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OPTIMAL COST ESTIMATION FOR IMPROVEMENT OF PRODUCT DESIGN

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While the concepts of design for manufacturability and concurrent engineering have made significant advances in integrating the design function with other areas in companies, major gaps remain in the timely and accurate provision of costing information to designers. Inappropriate design could increase the redesign cost and delay the product realization. This present 3-step research aims to reduce the design cost of the product. The first step sets up the optimal cost, which is the engineering target based on the function. The second step estimates the current function cost according to the unit through the function and quantitative analysis for the basic model. In the third step, the design of a unit is reviewed according to the priority of the difference between the optimal cost and the function cost. Arranging the unit design parameters, the best design option is set up according to the level.

Significance: The cost improvement becomes a more realistic by presenting the optimal cost for design and production. This induces the product design that incorporates the ideal cost of applying the optimal cost of engineering target as a medium.

Keywords: Design of product, Cost Estimating, Cost Engineering, Design for Cost

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1. INTRODUCTION

Achieving stable growth and maximizing profit in the rapidly changing management environment is an important goal for a company. There are 3 ways to assure this profit. The first is increasing the buyer-based price (Thomas et al., 2002). This simply increases the current sales price. The second is increasing the sales volume. The third is reducing the production cost. The third way has the advantages of being independent of the customers.

Such cost reduction is especially important during economic recession. The weight of research and development between companies has become a core factor. In the overall product costs according to its life cycle costing, 85% of the cost decision rate from the planning step of a product to the production step is decided in the design process. Of course, 80% of the cost is actually generated from the production preparation step to the production completion step (Fabrycky et al., 1991).

Once confirmed, it is hard to improve the cost later. Therefore, the decision of how much cost is used in the product function before the design step is important. Many cost waste factors exist in this process due to incorrect design. In avoid such losses, reasonable material and processing costs need to be determined through the technical review in advance and cost simulation should be conducted when designing a product (Burman, 1998).

This is an essential process in order to avoid waste in advance. On this basis, the present research will enable product design engineers to design and develop products with the optimum cost by determining the function cost.

2. STUDY OF PREVIOUS RESEARCH

To establish decisions that affect the cost structure in a product design step, quick and accurate information is required to estimate the cost from the initial design step. Cost estimating methods are divided into analogy-based techniques, parametric cost model, and engineering approaches.

The analogy-based technique is a method used instead of actual product cost information based on the degree of similarity between a new product and an existing product. However, this method has difficulties in measuring the degree of similarity between a new product and an existing product and incorporating the technological process of factors. Nevertheless, the actual result information of the specific product produced in the past is used as standard information to estimate the cost of a similar product and relatively standardized product. This method requires appropriate past experience data, and has the advantage of being supplying quick estimation (Weustink et al., 2000, Brinke et al., 2000).

In their research on this method, Brinke et al. designed the cost decision factors and classified the eigen values, manufacture method, and production plan. The users insert the data for the target similarity degree between the object products according to the ranges, and the system forms several options according to the similarity satisfaction degrees and compares the cost estimation. However, the comparison analysis becomes more difficult when the design eigen values or manufacture method and the order quantity and types get larger due to the increase in the possible options (Brinke et al., 2000).

Rehman and Guenov (1998) searched similar products in the order of product, half-finished products, and parts in order to estimate the cost by editing the product structure and process. They used the rule basis and the case basis simultaneously, but no specific process, function, and examples are presented.

The parametric cost model clearly analyzes the relationship between the cost and the parameter, and estimates the product cost statistically (NASA's Parametric Cost Estimating Handbook, 2009). This method is very efficient when the cost drivers are easily understood. In similar research, Roy and colleagues presented the relationship between the function and the product parameter (Roy et al., 2008).

The engineering approach method is based on the detailed analysis of product form and manufacturing process, and on the fact that the cost depends on what process it needs. It is closely related to the process plan, and it is mainly used when developing new products having no existing similar products. Ben-Arieth(2000) established the processing plan by product and tool shape setting limits to lathe processing products, and presented a method for calculating the processing time by searching for the cutting condition required for cutting in advance using the experience data from the established database. However, he limited the range of the research to only the machine processing time decision.

