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Suppliers capability and price analysis chart

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Abstract

To remain competitive in customer-oriented economics, the major parties in the supply chain should be integrated and managed effectively to respond to customer needs. Thus, the efficiency of the entire supply chain is a main concern, and is determined by the members of that supply chain. Partner selection thus becomes one of the key steps in supply chain construction. Given buyer–supplier information asymmetry, obtaining complete information from suppliers is difficult, since some supplier attributes cannot be definitely and quantitatively measured. This study establishes a suppliers capability and price analysis chart (SCPAC) focused on the case where the specification limits are symmetric about the target for evaluating supplier performance which applies the process incapability index C_{pp} introduced by Greenwich and Jahr-Schaffrath (International Journal of Quality & Reliability Management 12 (1995) 58) to measure supplier quality performance and the price index I_p is proposed here to display the difference between budget and component price. Practitioners can instantly and visually obtain information based on the locations of suppliers and price indices on SCPAC. SCPAC also provides clear directions for quality improvement, such as process accuracy and precision. SCPAC thus is an effective and efficient method for evaluating suppliers, which can simplify supplier evaluation, facilitate their effective visual selection, and provide insights into the process situation of suppliers who can become technological innovation partners.
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Keywords: Process incapability index; Supplier selection; Price index; Suppliers capability and price analysis chart

1. Introduction

To remain competitive in customer-oriented economics, the major parties in the supply chain, including suppliers, manufacturers, contract manufacturers, distributors and retailers, must synchronously participate in designing, manufacturing, distributing, marketing and even standing. All of these parties thus should be integrated and managed effectively to respond to customer needs and contribute the profit to the whole supply chain. Members of the supply chain thus are the

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critical determinant of supply chain behavior. Partner selection thus becomes one of the key steps in constructing the supply chain. Thomas and Janet (1996) investigated the importance of supplier selection, and noted that: 'it commits resources while simultaneously impacting such activities as inventory management, production planning and control, cash flow requirements, and product quality.' Moreover, Burton (1988) and Carr and Pearson (1999) found that purchased materials and services represent up to 80% of the total product costs of high-technology firms. Additionally, Weber et al. (1991) found that automotive manufacturers spend over 50% of their revenues on components and parts purchased from outside vendors. Clearly, careful supplier evaluation and selection is essential. Good suppliers allow enterprises to achieve good manufacturing performance and make the greatest benefits for practitioners.

Supplier selection is complicated by the need to consider various criteria. Dickson (1966) examined the importance of supplier evaluation criteria and presented 23 supplier attributes that managers consider in such an evaluation, including quality, delivery, price, performance history and others, following a survey of industrial purchasing managers. Additionally, Choi and Hartley (1996) presented 26 supplier selection attributes from a survey of US automotive companies. Nakato and Michael (1998) presented 14 supplier selection attributes from a survey of Japan automotive and electronic companies. Moreover, Lamberson et al. (1976) and Monzcka and Trecha (1988) proposed linear weighting techniques for assessing supplier performance. These methods frequently considered many supplier performance attributes simultaneously, and weighted those attributes based on the opinions of purchasing managers or staff. The experience and knowledge of purchasing staff thus significantly compromises the reliability of supplier evaluation using the above methods. Such methods thus are not objective and may lead to arbitrary decision-making, due to human psychological bias. Additionally, simultaneously considering all supplier attributes is complex and difficult and requires spending considerable time and money to obtain relevant correct information, especially in buyer–supplier informational asymmetry, as well as some attributes cannot be quantitatively and definitely measured. This study applies the process incapability index C_{pp} introduced by Greenwich and Jahr–Schaffrath (1995) to develop a graphic evaluation model for measuring supplier quality performance, and moreover provides the price index I_p to indicate the difference between budget and price. Furthermore, this study combines process incapability index C_{pp} and price index I_p to create a suppliers capability and price analysis chart (SCPAC). This chart proposed here focuses on the quality characteristic with nominal-the-best specifications, that is, the specifications limits are symmetric about the target. Practically, this is the common situation. Practitioners can consider the two factors of quality and price simultaneously to assess suppliers, and moreover can instantly and visually obtain information through the locations of suppliers and price indices on SCPAC.

