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The Process Optimization of Non-additive Multi-Quality Characteristics Associated with Cost Model

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Abstract—An approach has been proposed in this study to achieve this project. In this study, three-quality characteristics: (1) times of signal error, (2) CPU utilization and (3) occupation of random access memory (RAM) of digital video recorder system (DVRS) for stability (or shut-down protection) will be executed and tested by static and dynamic digital-digital S/N ratios in Taguchi Method. Besides, a generalized form of grey relational grade derived by a utility function will be used to determine the optimal setting of DVRS configuration and an alternative form of grey relational grade derived by a quadratic loss function will be used to determine the weight of multi-quality characteristics. Finally, we take the quality levels of sub-units (or control factors) of DVRS, weights of sub-units, costs of sub-units and quality weights of characteristics into consideration to develop a hardware quality and cost optimization model. According to the optimized model, the optimal configure of DVRS can be determined under different budgetary constrains.

Keywords—Digital video recorder system, Taguchi Method, S/N ratio, utility function, grey relational grade, quadratic loss function

1. INTRODUCTION

Digital Video Recorder System (DVRS) stores, pauses, displays … etc. videos on hard drives for security through Internet. Since the importance in security facilitate, operating stability (or shot-down protection) of DVRS cannot be ignored. There are four primary parts to a DVRS: (1) a hard drive, (2) a video capture card, (3) a charge-coupled device (CCD) camera and (4) a LAN card. Personal computers (PCs) already have a hard drive and a LAN card, and the other two elements are becoming more common. Therefore, lower the cost and increase the quality to generalize the use of DVRS, and raise the competition force of DVRS firms are the major objectives in this study.

Except for improving the configuration of DVRS and constructing its optimal cost model, resolving three problems for multi-quality characteristics in Taguchi Method is another objective in this study. The required resolved problems are listed in the following:

(1) In Taguchi Method, non-additive multi-quality characteristics were not been discussed properly. In order to improve it, a generalized form of grey relational grade (GF-GRG) Lin et al. (2004) derived by utility function will be used for non-additive multi-quality characteristics.

(2) Most of researchers assume the importance of all quality characteristics are equal, however, they are unequal usually. In order to determining the weights assigned to the characteristics, an alternative form of grey relational grade (AF-GRG) Lin et al. (2002) will be employed.

(3) In Taguchi Method, it often exists variant costs among levels of a factor, thus the optimal quality and cost model will be constructed to maximize quality under a budgetary constrain.

Based on above, a case of DVRS will be examined. Three quality characteristics of stability (or shut-down protection) in DVRS are: (1) times of signal error, (2) CPU utilization and (3) random access memory (RAM) occupation will be executed and tested by dynamic S/N ratio in Taguchi Method. After testing the relativity, a GF-GRG proposed by Lin et al. (2004) will be used to treat and integrate the non-additive multi-quality characteristics and an AF-GRG proposed by Lin et al. (2002) will be used to determine the weights for GRG. Finally, a quality and cost model will be constructed to maximize the integrated quality characteristic obtained by GF-GRG, and the model also takes weights of factors, weights of characteristic and cost of levels of factor into consideration. Figure 1 illustrates the framework and three required-solved-problem (RSP) of this Research.

2. LITERATURE REVIEW

The related literatures in this study include the fields of: (1) dynamic characteristics in Taguchi Method, (2) multi-quality characteristics, (3) modified grey relational grade, (4) digital video image system and (5) optimization model for quality and cost.

For dynamic problems, Taguchi (1987) used the general procedure to derive the appropriate objective functions or the S/N ratio. Phadke (1989) classified dynamic characteristics into four common types of dynamic problems, and they are: (1) continuous-continuous, (2)

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continuous-digital, (3) digital-continuous and (4) digital-digital. McCaskey and Tsui (1997) discussed appropriate two-step procedures under various models and presented illustrative examples in dynamic robust design experiment. Tsui (1999) investigated the response model approach for the dynamic robust design problem and derived relationships between the effect estimates of the loss model approach and those of the response model approach. Li (2001) proposed three models for the establishment of the optimal operating conditions by selection of the optimal threshold value for digital-digital dynamic quality characteristic.

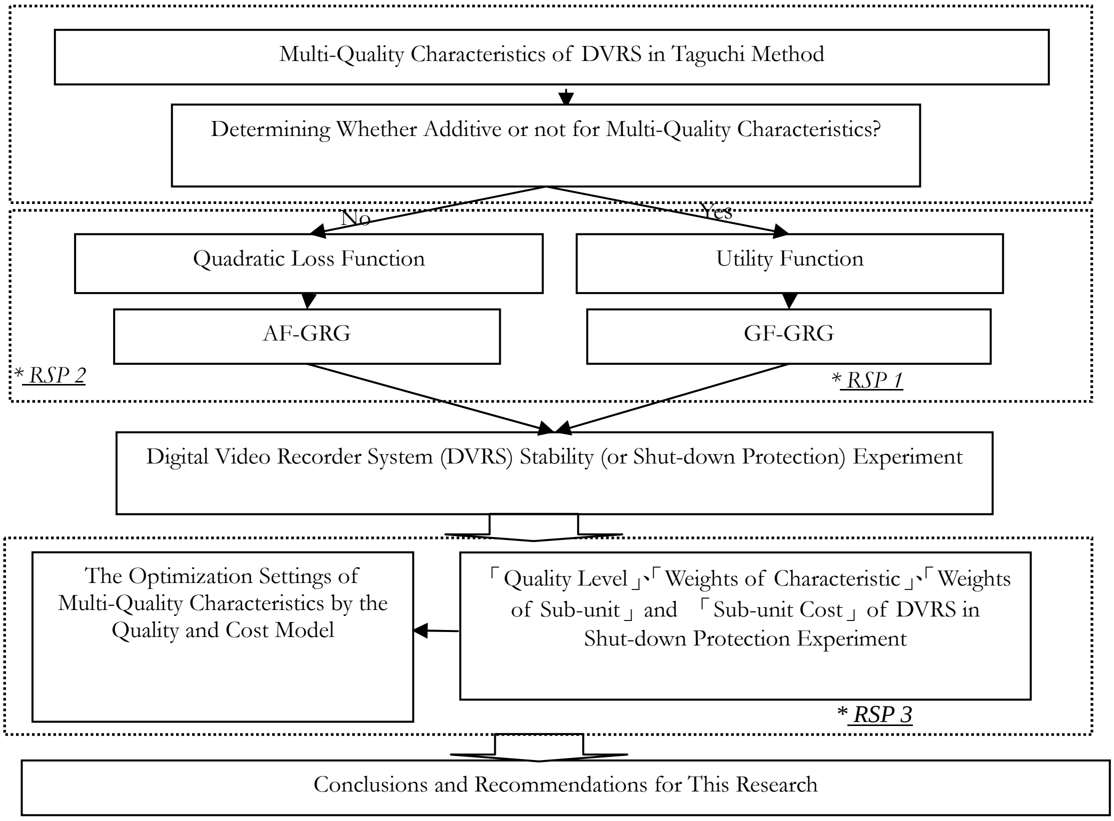

Figure 1. Framework and Three Required Solved Problems of This Research.