Wei and Egbelu(2000) arranged the possible process orders from the shape data of the machine processing products. Among these, they presented every possible process order expressing the process order that can minimize the machine processing cost using the tree structure composed of AND/OR, and calculated the processing cost according to each process plan using the cutting volume in each process. However, they did not take into consideration the calculating method for material cost or labor cost.

In these previous studies, the analogy-based techniques have difficulties in measuring the degree of similarity between a new product and an existing product, and incorporating the technical change factors. The parameter method has the limitation of analyzing the technical parameter relationship of a product and morphological characteristics. The engineering approach emphasizes the processing cost calculation, limits subjects mainly to the machine processing, and aims at the cost calculation for single products rather than assembled products. This research aims at both single and assembled products in terms of the product structure, and includes the processing cost in terms of cost composing factors to overcome the aforementioned limitations. In order to standardize the qualitative function of a product, the analytic hierarchy process (AHP) method is used to produce easier, faster, and more accurate results. The product function cost and optimal cost estimation are used to incorporate the product design and development method theories that reflect the optimal cost in the design.

3. METHODOLOGY

3.1 Estimating the optimal cost for designers

Generally, companies set the allowable cost at maximum, and simultaneously set the target cost that will give them the essentially required profits. Therefore, deciding the product price in the traditional way can be formulated by the equation: Cost + Profit = Selling price. However, market competition makes it difficult for suppliers to decide the selling price as the selling price and profit are fixed parameters. The target cost is set based on these considerations (Thomas, et al., 2002). These methods establish the target cost from a manageable and financial point of view.

Of course, the manageable target cost must be taken into consideration in this research, but the method to set up the engineering-side target cost is presented. This is a more realistic cost improvement by presenting the optimal cost for design and production. This induces the product design that incorporates the ideal cost of applying the optimal cost of engineering target as a medium.

Definition of Terms

To define several new terms, the optimal cost of the engineering target is the most desirable cost when designing products. The optimal cost is defined as the optimal material cost (OMC) plus the optimal processing cost (OPC).The product materials are composed of basic function, secondary function, and loss from the functional point of view. The basic function is an inevitable function for the product design (Bytheway, 1965).

This basic function is the material used to show its primary function, so it is the optimum for a product to be composed of basic function only. The secondary function is defined as a function that assists the basic function. The cost used in the basic and secondary functions of a product is defined as the cost of the basic and secondary functions, respectively. The OMC is defined by the following equation and sets up the aim heuristically:

OMC = Basic function + Secondary function × 1/2

The OPC is calculated in the same way as the OMC, but the working time is analyzed and converted to the processing cost. A product is made completely when all the related production process works are finished in the production. Therefore, the process cost is calculated as it classifies each process work into basic function, secondary function, and loss. The work time that is directly connected to the core work accompanying the assembly, processing, modification, and deterioration in the processing time of the processes is defined as the basic function. The secondary function is defined as the work supporting the basic function. Only the basic function is the work for its primary purpose, and it is desirable for the processing time to be composed of the basic function only. Like this, the optimal processing cost is set up with the processing cost of process work heuristically: Processing cost of process work = basic function + secondary function × 1/2.

How to Set Up the Optimal Cost

The calculation for the optimal cost based on the basic model or functional analysis of similar products can be defined as follows.

Step1. Prepare the information and process the flowchart of the basic model and similar products. Arrange the product according to the unit price and standard time for each process.

Step2. Define the purpose function of a product, and survey the composition unit and product process with 3 evaluation factors: basic function, secondary function, and loss (Bytheway, 1965).

