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Taguchi methods, production, management, optimum condition, innovation

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DEVELOPMENT OF PERFECTLY DESIGN SYSTEM USING TAGUCHI METHODS

As swift development with low cost was required for the manufacturing in industry, CAE simulation was used to predict the result of the design process, and Taguchi methods was used to decide optimum conditions for minimizing the dispersion. In this study, the perfectly design system without trial production using CAE and Taguchi methods was developed and evaluated. Software for original Taguchi methods and software for productivity management were firstly created, these softwares were combined with established CAE, and software package was developed for estimating the optimum combination of design parameters. Then the quality and the functionality were advanced to gain the optimum condition for the maximum profit considering the function of the grading of products, the delinquent charge and the loss function in the quality engineering based on the developed software. The research results are summarized as follows. (1) Perfectly design system without trial production using Taguchi methods was developed for calculations of the grading products, adding the delinquent charge and the loss function. (2) The evaluation with Kami-copter contributes to the profit evaluation of the grading; the delinquent charge and the loss function with high dimensional accuracy and is evaluated effective on industry.

1. INTRODUCTION

Recently, the acceleration and the cost saving for development has been a great issue to the manufacturing industry. Hence application of the design and processing simulation has expanded as it contributes to period shortening of product development without spending cost and time.

Meanwhile, a lot of studies on the Taguchi methods have done and adapted as the methods of searching the optimum condition in experiments [1], [2], [3]. The Taguchi methods combines two methods; "one of reducing the number of trial with the design of experiments methods" and "one of considering the dispersion by taking in the influence of errors positively ", and searches for the optimum condition efficiently. Once we created our own Taguchi methods software and the productivity management software, combined them with established Computer Aided Education (CAE) and developed the program to

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estimate the optimum combination of design parameters [4] as the management system to utilize CAE effectively.

In this report, the quality and the functionality of the system were advanced to gain the optimum condition for the maximum profit of products considering the function of the grading of products, the delinquent charge and the loss function. Finally, the comprehensive evaluation of this system was conducted.

2. PERFECTLY DESIGN SYSTEM WITHOUT TRIAL PRODUCTION

2.1. BRIEF OVERVIEW OF TAGUCHI METHODS

The designer always desire to pursue accuracy and functionality at the design phase and set the optimum parameter. In Taguchi methods, as shown on the Table 1, what equivalent to the design parameter is called "control factor" (A, B, C), the type or value is called "level of control factors" (A_1, A_2, A_3, B_1, B_2, B_3, C_1, C_2, C_3), the intended accuracy or the characteristic value is called Nominal-is-Best Response (NBR) , the cause of coming up an error and a dispersion is called "noise factor" (D), the type or value of noise factor is called "level of noise factor" (D_1, D_2, D_3, D_4). It is very difficult to examine all the combination, therefore, the conditions are assigned with the orthogonal array which are used in Design of Experiments, the combination using the levels of minimum control factors is determined.

Experimenting or performing CAE analysis based on the combination, the error and the dispersion are generated in NBR as a result because the noise factor varies according to the level. As a result, two or more NBR are calculated at every combination using the levels of the minimum control factor. The average value (μ) and the standard deviation (σ) are calculated, finally, the Signal to Noise (SN) ratio and the sensitivity of the nominal-is-best response are obtained by the equation (1), (2).

$$SN\ ratio\ (db) = 10 \log (\mu^2/\sigma^2) \tag{1}$$

$$Sensitivity\ (db) = 10 \log \mu^2 \tag{2}$$

Based on this result, the SN ratio and the sensitivity of NBR are calculated at every level of each control factor by additivity of factorial effects, and a graph of factorial effects are created. It means that the large SN ratio one make the dispersion in NBR small and the high sensitivity one make the NBR large in the level of each parameter.

Table 1. Control factor and noise factor in the Taguchi methods

	Name	Level			
Control factors	A	A_1	A_2	A_3	
	B	B_1	B_2	B_3	
	C	C_1	C_2	C_3	
Noise factors	D	D_1	D_2	D_3	D_4

The level of the control factor which makes large SN ratio is highly appreciated in industry because it decreases the dispersion. Therefore, there is a custom of two step optimization to make the large SN ratio as possible in Taguchi methods. Moreover comparing the difference of the profit of the SN ratio and the sensitivity in case of the optimum conditions acquired eventually and the worst condition to the estimation, the repetition of the estimation in the experiment is confirmed. We can calculate the SN ratio and the sensitivity of the all combinations using every levels of control factors regarding the nominal-is-best response, furthermore we can consider the error effect to the result.