Good quality is essential to corporations in maintaining competitiveness and customer loyalty. In supply chain management, improving product quality is no longer merely the responsibility of the manufacturer, but is also the responsibility of the suppliers who provide the parts and components. Supplier manufacturing capability determines finished product quality and customer satisfaction. Supplier manufacturing capabilities thus are the key consideration in supplier selection. Dickson (1966) identified price, quality and delivery performance as the three most important criteria in supplier evaluation. Moreover, Weber et al. (1991) reviewed 74 articles from 1967 to 1990 based on the 23 vendor selection criteria presented by Dickson (1966) and concluded that quality was the most important factor, followed by delivery performance and price on supplier evaluation, with quality being of "extreme importance" and delivery being of "considerable importance". In the Just-In-Time (JIT) manufacturing system, quality and delivery are still the two most important criteria for supplier selection. Pearson and Ellram (1995) examined supplier selection and evaluation criteria in small and large electronics firms and concluded that quality was the most important criterion in supplier selection and evaluation for both small and large electronic firms. Furthermore, Thomas and Janet (1996) surveyed purchasing managers of US automotive companies and concluded that quality (conformance to specifications) and delivery (meeting delivery deadlines) remained the most important criteria across all levels, even 30 years after the study of Dickson (1966) on supplier selection. Olhager and Selldin (2004) investigated supply chain management strategies and practices in a sample of 128 Swedish manufacturing firms and concluded that many aspects are important when companies choose supply chain partners, but quality is the single most important criterion. From a survey conducted in 1998 on ''Excellent suppliers'', the weights of elements involved in supplier assessment are 44% quality, 36% delivery on time, 24% overall costs, 19% services, 6% technology and less than 5% for the remainder, including innovation, problem solving, knowledgeable personnel, good communication and accurate paperwork (see Kevin, 1998). Chrysler, the car manufacturer, evaluates suppliers based on four factors: quality, cost management, delivery and technology. Moreover, Chrysler weights each of these factors, with quality being weighted as 40% and the remaining three factors as 20% each (see Lewis, 1995). Hill (2000) and Thomas and Janet (1996) indicated that quality had emerged as order qualifiers because suppliers with unacceptable quality performance are dropped during the screening phase. Total quality management (TQM) has had considerable success in terms of its implementation in companies. Forza and Filippini (1998) indicated that suppliers have a clear influence on several quality dimensions and proposed TQM should link with suppliers, which incorporates an orientation towards quality and guarantees stable inputs for the production process. Hence, quality is fundamental to corporate competitiveness.

Price is another important factor that practitioners place a heavy emphasis on. Low cost is one competitive advantage that enterprises can use in a competitive market, because manufacturers would like suppliers to be able to provide components with process capability that satisfies the expected quality level and is also affordable. Restated, buyers want high-quality products at a cheap price. Consequently, price and quality are the two key considerations. In supplier selection, a high-quality and high-price supplier is undesirable because of cost considerations. Buyers prefer suppliers that offer products with adequate quality but at a lower cost.

Hence, quality and price are two fundamental and necessary requirements for supplier selection. A reliable method is essential for practitioners to evaluate suppliers' process capability and price restriction. Process capability indices have been widely adopted in the manufacturing industry, providing single number and unitless measures of process potential and performance, such as the indices C_p, C_{pk}, C_{pm} and C_{pp}. The process incapability index C_{pp}, developed by Greenwich and Jahr-Schaffrath (1995), is easy to apply, and provides more process information than other process indices. For example, this index provides information on process inaccuracy and process imprecision. This additional process information can help to clarify the process situations of suppliers and suggest clear directions for process improvement. Singhal (1991) provided a multi-process performance analysis chart (MPPAC), based on indices C_p and C_{pk}, for measuring the performance of a multi-process product with symmetric bilateral specifications. However, indices C_p and C_{pk} are not suitable because index C_p does not take process location into account and neither C_p or C_{pk} consider process centering (the ability to distinguish on-target and off-target processes). Consequently, index C_{pp} is preferred to indices C_p and C_{pk}. Chou (1994) proposed using the C_p, C_{pu} and C_{pl} indices to assess two suppliers' processes. However, in reality, usually more than two suppliers are available to choose from. Accordingly, the SCPAC defined here based on index C_{pp} and price index I_p is used to assess suppliers more efficiently and reliably. Furthermore, the directions of quality improvement for all processes are visualized clearly on SCPAC based on supplier location, further enhancing the partnership between buyers and suppliers, because this way benefits both. The SCPAC thus is a powerful tool enabling practitioners to monitor supplier process capability and the difference between budget and price over long periods.