The multi-quality characteristics related researches are popular in those ten years (Logothetis and Haigh, 1988; Hung, 1990; Shiau, 1990; Chen, 1997; Su and Tong, 1997 et al., 1997; Wang, 2001; Huang, 2002; Chen, 2003). Tong et al. (1997) proposed a procedure to achieve the optimization of multi-response problems in the Taguchi method and the procedure includes four phases, i.e. computation of quality loss, determination of the multi-response signal to noise ratio, determination of the optimal factor/level combination and performing the confirmation experiment. Huang (2002) proposed a procedure to optimize multi-response process on the basis of the grey relational theory when responses are uncorrelated, and the grey relational theory well-matched the principal components analysis were be used to optimize multi-response process when responses were correlated.

Lin et al. (2002) reformed an AF-GRG by using quadratic loss function to solve the problem of measurement tolerance and determine the weights of GRG. In decision theory, an adaptable form is built since different decision makers may have different utility function or value function (Kenney and Raiffa, 1976). Lin et al. (2004) proposed a GF-GRG by using utility functions or value functions to relax the assumption of independence (i.e., additive independence or preferential independence).

Everitt et al. (1995) describes a multi-spectral digital video imaging system for remote sensing research. The system provides high quality color infrared (CIR) composite imagery along with its narrowband B & W image components. Today, PC has become the most critical component for DVRS. Most DVRSs today use non-real time capture cards, which capture video and convert the analog signal to digital. Once captured and converted, the data are sent to the system's CPU where it is compressed. Because these recorders rely on a CPU to process and compress the video signal, they tend to quickly "maxout" the CPU's processing power and time limit the number of cameras and frames that they can record McCall (2004). Besides, high memory integration increases data transferring efficiently. Therefore, a faster CPU, more RAM memory, and a high-performance hard drive will produce better quality performance Anderson et al. (2001).

Jung and Choi (1999) proposed two optimization models for selecting the best commercial off-the-shelf (COTS) products for the modules in a software system development, considering modules weights and available budget. The concept of COTS can also be applied to hardware system development.

3. DVRS HARDWARE STABILITY EXPERIMENT

The DVRS and its experimental environment parameter settings will be discussed.

3.1 Experiment equipments and configuration

In this case study, several experiment equipments of DVRS are shown in Appendix 1.

In this study, the example of controlling center will be set up in Hualien (client) and monitoring National Dong Hwa University workstation (sever) which is setting up at the laboratory simultaneously. Figure 2 illustrates the DVRS and the experimental configuration and the program driver of DVRS is NetEyes (AS404).

In Figure 2, static image and dynamic video play circularly and are captured by a CCD camera. This captured signal is reproduced by three multiplexers and becomes four individual signals in each video recorder machine. Then, there are four camera panes monitor revealed on each video recorder machine and client computers can receive the captured signals from these three video recorder machines.

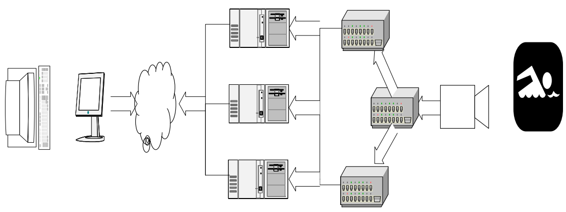

Figure 2. The DVRS and Its Experimental Configuration.

3.2 Control factor, signal factor, noise factor and response of DVRS identifying

For DVRS hardware stability experiment, it is important that control factor, signal factor and noise factors influence quality characteristics and should be identified by means of a thorough brainstorming session. Figure 3 illustrates the control, signal and noise factors in DVRS hardware stability experiment.

In this study case, noise factors are difficult to control by the designer, such as the external noise (network noise) and unit-to-unit variation (outlier). In the process of capturing static image and dynamic video via Internet, network flow is sometimes unstable. Besides, the variation that is inevitable in a manufacturing process leads to variation in the product parameters from unit to unit. Hence, the external noise is not considered in this study. However, experiment equipments were purchased at the same time and were availably controlled.

The control factors and their chosen levels of the DVRS hardware stability experiment are listed on Table 1. It is consisted into $L_{18}(2^1 \times 3^7)$ orthogonal array (OA) of the experimental matrix. There are six control factors: Factor A: the types of power supplier, Factor B: the types of CPU and matched motherboard, Factor C: the level of Ram, Factor D: the level of VGA card, Factor E: the space of hard disk buffer, Factor F: the types of operating system, and Factors G and H: the noise terms. Here, these six control factors except Factor F are hardware (sub-units), thus, the OA layout can be simplified without regarding the interactions within them. Furthermore, the orthogonal property is interpreted in the combinatorial sense – that is, for any pair of columns all combinations of factor levels occur and they take place an equal number of times.

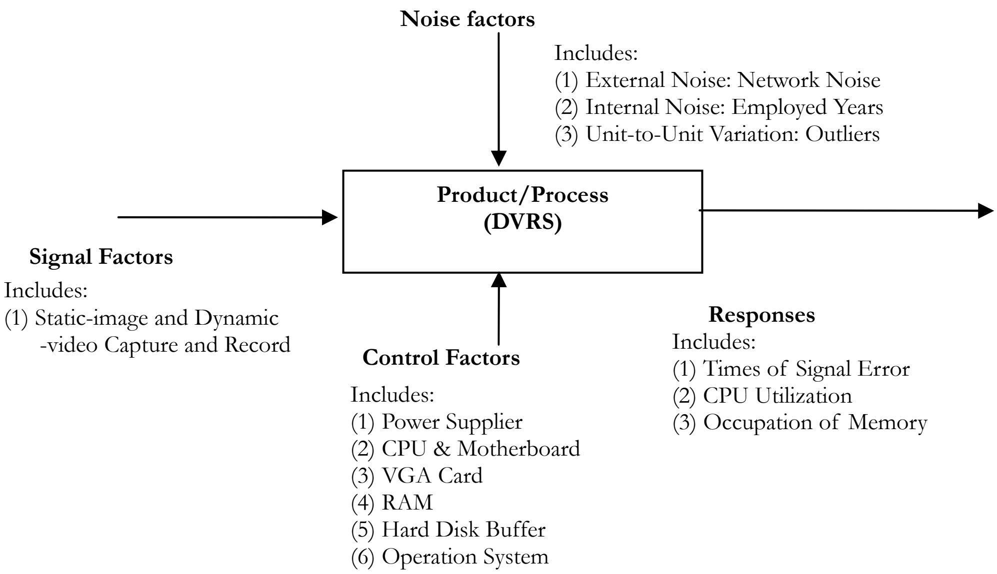

Figure 3. The Control, Signal and Noise Factors in DVRS Hardware Stability Experiment.