2.2. ALGORITHM OF THIS SYSTEM

The Fig.1 shows the algorithm of our developed trial production less CAE system. The system consists of four sections; “Part I” is our Taguchi methods, “Part II” is the established

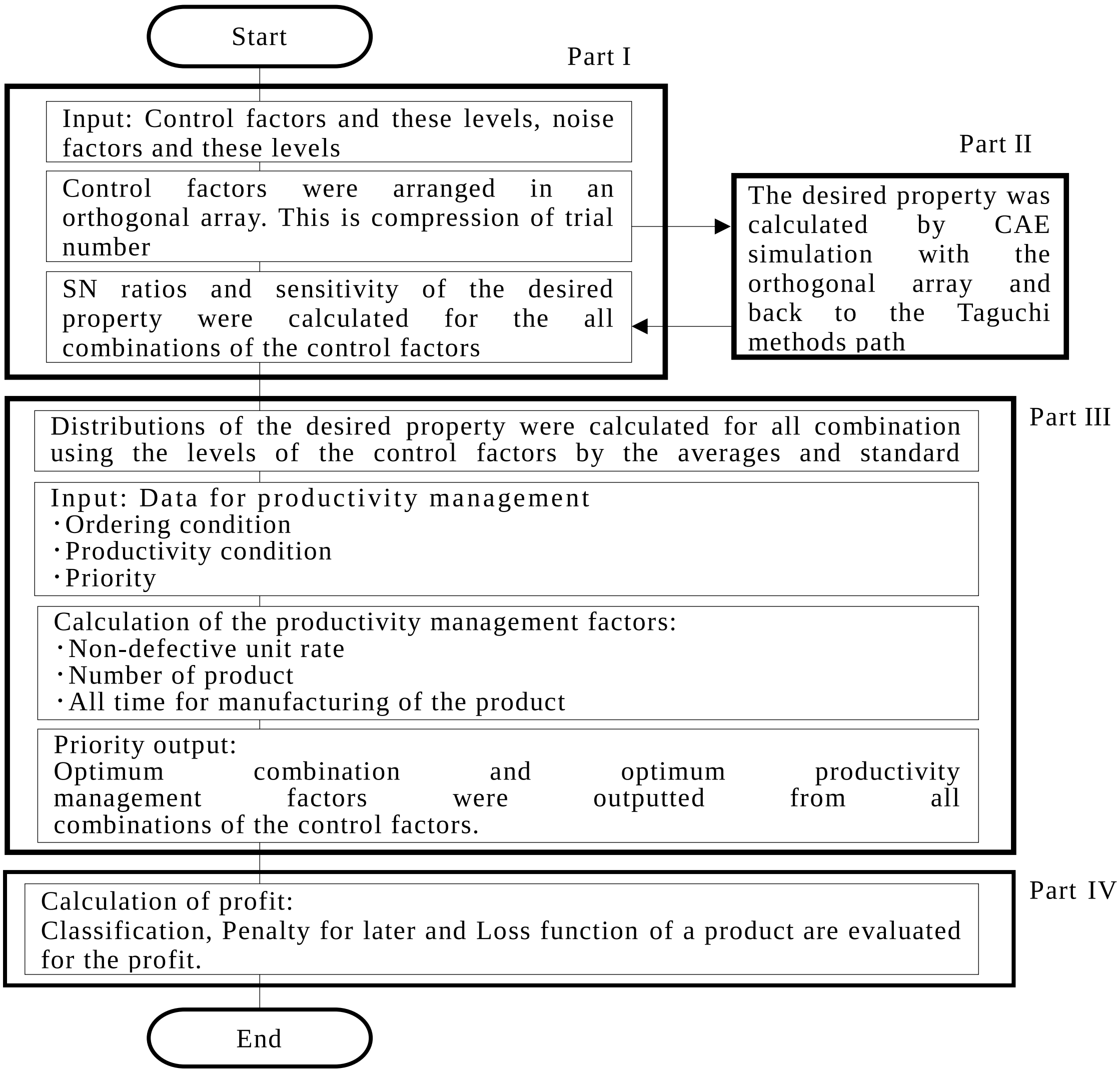


Fig. 1. Flow chart of the software for the perfect simulation system of CAE without trial working for the products

CAE, “Part III” is productivity management and “Part IV” is profit evaluation. In “Part I”, it is based on the premise the analysis with established CAE. It is easy to replace the CAE analysis with experiments.

