A Modified Target Costing Technique to Improve Product Quality from Cost Consideration

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Abstract

The target costing technique, mathematically discussed by Sauers, only uses the C_p index along with Taguchi loss function and $\overline{X}-R$ control charts to set up goal control limits. The new specification limits derived from Taguchi loss function is linked through the C_p value to $\overline{X}-R$ control charts to obtain goal control limits. This study further considers the reflected normal loss function as well as the C_{pk} index along with its lower confidence interval in forming goal control limits. With the use of lower confidence interval to replace the point estimator of the C_{pk} index and reflected normal loss function proposed by Spiring to measure the loss to society, this modified and improved target costing technique would become more robust and applicable in practice. Finally, an example is provided to illustrate how this modified and improved target costing technique works.

Key Words: Target costing technique, Loss function, Process capability index, Confidence interval, Control chart, Goal control limit

1. Introduction

Dekker and Smidt (2003) have reported that the target costing technique, originally developed by the Japanese companies, has been widely used in a competitive and unpredictable environment when cost reduction is the main objective for a company. Ewert and Ernst (1999) have characterized the essence of the target costing technique by three elements: (1) a market orientation, as the selling price is the starting point to determine the target cost; (2) a coordination function, as the target cost coordinates the activities of product designers; and (3) strategic learning in interaction with other factors, which influence the long-term cost structure. The major philosophy of the target costing technique is the market-driven costing, where an estimation of the attainable selling price and the required profit margin are used to determine the allowable cost for a new product (Cooper and Slagmulder, 1997; Dekker and Smidt, 2003; Wu, 2004c).

Sauers (1999~2000), on the other hand, has discussed the target costing technique mathematically. From a mathematical viewpoint, the philosophy is to start with the anticipated acceptable market price and then the companies subtract the desired profit margin to obtain a target manufacturing cost. Later, design and manufacturing engineers are responsible to bring the product into being at this cost. As a result, price can be driven down to the process level, and continuous improvement can be acted by listening to the price concern of the marketplace. Specifically, the specification limits or implied tolerance, derived from the "nominal-is-best" Taguchi loss function, can be linked through a predetermined C_p value along with the traditional $\overline{X}-R$ control charts to form goal control limits, which form the foundation for directed continuous improvement efforts by considering the price from the marketplace. In addition, the target costing technique has been expanded by considering the normality-based C_{pk} index to set up goal control limits as well as by applying the lower bound of the C_p index to reduce sampling error (Wu, 2003a, 2003b, 2004a, 2004b).

In practice, the C_p and C_{pk} indices are estimated by $\hat{C}_p$ and $\hat{C}_{pk}$, respectively, from the sample data. Unfortunately, the point estimators of the C_p and C_{pk} indices, $\hat{C}_p$ and $\hat{C}_{pk}$, could mislead the assessment of process performance due to the sampling error (Porter and Oakland, 1991). To overcome the sampling error, using confidence intervals might be the simplest and have the advantage without making prior judgments about the process capability (Porter and Oakland, 1991). It is worth to note that using $\overline{R}/d_2$ (based on the range) to estimate $\hat{\sigma}$ is more appropriate if $\overline{X}-R$ control charts are applied to ensure the process is in statistical control (Smith, 1998).

This study will focus on the use of the "nominal-is-best" Taguchi loss function as well as the reflected normal loss function along with the lower confidence interval of the $\hat{C}_{pk}$ index based on $\overline{X}-R$ charts. Section 2 reviews both Taguchi loss function and reflected normal loss function. Section 3 summarizes $\overline{X}-R$ charts, the C_{pk} index, and the $\hat{C}_{pk}$ index estimated from the sample data along with its lower confidence interval. In Section 4, the mathematical expression of the proposed and modified target costing technique is discussed. An illustrative example and conclusions are provided in Sections 5 and 6, respectively.