Section 2 introduces the characteristics of incapability index C_{pp} and also defines the price index I_p. Subsequent sections then describe the SCPAC and discuss the application of SCPAC. Finally, a practical example is presented and conclusions are drawn.

2. Process incapability index C_{pp} and price index I_p

Process capability indices are generally used to determine whether a production process is capable of quality characteristic within a specification tolerance. The advantages of using process capability indices to measure process capability are that it is easily understood, straightforward to apply, and transforms process performance into a single unitless number, and thus reflects the ability of a process to meet specifications limits. Juran et al. (1974) proposed the process index C_p which is widely adopted in manufacturing. The index C_p gives a poor account of the process location. Kane (1986) corrected the disadvantages of the C_p index by developing the C_{pk} index. Boyles (1991) noted that indices C_p and C_{pk} are yield-based, and neither C_p nor C_{pk} is dependent on the target value T, meaning that neither index accounts for process centering. Chan et al. (1988) introduced the index C_{pm} to gain sensitivity towards deviations of process mean from the target value. In fact, the denominator of index C_{pm} is expected quadratic loss function, introduced by Taguchi (1985), and thus the index C_{pm} reflects the process loss more accurately than C_p and C_{pk}. Pearn et al. (1992) developed the index C_{pmk}, which considers both process yield and process expected loss. For all of the above indices, the process capability increases with the value of the process capability index.

Greenwich and Jahr-Schaffrath (1995) proposed the process incapability index, C_{pp}, defined as follows:

$$C_{pp} = \left(\frac{\mu - T}{D}\right)^2 + \left(\frac{\sigma}{D}\right)^2,$$

where T denotes the target value; $d = (\text{USL} - \text{LSL})/2$; $D = d/3$; USL represents the upper specification limit; LSL is the lower specification limit, μ denotes the process mean, and σ represents the process standard deviation.

In fact, C_{pp} is a simple transformation of C_{pm} and can be rewritten as $C_{pp} = (1/C_{pm})^2$. Contrary to other process indices, process capability decreases with increasing value of a process incapability index, which is why C_{pp} is called process incapability index. Furthermore, C_{pp} provides more information regarding the process, including process inaccuracy and imprecision, than other process indices, since $(\mu - T)^2/D^2$, called C_{ia} (inaccuracy index), can be used to reflect the departure of the process mean from the target value and σ^2/D^2, called C_{ip} (imprecision index), can be used to reflect the extent of process variation. Thus, $C_{pp} = C_{ia} + C_{ip}$ can provide the accurate orientation of quality improvement. For example, when the process is non-capable, and index C_{pm} measures process capability alone, the value of C_{pm} indicates that the process is non-capable only, but does not indicate how to modify the process to enhance the process capability. If C_{pp} index is used to measure the process capability, the C_{ia} and C_{ip} indices can indicate how to improve the process, for example through reducing the process variability, deviation from the target, or both.

The UMVUE and the probability density function of C_{pp} defined by Chen (1998) and the $100(1-\alpha)$ percent confidence interval of C_{pp} developed by Greenwich and Jahr-Schaffrath (1995) can help practitioners assess process performance more reliably, dealing with sampling error properly because parameters μ and σ cannot be identified and should be estimated from sample data. Pearn et al. (2002) identified C_{pp} index as a useful tool for practitioners to assess process performance, and designed the statistical testing hypotheses method for determining whether a given process performs as required. Moreover, Huang et al. (2002) used the process incapability index C_{pp} to design a single integrated process capability index for measuring the process performance of a nominal-the-best product family, and showed the relationship between the process capability index C_{pp} and process yield. C_{pp} thus is effective for evaluating the process capability.