In “Part I”, the combination of the design parameter which must be examined in the design phase is narrowed down to the minimum with the orthogonal array currently used in Taguchi methods. Considering the dispersion of the noise factor’s levels, entering the average and the standard deviation as the dispersion parameter into the system, the accuracy of the system is improved.

In “Part II”, the established CAE section, the intended characteristic value to the pair of the minimum parameter is calculated by the software. In that case, the all combinations of the minimum parameter is the input values of CAE, and the intended characteristic value is the output of CAE. By this, the intended characteristic value is obtained as the CAE analysis result as the combination using the levels of the minimal control factors. Then going back to “Part I”, the average, the standard deviation, the SN ratio and the sensitivity are calculated.

This is method for estimation of SN ration and Sensitivity regarding all combinations of each lever. For example, seven control factors, *a*, *b*, *c*, *d*, *e*, *f*, *g* are set. The equation (3) shows the estimate of the SN ratio, $SN_{a4.b2.c1.d3.e2.f1.g2}$, the equation (4) shows the Sensitivity, $S_{a4.b2.c1.d3.e2.f1.g2}$ under the condition, *a4.b2.c1.d3.e2.f1.g2* of the combination using the levels of the control factors which has not been performed CAE analysis based on the orthogonal array.

$$SN_{a4,\ b2,\ c1,\ d3,\ e2,\ f1,\ and\ g2}= SN_{a4}+SN_{b2}+SN_{c1}+SN_{d3}+SN_{e2}+SN_{f1}+SN_{g2}-(7-1)SN_{ave} \quad (3)$$

$$S_{a4,\ b2,\ c1,\ d3,\ e2,\ f1,\ and\ g2}= S_{a4}+S_{b2}+S_{c1}+S_{d3}+S_{e2}+S_{f1}+S_{g2}-(7-1)\ S_{ave} \quad (4)$$

SN_{ave} shows the average value of the SN ratio and S_{ave} shows the average value of the sensitivity to all control factors and the levels. In addition, the right last constant 7 of the equation (3), (4) shows the numbers of all control factors.

In “Part III”, the necessary data to calculate the cost of material and labor, the machining time and the acceptable value of the intended characteristic value are entered. With the characteristic value and the average and the standard deviation calculated in “Part I”, the efficiency percentage is calculated using the function 5 on the assumption that the characteristic value follows the standard normal distribution. Next, the productivity factors of the machining time and cost is calculated and the optimum combination to obtain the intended accuracy, the machining time and cost from among all level combinations of control factors.

In “Part IV”, in order to evaluate profits rigorously, the quality and the functionality of the system were advanced considering the function of the grading of products, the delinquent charge and the loss function in the quality engineering based on the developed software.

2.3. EXPLANATION OF PRODUCTIVITY MANAGEMENT

It is rare case that the both the SN ratio and the Sensitivity of the intended characteristic value are achieved by one combination using the levels of the control factors at the same time. Moreover, the cost or machining time frequently far away from the designer's desire. Therefore, on this system, the model which calculates cost, machining time and the efficiency percentage is established based on the productivity management data calculated by Taguchi methods, and the combination using the levels of the control factors which can store some items for the designer's desires is chosen.

The productivity computational model is explained. The Fig. 2 shows the frequency distribution of one combination using the levels of each control factor. The abscissa axis is the characteristic value (calculation result) with designer's desire. If the tolerance is specified as a regulatory value of the characteristic value, the Non-defective unit rate G can calculate. Furthermore, if the values of the processing conditions, the estimate of the efficiency percentage and the expense of the material, consumable goods and the mechanical depreciation are decided, the productivity such as the production cost and the machining time by the equation of the computational model of the productivity as from the following equation (5) to (9).

From the methods (2) of the computation model of the productivity shown below. First, if the average value μ, the standard deviation σ and the common difference η_{tol} as the regulatory value of the characteristic value by a designer is decided as a self-dependence function, the efficiency percentage G is decided as an dependent variable. This detailed figure can be calculated by the above-referenced cumulative-distribution-function.

$$G = f(\eta_{tol}, \mu, \sigma) \tag{5}$$

All the production volumes N to which should be produced are calculated from the award volume N_{ord} and the efficiency percentage G by the equation (6).