2. Taguchi and Reflected Normal Loss Functions

Quality defined by Taguchi is measured in terms of the loss imparted to the society from the time a product is shipped (Gitlow, Oppenheim, Oppenheim, 1995). The losses include warranty costs, dissatisfied customers, and other problems due to performance failures (Garvin, 1988). The basic underlying principle is that the smaller the loss caused to society by a product, the better the product's quality. Typically, the loss to society can be measured by three types of loss functions, i.e., smaller-is-better, nominal-is-best, and larger-is-better loss functions. The formula of the "nominal-is-best" Taguchi loss function is as follows:

$$L(y) = k(y-T)^2, \quad (1)$$

where $L(y)$ is the average or expected loss over all customers, k is the quality loss coefficient, and T is the target value. Consider a component with product specification limits $T \pm \Delta$, and the specification limits are 2Δ. Let A_0 be the expected or long run average costs occurred for products made at the specification limit Δ, then k can be determined as

$$k = \frac{A_0}{\Delta^2}. \quad (2)$$

Equation (3) is presented as follows by integrating both Equations (1) and (2), and Figure 1 shows the relationship.

$$L(y) = \frac{A_0}{\Delta^2}(y-T)^2. \quad (3)$$

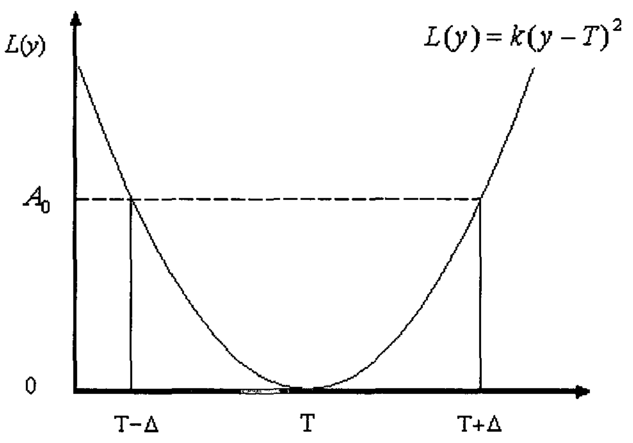

Figure 1. The Nominal-is-Best Taguchi Loss Function

The loss to society is minimized when the products are produced at the target value. On the other hand, the loss increases when the product is away from the target value. In contrast to Taguchi loss function with infinite maximum loss, Spiring (1993) has developed the reflected normal loss function to provide a quantifiable maximum loss and magnitude of losses associated with extreme deviations from the target value. The general format and figure of this reflected normal loss function are depicted in Equation (4) and Figure 2:

$$L(y) = K\left\{1 - \exp\left(-\frac{(y-T)^2}{2\gamma^2}\right)\right\} = K\left\{1 - \exp\left(-\frac{8(y-T)^2}{\Delta^2}\right)\right\}, \quad (4)$$

where y represents the quality measurement, K is the maximum-loss parameter, T is the target value, and γ is a shape parameter, which is defined as $\Delta/4$, where Δ is the distance from the target value to the point where K first occurs. The target value, shape, and maximum-loss parameters allow customization of the loss function to meet practitioners' requirements.

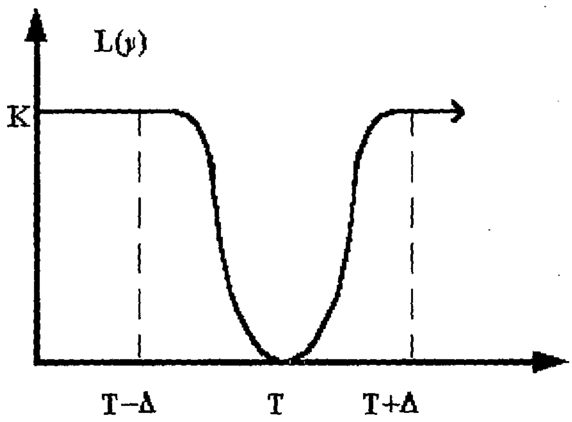

Figure 2. The Reflected Normal Loss Function

The reflected normal loss function is asymptotic to the maximum loss incurred only at $\pm\infty$. The term of $\gamma = \Delta/4$ ensures that the loss function at $T \pm \Delta$ will be $0.9997K \approx K$. The expected loss associated with the reflected normal loss function defined by Spiring (1993) is