Step3. Write the pairwise comparison matrix (PCM) for the basic function, secondary function, and loss which are the evaluation standard (Saaty, 1983). The criterion range used in the PCM is expressed as numbers ranging from 1 to 9, or reciprocal numbers, as shown in Table 1(Saaty, 1986). The matrix A is made up through the pairwise comparison according to the scale of weight, which is the reciprocal matrix where the elements of the principal diagonals all become 1. W_i and W_j mean the weight of the i^{th} property and j^{th} property, respectively.

$$A = \begin{bmatrix} 1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & 1 & \ldots & w_2/w_n \\ \vdots & \vdots & & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & 1 \end{bmatrix}$$

Step4. Calculate the weight of the basic and secondary functions for all the composition units and processing processes. In the weight calculation, Saaty indicates the characteristic vector law that is the best suited for the weight estimation method when the consistency of the decision data is not complete, and many calculation software programs using the characteristic vector law for the actual application have been developed (Zahedi, 1994). Studying this method, matrix A times column vector showing the relative weight $W^T = (w_{1,} w_2 \ldots w_n)$ gives AW=λW, which when matrix A is know is expressed as the following characteristic equation.

In (A-λ·I) W=0, λ is the eigenvalue of matrix A, I is the identity matrix, and vector W is eigenvector. If matrix A has complete cardinal consistency, from the roots $\lambda_i(i = 1,2, \ldots n)$ of the characteristic equation, the largest root would only have $\lambda_{max} = n$ and the rest of the roots would be 0. Finding the eigenvector W corresponding to the eigen value n, and making $\sum w_j = 1$ normalized, they become the weights for each property.

Table 1. Fundamental Scale of Absolute Numbers

Weight	Definition	Explanation
1	Equally important	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strongly important	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	A factor is being proved to be superior.
9	Extreme importance	An activity is favored very strongly over another; its dominance demonstrated in practice
2,4,6,8	Middle of the scales defined above	When values between the scales defined above are required.

Step5. Test the consistency. After comparing the comparative subjects, test the consistency for the evaluation using the consistency ratio (CR) value. The requirement for matrix A to have consistency requires this matrix to become the reciprocal matrix, and the necessary and sufficient condition would be that the characteristic root of this matrix becomes n (Vargas et al., 1982). If matrix A is exactly agreed cardinally, i.e.$a_{ij} \cdot a_{jk} = a_{ik}$ is always true, it means$\lambda_{max} = n$, and if it is not agreed, λ_{max} always has values larger than n. The degree of disagreement can be measured by $\lambda_{max} - n$ if granting weights does not have consistency in the relative comparison. If an estimate is $a_{ij} = (1 + \delta_{ij})w_i/w_j$, δ_{ij} and is the perturbation aboutw_i/w_j, if$\delta_{ij} > -1$, the formula is formed as below using $a_{ji} = 1/a_{ij}$ and $A \cdot W = \lambda_{max} \cdot W$.

$$\lambda_{max} - n = \frac{1}{n} \sum_{1 \le i < j \le n} \frac{{\delta_{ij}}^2}{1+\delta_{ij}} \ge 0$$

Therefore, if an estimate a_{ij} is exactly agreed with w_i/w_j, $\delta_{ij} = 0$ and $\lambda_{max} = n$ becomes true, and if not, λ_{max} is more than n (Vargas et al., 1982). When the degree of agreement for $\lambda_{max} - n = 0$ is defined as the consistency index (CI), CI=$\mu = \frac{\lambda_{max} - n}{n-1} = \frac{-\sum \lambda_1}{n-1}$ (If λ_1 is the characteristic root of matrix A except λ_{max})

We can test the consistency about the two-variable comparison by verifying the null hypothesis $H_0: \lambda_{max} - n = 0$. Assuming δ_{ij} conforms to the normal distribution, the test statistic $\mu=(\lambda_{max} - n)/n-1$ conforms the χ^2distribution.

The consistency is tested by using the CR (Ed- this abbreviation has already been defined above) of the CI divided by the random index (RI) that was gained for the experiential data instead of using the test statistic μ. The RI means the agreement index found from the reciprocal matrix after randomly drawing out from positive numbers from 1 to 9. Table 2 refers to the average value results of the RI from 500 samples (Vargas *et al*., 1982).

Table 2. Average random index (RI)

n	1	2	3	4	5	6	7	8	9	10
R.I	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Saaty mentioned that if the value of CR (CI/RI) lies within 10%, it would be the confident result which is reasonable for ordinal rank.