To clarify the relationship between the component price and the price the buyers expect to pay, this study proposes a price index I_p as follows:

$$I_p = \frac{p - p_0}{p_0},$$

where P denotes the component price and P_0 represents the price buyers expect to pay. If $I_p = 0$, the component price the supplier offers equals the price the buyer expects to pay. Moreover, $I_p > 0$ means that the component price offered by the supplier is greater than the price the buyer expects to pay. Finally, $I_p < 0$ means that the component price the supplier offers is less than the price the buyer expects to pay. Practitioners can use price index I_p to understand the difference between the budget and the component price offered by the supplier. This useful information can improve efficiency when selecting suppliers.

3. Suppliers capability and price analysis chart

Singhal (1991) introduced an MPPAC to measure the performance of a multi-process product and indices C_{pu} and C_{pl} are used to represent the X- and Y-coordinates, respectively. Meanwhile, C_p is the average of C_{pu} and C_{pl}, and C_{pk} is the minimum vale of the X- and Y-coordinates, i.e. $C_p = 1/2\ (C_{pu} + C_{pl})$, $C_{pk} = \min\{C_{pu}, C_{pl}\}$. Neither the C_p nor the C_{pk} indices are suitable for use since both do not take process centering into account. Consequently, this study applies the process incapability index C_{pp} in place of C_p and C_{pk} to establish the SCPAC for supplier evaluation.

Boyles (1991) referred to a process capability plot, called the (μ, σ) plot, and showed that this plot provides an effective graphical method for assessing process capability. Vännman (1997) modified the Boyles' (μ, σ) plot and defined another process capability plot, called the (δ, γ) plot, because parameters δ and γ are invariable irrespective of the specification limits. The definitions of δ and γ are

$$\delta = \frac{\mu - T}{d},$$

$$\gamma = \frac{\sigma}{d}.$$

The process parameters μ, σ and the given specification limits can be used to uniquely determine the parameters δ and γ. Moreover, the parameter δ can be used to measure the distance of the target value T from the process mean relative to d, and the parameter γ can be used to measure the size of the process standard deviation σ relative to d. From the definitions of parameters δ and γ, $\mu < T$ can be understood when $\delta < 0$ and $\mu > T$ when $\delta > 0$. Furthermore, if the process is on target, i.e. $\mu = T$, then $\delta = 0$; if $\mu = \text{LSL}$ then $\delta = -1$ and if $\mu = \text{USL}$ then $\delta = 1$. Like indices C_{ia} and C_{ip} separated from index C_{pp}, the four indices including C_{ia}, C_{ip}, δ and γ can provide more information about process inaccuracy and process imprecision. Index C_{ia} can be rewritten as $C_{ia} = 9\delta^2$, and index C_{ip} can be rewritten as $C_{ip} = 9\gamma^2$. Index C_{pp} thus can be rewritten as $C_{pp} = 9(\delta^2 + \gamma^2)$.

The process capability indices C_{pu} and C_{pl} are the two most common process capability indices for measuring unilateral tolerances covering smaller-the-better and larger-the-better process capabilities. The indices C_{pu} and C_{pl} can be defined as

$$C_{pu} = \frac{\text{USL} - \mu}{3\sigma},$$

$$C_{pl} = \frac{\mu - \text{LSL}}{3\sigma}.$$

Based on the definition of C_{pu} and C_{pl}, let $x = C_{pu}$, $y = C_{pl}$ and use the indices C_{pu} and C_{pl} to represent the X- and Y-coordinates, respectively, in the SCPAC. Assume the specification interval is bilateral with the target at the midpoint of the specification interval, that is, $T = m$. The parameters δ and γ can be transformed into $\delta = (y - x)/(x + y)$, $\gamma = 2/[3(x + y)]$; similarly, the index C_{pp} can be rewritten as

$$C_{pp} = 9 \times \left(\frac{y - x}{x + y}\right)^2 + \frac{4}{(x + y)^2}.$$

The embryo SCPAC is obtained by drawing a contour plot of C_{pp}, see Fig. 1. According to Motorola's requirement defined by Harry (1988) and six capability zones defined by Pearn and

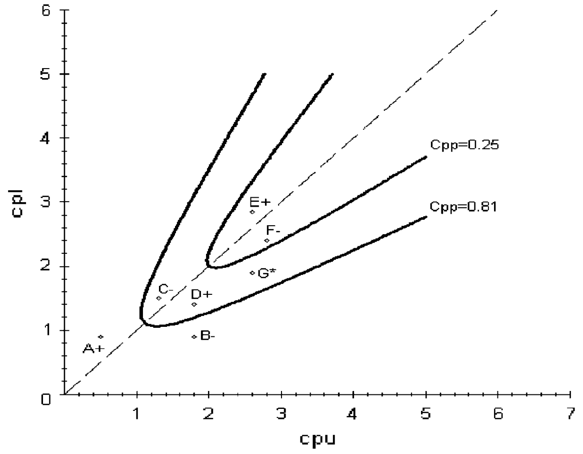

Fig. 1. SCPAC.