They are called for by equation (6) from award volume N_{ord} and the efficiency percentage G.

$$N = N_{ord} / G \tag{6}$$

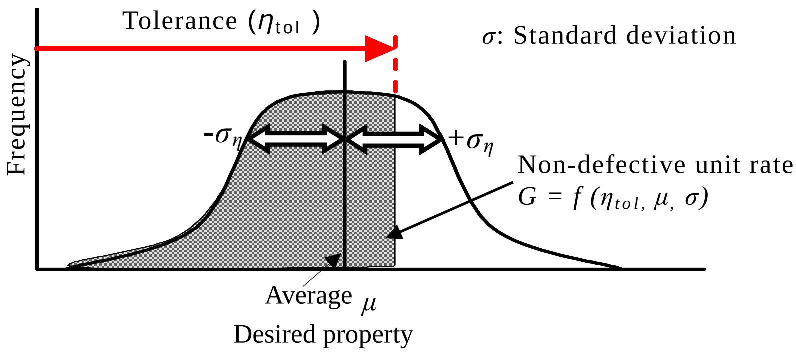


Fig. 2. Cumulative distribution function

Table 2. Priority items and its combinations for the productivity

Each priority item	Total time	Total cost	Non defective unit rate	Accuracy
Productivity	Fastest	Lowest	Maximum	Highest

If the machine tool V used in order to manufacture it, all the production volumes N, a setup time and the required process and processing conditions are decided, hours-worked T_V of the machine tool V is calculable, and it can calculate machining time T_m for an industrial good by the equation (7).

$$T_m=\sum_{1}^{Final\ Machine\ Number} T_V \quad (7)$$

Total machining time T_{all} is calculable by the equation (8) from all the production volumes N and machining time T_m.

$$T_{all}=N\,T_m \quad (8)$$

C_{all} as Gross-product cost could be calculated following the equation (9) if it is reflected on C_{mat}, as material cost, C_{was} as unit price, $C_{dis}(1\text{-}G)$ *as* abandonment cost, $C_{m\text{-}pri}$ as depreciation expense and C_m as labor cost per time.

$$C_{all}=\left(C_{mat}+C_{was}+C_{dis}\,(1\text{-}G)+C_{m\text{-}pri}\right)N+T_{all}\,C_m \quad (9)$$

The factors of the productivity for the all combinations using the levels of the control factors can be calculated by using the above equations.

Finally, in order to determine the optimum combination using the levels of control factors, after entering the data of the priority which a designer wants to consider on production management, the magnitude relation of each data on the productivity of all combinations of control factors calculated previously are judged, arranged, ordered and outputted on a display. The priority order is as shown in the Table 2, the total machining time T_{all} is the shortest, the total cost of production C_{all} is the lowest, the efficiency percentage G is the maximum and high dimensional accuracy of the characteristic value. Moreover, entering the regulation value from the designer on these four items, it also made it possible to consider the combination using the levels of the control factors which cleared them.

3. EXPLANATION OF PROFITS EVALUATION

3.1. EVALUATION FUNCTION OF FINISHED PRODUCT

In order to evaluate profits rigorously, first, the function of the graded evaluation of product is added into the software.

The finished product is frequently graded according to accuracy, the upper class, the average class, etc., even if it fulfills ordering conditions. Moreover, even if it does not fulfill

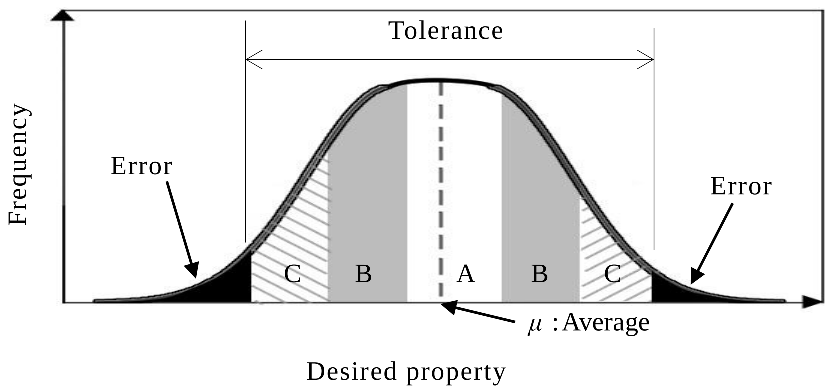


Fig. 3. Classification of a product with a normal division

the conditions, it is occasionally sold as an off-grade production and contributes to profits. On the other hand, this system gets the frequency distribution of the characteristic to the all combination using the levels of the control factors at the stage of the "productivity management section". An example is shown in the Fig. 3.