Table 1. Control Factors and Their Chosen Levels

Control Factors		Levels		
		1	2	3
A	Power Supplier	250W	300W	—
B	CPU and matched Motherboard	Intel Pentium 4	Intel Celeron	AMD
C	RAM(DDR333)	128MB	256MB	512MB
D	VGA Card	32MB Memory	64MB Memory	128MB Memory
E	Hard Disk Buffer	2MB	4MB	8MB
F	Operating System	Windows XP	Windows 2000	Windows 2000 (Sever)

In this study, we made a static-image and dynamic-video mixed cycle to execute repeatedly during the same period of time. It can record dynamic movie and capture static image in different situations and convert automatically. Furthermore, it can increase instantaneous system resource loading and to be a signal factor in dynamic system of DVRS. In each six-second cycle, two-second dynamic video and four-second static image play by turns and execute repeatedly. Each experimental set runs three days and has 43,200 cycles.

For DVRS hardware stability (or shut-down protection) experiments, three types of measurable quality characteristics (or responses) are considered. They are the smaller-the-better and are: (1) times of signal error, (2) CPU utilization, and (3) RAM occupation.

4. S/N RATIOS OF MULTI-QUALITY CHARACTERISTICS IN DVRS

4.1 S/N Ratio of times of signal error

In dealing with the dynamic S/N ratio of times of transmit-receive signal error in DVRS, the input and output of video capture and dynamic video record fails into four categories: n_{00}, n_{01}, n_{10} and n_{11}. Where n_{00} is correctly capture, n_{01} is missing capture, n_{10} is missing record and n_{11} is correctly record. Table 2 shows the transmit-receive relationship for digital communication.

Suppose under certain settings of control factors and noise conditions, the probability of receiving 1, when 0 is transmitted, is p, that is, $p = n_{01}/t_0$. Similarly, suppose the probability of receiving 0, when 1 is transmitted, is q, that is $q = n_{10}/t_1$. Therefore, the contents of Table 3 can be re-arranged from contents of Table 2 to be integrated transmit-receive relationship for digital communication. The average times of input (transmitted signal) and output (received signal) of them are shown on Table A.2 in Appendix 2.

The relationship between $\overline{p}$, p and q will be obviously depend on the continuous distribution and $\overline{p} = \overline{q}$. The two inputting S/N ratios in dynamic system, η_p and η_q,

Table 2. Transmit-Receive Relationships for Digital Communication (Taguchi, 1987)

Output / Input		Receive Signal 0	Receive Signal 1	Total
Transmit Signal	0	n_{00}	n_{01}	t_0
	1	n_{10}	n_{11}	t_1
Total		r_0	r_1	n

Note: $t_0 = n_{00} + n_{01}$, $t_1 = n_{10} + n_{11}$, $r_0 = n_{00} + n_{10}$, $r_1 = n_{01} + n_{11}$ and $n = t_0 + t_1 = r_0 + r_1 = 43,200$ (cycles).

Table 3. Integrated Transmit-Receive Relationships for Digital Communication

Output / Input		Probabilities Associated with the Received Signal 0	Probabilities Associated with the Received Signal 1	Total
Transmitted Signal	0	1-p	p	1
	1	q	1-q	1
Total		1-p+q	1+p-q	2

can be determined by fraction defective type S/N ratio Shiau (1990):

$$\eta_p = 10\log_{10}(\frac{1}{p} - 1)\text{, and} \quad (1)$$

$$\eta_q = 10\log_{10}(\frac{1}{q} - 1)\,. \quad (2)$$

According to two inputting S/N ratios, η_p and η_q, in dynamic system. Taguchi (1987) suggested the use of the average of both η_p and η_q for estimating $\overline{\eta}$ as

$$\begin{aligned}\overline{\eta} &= \frac{1}{2}\left(\eta_p + \eta_q\right) \\ &= \frac{10}{2}\log_{10}[(\frac{1}{p} - 1)(\frac{1}{q} - 1)] \\ &= 10\log_{10}(\frac{1}{\overline{p}} - 1)\,. \end{aligned} \quad (3)$$

Eq. (3) asserts that the effect of equalization is to make the two S/N ratios equal to the average of the S/N ratios before equalization. Rewrite Eq. (3) as follows.

$$\overline{p} = \frac{1}{1 + \sqrt{(\frac{1}{p} - 1)(\frac{1}{q} - 1)}}\text{, and} \quad (4)$$

$$\eta_1 = -10\log_{10}[\frac{1}{(1 - 2\overline{p})^2} - 1]\,. \quad (5)$$

Here, Eq. (5) is the digital-digital type dynamic S/N ratios Taguchi (1987) and can be employed to determine the S/N ratios of times of signal error. The obtained data and the digital-digital type dynamic S/N ratios of times of signal error, η_1, are shown on Table A.3 in Appendix 3.

4.2 S/N ratios of CPU utilization and memory occupation

On account of dynamic video record raises CPU utilization and requires larger memory occupation (or reduce memory available), two outputs of static capture and dynamic record are considered in DVRS hardware stability (or shut-down protection) experiment. The concepts of upper bound and lower bound assist to determine the S/N ratios of CPU utilization, η_2, and the S/N ratios of memory occupation, η_3. Here, b_2^U is defined as average CPU utilization when recording dynamic video, b_2^L is defined as average CPU utilization when capturing static image, b_3^U is defined as average RAM available when capturing static image, and b_3^L is defined as average RAM available when recording dynamic video. Therefore, $(b_3^U - b_3^L)/R$ can be defined as the average memory occupation ratio, where R is the total memory, with 128MB has 130,544K, 256MB has 261,616K and 512MB has 523,760K. For keeping stable system operating, the S/N ratios of CPU utilization and memory occupation ratio are both the smaller-the-better. A combined smaller-the-better S/N ratio of b_2^U and b_2^L, η_2, is

$$\eta_2 = -10\log[\frac{1}{2}\sum_{i=1}^{n}((b_2^U)^2 + (b_2^L)^2)], \tag{6}$$

and smaller-the-better S/N ratio of $(b_3^U - b_3^L)/R$, η_3, is

$$\eta_3 = -10\log[\sum_{i=1}^{n}(\frac{b_3^U - b_3^L}{R})^2]. \tag{7}$$

Based on Eqs. (5), (6) and (7), the values of η_1, η_2 and η_3 are shown on Table 4. After testing and examining the Pearson correlations of η_1, η_2 and η_3, we know that dependent exists among η_1 and η_2. Therefore, we can regard these three S/N ratios as non-additive quality- characteristics and treat them by GF-GRG.