Step6. Calculate the costs of the basic function (BC), secondary function (SC), and loss (LC) by multiplying the weights of the basic function, secondary function, and loss by the current unit price for each unit. Supposing the unit number a product is composed of is j, the OMC for each unit, omc_j, is calculated with $omc_j = bc_j + \frac{1}{2} sc_j$. Therefore, the OMC for overall units is estimated by OMC=$\sum_{j=1}^{n} bc_j + \frac{1}{2}\sum_{j=1}^{n} sc_j$. In the same manner, supposing the process number that needs to be worked when producing products is j, the OPC for each process is $opc_j = bc_j + \frac{1}{2} sc_j$. Hence, the OPC for overall units processing process can be calculated by OPC=.$\sum_{j=1}^{n} bc_i + \frac{1}{2}\sum_{j=1}^{n} sc_j$.

3.2 Function-based cost estimating

In this step, the cost is estimated based on similar products or the function of the basic model that form the basis of the new products or the developed products (ROY et al., 2008). FUCE (Function-Based Cost Estimating) by ROY estimates the cost through 6 steps. This is an estimation method analyzing the parameter related to the product cost and the function relevance. However, deviation arises due to variation in the expert abilities, setting up the parameter is very complicated, and loss factors may also be included. This research estimates the cost through the following steps to evaluate the product function in order to overcome those difficulties.

Step1. Define product decomposition.

Step2. Define the function. Clarify the functions for an end and a means to express the functions that composition units have by noun and verb, and arrange the function that the unit itself has. The product defined the primary function from functional analysis system techniques (Bytheway, 1971).

Step3. Function evaluation. Understand the clearly defined function quantitatively, and use it to perform the value evaluation. It is difficult to be quantitative since it is an abstract idea of the function. Make the weight of the function qualitative in the same way as in the previous Steps 3~5 of Stage 2 for the defined function.

Step4. Apply functions to the cost estimate. Using the functional weight (w_{ij}) for each composition unit calculated in Step 3, the function cost for a unit is estimated as follows. Defining i is the number of product functions, j is the number of units, u_j is the j^{th} unit, the current cost of the j^{th} unit is c_j, the weight of the function is w_{ij}, fc_{ij} is the unit function cost corresponding to the i^{th} function and the j^{th} unit. It can be calculated by $fc_{ij} = c_j \times w_{ij}$.

The function cost for the processing cost can also be estimated in the same way. So, if the process for each product is p_j, j is the process number, the cost of the current process is c_j, j is the number of processes, the function weight of process is w_{ij}, and fc_{ij} is defined as the function cost of the process corresponding to the j^{th} process and the i^{th} function. It can be calculated by $fc_{ij} = c_j \times w_{ij}$.

Step5. If the optimal function cost for each unit is defined .The optimal function cost (ofc_{ij}) can be calculated by $ofc_{ij} = omc_j \times w_{ij}$ using the functional weight (w_{ij}) for each composition unit calculated in omc_j and Step 3.

Step6. The current cost and room for cost reduction can be calculated according to the function calculated in the above step. In order to satisfy the function cost, the product design and improvement are evaluated to set up the ideal cost in both the function and structure based on the optimal cost.

4. INDUSTRIAL APPLICATIONS

The suggested model was applied to a domestic electronics company, and the availabilities verified. Using the suggested methodology, the application was performed by 2 designers, 1 production engineer, 1 part purchaser, 1 quality assurance person, 1 sales manager, 1 cost manager, and 7 more people concerned with a **HDD**(Hard Disk Driver). The product is the hard disk driver of the computer. The **HDD** is composed of 24 units.

4.1 Calculation for the optimal cost

The optimal cost design that incorporates the optimal cost for the basic model of a **HDD** is decided. The optimal cost according to the composition units of a selected product and the eigen value of the design are investigated.

Write the Survey for each composition units.

Fifteen project members completed the Survey shown in Table 3 and the results are summarized. The summed results are distributed. Firstly, if the answer is distributed on one side, the mode is chosen. Secondly, if the mode is more than two items, the adjacent middle value is taken, and if it is far apart, both values are approved and two comparison tables are prepared for investigation.

In statistics, the **mode** is the value that occurs the most frequently in a data set or a probability distribution. The weight of 3×3 pairwise Comparison Matrices of Arm are arranged in Table 4.