$$\mathrm{E}(L(y)) = K - K\int \exp\left(-\frac{(y-T)^2}{2\gamma^2}\right) f(y)\,dy, \quad (5)$$

where $f(y)$ is the associated probability density function. If the quality characteristic follows a normal distribution with a mean of μ and a standard deviation of σ, the expected loss becomes:

$$\begin{aligned} EL(y) &= K - K\int \frac{1}{\sqrt{2\pi}\,\sigma}\exp\left\{-\frac{1}{2}\left(\frac{(y-T)^2}{\gamma^2}+\frac{(y-\mu)^2}{\sigma^2}\right)\right\}dy \\ &= K\left\{1-\frac{\gamma}{\sqrt{\sigma^2+\gamma^2}}\exp\left(-\frac{(\mu-T)^2}{2(\sigma^2+\gamma^2)}\right)\right\}, \end{aligned} \quad (6)$$

where the minimum is incurred at μ = T. For the applications of the reflected normal loss function in practice, please refer to Spiring and Yeung (1998).

3. $\overline{X}$-R Charts and the C_p and C_{pk} Indices

Vardeman and Jobe (1999) stated that control charts are the devices for the routine and organized plotting of process performance measures, and the major purpose is to identify process changes such that the process can be either intervened or remedied or to identify the source of an unexpected process improvement. Specifically, control charts, such as $\overline{X}-R$ charts, can be served (1) to ensure the process is in statistical control, (2) to provide alarms when the process shows out-of-control signals, and (3) to provide prerequisite information for process capability analysis (Amsden, Butler, and Amsden, 1989; Sauers, 1999-2000). The formulas of $\overline{X}-R$ control charts are defined as follows:

$$\text{UCL(R)} = D_4\overline{R}, \quad (7)$$

$$\text{CL(R)} = \overline{R}, \quad (8)$$

$$\text{LCL(R)} = D_3\overline{R}, \quad (9)$$

$$\text{UCL}(\overline{X}) = \overline{\overline{X}}-3\frac{\hat{\sigma}}{\sqrt{n}} = \overline{\overline{X}}-3\frac{\overline{R}}{d_2\sqrt{n}} = \overline{\overline{X}}+A_2\overline{R}, \quad (10)$$

$$\text{CL}(\overline{X}) = \overline{\overline{X}}, \quad (11)$$

and

$$\text{LCL}(\overline{X}) = \overline{\overline{X}}-3\frac{\hat{\sigma}}{\sqrt{n}} = \overline{\overline{X}}-3\frac{\overline{R}}{d_2\sqrt{n}} = \overline{\overline{X}}-A_2\overline{R}, \quad (12)$$

where UCL, CL, and LCL stand for upper control limit, center line, and lower control limit, respectively. $\hat{\sigma}=\overline{R}/d_2$, n is the sample size of the subgroup, and the parameters of D_4, D_3, A_2, and d_2 can be found in the text of Vardeman and Jobe (1999).

When the process is in control, process capability analysis can be conducted to examine the capability of a process. The well-known C_p and C_{pk} indices are the tools to evaluate the capability of a process when the process data are normally distributed. The formulas of the C_p and C_{pk} indices are

$$C_p=\frac{USL-LSL}{6\sigma}=\frac{\Delta}{3\sigma} \tag{13}$$

and

$$C_{pk}=\min(C_{pu},C_{pl})=\min\left(\frac{USL-\mu}{3\sigma},\frac{\mu-LSL}{3\sigma}\right), \tag{14}$$

where USL and LSL are the upper specification limit and lower specification limit, respectively, and 2Δ is the distance between USL and LSL. In addition, μ is the mean, the sum of the numerical values of the measurement divided by the number of items examined, and σ is the standard deviation, the square root of the average squared deviates from the mean.