Table 4. OA ($L_{18}(2^1 \times 3^7)$) and the Values of η_1, η_2 and η_3

Ex. No.	Factors								S/N Ratios		
	A	B	C	D	E	F	G	H	η_1	η_2	η_3
0	–	–	–	–	–	–	–	–	40.334	-34.752	62.377
1	1	1	1	1	1	1	1	1	30.225	-35.959	27.029
2	1	1	2	2	2	2	2	2	32.377	-35.778	36.174
3	1	1	3	3	3	3	3	3	35.562	-35.578	41.631
4	1	2	1	1	2	2	3	3	31.441	-36.457	28.318
5	1	2	2	2	3	3	1	1	32.377	-36.272	36.247
6	1	2	3	3	1	1	2	2	32.216	-36.164	43.349
7	1	3	1	2	1	3	2	3	31.169	-36.502	29.039
8	1	3	2	3	2	1	3	1	32.066	-36.320	32.291
9	1	3	3	1	3	2	1	2	31.926	-36.057	40.933
10	2	1	1	3	3	2	2	1	33.097	-35.891	25.924
11	2	1	2	1	1	3	3	2	32.377	-35.907	34.488
12	2	1	3	2	2	1	1	3	31.441	-35.891	45.171
13	2	2	1	2	3	1	3	2	32.675	-36.116	28.975
14	2	2	2	3	1	2	1	3	33.431	-36.099	34.647
15	2	2	3	1	2	3	2	1	32.216	-36.004	40.959
16	2	3	1	3	2	3	1	2	31.169	-36.227	26.942
17	2	3	2	1	3	1	2	3	31.926	-36.395	35.256
18	2	3	3	2	1	2	3	1	30.927	-36.152	43.524

5. OPTIMIZING NON-ADDITIVE MULTI-QUALITY CHARACTERISTICS

In order to integrate the non-additive multi-quality characteristics, a GF-GRG can be determined and regarded as an integrated quality performance index.

5.1 Normalization

Let x_0 be the referential series with k entities, $x_0 = (x_0(1), x_0(2), \cdots, x_0(n))$, and x_i be the compared series, $x_i = (x_i(1), x_i(2), \cdots, x_i(n))$, $i = 1, 2, \ldots, m$.

Before calculating the grey relational coefficients, the data of series can be treated based on the following three kinds of situation and the linearity of normalization to avoid distorting the normalized data Hsia (1997). There are:

1. Upper-bound effectiveness measuring (i.e., larger-the-better)

$$x_i^*(k) = \frac{x_i(k) - \min_k x_i(k)}{\max_k x_i(k) - \min_k x_i(k)}, \quad (8)$$

where $\max_k x_i(k)$ is the maximum value of entity k and $\min_k x_i(k)$ is the minimum value of entity k.

2. Lower-bound effectiveness measuring (i.e., smaller-the-better)

$$x_i^*(k) = \frac{\max_k x_i(k) - x_i(k)}{\max_k x_i(k) - \min_k x_i(k)}, \quad (9)$$

3. Moderate effectiveness measuring (i.e., nominal-the-best)

$$x_i^*(k) = \frac{|x_i(k) - x_{ob}(k)|}{\max_k x_i(k) - x_{ob}(k)}, \text{ if } \min_k x_i(k) \le x_{ob}(k) \le \max_k x_i(k), \quad (10)$$

$$x_i^*(k) = \frac{x_i(k) - \min_k x_i(k)}{x_{ob}(k) - \min_k x_i(k)}, \text{ if } \max_k x_i(k) \le x_{ob}(k), \text{ or} \quad (11)$$

$$x_i^*(k) = \frac{\max_k x_i(k) - x_i(k)}{\max_k x_i(k) - x_{ob}(k)}, \text{ if } x_{ob}(k) \le \min_k x_i(k) \quad (12)$$

where $x_{ob}(k)$ is the objective value of entity k.

5.2 Calculating GF-GRG

A collection of entities $x_i^*(k)$, $i = 1, 2, \cdots, m$, $k = 1, 2, \cdots, n$, is assumed mutually utility independent. This does not imply that the utility function is additive or universal called independence, thus the entities $\Delta_{0i}(k)$ is the absolute value of difference between the x_0^* and x_i^* at the kth entity, that is, $\Delta_{0i}(k) = \left|x_0^*(k) - x_i^*(k)\right|$, $k = 1, 2, \cdots, n$. It is also mutually independent and can be characterized by an multi-linear utility function, u, as Keeney and Raiffa (1976):

$$u(\Delta_{0i}(1), \Delta_{0i}(2), \cdots, \Delta_{0i}(n)) = \sum_{k=1}^{n} \lambda_k u_k(\Delta_{0i}(k)) + \lambda \sum_{\substack{k=1 \\ k'>k}}^{n} \lambda_k \lambda_{k'} u_k(\Delta_{0i}(k)) u_{k'}(\Delta_{0i}(k')) + \cdots + \lambda^{n-1} \lambda_1 \cdots \lambda_n u_1(\Delta_{0i}(1)) \cdots u_n(\Delta_{0i}(n)), \quad (13)$$

where

(i) u is normalized $u(\min_i \Delta_{0i}(1), \min_i \Delta_{0i}(2), \cdots, \min_i \Delta_{0i}(n)) = 0$ and $u(\max_i \Delta_{0i}(1), \max_i \Delta_{0i}(2), \cdots, \max_i \Delta_{0i}(n)) = 1$;

(ii) $u_k(\Delta_{0i}(k))$ is a conditional utility function on $\Delta_{0i}(k)$ normalized by $u_k(\min_i \Delta_{0i}(k)) = 0$ and $u_k(\max_i \Delta_{0i}(k)) = 1$, $k = 1, 2, \cdots, n$;

(iii) $\lambda_k = u(\min_i \Delta_{0i}(1), \cdots, \max_i \Delta_{0i}(k), \cdots, \min_i \Delta_{0i}(n))$, $k = 1, 2, \cdots, n$; and

(iv) λ is a scaling constant that is a solution to $1 + \lambda = \prod_{k=1}^{n} (1 + \lambda \lambda_k)$.

Here, function u_k is defined over the entity score $\Delta_{0i}(k)$ as the k-th component utility function, λ_k is a scaling factor for u_k and λ is another scaling constant. If $\sum_{k=1}^{n} \lambda_k = 1$, then $\lambda = 0$, thus, Eq. (13) can be formed to be an additive utility function as:

$$u(\Delta_{0i}(1), \Delta_{0i}(2), \cdots, \Delta_{0i}(n)) = \sum_{k=1}^{n} \lambda_k u_k(\Delta_{0i}(k)) \quad (14)$$

It implies existing a utility function for GF-GRG and is

$$\Gamma_{0i}^{u} = \frac{\Delta \min + \Delta \max}{u + \Delta \max} \quad (15)$$

Based on Eqs. (13) and (15), GF-GRG can be obtained and shown on Table 5.