Table 3. Survey example

Survey (Arm)
The following. Survey is to calculate the weight of evaluation factors for basic function, secondary function, and loss of composition unit of a **HDD**. The purpose function of a **HDD** is to save and play the data. Unit: <Arm> Please check how important the role of arm is as it is a means to achieve the purpose function. 1. How much more important roles do you think the basic function plays than the secondary function does? Absolutely important(9), Very important(7), Important(5), Little important(3), Equally important(1), Little unimportant(1/3), Unimportant(1/5), Very unimportant(1/7), Not important at all(9/1) 2. How much more important roles do you think the basic function plays than the loss does? Absolutely important(9), Very important(7), Important(5), Little important(3), Equally important(1), Little unimportant(1/3), Unimportant(1/5), Very unimportant(1/7), Not important at all(9/1) 3. How much more important roles do you think the secondary function plays than the loss does? Absolutely important(9), Very important(7), Important(5), Little important(3), Equally important(1), Little unimportant(1/3), Unimportant(1/5), Very unimportant(1/7), Not important at all(9/1)

Table 4. Pairwise Comparison Matrices of Arm

Arm	Basic function	Secondary function	Loss	weight
Basic function	1	1l9	1/5	0.054
Secondary function	9	1	5	0.743
Loss	5	1/5	1	0.203

CI=0.0603<0.1 matrix has no logical contradiction. Therefore, Arm (No.1) contains 5.4% of the basic function, 74.3% of the secondary function, and 20.3% of the loss. By the same method, the weight of the basic function, secondary function, and loss for all the units is calculated as shown in Table 5.

Table 5. Weight calculation result of units

No	Composition units(U)	Basic Function	Secondary Function	Loss	CI
1	Arm	0.054	0.743	0.203	0.0603
2	Disk	0.817	0.125	0.058	0.0694
3	Pivot Bearing	0.735	0.078	0.186	0.0328
4	Retainer ring	0.817	0.125	0.058	0.0694
5	S- machined	0.143	0.429	0.429	0
6	noise barrier	0.045	0.651	0.304	0.0710
7	cover damper	0.063	0.791	0.146	0.0407
8	cover	0.063	0.791	0.146	0.0407
9	filter	0.052	0.66	0.287	0.0412
10	gasket cover	0.052	0.287	0.66	0.0412
11	insulator	0.058	0.817	0.125	0.0694
12	motor	0.699	0.128	0.173	0.0404
13	clamp	0.11	0.727	0.164	0.0688
14	spacer	0.31	0.496	0.194	0.0269

15	latch pin	0.063	0.791	0.146	0.0407
16	yoke top	0.058	0.817	0.125	0.0694
17	yoke bottom	0.058	0.817	0.125	0.0694
18	magnet top	0.882	0.059	0.059	0
19	magnet-B	0.882	0.059	0.059	0
20	vcm damper	0.052	0.66	0.287	0.012
21	crash stop	0.062	0.673	0.265	0.0146
22	FPC	0.25	0.50	0.25	0
23	base	0.54	0.743	0.203	0.0603
24	HGA	0.882	0.059	0.059	0

Using the weight (w_i) of each basic function, secondary function, and loss calculated above for each unit, the rate is distributed to the current cost (c_j) to calculate the **BC,** $bc_j = c_j \times w_j$, the **SC,** $sc_j = c_j \times w_j$, and the **LC**. In addition, the **OMC** can be estimated as shown in Table 6 below.

Table 6. Optimal Material Cost (OMC) calculation result of units

No	Composition Units	Current Cost (c_j)	Basic Function ($bc_j = c_j \times w_j$,)	Secondary Function ($sc_j = c_j \times w_j$)	Loss	Optimal Cost($=bc_j + \frac{1}{2} sc_j$)	Material omc_j
1	Arm	1,846.0	99.7	1,371.6	374.7	785.5	
2	Disk	7,500.0	6,127.5	937.5	435.0	6,596.3	
3.	Pivot Bearing	1,650.0	1,212.8	128.7	306.9	1,237.5	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	
24	HGA	17,064	15,050.4	1,006.8	1,006.8	15,553.8	
Total		39,419	27,661.5	7,585.3	4,170.5	31,454.2	

Therefore, the **OMC** of a **HDD** is estimated as **OMC**=$\sum_{j=1}^{24} bc_j + \frac{1}{2}\sum_{j=1}^{24} sc_j$ = 31,452.2 won.

