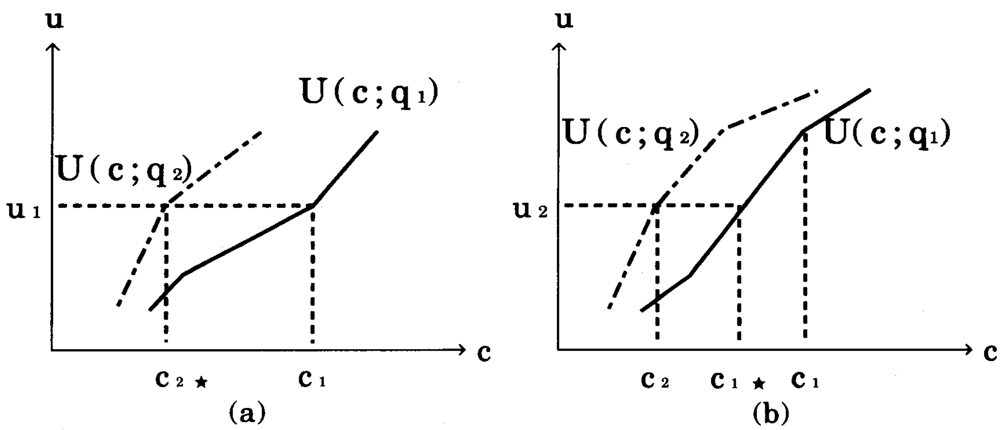

Figure 6 Cost-Performance Curves for Different Target Sales Quantities

Let performance of product 2 under cost constraint c_2 be u_2. And denote cost constraint of product 1 that realizes u_2 and cost constraint of product 1 as $c_{1\bigstar}$ and c_1, respectively. In order to make meaningful the differentiation of products 1 and 2, it is necessary that the relations

$p_1 > c_1 > c_{1\bigstar} > c_2$, $p_1 > p_2 > c_2$

hold. In order to set cost constraint c_1 of product 1, it is needed to take properly large $c_1 - c_{1\bigstar}$ within the range of $p_1 > c_1 > c_{1\bigstar}$. If $(p_1 - c)\, q_1 > (p_2 - c_2)\, q_2$ holds, the profit gained from product 1 exceeds one from product 2. CPC enables us to obtain useful information on decision making in PD, as shown in the above consideration.

4. An Application to a Practical Problem

We will show a practical method of CPCM by applying to PD of copying machine which has been already developed.

Suppose a copying machine to be installed at a corner of small office. The development concepts of this copying machine are low price, small size and easy operation. Seven evaluation items E_i $(i=1,\ldots,7)$ are considered for this copying machine, i.e., copy quality, copy speed, compactness, operability, maintainability, environmental friendliness, and running cost. The copying machine consists of 9 functional units of main frame unit, cover unit, operation panel unit, scanning unit, image processing unit, development unit (toner supply), transfer unit, fusing unit, and electrical components unit. Of these units, design alternatives for functional units of main frame, cover, operation panel and electrical components are supposed given and thus excluded from selection. Practically it is needed to decide alternatives for six functional units. Two alternatives a_{jk} $(k=1, 2)$ are proposed for each subsystem F_j $(j=1,\ldots,6)$. Two alternatives for functional units of paper feeding, scanning, image processing, development, transfer and fusing units correspond to methods of paper holding, mirror unit drive, installation and removal of multiple units, toner change, field application, installation and removal of multiple parts, respectively. Hierarchical diagram in PD of copying machine is shown in Figure 7.