5.3 Determining the relative weights of GRG

Lin et al. (2002) proposed alternative form of GRG (AF-GRG) by using quadratic loss function. The alternative form has been solved the difficulties of setting the distinguishing factor to determine the grey coefficients and the relative weight for GRG has been determined. The AF-GRG proposed by Lin et al. is illustrated as follows.

A collection of entities $x_i(k)$, $i = 1, \cdots, m$, $k = 1, \cdots, n$, is mutually (or completely) independent, so entities $\Delta_{0i}(k)$, $k = 1, \cdots, n$, is also mutually independent. A loss function is a continue function (Taguchi, 1987; Ross, 1989), and it's Taylor expansion Thomas and Ross (1992) of $\Delta_{0i}(k)$, $k = 1, \cdots, n$, at $T_1, T_2, \cdots, T_n$ is given as:

Table 5. Results of GF-GRG and Its Ranking

Exp. No.	u	Γ_{oi}^{u}	Ranking
0	0.000	1.000	–
1	0.967	0.508	**15**
2	0.885	0.531	**2**
3	0.731	0.578	**1**
4	0.983	0.504	**17**
5	0.942	0.515	**11**
6	0.917	0.522	**9**
7	0.989	0.503	**18**
8	0.958	0.511	**13**
9	0.916	0.522	**8**
10	0.914	0.523	**7**
11	0.904	0.525	**5**
12	0.899	0.527	**6**
13	0.935	0.517	**10**
14	0.905	0.525	**3**
15	0.902	0.526	**4**
16	0.971	0.507	**16**
17	0.963	0.510	**14**
18	0.943	0.515	**12**

$$L(\Delta_{0i}(1), \Delta_{0i}(2), \cdots, \Delta_{0i}(n)) = L(T_1, T_2, \cdots, T_n) + \sum_{k=1}^{n} L'_{\Delta_{oi}(k)}(T_1, T_2, \cdots, T_n)(\Delta_{0i}(k) - T_k) + \frac{1}{2!}\sum_{k=1}^{n} L''_{\Delta_{oi}(k)}(T_1, T_2, \cdots, T_n)(\Delta_{0i}(k) - T_k)^2 + \sum_{k_1=1}^{n-1}\sum_{k_2=k_1+1}^{n} L''_{\Delta_{oi}(k_1)\Delta_{oi}(k_2)}(T_1, T_2, \cdots, T_n) (\Delta_{0i}(k_1) - T_{k_1})(\Delta_{0i}(k_2) - T_{k_2}) + R_3, \tag{16}$$

where T_k, $k = 1, \cdots, n$, is the target value of loss function. It is note that R_3 is very small and the loss function can be rewrote as:

$$L(\Delta_{0i}(1), \Delta_{0i}(2), \cdots, \Delta_{0i}(n)) = l_0 + \sum_{k=1}^{n} l_k(\Delta_{0i}(k) - T_k) + \sum_{k=1}^{n} \lambda_k(\Delta_{0i}(k) - T_k)^2 + \sum_{k_1=1}^{n-1}\sum_{k_2=k_1+1}^{n} \lambda_{k_1 k_2}(\Delta_{0i}(k_1) - T_{k_1})(\Delta_{0i}(k_2) - T_{k_2}). \tag{17}$$

If let $\Delta_{0i}(1) = T_1$, $\Delta_{0i}(2) = T_2$, ..., $\Delta_{0i}(n) = T_n$, then we can know that $L(\Delta_{0i}(1), \Delta_{0i}(2), \cdots, \Delta_{0i}(n)) = l_0 = 0$ and loss function $L(\Delta_{0i}(1), \Delta_{0i}(2), \cdots, \Delta_{0i}(n))$ has minimum loss value. Therefore,

,

$$\frac{\partial L(\Delta_{0i}(1), \Delta_{0i}(2), \cdots, \Delta_{0i}(n))}{\partial \Delta_{0i}(k)}\Big|_{\Delta_{0i}(1)=T_1, \Delta_{0i}(2)=T_2, \cdots, \Delta_{0i}(n)=T_n}, = l_k = 0, \text{ for all } k; \tag{18}$$

$$\frac{\partial L'(\Delta_{0i}(1), \Delta_{0i}(2), \cdots, \Delta_{0i}(n))}{\partial \Delta_{0i}(k)}\Big|_{\Delta_{0i}(1)=T_1, \Delta_{0i}(2)=T_2, \cdots, \Delta_{0i}(n)=T_n} = 2\lambda_k > 0, \text{ for all } k; \tag{19}$$

here, assumed $\Delta_{0i}(k)$, $k = 1, \cdots, n$, is mutually independent, therefore

$$\frac{\partial^2 L(\Delta_{0i}(1), \Delta_{0i}(2), \cdots, \Delta_{0i}(n))}{\partial \Delta_{0i}(k_1)\ \partial \Delta_{0i}(k_2)}\Big|_{\Delta_{0i}(1)=T_1, \Delta_{0i}(2)=T_2 \cdots, \Delta_{0i}(n)=T_n} = \lambda_{k_1 k_2} = 0, \text{ for all } k_1 \text{ and } k_2, \text{ but } k_1 \neq k_2. \tag{20}$$

If the target value $T_k = 0$, $k = 1, \cdots, n$, then the loss function can be became:

$$L(\Delta_{0i}(1), \Delta_{0i}(2), \cdots, \Delta_{0i}(n)) = \sum_{k=1}^{n} \lambda_k(\Delta_{0i}(k) - T_k)^2 = \sum_{k=1}^{n} \lambda_k \Delta_{0i}^2(k). \tag{21}$$

Suppose the upper tolerance, $t_u(k)$, exists and can be normalized based on Eq. (8) to (12), then $t_u^*(k)$ is normalized upper tolerance at entity k. If the normalized value of entity k, $x_i^*(k)$, equals to $t_u^*(k)$, then it exists a loss value A_k, that $A_k = L(0, \cdots, 0, \Delta_{0i}(k), 0, \cdots, 0) = \sum_{k=1}^{n} \lambda_k \left|x_0^*(k) - t_u^*(k)\right|^2 = \lambda_k \Delta_{0t_u}^2(k)$, where $\Delta_{0t_u}(k) = \left|x_0^*(k) - t_u^*(k)\right|$, then the coefficient λ_k can be computed as: $\lambda_k = A_k / \Delta_{0t_u}^2(k) > 0$. Fortunately, the subjective real loss cost or opportunity cost can be used to substitute the loss value at the k-th entity. Based on the right hand side of Eq. (21) and the restraint of weight in [0, 1], it is possible to taking average of λ_k (i.e., the relative weight, $w_k = \frac{\lambda_k}{\sum_{k=1}^{n} \lambda_k} \in [0, 1]$) and root it, an Euclidean distance Δ' can be defined as:

$$\Delta' = \sqrt{\sum_{k=1}^{n} \frac{\lambda_k}{\sum_{k=1}^{n} \lambda_k} \Delta_{0t_u}^2(k)} = \sqrt{\sum_{k=1}^{n} w_k \Delta_{0t_u}^2(k)} \tag{22}$$