4.2 Analysis of function cost of a product

Set-up for the function according to each unit.

The function definition of the object product and the unit, which is the composition factor, can be expressed by the noun + verb phrases shown in Table 7.

Table 7. Function definition result of units and product

Level 0	Level 1	Level 2	Level 3	Units
Stably record and play	Record and play the data	Revolve the disk F1	Smooth revolution	Motor
			hub support	Motor
			Balance support	spacer
			Disk fixation	spacer
			Shaft fixation	clamp
			stator fixation	Motor
			Magnetic field path formation	Motor
			Coil support	Motor
			Magnetic field generation	Motor
			Magnetic field path formation	Motor
			Magnet fixation	Motor

			Cover assembly Bearing support	Motor Motor
	⋮	⋮	⋮	⋮
	Remove the noise	Protect the data F5	Part fixation Part fixation Appearance protection Part assembly Cover assembly Balance support latch fixation	base cover cover damper s-machined actuator actuator

Many of composition factors in Table 6 are defined by more than two functions. The function of the primary function, secondary function, or the unnecessary function of composition factors (unit level) needs to be classified among those plural functions. Showing the link among each function systematically, the arrangement is made for the primary function of a **HDD**(Hard Disk Driver) F_1 : Revolves the disk. F_2 : Controls the head position. F_3 : Magnetizes the disk F_4.: Removes noise. F_5: Protects data.

Evaluation for functions

APH (Analytic Hierarchy Process*)* is used as explained previously. In order to calculate the weight of F_1~F_5 functions arranged previously for the **HDD**(Hard Disk Driver) . A questionnaire was prepared to determine the contribution of the disk, which is the composition unit of HDD, between the functions. The pairwise comparison method was used to decide the weight, as shown in Table8. The calculated CI=0.0559<0.1 also has no logical contradictions.

Table 8. Pairwise Comparison Matrices of Disk

Disk	F_1	F_2	F_3	F_4	F_5	weight
F_1	1	$1/5$	$1/9$	1	1	0.051
F_1	5	1	$1/9$	2	2	0.14
F_1	9	9	1	9	9	0.687
F_1	1	$1/2$	$1/9$	1	1	0.061
F_1	1	$1/2$	$1/9$	1	1	0.061

Therefore, the contribution degree of the Disk (No.2) function is decided as w_{21}= 0.051, w_{22}= = 0.14, w_{23}= =0.687, w_{24}= =0.061, and w_{25}= =0.061. In the same way, the results for all the units are determined, as shown in Table 9.

Table 9. Weight calculation result of units

No	Composition units	F_1	F_2	F_3	F_4	F_5	CI
1	Arm	0.05	0.55	0.05	0.05	0.3	0.0227
2	Disk	0.05	0.14	0.69	0.06	0.06	0.0559
3	Pivot- Bearing	0.05	0.79	0.05	0.05	0.05	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
24	HGA	0.04	0.04	0.66	0.04	0.21	0.0835

Understanding the cost according to the functions of a product

The function cost (fc_{ij}) for each function is distributed to $fc_{ij} = c_j \times w_{ij}$ using the weight (w_{ij}) for each unit and the current cost (c_j) that a unit was calculated previously. For example, the Arm has 5 functions, and the weight of each function calculated before w_{11}=0.05, w_{12}=0.55, w_{13}=0.05, w_{14}=0.05, and w_{15}=0.3.

Therefore,fc_{11} = 1,846×0.05 = 92, fc_{12} = 1,015, fc_{13} = 92, fc_{14}=92, and fc_{15} = 554 can be calculated as above. So, from the current cost of 1,846 won of the Arm is distributed as 92 for F_1, 1,015 for F_2, 92 forF_3, 92 for F_4, and 554 won for F_5. If the current cost is distributed according to the functions for all units, the function cost for each unit is obtained as shown in Table 10.

