Establishment of Manufacturing Cost Target by Weight Analysis with Design Parameters

—— System Design and Development ——

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Abstract

In this paper, a new method to establish the manufacturing cost target is proposed. In general, it is established from each of economical and/or technological aspect. In particular, we describe a new method to establish it from the viewpoint of technological aspect. In this method, the cost target is established on the basis of a relation between the primal design parameters and the manufacturing cost of product. Further, the system design and development to establish the manufacturing cost target is described.

In order to show how the proposed method works, a practical example of over-head conveyor system is illustrated.

Keywords: value engineering, cost target, constrained simplex, design parameter, weight analysis

1. Introduction

Ever since total quality control (TQC) was installed to the enterprise, it has been applied in the streamlining of departments of information, planning, research and development, production technology and so on. Recently the management of the departments mentioned above has been highly emphasized in the design and development of value engineering. This belongs to the question how to evaluate the balance between the function and the cost of the product in the process of design, development and production.

Value engineering (VE) is an organized application of common sense and technical knowledge directed at finding and eliminating unnecessary costs in product, service or project [1]. Two elements of value equation are function and cost. The value is defined based on function (F) and cost (C) as follows: $V = F/C$, that is, as the cost of the product decreases, the value increases. Subsequently, as the function increases, so too does the value increase [2]. They are identified and balanced against one another. The objective of VE is to identify all elements of function and cost.

For the designers of a new product, a cost target is regarded as a primal design parameter as well as the target of performance and schedule of the product. The cost target shows an upper limit of the product cost. The design activities complete after the cost target is achieved. The cost target should be reasonable and incentive for the designers. The cost target is usually established in all over the life cycle of the product. Especially the manufacturing cost target (MCT) is the most popular one.

In this paper, a new method to establish the MCT is proposed. In general, it is established from each of economical and/or technological aspect. In particular, we describe a new method to establish it from the viewpoint of technological aspect. In this method, the cost target is established on the basis of a relation between the primal design parameters and the manufacturing cost of the product.

In order to show how the proposed method works, a practical example of over-head conveyor system is illustrated.

2. Nature of Cost Target

On the design and development activities of a new product, the cost target [3] is regarded as a kind of primal design parameter as well as the target to realize the performance and the development schedule of the product. The cost target indicates an upper limit that is allowed to the new product cost or the product cost of orders received. It must be reasonable and incentive to the designers. As a rule, the cost target must be established at a level that insures profitability of the product and is attained by extra efforts of the designers.

It goes without saying that activities for the development and design do not complete, unless the cost target is achieved. It is a fundamental concept of cost management in the development and design phases. The cost target has to be established in all over the life cycle of the product. Namely, it must be established as each target of the costs for the design and development activities, for purchasing and manufacturing activities, for physical distribution activities, and for user's operation. The MCT with such nature is the most popular one.

3. How to Establish Cost Target

The MCT is established from each of economical and/or technological aspects [4]. From the economical aspect, the cost target is determined by subtracting a gross margin from a market price for the product as follows :

Market Price - Gross Margin = Manufacturing Cost Target

This equation can not be applied if either the market price or the market price proportionate to others is not established.

On the other hand, some methods have been proposed to establish the cost target from the technological aspect [5] [6]. In the design and development phases, the most theoretical and applicable method of them is the traditional multiple regression [7], which is able to express the regression formula with linear or non-linear functions.

In this paper, the method to establish the design-cost formula (DCF) with plural design parameters will be mainly described. The DCF means the relation between the design parameters and the cost of product. The DCF is identified through analyzing the relation of the design parameters and the manufacturing cost in normal condition.

The method has following properties:

① We can flexibly select the design parameters, and/or number of design parameters, which have an influence on the establishment of MCT greatly. by doing this, we can directly effect volition of decision-makers concerning with the MCT problem.

② We can determine the unknown design parameters after setting the weight of a part of selected design parameters in advance. From this, we can effectively formulate the DCF with flexibility.