Therefore, the quadratic loss function has been used to determine the relative weight of GRG (Lin et al., 2004), and it is

$$w_k = \frac{\lambda_k}{\sum_{k=1}^{n} \lambda_k}. \tag{23}$$

In this case of DVRS, loss value A_k is defined as the expected value of loss, that is, $A_k = c_k\overline{p} = (c_1\overline{p},\ c_2\overline{p},\ c_3\overline{p})$ = (0.4716, 0.4218, 0.2489), where c_k is the average repurchase (or repair) cost of Characteristic k, k = 1, 2, 3. $\Delta_{0i}(k)$ can be calculated by compared series normalized data x_i^* and λ_k can be obtained by $\lambda_k = A_k / \Delta_{0t_u}^2(k)$. Table 6 shows the values of λ_k, $\sum_{k=1}^{3}\lambda_k$ and w_k.

6. QUALITY AND COST OPTIMIZATION MODEL FOR DVRS

A DVRS of this study consists of three quality characteristics, where a specific display of each quality characteristic can call upon a series of sub-unit. Six sub-units (or control factors) of DVRS are associated with each quality characteristic. Figure 4 shows the hierarchy of multi-quality characteristics for DVRS.

For adequate assembling DVRS, the goal of this study is to determine the best alternative of specific sub-unit to meet the restrict budget and further to solve the problem of variant cost among the levels of factor (or sub-unit) in Taguchi Method. The optimization model of DVRS for evaluating overall quality level, Q_{BG}, under budgetary constrain, BG, is shown as follows.

$$Max \quad Q_{BG} = a\left(\sum_{f=A}^{m} s_f \left(\sum_{l=1}^{n_f} q_{fl} \sum_{k=1}^{v} w_{flk} d_{flk}\right)\right)$$

$$s.t. \quad \sum_{f=A}^{m}\sum_{l=1}^{n_f}\sum_{k=1}^{v} d_{flk} = 1,$$

$$\sum_{f=A}^{m}\sum_{l=1}^{n_f}\sum_{k=1}^{v} c_{fl} d_{flk} \le BG,$$

$$d_{flk} = 0 \text{ or } 1,\ \forall f,\ l \text{ and } k. \tag{24}$$

In order to compensate the different number of levels of sub-units, we multiply the leveling term, a, in the objective function, where a is defined as $a = \sqrt[m]{\prod_{f=A}^{m} n_f}$. The notations are defined in the following: m is the number of sub-unit for DVRS; n_f is the number of selectable alternatives for Sub-unit f, f = A, B, …, m; v is the number of characteristics; w_{flk} is the weight of Characteristic k assigned to Alternative l for Sub-unit f, l = 1, 2, …, n_f; f = A, B, …, m; k = 1, …, v; s_f is the weight assigned to Sub-unit f, f = A, B, ..., m; q_{fl} is the quality level of Alternative l in Sub-unit f, l = 1, 2, ..., n_f; f = A, B, …, m; c_{fl} is the cost of Alternative l in Sub-unit f, l = 1, 2, ..., n_f; f = A, B, …, m; BG is the restrict budget for DVRS; d_{flk} is the decision variable of the models, where d_{flk} = 1, if Alternative l of Sub-unit f for Characteristic k is selected, or 0 for otherwise. In the first constrain, one alternative is mutually exclusive selected for each sub-unit. Furthermore, in the second constrain, the available budget BG is restricted and the lower and upper bounds of BG are

Table 6. The Values of λ_k, $\sum_{k=1}^{3}\lambda_k$ and w_k

Exp. No	λ_1	λ_2	λ_3	$\sum_{k=1}^{3}\lambda_k$	w_1	w_2	w_3
1	0.472	0.886	0.265	1.623	0.290	0.546	0.163
2	0.761	1.228	0.482	2.473	0.308	0.497	0.195
3	2.116	1.893	0.768	4.784	0.442	0.397	0.161
4	0.609	0.445	0.285	1.339	0.455	0.332	0.213
5	0.761	0.559	0.484	1.805	0.422	0.310	0.269
6	0.731	0.648	0.913	2.295	0.319	0.282	0.399
7	0.574	0.422	0.298	1.293	0.444	0.326	0.230
8	0.705	0.526	0.365	1.596	0.442	0.329	0.229
9	0.682	0.758	0.719	2.161	0.315	0.351	0.333
10	0.920	0.996	0.249	2.166	0.425	0.460	0.115
11	0.761	0.968	0.425	2.156	0.353	0.450	0.197
12	0.609	0.996	1.117	2.726	0.224	0.366	0.411
13	0.822	0.695	0.296	1.813	0.453	0.383	0.164
14	1.012	0.712	0.430	2.154	0.470	0.331	0.200
15	0.731	0.825	0.721	2.279	0.321	0.362	0.317
16	0.574	0.594	0.263	1.431	0.401	0.415	0.184
17	0.682	0.479	0.450	1.610	0.423	0.297	0.279
18	0.545	0.660	0.930	2.137	0.255	0.309	0.436

$\sum_{f=A}^{m}\min_{l}(c_{fl}) \le BG \le \sum_{f=A}^{m}\max_{l}(c_{fl})$. Therefore, it is infeasible if BG is less than the lower bound, $\sum_{f=A}^{m}\min_{l}(c_{fl})$, and it is greater than the upper bound, $\sum_{f=A}^{m}\max_{l}(c_{fl})$. In the third constrain, d_{flk} is the decision variable and d_{flk} = 1 if Alternative *l* in Sub-unit *f* is selected for characteristic *k*.