Table 10. Function cost calculation result of units

No	Composition units	c_j	F_1	F_2	F_3	F_4	F_5
1	Arm	1,846	92	1,015	92	92	554
2	Disk	7,500	375	1,050	5,175	450	450
3	Pivot- Bearing	1,650	83	1,304	83	83	83
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
24	HGA	17,064	683	683	11,262	683	3,583
	Total	39,419	4,432	6,503	17,242	3,442	7,775

Calculation for optimal function cost

This step calculates the optimal function cost of a product and the optimal function cost of each unit. For the former, the weight of the **OMC** is calculated in the previous step. That is, if the optimal function cost of a product is ofc_i , it can be calculated by $ofc_i = omc_j \times w_i$.

ofc_1=33,395×0.276 = 9,217, ofc_2 = 5,677, ofc_3 = 15,195, ofc_4 = 1,135, ofc_5 = 2,471

Secondly, for the optimal function cost of each unit, the OMC (omc_j) calculated previously and the function weight (w_{ij}) of a unit are used. That is, the optimal function cost (ofc_{ij}) for each unit is calculated by $ofc_{ij} = omc_j \times w_{ij}$. For example, because the **OMC** omc_1 of Arm of unit No.1 = 786 won, and the weight for each function is w_{11}=0.05, w_{12}=0.55, w_{13}=0.05, w_{14}=0.05, and w_{15}=0.3, the optimal function cost for F_1 is ofc_{11} = 0.05 ×789 = 39 , that for F_2 is ofc_{21} = 0.55 ×789 = 432. In the same way, that for F_3 is ofc_{31} = 39 , F_4 is ofc_{41} = 39, F_5 is ofc_{51} = 236. By applying to every unit, the optimal function cost is calculated as shown in Table 11.

Table 11. Optimal function cost calculation result of units

No	Composition units	omc_j	F_1	F_2	F_3	F_4	F_5
1	Arm	786	39	432	39	39	236
2	Disk	6,596	330	923	4,551	396	396
3	Pivot- Bearing	1,277	64	1,009	64	64	64
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
24	HGA	15,554	622	622	10,266	622	3,266
	Total	31,454	3,343	4,926	15,267	2,166	5,631

Comparison of the cost

As arranged in Table12, the optimal cost is investigated from the point of both function and structure based on the optimal cost in order to satisfy the function cost.

4.4. Result of case study

Figure 1 shows the comparison between the existing product, basic model, and the newly developed model through the activity of the new model. The method achieved reductions of 17.2% for material cost and 21% for the number of units.

Table 12. Total Summary for Optimal Cost

No	Cost			F_1			F_2			F_3			F_4			F_5		
	c_j	omc_j	$c_j - omc_j$	fc_{ij}	ofc_{ij}	$fc_{ij} - ofc_{ij}$	fc_{ij}	ofc_{ij}	$fc_{ij} - ofc_{ij}$	fc_{ij}	ofc_{ij}	$fc_{ij} - ofc_{ij}$	fc_{ij}	ofc_{ij}	$fc_{ij} - ofc_{ij}$	fc_{ij}	ofc_{ij}	$fc_{ij} - ofc_{ij}$
1	1,846	786	1,061	92	39	53	1,015	432	583	92	39	53	92	39	53	554	236	318
2	7,500	6,596	904	375	330	45	1,050	923	127	5,175	4,551	624	450	396	54	450	396	54
3	1,650	1,277	373	83	64	19	1,304	1,009	295	83	64	19	83	64	19	83	64	19
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
24	17,064	15,554	1,510	683	622	61	683	622	61	11,262	10,266	996	683	622	61	3,583	3,266	317