③ We can yield an optimal solution for the MCT problem without depending on the function of DCF, that is linear or nonlinear functions by finite trial.

Further, the cost data being applied into the formula is an actual manufacturing cost in normal condition. The actual manufacturing cost is affected on the production volume, the prices and the market condition etc..

Therefore, it must be modified to the cost in normal condition.

4. Weight Analysis by Design Parameters

In this method, at first, we choose the design parameters that commit the relation between the manufacturing cost and the cost of product. We make clear what weight the design parameters have. The method is proposed on the basis of the constrained simplex revised [8].

The relation between the design parameters X_j, $(j=1,2,...,n)$ and the normal manufacturing cost P_i,$(i=1,2,...,m)$ is given in advance in Table 1.

Here, X_{ij} means that the design parameter is to what degree in order to commit the manufacturing cost. The manufacturing cost function $U(X)$ is expressed as that one of n design parameters (n : variables) as follows:

$$U(X)=U(X_1,\ X_2,\ ...,\ X_n)$$

U is shown as a linear combination formula with a weight vector β for vector X.

$$U(\beta,X)=\beta X$$

where $\beta=(\beta_1,\beta_2,...,\beta_n)$, $X=(X_1, X_2, ..., X_n)^T$, The symbol T shows the transposition.

Table 1 Design parameters and normal manufacturing cost

manufacturing cost	design parameters					
	X_1	X_2	...	X_j	...	X_n
P_1	X_{11}	X_{12}	...	X_{1j}	...	X_{1n}
P_2	X_{21}	X_{22}	...	X_{2j}	...	X_{2n}
...	...	...	...	...	...	...
P_i	X_{i1}	X_{i2}	...	X_{ij}	...	X_{in}
...	...	...	...	...	...	...
P_m	X_{m1}	X_{m2}	...	X_{mj}	...	X_{mn}

Supposing formula $U(\beta, X)$, we have to find such that minimizes a remainder of manufacturing cost $P=(P_1, P_2, ..., P_n,)$ and βX.

That is, $\min / P-\beta X /$

Then the algorithm to find the weight of design parameters is as follows:

The Algorithm for Establishment of Manufacturing Cost Target

Step 1. Make the initial simplex composed of $n+1$ vertices β_i $(i=1,2,...,n+1)$ on β. Compute $U(\beta_i, X_j).(i=1,2,..., n+1 ; j=1,2,...,m)$

$$\begin{cases} U(\beta_i, X_1)=U(\beta_{i1},\beta_{i2},...,\beta_{in} ; X_{11}, X_{12},..., X_{1n}) \\ U(\beta_i, X_2)=U(\beta_{i1},\beta_{i2},...,\beta_{in} ; X_{21}, X_{22},..., X_{2n}) \\ \quad ... \quad ... \quad ... \\ U(\beta_i, X_m)=U(\beta_{i1},\beta_{i2},...,\beta_{in} ; X_{m1}, X_{m2},..., X_{mn}) \end{cases}$$

Step 2. Find remainder of U evaluated in step 1 and the normal manufacturing cost.

$$\begin{cases} U(\beta_1, X_1)-P_1=d_{11} \\ U(\beta_1, X_2)-P_2=d_{21} \\ \quad ... \\ U(\beta_1, X_m)-P_m=d_{m1} \end{cases} \quad \begin{cases} U(\beta_2, X_1)-P_1=d_{12} \\ U(\beta_2, X_2)-P_2=d_{22} \\ \quad ... \\ U(\beta_2, X_m)-P_m=d_{m2} \end{cases} \quad \begin{cases} U(\beta_{n+1}, X_1)-P_1=d_{1n+1} \\ U(\beta_{n+1}, X_2)-P_2=d_{2n+1} \\ \quad ... \\ U(\beta_{n+1}, X_m)-P_m=d_{mn+1} \end{cases}$$

Further, let

$$\begin{cases} D_1=\max(d_{11}, d_{21}, ..., d_{m1}) \\ D_2=\max(d_{12}, d_{22}, ..., d_{m2}) \\ \quad ... \\ D_{n+1}=\max(d_{1n+1}, d_{2n+1}, ..., d_{mn+1}) \end{cases}$$

where $\max(a_1, a_2, ..., a_n)$ indicates the maximum value of $a_1, a_2, ..., a_n$.