Since μ and σ are typically unknown, estimations from the sample data are required. If $\overline{X}-R$ charts are implemented prior to process capability analysis, the estimations of the C_p and C_{pk}, $\hat{C}_p$ and $\hat{C}_{pk}$, are

$$\hat{C}_p=\frac{USL-LSL}{6\hat{\sigma}}=\frac{\Delta}{3\hat{\sigma}} \tag{15}$$

and

$$\hat{C}_{pk}=\min(\hat{C}_{pu},\hat{C}_{pl}), \tag{16}$$

where

$$\hat{C}_{pu}=\frac{USL-\overline{\overline{X}}}{3\hat{\sigma}}=\frac{USL-\overline{\overline{X}}}{3\overline{R}/d_2}=\frac{(T+\Delta)-\overline{\overline{X}}}{3\hat{\sigma}} \tag{17}$$

and

$$\hat{C}_{pl}=\frac{\overline{\overline{X}}-LSL}{3\hat{\sigma}}=\frac{\overline{\overline{X}}-LSL}{3\overline{R}/d_2}=\frac{\overline{\overline{X}}-(T-\Delta)}{3\hat{\sigma}}, \tag{18}$$

where $\overline{\overline{X}}$ can be computed directly from $\overline{X}$ chart.

The point estimators of process capability indices, such as $\hat{C}_{pk}$, could mislead the assessment of process performance due to the sampling error (Porter and Oakland, 1991). In order to reduce the sampling error, the simplest approach is to use confidence intervals, especially the lower confidence intervals. If $\overline{X}-R$ charts are applied prior to process capability analysis, $\hat{\sigma}$ can be more appropriately replaced by $\overline{R}/d_2$ (Smith, 1998). The study of Li, Owen, and Borrego (1990) provides both mathematical method and numerical figures to construct the lower confidence interval of the $\hat{C}_{pk}$ index based on the range. The procedure is summarized as follows: Let $LSL=\overline{\overline{X}}-k_1(\overline{R}/d_2)=\overline{\overline{X}}-k_1\hat{\sigma}$ and $USL=\overline{\overline{X}}+k_2(\overline{R}/d_2)=\overline{\overline{X}}+k_2\hat{\sigma}$. From Equations (17) and (18), $\hat{C}_{pu}$ and $\hat{C}_{pl}$ becomes

$$\hat{C}_{pu}=\frac{\overline{\overline{X}}+k_2(\overline{R}/d_2)-\overline{\overline{X}}}{3\overline{R}/d_2}=\frac{k_2}{3} \tag{19}$$

and

$$\hat{C}_{pl}=\frac{\overline{\overline{X}}-(\overline{\overline{X}}k_1(\overline{R}/d_2))}{3\overline{R}/d_2}=\frac{k_1}{3}\ . \tag{20}$$

A $100\gamma\%$ lower confidence limit, c_u, for C_{pu} satisfies $P_r=(C_{pu}\geq c_u)=\gamma$. The formula is as follows:

$$P_r(\frac{USL-\mu}{3\sigma}\geq c_u)=P_r(\frac{\overline{\overline{X}}+k_2(\overline{R}/d_2)-\overline{\overline{X}}-\mu}{3\sigma}\geq c_u)=P_r(\frac{\overline{\overline{X}}-\mu+k_2(\overline{R}/d_2)-\overline{\overline{X}}}{\sigma/\sqrt{n}}\geq 3\sqrt{n}\,c_u)$$
$$=P_r(Z+\frac{k_2\sqrt{n}R}{d_2\sigma}\geq 3\sqrt{n}\,c_u) \tag{21}$$

A $100\gamma\%$ lower confidence limit, c_l, for C_{pl} satisfies $P_r=(C_{pl}\geq c_l)=\gamma$. The formula is

$$P_r(\frac{\mu-LSL}{3\sigma}\geq c_l)=P_r(\frac{\mu-(\overline{\overline{X}}-k_1(\overline{R}/d_2))}{3\sigma}\geq c_l)=P_r(\frac{\mu-\overline{\overline{X}}+k_1(\overline{R}/d_2)}{\sigma/\sqrt{n}}\geq 3\sqrt{n}\,c_l)$$
$$=P_r(-Z+\frac{k_1\sqrt{n}R}{d_2\sigma}\geq 3\sqrt{n}\,c_l). \tag{22}$$