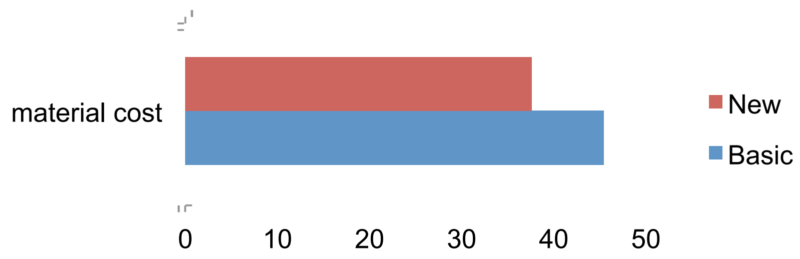

Figure 1. Result of case study

5. CONCLUSIONS

Many studies on cost estimation have attempted to ensure the accuracy and calculate the cost of a new product. These research efforts have been successful in estimating the cost in advance and establishing plans. However, the present research was focused on how the design could be performed without any cost loss in the design process. From this point of view, the basic function, secondary function, and loss were estimated and clearly defined so that designers could design a product with the basic function cost only in order to prevent the cost loss. Furthermore, examples of applications to company products were suggested and by diagnosing the instruction activities, a cost reduction of 10%~30% was verified. The cost estimation method was derived from the analogy-based techniques used in the existing studies, but it differed since the lowest rank unit of estimation was on the product function. Moreover, with the optimal cost concept, both the function and cost could be pursued and incorporated in the design process.

6. ACKNOWLEDGEMENT

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7. REFERENCES

1. Bytheway, C.W.(1971) 'FAST diagrams for creative functional analysis.' SAVE Comm. J. Value Eng., 71–.73, 6–.10.
2. Bytheway, C.W.(1965) 'Basic Function Determination Technique', SAVE PROCEEDINGS 1965 FIFTH NATIONAL CONFERENCE, Vol. II, pp. 21-23.
3. Ben-Arieth,D. (2000) 'Cost Estimation System for Machined Parts', International Journal of production Research, Vol. 38, No.17, pp. 4481-4494.

4. Burman, D. (1998) 'Design to cost approach to Product development.' SAVE International conference proceedings, pp.48-52.
5. Fabrycky, W.J. (1991) 'Life Cycle Cost and Economic Analysis' Prentice Hall, New York.
6. Bounou, M. Lefebvre, S and X. Dai Do (1995). 'Improving the quality of an optimal power flow solution by Taguchi method' International journal of Electrical Power and Energy Systems. Vol.17, pp. 113-118.
7. NASA's.(2009). 'Parametric Cost Estimating Handbook' Joint Government/Industry Parametric Cost Estimating Initiative Steering Committee .Chapter.1, pp.1-4
8. Rehman,S. and Guenov, M. D.,(1998) 'A Methodology for Modeling Manufacturing Costs at Conceptual Design' Computer and Industrial Engineering, Vol. 35, No. 3-4,,pp623-626.
9. Roy, R., Souchoroukov, P. and Griggs, T. (2008) 'Function-based cost estimating' International Journal of Production Research. Vol. 46, pp. 10- 15.
10. Saaty, T. L.(1983) 'Priority setting in complex problems' IEEE Transactions on Engineering Management, Vol. 30, pp. 140-155.
11. Saaty. T. L. (1986) 'Axiomatic Foundation of the Analytic hierarchy Process' Management Science, Vol. 32, No. 7, pp.843.
12. Thomas T. Nagle and Reed K. Holden.(2002) 'The Strategy and Tactics of Pricing' Journal of Revenue and Pricing Management, Vol. 1, pp. 286– 287.
13. Ten Brinke, E., Lutters, E., Streppel, T. and Kals,H. J. J.(2000) 'Variant-Based Cost Estimation Based on Information Management' International Journal of Production Research, Vol.38, No. 17, pp.4467-4479.
14. Vargas L.G. and Saaty. T.L. (1982) 'The logic of Priorities' Kluwer-Nijhoff Boston Publishing.
15. Wei, Y. and Egbelu, P. J.(2000) 'A Framework for Estimating Manufacturing Cost From Geometric Design Data' International Journal of Computer Integrated Manufacturing, Vol.13, No.1, pp. 50-63.
16. Weustink, I.F. Ten Brinke, E. Streppel, T.and Kals, H. J.J.(2000) 'A Generic Framework for Cost Estimation and Cost Control in Product Design' Journal of Materials Processing Technology, Vol.103.No.1,pp.141-148
17. Zahedi, F.(1994) 'The Analytic Hierarchy Process- A Survey of the Method and its Applications' Interfaces, Vol.16, July-August, pp.96~108.

BIOGRAPHICAL SKETCH

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