Here, let $D=\min(D_1, D_2, ..., D_{n+1})$. When $D<\chi^2$, the β corresponding to D becomes the best weight determining the manufacturing cost, where χ^2 is χ^2-distribution. Otherwise, go to Step 3.

Step 3. Sorting $D_1, D_2, ..., D_{n+1}$ which shows the remainder of U and P in ascending order. The order sorted in ascending order corresponds to the preference order of designers.

Now suppose that $d_1^* \leqq d_2^* \leqq ... \leqq d_{n+1}^*$, $\forall d_i^* \in D$ $(i=1,2,...,n+1)$

$$D = \{ D_1, D_2, ..., D_{n+1} \}$$

Further, the weight vector β corresponding to $d_1^*, d_2^*, ..., d_{n+1}^*$ is defined as follows.

$$\beta_1^* \geqq \beta_2^* \geqq ... \geqq \beta_{n+1}^*, \ \forall \beta_i^* \in \mathrm{B}, \ \mathrm{B} = \{\beta_1, \beta_2, ..., \beta_{n+1}\}$$

where $x \geqq y$ means that x is preferred to y.

Step 4. Find a new weight obtained by the following calculation in place of the worst weight β_{n+1}^*.

$$\beta_\alpha = \alpha \beta_1^* + (1-\alpha)\beta_{n+1}^* \quad 0 \leqq \alpha \leqq 1$$

Evaluate $U(\beta_\alpha, X_j)$, $(j=1, 2, ..., m)$ in regard to β_α and find the remainder of U and P.

$$\begin{cases} U(\beta_\alpha, X_1) = U(\beta_{\alpha 1}, \beta_{\alpha 2}, ..., \beta_{\alpha n} \ ; X_{11}, X_{12}, ..., X_{1n}) \\ U(\beta_\alpha, X_2) = U(\beta_{\alpha 1}, \beta_{\alpha 2}, ..., \beta_{\alpha n} \ ; X_{21}, X_{22}, ..., X_{2n}) \\ \quad ... \qquad\qquad ... \qquad\qquad ... \\ U(\beta_\alpha, X_m) = U(\beta_{\alpha 1}, \beta_{\alpha 2}, ..., \beta_{\alpha n} \ ; X_{m1}, X_{m2}, ..., X_{mn}) \end{cases}$$

$$\begin{cases} U(\beta_\alpha, X_1) - P_1 = d_{\alpha 1} \\ U(\beta_\alpha, X_2) - P_2 = d_{\alpha 2} \\ \quad ... \\ U(\beta_\alpha, X_m) - P_m = d_{\alpha m} \end{cases}$$

Further, let $d_\alpha^* = \min(d_{\alpha 1}, d_{\alpha 2}, ..., d_{\alpha m})$.

Step 5. Put d_α^* into $d_1^*, d_2^*, ..., d_{n+1}^*$ on the basis of the preference order.

If $d_\alpha^* \geqq d_n^*$, then go to Step 6 in order to find better β. Otherwise, go to Step 8.

Step 6. If $d_\alpha^* < d_1^*$, then$\beta_{n+1} = \beta_\alpha$. Go to Step 1. If $d_\alpha^* > d_1^*$, then it becomes worse than the worst weight β_1^* before now. In order to find a better weight, the following expression is computed.

$$\beta_\omega = \omega \beta_\alpha^* + (1-\omega)\beta_1^* \quad \omega > 1$$

Further, evaluate $U(\beta_\omega, X_j)$, $(j = 1,2,...,m)$ forβ_ω ,and find the remainder of U and P.