When both specification limits are used, a $100\gamma\%$ lower confidence limit, c_k, for C_{pk} satisfies $P_r=(C_{pk}\geq c_k)=\gamma$. Since we want the minimum of C_{pu} and C_{pl} to be greater than

c_k, we must have $P_{\gamma} = (C_{pu} \geq c_k$ and $C_{pl} \geq c_k)$.

From a practical viewpoint, if we want to ensure the product quality is at least as good as the c_k value (the designated C_{pk} value), the $\hat{C}_{pk}$ value with the sampling error is to be greater than the c_k value. If a 95% lower confidence limit is used, Table 1, summarized from Table 3 of Li, Owen, and Borrego (1990), can be applied to determine the minimum $\hat{C}_{pk}$ value if 95% of the time $C_{pk} \geq c_k$, where c_k is the chosen or designated value. For example, if the $\hat{C}_{pk}$ value from the sample data is 1.55 with $n = 5$ and $m = 20$ with γ = 0.95, the product quality is not worse than the c_k value (C_{pk}) of 1.16. The calculations are described in Table 2. On the other hand, if the C_{pk} value (c_k value) is chosen to be 1.50, then the $\hat{C}_{pk}$ value estimated from the sample data with $n = 5$ is to be 1.924.

Table 1. The c_k and $\hat{C}_{pk}$ Values with the Subgroup of Size 20 (m = 20)

c_k	$\hat{C}_{pk}$		
	n = 4	n = 5	n = 6
1.00	1.418	1.365	1.329
1.10	1.532	1.476	1.438
1.20	1.645	1.587	1.548
1.30	1.759	1.699	1.659
1.40	1.874	1.811	1.769
1.50	1.989	1.924	1.880

Table 2. The Computation of the c_k Value

c_k	$\hat{C}_{pk}$
1.10	1.476
1.16	1.55
1.20	1.587

4. A Modified and Improved Target Costing Technique

If a quality improvement program is implemented and the average loss of $L(y)$ is reduced to be $hL(y) = L'(y) = k\Delta'^2$, where $0 < h < 1$, then Δ' becomes

$$\Delta' = \sqrt{\frac{L'(y)}{k}} = \Delta\sqrt{\frac{L'(y)}{A_0}} = \Delta\sqrt{\frac{hL(y)}{A_0}}, \tag{23}$$

where $k = A_0/\Delta^2$. If the product quality is to be ensured at least as good as the c_k value, the $\hat{C}_{pk}$ value with the sampling error should be greater than the c_k value. If a 95% lower confidence limit is used, Table 1 or Equations (21) and (22) can be applied to determine the minimum $\hat{C}_{pk}$ value if 95% of the time $C_{pk} \geq c_k$. Therefore, the product quality can be evaluated by the $\hat{C}_{pk}$ value and be transformed as the C_{pk} or c_k value based upon Table 1 or Equations (21) and (22).

If the 95% lower confidence interval is considered, the C_{pk} value is, say, to be c_1. If the management decides that the product quality measured by the C_{pk} index is not lower than c_2, $c_2 \geq c_1$, the new $\hat{C}_{pk}$ value, denoted as $\hat{C}'_{pk}$, can be determined by Table 1 or Equations (21) and (22) and the formula becomes

$$\hat{C}'_{pk} = \min\left(\frac{T+\Delta' - \overline{\overline{X}}}{3\hat{\sigma}'}, \frac{\overline{\overline{X}} - T + \Delta'}{3\hat{\sigma}'}\right), \tag{24}$$

where

$$\hat{\sigma}' = \min\left(\frac{T+\Delta' - \overline{\overline{X}}}{3\hat{C}'_{pk}}, \frac{\overline{\overline{X}} - T + \Delta'}{3\hat{C}'_{pk}}\right)$$

$$= \min\left(\frac{T - \overline{\overline{X}} + \Delta\sqrt{\frac{hL(y)}{A_0}}}{3\hat{C}'_{pk}}, \frac{\overline{\overline{X}} - T + \Delta\sqrt{\frac{hL(y)}{A_0}}}{3\hat{C}'_{pk}}\right) \geq 0. \tag{25}$$