Weight w_i of each evaluation value E_i is calculated by the pairwise comparisons of AHP and its validity is checked by consistency index and consistency ratio. Weight w_{ij} which

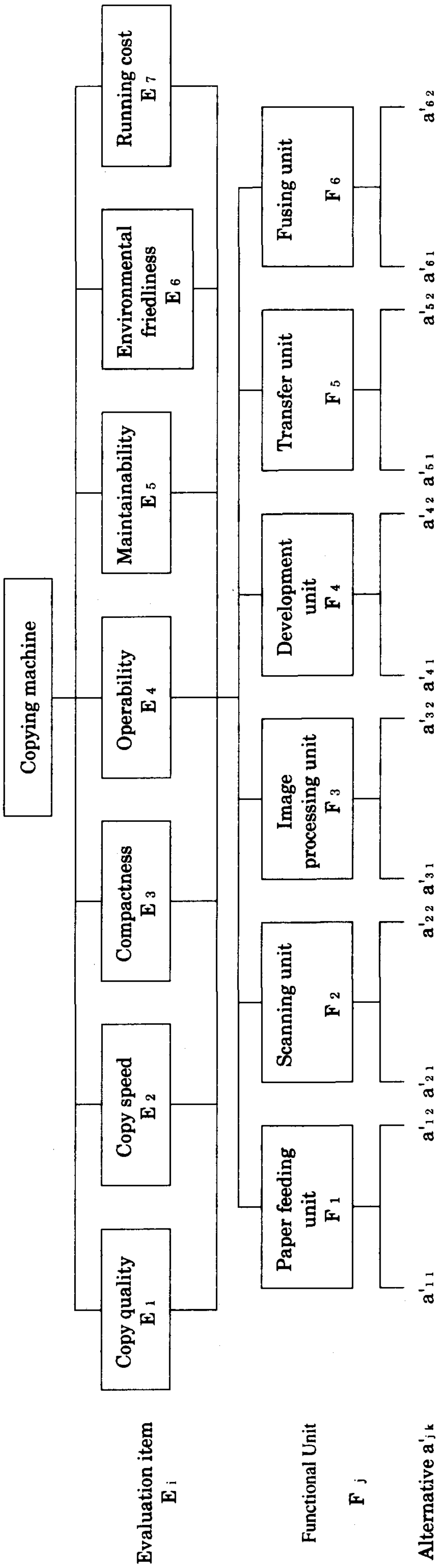

Figure 7 Hicrarchical Diagram in Product Development of Copying Machine

expresses the importance of functional unit F_j for evaluation item E_i and evaluation value u'_{ijk} of alternative a'_{jk} in subsystem F_j for evaluation item E_i are calculated by the pairwise comparisons of AHP and its validity is checked in the same way. Using w_i, w_{ij} and u'_{ijk}, evaluation value u'_{jk} of alternative a'_{jk} is obtained. Target sales quantity of this machine is set at q_1=220,000 and cost per product c'_{jk} of alternative a'_{jk} in subsystem F_j is estimated based on the accomplishments' values. The series of cost values are converted in a certain form. For purposes of comparison, costs c'_{jk} in the case of target sale quantity q_2=350,000 are also calculated. Evaluation values u'_{jk} and costs c'_{jk} are summarized in Table 1.

Here, decision maker in PD is interested in selecting a CA for all functional units so as to maximize total performance under cost constraint.

Table 1 Evaluation Values and Costs of Alternatives

F_j	F_1		F_2		F_3		F_4		F_5		F_6	
a'_{jk}	a'_{11}	a'_{12}	a'_{21}	a'_{22}	a'_{31}	a'_{32}	a'_{41}	a'_{42}	a'_{51}	a'_{52}	a'_{61}	a'_{62}
u'_{jk}	0.054	0.093	0.053	0.059	0.196	0.113	0.091	0.074	0.058	0.072	0.078	0.059
c'_{jk}	113.9 109.2	124.4 119.3	166.8 161.9	198.2 192.6	100.6 97.2	102.4 98.4	32.1 31.1	35.4 33.8	18.2 17.2	80.0 77.7	82.1 79.8	70.8 69.1

Note: for c'_{jk}, cost of upper figures: q_1 =220,000; cost of lower figures: q_2 =350,000.