$$\begin{cases} U(\beta_\omega, X_1) = U(\beta_{\omega 1}, \beta_{\omega 2}, ..., \beta_{\omega n} \ ; X_{11}, X_{12}, ..., X_{1n}) \\ U(\beta_\omega, X_2) = U(\beta_{\omega 1}, \beta_{\omega 2}, ..., \beta_{\omega n} \ ; X_{21}, X_{22}, ..., X_{2n}) \\ \quad ... \qquad\qquad ... \qquad\qquad ... \\ U(\beta_\omega, X_m) = U(\beta_{\omega 1}, \beta_{\omega 2}, ..., \beta_{\omega n} \ ; X_{m1}, X_{m2}, ..., X_{mn}) \end{cases}$$

$$\begin{cases} U(\beta_\omega, X_1) - P_1 = d_{\omega 1} \\ U(\beta_\omega, X_2) - P_2 = d_{\omega 2} \\ \quad \cdots \\ U(\beta_\omega, X_m) - P_m = d_{\omega m} \end{cases}$$

Further, let $d_\omega{}^* = \min(d_{\omega 1}, d_{\omega 2}, \ldots, d_{\omega m})$.

Step 7. Put $d_\omega{}^*$ into $d_\alpha > d_1^* > d_2^* > \ldots > d_n^* > d_{n+1}^*$ on the basis of the preference order.
If $d_\omega{}^* < d_\alpha{}^*$, then $\beta_{n+1} = \beta_\alpha$.Otherwise, $\beta_{n+1} = \beta_\omega$ and go to Step 1.

Step 8. If $d_\alpha{}^* > d_{n+1}^*$, then $\beta_{n+1} = \beta_\alpha$.Otherwise, find$\beta_\gamma$ by making use of the following expression.

$$\beta_\gamma = \gamma\, \beta_{n+1}{}^* + (1-\gamma)\beta_1^* \quad 0 \leqq \gamma \leqq 1$$

Further, using$\beta_\gamma$obtained above, evaluate $U(\beta_\gamma, X_j)$, $(j=1,2,\ldots,m)$ in regard toβ_γ and find the remainder of U and P.

$$\begin{cases} U(\beta_\gamma, X_1) = U(\beta_{\gamma 1}, \beta_{\gamma 2}, \ldots, \beta_{\gamma n} \;;\; X_{11}, X_{12}, \ldots, X_{1n}) \\ U(\beta_\gamma, X_2) = U(\beta_{\gamma 1}, \beta_{\gamma 2}, \ldots, \beta_{\gamma n} \;;\; X_{21}, X_{22}, \ldots, X_{2n}) \\ \quad \cdots \qquad \cdots \qquad \cdots \\ U(\beta_\gamma, X_m) = U(\beta_{\gamma 1}, \beta_{\gamma 2}, \ldots, \beta_{\gamma n} \;;\; X_{m1}, X_{m2}, \ldots, X_{mn}) \end{cases}$$

$$\begin{cases} U(\beta_\gamma, X_1) - P_1 = d_{\gamma 1} \\ U(\beta_\gamma, X_2) - P_2 = d_{\gamma 2} \\ \quad \cdots \\ U(\beta_\gamma, X_m) - P_m = d_{\gamma m} \end{cases}$$

Further, let $d_\gamma{}^* = \min(d_{\gamma 1}, d_{\gamma 2}, \ldots, d_{\gamma m})$. Go to Step 9.

Step 9. Put $d_\gamma{}^*$into $d_1^* > d_2^* > \ldots > d_n^* > d_{n+1}^*$ on the basis of preference order. If $d_\gamma{}^* > d_{n+1}^*$, then $\beta_{n+1} = \beta_\gamma$,and go to Step 1. Otherwise, $\beta_i = 1/2(\beta_i^* + \beta_1^*)$ $(i=1,2,\ldots,n+1)$ and go to step 1.
On the basis of the procedure mentioned above, an optimal solution for MCT is yielded with finite trials, and the algorithm terminates.