Suppose a quality improvement program is implemented by considering the reflected normal loss function, the general loss is expected to be reduced to $L_1(y) = hK$, where $0 < h < 1$. If the loss function $L_1(y)$ in Equation (4) is defined in the interval $[T - \Delta', T + \Delta']$, at the point y at which $8(y-T)^2 = \Delta'$ we have

$$L_1(y) = hK = K\left\{1 - \exp\left(-\frac{8\Delta'}{\Delta^2}\right)\right\} \tag{26}$$

and

$$\Delta' = \sqrt{\frac{-\Delta^2}{8}\ln(1-h)} = \Delta\sqrt{-\frac{\ln(1-h)}{8}}. \tag{27}$$

If the 95% lower confidence interval is considered, the C_{pk} value is to be c_1. If the management decides that the product quality measured by the C_{pk} index is not lower than c_2, $c_2 \geq c_1$, the new $\hat{C}_{pk}$ value, denoted as $\hat{C}'_{pk}$, is expressed in Equation (24). The $\hat{\sigma}'$ value can be described in terms of $\hat{C}'_{pk}$, Δ', Δ, T, and $\overline{\overline{X}}$:

$$\hat{\sigma}' = \min\left(\frac{T+\Delta'-\overline{\overline{X}}}{3\hat{C}'_{pk}}, \frac{\overline{\overline{X}}-T+\Delta'}{3\hat{C}'_{pk}}\right)$$

$$= \min\left(\frac{T-\overline{\overline{X}}+\Delta\sqrt{-\frac{\ln(1-h)}{8}}}{3\hat{C}'_{pk}}, \frac{\overline{\overline{X}}-T+\Delta\sqrt{-\frac{\ln(1-h)}{8}}}{3\hat{C}'_{pk}}\right) \geq 0. \tag{28}$$

When $\hat{\sigma}'$ is known from either Equation (25) or Equation (28), the goal control limits for $\overline{X}-R$ control charts are formed as follows:

$$\mathrm{UCL}(\overline{X}) = \overline{\overline{X}}+3\frac{\hat{\sigma}'}{\sqrt{n}} = \begin{cases} \overline{\overline{X}}+3\frac{1}{\sqrt{n}}\frac{T+\Delta'-\overline{\overline{X}}}{3\hat{C}'_{pk}} = \overline{\overline{X}}+\frac{T+\Delta'-\overline{\overline{X}}}{\hat{C}'_{pk}\sqrt{n}} (\text{if } \hat{C}_{pu} \leq \hat{C}_{pl}) \\ \overline{\overline{X}}+3\frac{1}{\sqrt{n}}\frac{\overline{\overline{X}}-T+\Delta'}{3\hat{C}'_{pk}} = \overline{\overline{X}}+\frac{\overline{\overline{X}}-T+\Delta'}{\hat{C}'_{pk}\sqrt{n}} (\text{if } \hat{C}_{pu} \geq \hat{C}_{pl}) \end{cases} \tag{29}$$

$$\mathrm{CL}(\overline{X}) = \overline{\overline{X}}, \tag{30}$$

$$\mathrm{LCL}(\overline{X}) = \overline{\overline{X}}+3\frac{\hat{\sigma}'}{\sqrt{n}} = \begin{cases} \overline{\overline{X}}-3\frac{1}{\sqrt{n}}\frac{T+\Delta'-\overline{\overline{X}}}{3\hat{C}'_{pk}} = \overline{\overline{X}}-\frac{T+\Delta'-\overline{\overline{X}}}{\hat{C}'_{pk}\sqrt{n}} (\text{if } \hat{C}_{pu} \leq \hat{C}_{pl}) \\ \overline{\overline{X}}-3\frac{1}{\sqrt{n}}\frac{\overline{\overline{X}}-T+\Delta'}{3\hat{C}'_{pk}} = \overline{\overline{X}}-\frac{\overline{\overline{X}}-T+\Delta'}{\hat{C}'_{pk}\sqrt{n}} (\text{if } \hat{C}_{pu} \geq \hat{C}_{pl}) \end{cases} \tag{31}$$