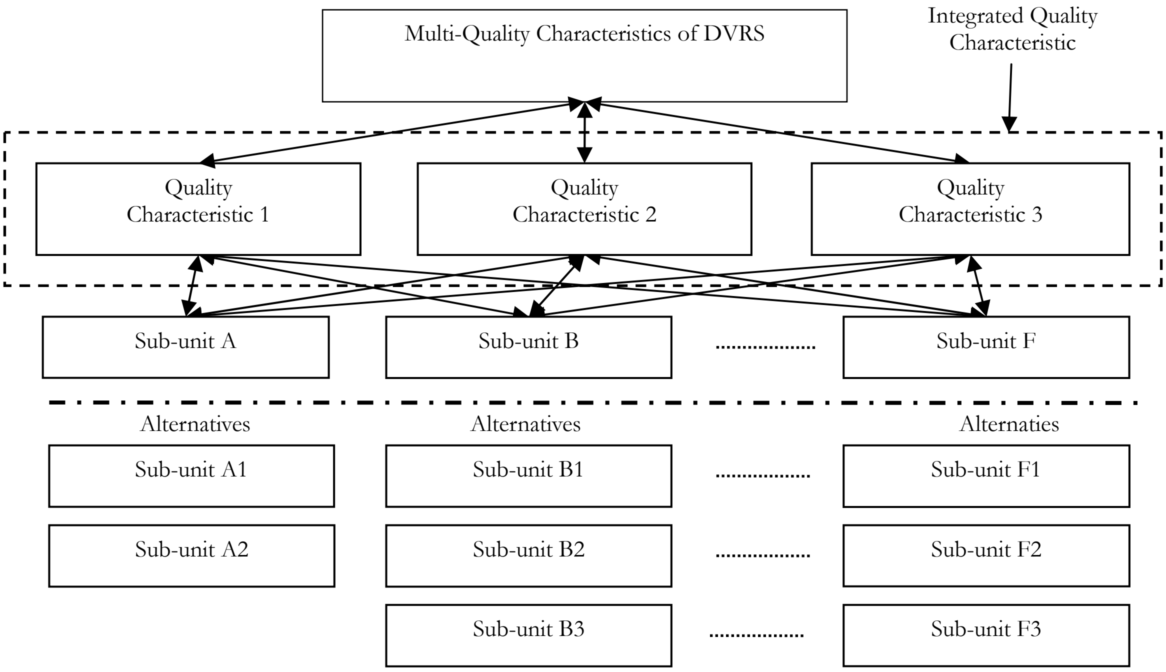

Figure 4. The Hierarchy of Multi-Quality Characteristics for DVRS.

6.1 Determining the Parameters of Quality and Cost Model

The system quality level, q_{fl}, can be estimated by the main effect of Sub-unit f from integrated quality characteristic, Γ''_{0i}, where Γ''_{0i} can be determined by GF-GRG in Eq. (15). The cost of sub-unit, c_{fl}, is only based on purchasing price. Weight of sub-unit, s_f, can be obtained by the ratio = (contrast of sub-unit *f* / total contrast). The assigned weight, w_{flk} for characteristics can be evaluated by Eq. (23). Table 7 shows the values of q_{fl} and c_{fl}, and s_f. On Table 7, the value of q_{B1} (= 0.532) is the mean of Γ''_{0i} on Table 5 associated with Alternative 1 (or Level 1) of Factor B (or Sub-unit B) in OA on Table 4, that is, 0.521 = (1/6)(0.578 + 0.531 + 0.508 + 0.523 +0.525 +0.567). And the value of S_B = 0.263 = {|0.532 –0.518| + |0.532 – 0.511} + |0.518 – 0.5111|} / {|0.521 - 0.519| + |0.532 – 0.518| + |0.532 – 0.511} + |0.518 – 0.5111| + …. + |0.515 – 0.520| + |0.515 – 0.526| + |0.520 – 0.526|}. Others are the same calculations. Table 8 shows the value of w_{flk} which is calculation by using Eq. (23) associated with Characteristic *k*, Level *l* and Factor *f*.

On Table 8, the value of w_{2B1} (= 0.302) is the weight for Characteristic 1, Level 2 and Factor B from Table 6, that is, 0.302 = (1/6)(0.290 + 0.308 + 0.442 + 0.425 + 0.353 + 0.224). Others are the same calculations. The values w_{flk} on Table 8 are the input values of Eq. (24).

6.2 Results of quality and cost model

According to Eq. (24), Table 9 shows the results of the optimal settings under the restrict budget from \$12,940 to \$21,350. On Table 9, the optimal solution within *BG* = \$21,350 is $A_{21}B_{12}C_{33}D_{23}E_{31}F_{13}$. Here, A_{21} indicates that we should choose Factor A at Level 2 and weighted by Characteristic 1 (that is, the value of 0.492 on Table 8) under *BG* = \$21,350 and so on.

In order to distinguish and determine the optimal setting under restricted budgetary, we can find the more cost decreasing and lower quality loss setting to be the acceptable setting. Table 10 shows the marginal variation of cost and quality. On Table 10, the values of NT\$3,200 = NT\$20,700 – NT\$17,490 and 0.0027 = 0.6052 – 0.6025. Others are the same calculations. According to Table 10, it is known that No. 2 has higher cost decrease and lower quality loss under the four budgetary constrains.

As the results, the optimal combination selected in this model is not the best combination in traditional Taguchi Method. It is because of the weighting process considering weights of Table 9 Optimal Settings (or Levels) of Quality and Cost Model under Different BG for sub-unit and weights of characteristic. It clearly indicates that quality and cost model considering weight of characteristic can make the quality characteristic more significant and select the optimal setting of unequal multi-quality characteristics more efficiently under limited budgetary. Therefore, DVRS firms can imitate their budget refer to optimal quality and cost model manufacturing the optimal setting under limited budget.

Table 7. The Values of q_{fl} and c_{fl} (NT$), and s_f

Sub-unit		A	B	C	D	E	F
q_{fl}	1	0.521	0.532	0.510	0.516	0.516	0.515
	2	0.519	0.518	0.519	0.518	0.517	0.520
	3	–	0.511	0.531	0.527	0.527	0.526
c_{fl}	1	750	4,050	750	3,100	990	5,500
	2	900	2,150	1,400	3,450	1,350	5,500
	3	–	1,850	2,600	3,600	4,200	6,000
s_f		0.042	0.263	0.271	0.151	0.142	0.130

Table 8. The Value of w_{flk}

Weight of η_1 Assigned to Alternative l of Sub-unit f, w_{fl1}

Factor / Level	A	B	C	D	E	F
1	0.508	0.302	0.365	0.319	0.315	0.318
2	0.492	0.361	0.357	0.311	0.318	0.329
3		0.337	0.277	0.369	0.367	0.352

Weight of η_2 Assigned to Alternative l of Sub-unit f, w_{fl2}

Factor / Level	A	B	C	D	E	F
1	0.500	0.403	0.365	0.347	0.333	0.327
2	0.500	0.297	0.328	0.325	0.341	0.338
3		0.301	0.306	0.328	0.326	0.335

Weight of η_3 Assigned to Alternative l of Sub-unit f, w_{fl3}

Factor / Level	A	B	C	D	E	F
1	0.488	0.276	0.238	0.334	0.362	0.366
2	0.512	0.347	0.305	0.379	0.345	0.332
3		0.376	0.458	0.286	0.294	0.302