According to deciding L_{cl} as sorting range for grade (Class A, Class B, Class C, Off-grade), it could be estimate Generation probability in that range. The evaluation value could be considered by multiplying M_{cl} as the estimated value and that factor. Total estimated value E could be calculated by cumulative-distribution-function [5] of Equation (10) according to combination of the control element.

$$E = h\ (\ L_{cl}\ ,\ M_{cl}\ , \mu,\ \ \sigma,\ \ N\ ) \tag{10}$$

$$B_{cl} = E - C_{all} \tag{11}$$

Thus, the graded profits for the all combinations using the levels of the control factors can be calculated.

3.2. PENALTY FOR LATER OF DELIVERY TIME

The Fig. 4 shows the delinquent charge function of this system. The abscissa axis shows the time and the ordinate axis shows the delay expense. In order to define the delinquent charge curve (straight-line group in a figure) $l(t)$, each coordinate value is inputted. The delivery time on the ordering condition is defined as T_{lim} and the limit of delivery time is defined as T_{end}.

The typical delinquent charge curve is shown in the Fig. 4. The total amount of the delinquent penalty is B_{la} of the shadow area and can be calculated by the equation (12).

$$B_{la} = \int_{0}^{T_{all} - T_{lim}} \ell(t)\, dt \tag{12}$$

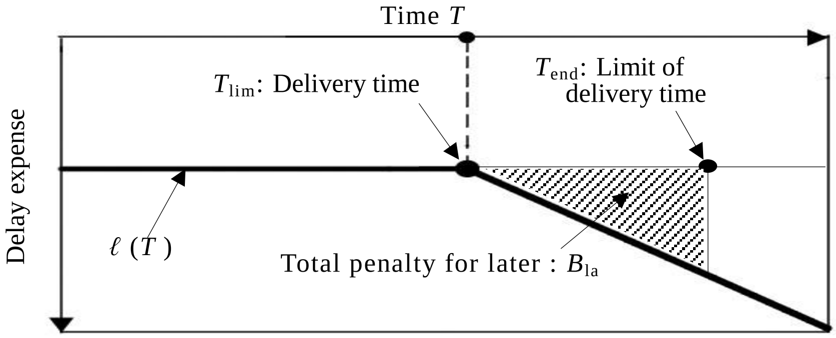


Fig. 4. Penalty for later of delivery time

3.3. LOSS FUNCTION TO INFLUENCE OF DISPERSION

In order to evaluate profits of finished products rigorously, third, the loss function on the influence of the dispersion of the finished product is added into the software.

As demonstrated in the Fig. 5 (a), the loss of the squared (parabola) deviation occurs as the loss function [6] (the equation (13) by the dispersion of the characteristic of finished products from the desired value. This loss function was introduced into this system. Furthermore, extending the utility, two models were defined; the case (b) with the dead region which excludes the loss function within the set acceptable value ($\pm r$) of the dispersion [the equation (14) which make the loss function (a) shift downward] and the case (c) that makes the loss function work when the set acceptable value is exceeded [the equation (15) which moves the loss function *y(x)* of the Fig. 5 (a) from side to side].

$$y = a x^2 \tag{13}$$

$$y = a x^2 - b \quad (\text{at } r \leqq |x|) \tag{14}$$

$$y = a\ |x| - r\ ^{2} \quad (\text{at } r < |x|) \tag{15}$$

Where a and b are invariable, r is the boundary value. The loss B_{lf} in the case of this combination is calculated with $G = f\,(\eta_{tol}, \mu, \sigma)$ and the equation 16 by the frequency distribution figured out in the"Part III" and the loss function *y(x)*.

$$B_{lf} = j\,(G, y\,(x)) \tag{16}$$

The final gross profit Btotal is calculated with the equation (17).