$$\mathrm{UCL}(R) = D_4\overline{R}' = D_4\, d_2\hat{\sigma}' = \begin{cases} D_4 d_2\frac{T+\Delta'-\overline{\overline{X}}}{3\hat{C}'_{pk}} (\text{if } \hat{C}_{pu} \leq \hat{C}_{pl}) \\ D_4 d_2\frac{\overline{\overline{X}}-T+\Delta'}{3\hat{C}'_{pk}} (\text{if } \hat{C}_{pu} \geq \hat{C}_{pl}) \end{cases} \tag{32}$$

$$\mathrm{CL}(R) = \overline{R}' = d_2\hat{\sigma}' = \begin{cases} d_2\frac{T+\Delta'-\overline{\overline{X}}}{3\hat{C}'_{pk}} (\text{if } \hat{C}_{pu} \leq \hat{C}_{pl}) \\ d_2\frac{\overline{\overline{X}}-T+\Delta'}{3\hat{C}'_{pk}} (\text{if } \hat{C}_{pu} \geq \hat{C}_{pl}) \end{cases} \tag{33}$$

and

$$\text{LCL}(R) = D_3\overline{R}' = D_3 d_2\hat{\sigma}' = \begin{cases} D_3 d_2 \dfrac{T+\Delta' - \overline{\overline{X}}}{3\hat{C}'_{pk}} (\text{if } \hat{C}_{pu} \le \hat{C}_{pl}) \\ D_3 d_2 \dfrac{\overline{\overline{X}} - T+\Delta'}{3\hat{C}'_{pk}} (\text{if } \hat{C}_{pu} \ge \hat{C}_{pl}) \end{cases} \quad (34)$$

5. An Example

To demonstrate the modified and improved target costing technique, the data from Wu (2003a) are used and shown in Table 3. The values of *USL*, *T*, and *LSL* are 50, 37, and 24, respectively. Assume the data are in statistical control and normally distributed. The UCL, CL, and LCL of $\overline{X}$ chart using Equations (10)-(12) are 35.98, 33.30, and 30.62, respectively, while 9.83, 4.65, and 0 are the values for UCL, CL, and LCL of R chart using Equations (7)-(9), where $\hat{\sigma}=\overline{R}/d_2= 1.999$, $d_2 = 2.326$, $A_2=0.577$, $D_4=2.115$, and $D_3=0$ for $n = 5$. The $\hat{C}_p$ and $\hat{C}_{pk}$ values using Equations (15) and (16) are 2.17 and 1.55. Since the $\hat{C}_{pk}$ value equals 1.55, the actual product quality using the 95% lower confidence interval is not going to be lower than 1.16, computed and shown in Table 2 in Section 3.

Suppose the target costing technique is applied, the expected or long run average cost from the product (A_0) is \$500, and Δ is 13. The quality loss coefficient k is A_0/Δ^2 = $500/13^2$ = 2.96. If the company decides to reduce the cost by 10% and C_{pk} is to be improved and set to 1.30 (the original C_{pk} is only 1.16), the new specification limit Δ' can be solved by $L'(y)$ = 0.9(500) = 450 = $2.96\Delta'^2$, where Δ' equals 12.33. When C_{pk} is set to 1.30, the new $\hat{C}_{pk}$ value using Table 1 should not be lower than 1.699. Therefore, the $\hat{\sigma}'$ value can be calculated by Equation (25):

$$\hat{\sigma}' = \min\left(\frac{37+12.33-33.30}{3(1.699)}, \frac{33.30-37+12.33}{3(1.699)}\right) = \min(3.145,\ 1.270) = 1.270$$