5. Practical Examples

In this section, we describe the method to get the cost target while illustrating a practical example of over-head conveyor system. The over-head conveyor system is composed of three large sub-assemblies. The primal design parameters of the sub-assemblies are shown in Fig.1.
The DCF is identified on the basis of the relation between the design parameters and the normal manufacturing cost given in Table 2.

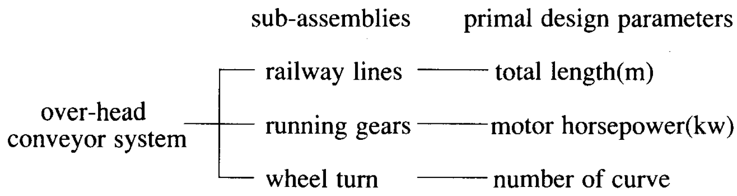

Fig.1 Primal design parameters of sub-assemblies

The DCF is identified on the basis of the relation between the design parameters and the normal manufacturing cost given in Table 2.

5.1 Weight Analysis by Design Parameters

In order to apply the weight analysis with design parameters into the identification of DCF, the design parameters of sub-assemblies shown in Fig.1 are used as factors (variables) to determine the DCF.

The system of weight analysis with design parameters is reasonably constructed as a decision support system, and the general flowchart is shown in Fig.2.

The computational result is shown in Fig.3 by making use of weight analysis with design parameters based on the general flowchart.

The average error rate shown in Fig.3 coincides with the result obtained by the regression analysis in the following section.

Therefore it has been confirmed that the proposed method is effective and reasonable from the computational result.

5.2 Multiple regression analysis

In order to apply the multiple regression analysis into the identification of DCF, the same design parameters in the case of weight analysis are used as factors (variables) to determine the DCF. The result of DCF obtained by applying the multiple regression analysis is as follows:

$$Y = 1063.13 + 15.4417 * X_1 + 96.6628 * X_2 + 56.8792 * X_3$$

$R^2 = 0.9288 \quad R = 0.9596 \quad (n = 38)$

Average error rate $= 6.837$ %

where Y : predicted manufacturing cost target

X_1 : total length

X_2 : motor horsepower

X_3 : number of curve

On the premise that interrelationships between the factors are non-correlative each other, the multiple regression analysis can be applied to identify the DCF. When the relations of them are correlative, the

Table 2 Design parameters and manufacturing cost

normal manufacturing cost (thousand yen)	design parameters total length (m)	motor horsepower (kw)	number of curve
7869.2	239.8	3.7	50
9271.8	355.4	5.5	57
7262.8	223.6	3.7	38
8447.7	320.4	5.5	51
7577.5	233.0	3.7	24
7203.7	285.2	3.7	21
3309.5	96.1	1.5	17
4651.4	99.8	2.2	30
8555.8	334.4	5.5	28
8790.1	351.4	7.5	27
8779.1	341.4	7.5	30
10138.0	460.0	7.5	20
5952.5	211.8	5.5	18
6205.5	211.8	5.5	20
9436.8	414.8	3.7	27
8723.3	443.0	3.7	18
6692.2	262.4	2.2	25
3156.0	85.8	3.7	6
4681.0	174.0	3.7	8
11644.1	444.4	5.5	26
5158.9	226.8	2.2	13
4176.8	126.8	2.2	9
4177.6	121.8	2.2	15
3503.5	141.4	3.7	5
3856.2	158.0	3.7	5
4055.0	178.8	3.7	11
5065.4	206.8	3.7	11
6276.8	286.8	3.7	10
4748.0	212.8	3.7	13
11482.4	450.0	3.7	28
8112.8	461.2	3.7	18
12263.9	502.4	5.5	42
7857.3	262.4	2.2	27
8433.5	342.4	3.7	24
9141.8	502.4	3.7	25
4746.0	197.4	2.2	13
7415.6	306.2	3.7	23
7052.8	260.0	2.2	18

principal component analysis is applied into the identification of DCF. That is, the obtained principal components are regarded as the factors of DCF.