For functional unit F_3 in Table 1, alternative a'_{32} is inferior to alternative a'_{31} in both evaluation and cost and thus is excluded as an unqualified alternative. As a result, only one alternative a'_{31} remains for F_3, so that F_3 is excluded from alternative selection. For the same reason, F_4 is excluded because alternative a'_{42} is excluded as an unqualified one. Hereinafter, for alternatives which remain after excluding unqualified alternatives, a_{jk} is used instead of a'_{jk}. In Figure 8, at q_1=220,000 , all the 16 CAs for 4 functional units, excluding the above two functional units, are plotted with total costs as the abscissa and total performance as the ordinate. This figure is drawn using the spread sheet and its macro functions.

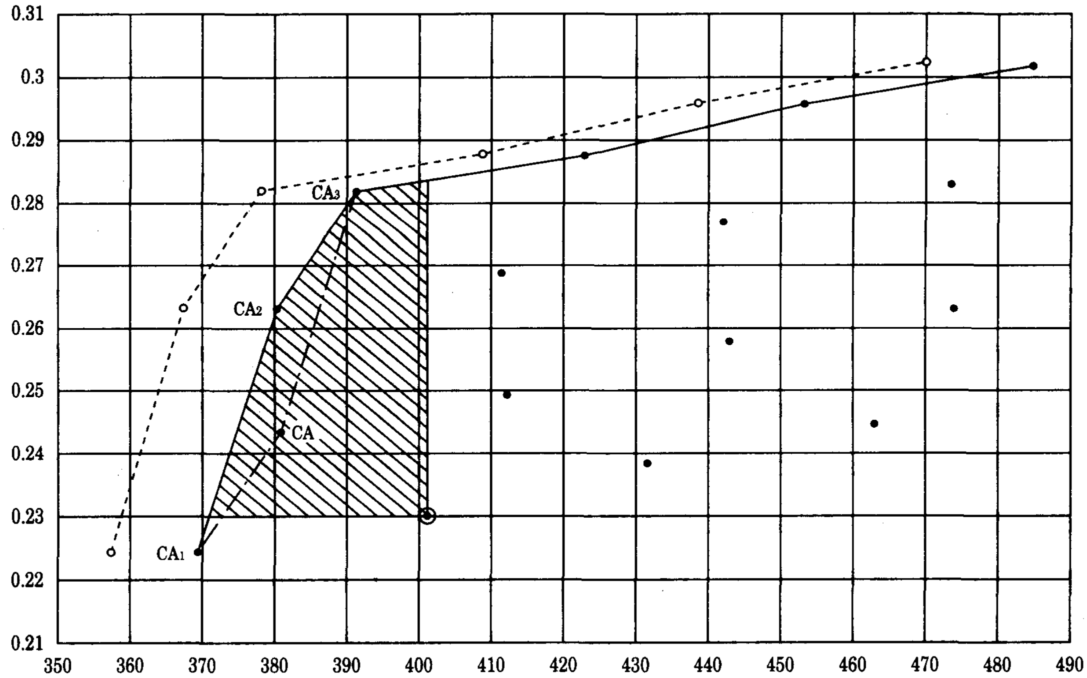

Figure 8 Cost-performance Curve of Copying Machine

The solid line indicates CPC obtained through optimization. The reason is understandable by the fact that total performance increases monotonously with increase in cost constraint where CPC selects the CA which attains maximum total performance under cost constraint. Optimal CA can be selected only from 6 CAs on the solid line. The remaining CAs under the curve are not relevant to optimal selection.

Total performance is improved remarkably with increase in cost under cost constraint c up to approximately 390, but with c over 390, the degree of improvement in performance is small compared with increase in cost. From this fact and the fact that c is needed to set at 400 or less when considering sales price, it is realistic to vary c between 370 and 400.

Then, we will consider the difference between CPCM and IDM. Here, suppose CA (a_{11}, a_{22}, a_{51}, a_{62}) (marked with ◎ in the figure) is selected. The cost of this CA is 401.1 and its performance is 0.23 (hereinafter this is written as CP (401.1, 0.23)). The CAs superior to this are 3 alternatives of CA, CA_2 and CA_3 in shaded region of the figure.