Table 9. Optimization Setting (or Level) of Quality and Cost Model for DVRS

No.	$\sum_{f=A}^{m}\sum_{l=1}^{n_f}\sum_{k=1}^{v} c_{fl} d_{flk}$ (BG)	d_{flk}: $A_{lk}\ B_{lk}\ C_{lk}\ D_{lk}\ E_{lk}\ F_{lk}$	Q_{BG}
1	NT$20,700 (NT$21,350)	$A_{21}\ B_{12}\ C_{33}\ D_{23}\ E_{31}\ F_{13}$	0.605
2	NT$17,490 (NT$19,000)	$A_{21}\ B_{12}\ C_{33}\ D_{32}\ E_{13}\ F_{13}$	0.603
3	NT$16,990 (NT$17,000)	$A_{12}\ B_{12}\ C_{33}\ D_{12}\ E_{13}\ F_{13}$	0.593
4	NT$14,940 (NT$15,000)	$A_{21}\ B_{33}\ C_{33}\ D_{12}\ E_{13}\ F_{13}$	0.579
5	NT$12,940 (NT$12,940)	$A_{13}\ B_{33}\ C_{12}\ D_{12}\ E_{13}\ F_{13}$	0.533

7. CONCLUSIONS

A procedure has been proposed in this study to achieve the optimization of multi-quality characteristic problems in the Taguchi method. The procedure includes three stages: (1) compute the static and dynamic S/N ratios in Taguchi Method, (2) determine the relative weight assigned to characteristics by using AF-GRG and integrate the non-additive multi-quality characteristics by using GF-GRG and (3) decide the optimal setting within different budgetary constrain by quality and cost optimization model which takes integrated quality level, weight of sub-unit, assigned weight of characteristic, and sub-unit cost into consideration. The conclusions of this study are as follows.

Table 10. Marginal Variations of Cost and Quality

No.	$\sum_{f=A}^{m}\sum_{l=1}^{n_f}\sum_{k=1}^{v} c_{fl}d_{flk}$	Marginal Cost Decreasing	Q_{BG}	Marginal Quality Loss
1	NT$20,700	-	0.605	-
2	NT$17,490	**NT$3,210**	0.603	**0.0027**
3	NT$16,990	NT$500	0.593	0.0096
4	NT$14,940	NT$2,050	0.579	0.0138
5	NT$12,940	NT$2,000	0.533	0.0462

In the first stage, three S/N ratios of multi-quality characteristics of DVRS have been determined in traditional Taguchi Method. According to Table 4, the optimal setting selected by η_1 and η_2 is Exp. No. 3, that is, $A_1B_1C_3D_3E_3F_3$, and the optimal setting selected by η_3 is Exp. No. 12, that is, $A_2B_1C_3D_2E_2F_1$.

After examining the relativity of these three characteristics, η_1 and η_2 are correlated. Therefore, GF-GRG has been employed to integrate these three non-additive characteristics and to be the integrated quality level of DVRS in the second stage. According to Table 5, the optimal setting selected by Γ''_{oi} is Exp. No. 3, that is, $A_1B_1C_3D_3E_3F_3$ .Furthermore, the weights of characteristics can be determined and are $w_k = (w_1, w_2, w_3) =$ (0.3756, 0.3747, 0.2497), where k = 1, 2, 3.

In the third stage, the integrated quality level, weight of sub-unit, assigned weight of characteristic and sub-unit cost has been taken into consideration to construct a quality and cost model. It can more accurately determine the optimal setting of multi-quality characteristics or more significantly considering weights of characteristic under different budgetary constrains for determining the optimal setting of multi-quality characteristics. The optimal setting selected by quality and cost model is $A_{21}B_{12}C_{33}D_{23}E_{31}F_{13}$ and it is not included by L_{18} orthogonal array of this study.

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APPENDIX 1.

Table A.1. Experimental Equipments of DVRS

Elements (Product No.)		Description
CCD Camera (D.S.P. Color High Resolution Camera, PIH-7817)		A CCD camera uses a small, rectangular piece of silicon rather than a piece of film to receive incoming light. Bundled with the capture control and video conferencing software, it is a perfect choice of high quality, low cost video conferencing solutions. This is a special piece of silicon called a charge-coupled device (CCD).
Video Capture Board (SA-404)		The video capture board will work on any PCs with Zoomed Video capability. It captures live video and audio with AVI file format to be stored in the hard drive of PC.
BNC Cable		BNC cable is used to connect two or more of your computers to share files and printers, etc..
Multiplexer (TS-PD48)		Multiplexer combines multiple inputs into an aggregate signal be transported via a single transmission channel. TS-PD48 can form 1 in by 8 out to 4 in by 4 group 2 out.
Video Recorder Machine-Sever		A video recorder machine can detect image or video signal and record them into video directory of declared hard drive. Besides, it is necessary to bundle with a Lan card to connect to internet and transmit video signal to be client computer received.
Computer -Client		Client computer can be any computer connected to internet and can received real-time video signal or files from sever computers.

APPENDIX 2.

Table A.2. The Average Times of Transmitted and Received Signals of Static Video Capture and Dynamic Video Record Falls into Four Categories

Exp. No.	n_{00}	n_{01}	n_{10}	n_{11}
0	43,199	1	1	43,199
1	43,195	5	21	43,179
2	43,197	3	13	43,187
3	43,199	1	9	43,191
4	43,196	4	15	43,185
5	43,197	3	13	43,187
6	43,197	3	14	43,186
7	43,196	4	17	43,183
8	43,197	3	15	43,185
9	43,197	3	16	43,184
10	43,198	2	14	43,186
11	43,197	3	13	43,187
12	43,196	4	15	43,185
13	43,198	2	17	43,183
14	43,198	2	12	43,188
15	43,197	3	14	43,186
16	43,196	4	17	43,183
17	43,197	3	16	43,184
18	43,196	4	19	43,181

APPENDIX 3.

Table A.3. The Values of p, q and $\overline{p}$, and η_1

x_i	p	q	$\overline{p}$	η_1
0	0.000023	0.000023	0.000023	40.333936
1	0.000116	0.000486	0.000116	30.224923
2	0.000069	0.000301	0.000069	32.376854
3	0.000023	0.000208	0.000023	35.561919
4	0.000093	0.000347	0.000093	31.440968
5	0.000069	0.000301	0.000069	32.376854
6	0.000069	0.000324	0.000069	32.215833
7	0.000093	0.000394	0.000093	31.168979
8	0.000069	0.000347	0.000069	32.065921
9	0.000069	0.000370	0.000069	31.925683
10	0.000046	0.000324	0.000046	33.096579
11	0.000069	0.000301	0.000069	32.376854
12	0.000093	0.000347	0.000093	31.440968
13	0.000046	0.000394	0.000046	32.674715
14	0.000046	0.000278	0.000046	33.431492
15	0.000069	0.000324	0.000069	32.215833
16	0.000093	0.000394	0.000093	31.168979
17	0.000069	0.000370	0.000069	31.925683
18	0.000093	0.000440	0.000093	30.927260

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