$$B_{total} = B_{cl} + B_{la} + B_{lf} \quad (17)$$

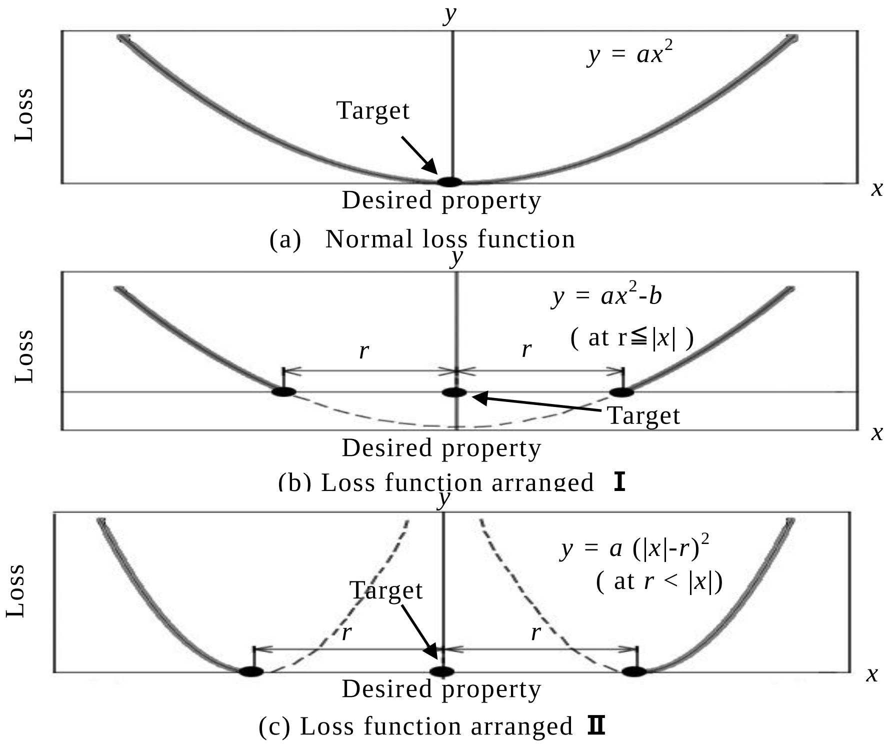


Fig. 5. Schematic view of the loss function

4. EVALUATION WITH KAMI-COPTER

4.1. CONTROL FACTOR, NOISE FACTOR, AND MANUFACTURE CONDITIONS

In order to evaluate this system comprehensively, the experiment with Kami-copter was performed for evaluation. The Fig. 6 shows an outline of the Kami-copter and the Table 3 shows the control and noise factors. L18 orthogonal array was used.

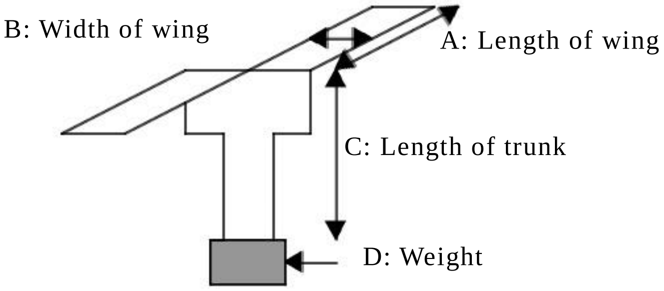


Fig. 6. Schematic view of the paper craft (Kami-copter)

Table 3. Control factor and noise factor for Kami-copter

Control factors	Name	Paper	A	B	C	D	Worker
	Levels	Paper1 ($64g/m^2$)	40	20	60	Clip:1 (0.4g)	Beginner part-timer
		Paper2 ($128g/m^2$)	50	30	80	Clip:2 (0.8g)	Standard part-timer
		Paper3 ($157g/m^2$)	60	40	100	Clip:3 (1.2g)	Expert
Noise factors	Name	Trial number					
	Levels	1		2		3	

Table 4. Cost table and experimental condition

Cost table regarding materials and tools	Name	Price of material (yen/unit)		Abandonment cost of defective item (yen/unit)		Cost of depreciation (yen)	
	Levels	Paper1	0.18	Paper	0.13	Scissors	0.01
		Paper2	1.26	Clip	0.05		
		Paper3	1.42				
		Clip	0.40				
Cost table regarding worker	Name			Labor cost (yen/hour)		Working time (sec/unit)	
	Beginner part-timer			700		120	
	Standard part-timer			850		80	
	Expert			1000		70	
Condition of experiment	Height of start for flying					2.4m	

Table 5. Order Condition (classification, penalty and loss function) for Kami-copter