Then, either of 2 CAs, namely, CA_2 (a_{12}, a_{21}, a_{51}, a_{62}) (CP (380.2, 0.263)) or CA_3 (a_{12}, a_{21}, a_{51}, a_{61}) (CP (391.5, 0.282)), is superior to the other 2 alternatives. From this, it is seen that either of 2 CAs on CPC can be selected paying attention to the magnitude of cost constraint.

Finally, we will evaluate a practical decision by using the concept of CPC. In this case, CA (a_{11}, a_{21}, a_{51}, a_{61}) (CP (381.0, 0.243)) was selected in practice. CA is inferior to CA_2 numerically and should be excluded as unqualified alternative. However, comparisons of costs and performances show that both alternatives make no remarkable difference. In such a case, formal or mechanical exclusion of unqualified alternatives involves risks and therefore it is important to examine technically the difference between two alternatives. In fact, as shown in Table 2, the difference among alternatives CA, CA_1, CA_2 and CA_3 results from the difference between two alternatives of functional units F_1 (paper feeding unit) and F_2 (fusing unit). If alternatives with lower maintainability of F_2 are to be avoided, it is natural to replace CA_2 with CA with little numerical difference. As a result, CPC is modified by a curve (chain line) connecting CA_1, CA and CA_3 in Figure 8. Then, the selection of alternatives will depend on the magnitude of allowable cost constraint. It is considered that the result of analysis suggests the following viewpoint: as the aim of CPC is to provide useful information for judgement, it is important to give technical and economic consideration to individual alternatives including unqualified ones where decision making varies delicately around CPC.

Table 2 Comparison of Four CAs

		F_2 : Fusing	
		Maintainability (M) Cost (H)	Maintainability (L) Cost (L)
F_1 : Paper feeding	Operability (H) Cost (H)	CA_3	CA_2
	Operability (M) Cost (L)	CA	CA_1

Note : H : high, M : medium, L : low

In the figure, broken line shows CPC at q_2=350,000. From this, it is seen that CPC at q_1=220,000 shifts leftward by scale merit. As a result, under total cost constraint c=381, at q_1=220,000, CA_2 (a_{12}, a_{21}, a_{51}, a_{62}) (CP (380.2, 0.263)) is selected whereas in the case of q_2=350,000, CA_3 (a_{12}, a_{21}, a_{51}, a_{61}) (CP (378.02, 0.282)) is selected. As shown in this example, scale merit gives an opportunity for selecting CA with higher performance under the same cost constraint or CA which realizes the same performance by lower cost constraint.

The result of analyses shows the importance of explicitly introducing target sales quantity into cost estimation mechanism of PD. The target sales quantity will play a key role in developing further extended models for PD.

5. *Treatment with Technological or Economic Dependent Alternatives*

In this chapter, we consider how to obtain CPC when technological or economic dependency exists among alternatives for plural functional units.

Definition 2 Technological or Economic Dependency

(1)Among alternatives of two or more functional units, there may be alternatives which cannot be adopted as CA by technological reason. These alternatives are referred as technologically dependent.

(2)Among alternatives of two or more functional units, there may be cases where cost of CA is not equal to sum of costs of respective functional unit alternatives by economic reason. These alternatives are referred as economically dependent.

If technological or economic dependency may exist, it is necessary to check the existence of dependency for all the CAs and take necessary corrective actions. This correction is easily made by using the spread sheet and its macros used for preparing Figure 8 (calculation of total performance and cost of CAs). The method is as follows:

Calculate total performances and costs of CAs prepared under the assumption that any dependency does not exist. Then, delete CAs with technological dependency. Correct costs of CAs with economic dependency. Using the features of spread sheet, plot costs as the abscissa and total performances as the ordinate for all the CAs. Starting from the CA with the lowest cost (if there are more than two, adopt the alternative with higher total performance), make monotonic subsequence described in Definition 1. The solid line obtained by successively connecting these CAs is CPC.