The goal control limits for $\overline{X}-R$ charts using Equations (29)-(34) are

$$\text{UCL}(\overline{X}) = 33.30 + 3\frac{1.270}{\sqrt{5}} = 35.004,$$
$$\text{CL}(\overline{X}) = 33.30,$$
$$\text{LCL}(\overline{X}) = 33.30 - 3\frac{1.270}{\sqrt{5}} = 31.596,$$

$UCL(R) = (2.115)(2.326)(1.270) = 6.25,$

$CL(R) = (2.326)(1.270) = 2.95,$

and

$LCL(R) = (0)(2.326)(1.270) = 0.$

Table 3. The Data Set from Wu (2003a)

Subgroup	Sample Size for Each Subgroup (n = 5)					Average ($\overline{X}$)	Range (R)
1	36	35	34	33	32	34.0	4
2	31	31	34	32	30	31.6	4
3	30	30	32	30	32	30.8	2
4	32	33	33	32	35	33.0	3
5	32	34	37	37	35	35.0	5
6	32	32	31	33	33	32.2	2
7	33	33	36	32	31	33.0	5
8	29	33	34	33	34	32.6	5
9	36	36	35	31	31	33.8	5
10	32	32	32	34	34	32.8	2
11	34	38	35	34	38	35.8	4
12	32	34	36	35	36	34.6	4
13	36	37	34	30	33	34.0	7
14	36	35	37	34	33	35.0	4
15	30	37	33	34	35	33.8	7
16	28	31	33	33	33	31.6	5
17	33	30	34	33	35	33.0	5
18	30	31	33	31	35	32.0	5
19	35	36	29	27	32	31.8	9
20	33	35	35	39	36	35.6	6
Total						666.0	93
Average						33.30	4.65

If the modified and improved target costing technique is applied by reducing the 10% cost and setting the C_{pk} value at 1.30, i.e., $\widehat{C}_{pk} = 1.699$ with the sampling error, the variation should be reduced. As a result, tighter goal control limits can be expected compared with the traditional $\overline{X}-R$ control limits, summarized in Table 4. When goal control limits are applied to $\overline{X}-R$ charts directly, all of the average ($\overline{X}$) and range (R) values should be within the goal control limits. Obviously, the average values of subgroups 11 and 20 are above UCL($\overline{X}$), and the average value of subgroup 3 is below LCL($\overline{X}$), whereas the range values of subgroups 13, 15, and 19 are above UCL(R). Therefore, a corrective action should be conducted.

Table 4. The Comparison between Traditional and Goal Control Limits

	Traditional Control Limits	**Goal Control Limits**
UCL($\overline{X}$)	35.98	35.00
CL($\overline{X}$)	33.30	33.30
LCL($\overline{X}$)	30.62	31.60
UCL(R)	9.83	6.25
CL(R)	4.65	2.95
LCL(R)	0	0

In this example, the target costing technique is applied to both reduce the cost and improve the process performance at the same time. It can also be used by either reducing the cost or improving the product quality. On the other hand, the reflected normal loss function can be applied by the similar procedure discussed above. As long as the $\hat{\sigma}'$ value can be calculated by Equation (28), the goal control limits, thus, can be established.

6. Conclusions

This study provides a modified and improved target costing technique by considering the lower confidence interval of the $\hat{C}_{pk}$ index which reduces the sampling error. The new specification limits derived from either Taguchi loss function or reflected normal loss function is linked through the lower confidence interval of the $\hat{C}_{pk}$ value to $\overline{X}-R$ charts to obtain goal control limits. The philosophy of the target costing technique is to relentlessly improve product quality and reduce costs such that a more robust product would be more competitive in the marketplace. Apparently, with the consideration of the lower confidence interval of the $\hat{C}_{pk}$ value along with Taguchi and reflected normal loss functions, this technique can be applied more effectively in practice.

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