Order condition	Production number		100
Classification	Class	Range of Characteristic value (sec)	Price (yen/unit)
	Class A	1.7～2.0	100
	Class B	1.4～1.7／2.0～2.2	50
Penalty	Beginning date	2009/01/01	
	First day penalty occurs (Delivery time)	2009/01/02 (2009/01/01)	
	Input of penalty function (yen/day)	-50	
	Limit value of penalty (yen) (Limit of delivery time)	-500 (From 2009/1/11) (2009/1/20)	
Loss function	Range of allowance	1.7～2.0 (sec)	
	Function type	$y = a\,(\lvert x\rvert - r)^2$ (at $r < \lvert x \rvert$) eq.(4-6)	
	Target value	1.85	
	Limit of allowance	0.20	
	Maximum loss (yen/unit)	15	

The Table 4 shows the order condition and cost table for the productivity management. The Table 5 shows the conditions for the functions of the grading, the delinquent charge and the loss function.

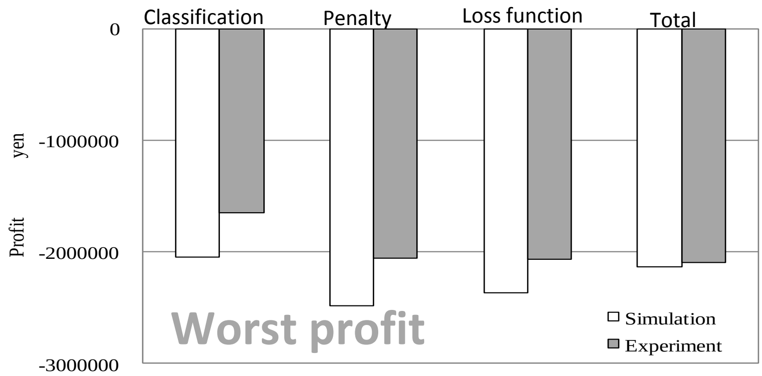
4.2. EVALUATION OF THIS SYSTEM

To evaluate this system comprehensively, first, after calculating the combination using the level of the control factors regarding the maximum profit and the minimum one on the

Table 6. Combination using the levels of the control factors for best and worst profits

	Condition the maximum profit produces (Best)						Condition the minimum profit produces (Worst)					
Condition	Paper	A	B	C	D	Worker	Paper	A	B	C	D	Worker
1. Classification	Paper1 (64g/m^2)	60	40	60	Clip:1 (0.4g)	Standard part-timer	Paper3 (157g/m^2)	60	40	60	Clip:2 (0.8g)	Beginner part-timer
2. Penalty	Paper1 (64g/m^2)	60	20	80	Clip:2 (0.8g)	Standard part-timer	Paper3 (157g/m^2)	60	40	60	Clip:2 (0.8g)	Beginner part-timer
3. Loss function	Paper1 (64g/m^2)	50	40	100	Clip:1 (0.4g)	Expert	Paper2 (128g/m^2)	50	20	80	Clip:2 (0.8g)	Expert
Total	Paper1 (64g/m^2)	40	20	100	Clip:1 (0.4g)	Expert	Paper2 (128g/m^2)	50	20	80	Clip:2 (0.8g)	Expert

a) Best profit of classification, penalty, loss function and its total in this system



b) Worst profit of classification, penalty, loss function and its total in this system

Fig. 7. Evaluation of the best and worst profit of classification, penalty, loss function and its total in this system

system; four cases with this system; the three cases that the grading, each of the delinquent charge and the loss function are evaluated in isolation and the case of the comprehensive evaluation of these three items, then the reappearance experiment of that combination was conducted.

The Table 6 shows the combination using the levels of the control factors for the maximum profit and the minimum one in the result of each added value. Regarding the combination using the levels of the control factors for the maximum and minimum profit, the experiments with 100 Kami-copters each and the profit calculations were performed. The Fig. 7 (a) and (b) show the comparison result with the calculation of this system. It shows that this system can calculate the each profits evaluation with high dimensional accuracy. That means that this system can be evaluated effective on industry.

5. CONCLUSION

In this chapter, the quality and the functionality of the system were advanced in order to gain the optimum condition for the maximum profit of products considering the function of the grading of products, the delinquent charge and the loss function in the quality engineering based on the developed software. The research results are summarized as follows. (1) "The trial production less CAE system with the profit evaluation function" was developed and enabled to calculate the grading products, adding the delinquent charge and the loss function. (2) The evaluation with Kami-copter experiment contributes to the profit evaluation of the grading, the delinquent charge and the loss function with high dimensional accuracy and it is evaluated effective on industry.

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