6. *Conclusion*

This study considers the following points for the problem of selecting CA in PD so as to maximize total performance under cost constraint:

1. CPCM for the choice of CA introducing target sales quantity are given by the joint use of AHP and EM, which enables us to treat with more general cases including dependent alternatives among functional units.
2. The property of CPC and its role in decision making are systematically described , especially the effect of introducing target sales quantity are clarified.
3. A practical application to PD of copying machines is presented by using CPCM and useful information is given in applying the method to other PD problems.

Modeling studies in the field of PD have not been made extensively compared with those in production problems, because actual circumstances are not always known and the ill-structured nature with multiple and qualitative factors makes these difficult. Thus, it is considered important to offer more prototype models in this field.

Acknowledgements

The author is grateful to Mr. Hideo Hashimoto and Mr. Toshio Watanabe, Imaging Business Strategy & Control Division of Ricoh Co., Ltd., for implementing the application and providing the results. He also thanks the referees for their useful comments to improve this paper.

References

[1] Kato, Y.:*Target Costing:Strategic Cost Management* (Japanese Book), Nihonkeizai-shimbunsya, 1993.

[2] Kusaka, Y. and M. Tsuji: *"A Proposal of Product Design Method under Cost Constraint: The Construction of Decision Support System for Product Development (Part 1)," Journal of Japan Industrial Management Association* (in Japanese), Vol.46, No.2, 1995, pp.99-106.

[3] Kusaka, Y.: *"A Choice of Combinatorial Alternative in Product Development," The Journal of Science Policy and Research Management,* Vol.12, No.3·4, 1999, pp.206-218.

[4] Senju, S. and T. Fushimi: *Economic Engineering -New Edition-* (Japanese Book), Japan Management Association, 1973.

[5] Tanaka, M.: *Value Engineering* (Japanese Book), Management Co., Ltd., 1985.

[6] Tejima, N.:*Practical Value Engineering* (Japanese Book), Union of Japanese Scientists and Engineers (JUSE), 1993.

[7] Tone, K.:*Decision Making Method in Game Sense:An Introduction to AHP* (Japanese Book), JUSE, 1986.

日本管理会計学会誌
管理会計学 1998年 第6巻第2号

論　文

コスト・パフォーマンス曲線を使用した製品開発

日下　泰夫*

＜論文要旨＞

価値観の多様化，企業間競争の激化の下で，顧客の要求する諸機能を有する製品を総合的な観点からバランスよく低コストで供給することは，製品開発の１つの重要な視点である．この領域では従来からコスト性能比(価格性能比)という用語が使用されてきたが，ここでの「性能」はコンピュータの演算速度のように単一の性能に限定され事後的に使用されることが多かった．この概念を，評価項目の多目標性と定性的特性を考慮した総合性能として，製品開発の意思決定に明示的，操作的に使用出来るようにすることが重要である．この観点から，コスト・パフォーマンス曲線(ＣＰＣ)を利用して，コスト制約下で総合性能を最大にする製品開発組合せ代替案を選択する方法が，階層分析法(ＡＨＰ)と動的計画法(ＤＰ)を使用して提案されている．

本研究は、上記の問題に対して，コスト制約下の製品開発で重要な役割を果たす製品の目標販売量を新たに導入することによって，拡張化されたＣＰＣを利用する方法を提案する．定式化と解析には，階層分析法(ＡＨＰ)と列挙法(ＥＭ)を結合的に使用する．次いで，このモデルを複写機の実際の開発事例に適用することによって，提案法の具体的利用法と他の諸問題に適用する際のいくつかの重要な視点を明らかにする．さらに，複数の機能ユニットの代替案間に技術的あるいは経済的従属性が存在する場合に対処する方法も示す．

提案法は，多目標的・定性的評価を処理するＡＨＰと表計算などの簡単なソフトウェアの使用を前提としたＥＭの結合的適用を通じて，拡張化されたＣＰＣを製品開発の意思決定に利用するプロトタイプ・モデルとして特徴づけられる．

＜キーワード＞

製品開発，コスト・パフォーマンス曲線，目標販売量，組み合わせ代替案，階層分析法，列挙法，複写機への適用

1997年12月 受付
1998年10月 受理
*獨協大学経済学部経営学科教授