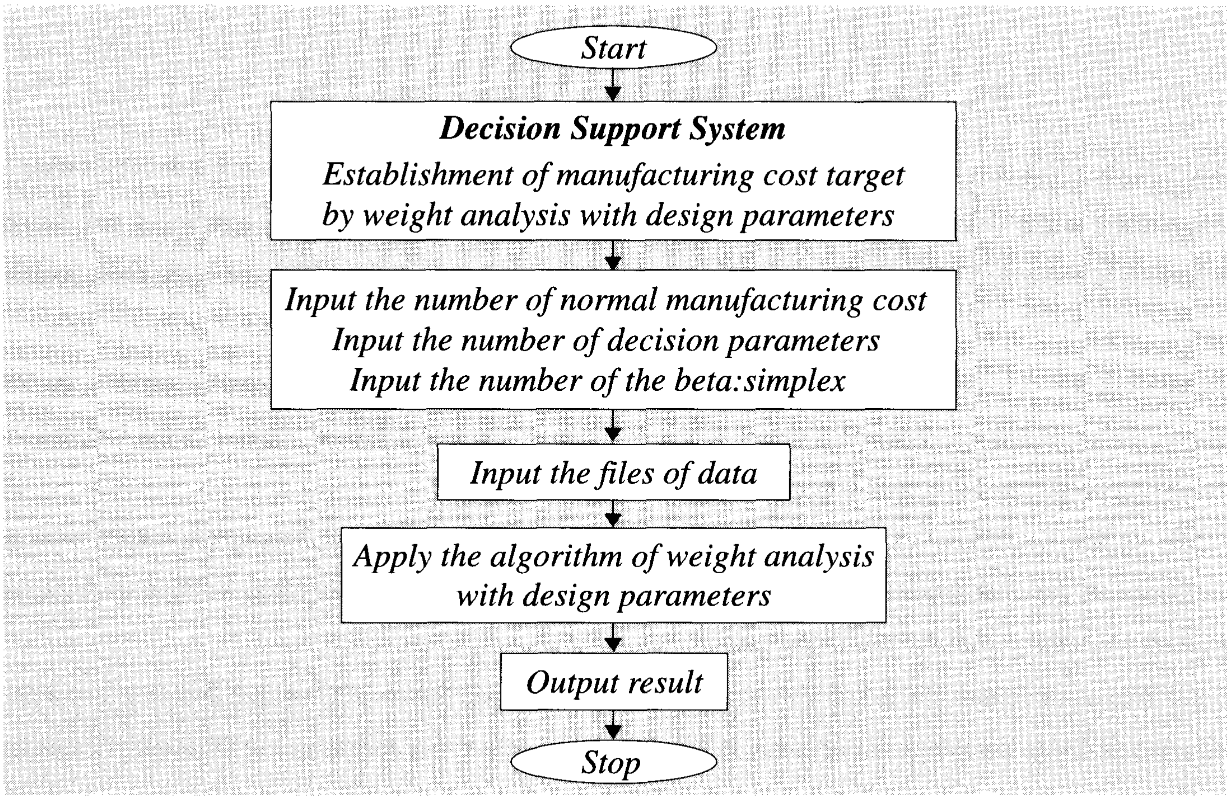

Fig.2 General flowchart for Decision support system of weight analysis

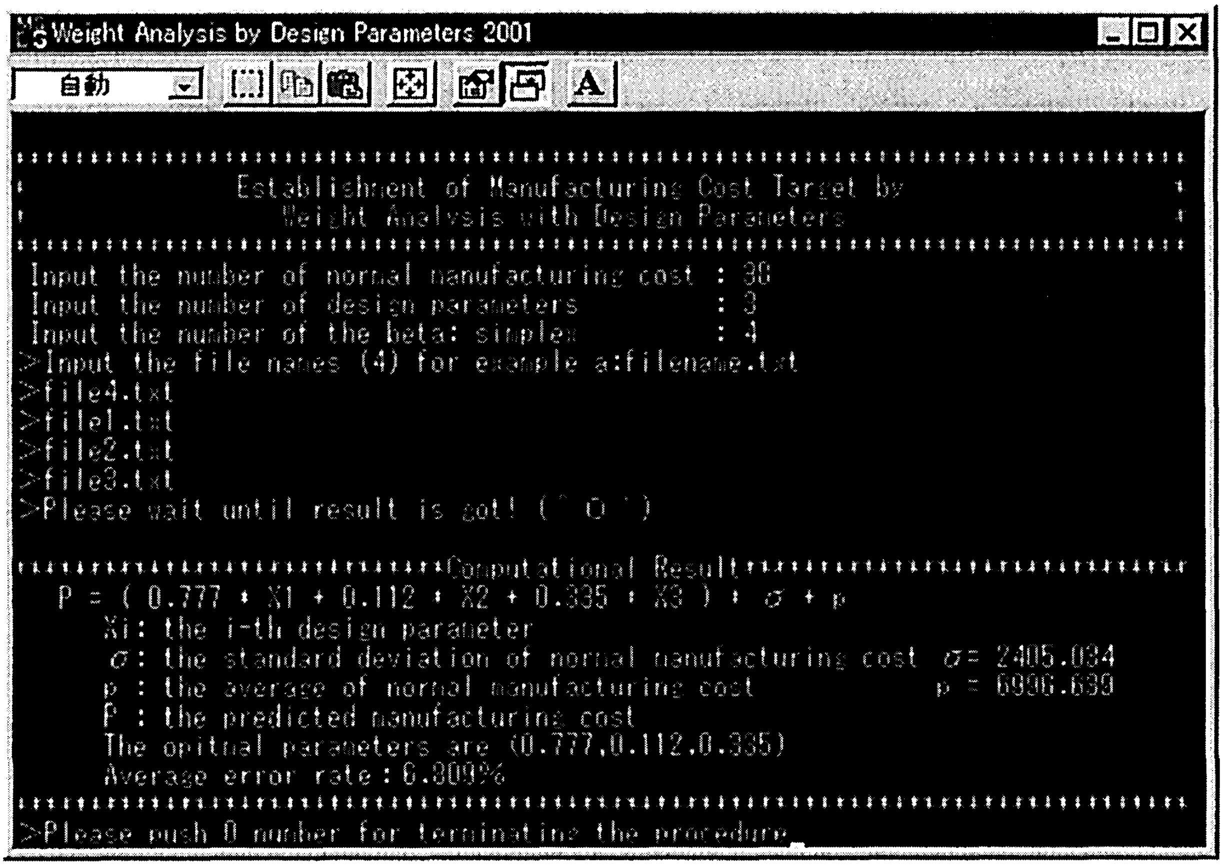

Fig.3 Computational Result by Weight Analysis with Design Parameters

6. Conclusion

Most of the product is committed in the development and design activities. It is essential the cost target is established in the development and design phase. As a matter of course, the development and design activities is controlled by the cost target. We described how to establish the MCT that is the most popular one.

In general, the cost target is established from each of economical and/or technological aspects. In this paper, we proposed the method to establish the MCT from the technological aspect. In the method the following properties have been confirmed.

① We can flexibly select the design parameters, and/or number of design parameters, which have an influence on the establishment of MCT greatly. by doing this, we can directly effect volition of decision-makers concerning with the MCT problem.

② We can determine the unknown weights of other design parameters after setting the weight of a part of selected design parameters in advance. From this, we can effectively formulate the DCF with flexibility.

③ We can yield an optimal solution for the MCT problem without depending on the function of DCF, that is linear or nonlinear functions with finite trial.

④ We can flexibly and reasonably establish the MCT in comparison with the traditional multiple regression analysis.

Therefore, it will become the most effective tool of cost control in the development and design activities. The proposed method can yield only an optimal solution for the MCT problem. In order to verify whether or not the proposed method is practically effective, we will need to establish the function of DCF while taking into consideration of the volition of decision-makers.

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