Chen (1997), a process is called "excellent" if $1.5 \leqslant C_{pk} \leqslant 2.00$, "super" if $C_{pk} \geqslant 2.00$ and satisfies the Motorola standard if index $C_{pk} \geqslant 1.5$ at index $C_p \geqslant 2.00$. Furthermore, the "super" capability zone can be obtained by transforming the index in $C_{pk} \geqslant 2.00$ to $C_{pp} \leqslant 0.25$; analogously, the Motorola requirement can be obtained by transforming the index in $C_{pk} \geqslant 1.5$ at index $C_p \geqslant 2.00$ to $C_{pp} \leqslant 0.81$ (see Appendix 1). This study decides Motorola's requirement as the process performance standard. Consequently, if the data of process capability from a number of suppliers is outside the $C_{pp} = 0.81$ contour region, then the process is classified as non-capable, like that of suppliers A and B in Fig. 1; conversely, if the data of process capability is located inside the $C_{pp} = 0.81$ contour region, then the process is identified as capable. Naturally, the result of the process capability data is located in the $C_{pp} = 0.81$ contour region but not in the $C_{pp} = 0.25$ contour region; then the process conforms with the requirement of Motorola, like those of suppliers C, D and G in Fig. 1 and the process is "super" capable such as those of suppliers E and F in Fig. 1 if the process capability data is located inside the $C_{pp} = 0.25$ contour region.

Price information must be provided simultaneously when supplier selection is based on a preset quality standard because practitioners always strongly emphasize price. The price index I_p is defined in Section 2 to assist practitioners in making supplier selection decisions. With the collection of the component price from the suppliers, the price index I_p of each supplier can be calculated. Transform the resulting price index values into symbols either "+" or "−" or "∗" as their superscripts. "+" means that the price the supplier offers is greater than what the buyer expects to pay. Moreover, "−" means that the price the supplier offers is below that which the buyer wishes to pay. Finally, "∗" indicates that the price the supplier offers equals the price that the buyer wants to pay. Practitioners can use the sign and value of the price index together or only the sign of the price index as supplier's superscript to display the price performance. Based on the C_{pp} index and price index I_p, an SCPAC is established by integrating evaluating quality and the price offered by the suppliers.

SCPAC makes it easy for practitioners to distinguish the process quality performance of each supplier with respect to supplier locations and adequate price level; for example, collecting sampling data from supplier candidates A, B, C, D, E, F, G and calculating the values of C_{pu} (X-axis) and C_{pl} (Y-axis) individually to plot on the SCPAC. Based on the locations on the SCPAC, the process information can be acquired. In Fig. 1, suppliers A and B obviously do not satisfy the expected quality standard, and thus can be eliminated from the list immediately. Suppliers C, D, E, F and G satisfy the quality standard. Given this, the next concern becomes price. The price index can be used to make good decisions. Furthermore, the SCPAC not only distinguishes supplier process capabilities, but also provides useful supplier process information about the location and spread of the studied characteristic. This information indicates a clear quality improvement direction to suppliers. The center line can form the origin of the coordinates, as shown in Fig. 1. Supplier location close to the center line corresponds to lower deviation between process mean to the target value and better process accuracy. Additionally, supplier location close to the origin of the coordinates corresponds to larger process variability, and supplier location of suppliers far from the origin of the coordinates corresponds to a smaller process variability and better process precision. SCPAC then provides an effective and efficient means of evaluating suppliers. The complete information provided by SCPAC is summarized below:

1. Fig. 1 shows that suppliers A and B are located outside the $C_{pp} = 0.81$ contour region, and clearly do not meet the expected quality requirement. Consequently, these suppliers can be eliminated immediately and put out of consideration.
2. Suppliers C, D, E, F and G are located inside the $C_{pp} = 0.81$ contour region, indicating that the process capabilities of these four suppliers meet the quality requirements. This is where the price index I_p should be taken into account. It helps practitioners to clarify the price level for each supplier. If the result of the process capability data is located in the same capable regions, the buyers rank the suppliers in an order of preference based on price index I_p.
3. Supplier F is located inside the $C_{pp} = 0.25$ contour region. The price index of supplier F is denoted as "−", $I_p < 0$, meaning the raw materials or components satisfy buyer demand in terms of quality and price. This supplier is the best choice because their process is "super" capability and moreover the price conforms to the budget of the buyer, yet only a few of these conditions exist in reality.
4. Supplier E is also located inside the $C_{pp} = 0.25$ contour region. However, the price index is denoted as "+", $I_p > 0$, which means the raw materials or components satisfy the quality standard but are not suitably priced. Despite the process of this supplier being "super" capable, the price is above the tolerance of the buyer. Such suppliers thus are not optimum choices.
5. Suppliers C, D and G are located in the $C_{pp} = 0.81$ contour region but not in the $C_{pp} = 0.25$ contour region, meaning the raw materials or components from these three suppliers satisfy buyer demands for quality. Considering the price index I_p, the price index of supplier D is denoted as "+", indicating the price of supplier D is more expensive among these three. Supplier D thus ranks last in terms of buyer preference. Suppliers C and G both satisfy the quality standard and meet an adequate price level. Nevertheless, the price of supplier C is less than the price the buyer wishes to pay but the price of supplier D is equal. Therefore, preferred supplier choice follows the order C > G > D.
6. Simultaneously distinguishing supplier process inaccuracy and imprecision according to the SCPAC. It is a helpful message for providing a clear direction for quality improvement, such as closeness to target, smaller process spread or both for suppliers. From Fig. 1, supplier B just needed to adjust the deviation from target, and then supplier B could enter the capability region and become a candidate, perhaps even winning the order. Analogically, supplier G must also adjust the deviation from target, creating the "super" capability process. Unfortunately, supplier A must improve both to increase the quality level.

4. Application of suppliers capability and price analysis chart

In practice, the true values of the process parameters μ and σ usually are unknown. Hence, these parameters must be estimated using appropriate sample data. However, deciding whether the process fits the preset criterion based only on the index values, calculated from the sample data, is extremely unreliable because sampling error can cause inappropriate decisions (see Chou, 1994; Vännman, 1997; Chen, 1998; Pearn et al., 2002; Huang et al., 2002). To avoid incorrect decisions, this study uses the confidence interval approach to boost reliability.

Based on the definitions of δ and γ, then under the assumption of a random sample from a normal distribution, the estimator $\hat{\delta} = (\bar{X} - T)/d$ can be identified as being asymptotically normally distributed with mean δ and variance γ^2/n, where n denotes the number of observations. Consequently, a $100(1-\alpha)$ percent confidence interval for δ can be constructed as

$$\left[\hat{\delta} - t_{\alpha/2,(n-1)} \times \hat{\gamma}/\sqrt{n}, \quad \hat{\delta} + t_{\alpha/2,(n-1)} \times \hat{\gamma}/\sqrt{n}\right],$$

where $t_{v,(n-1)}$ is the 100 vth upper percentile of the t-distribution with $n-1$ degrees of freedom. Moreover, according to the definitions of indices C_p and γ, γ can be transformed into $\gamma = (3C_p)^{-1}$. Since $(n-1)C_p{}^2/\hat{C}_p^2$ is distributed as χ^2_{n-1}, $(n-1)\hat{\gamma}^2/\gamma^2$ is approximately distributed as χ^2_{n-1}, which can be inferred from $(n-1)$ $C_p^2/\hat{C}_p^2$, where χ^2_{n-1} is a chi-square distribution with $n-1$ degrees of freedom. The $100(1-\alpha)$ percent confidence interval for γ can be constructed as $\{[(n-1)\ \hat{\gamma}^2/\chi^2_{\alpha/2,(n-1)}]^{1/2}, [(n-1)\ \hat{\gamma}^2/\chi^2_{(1-\alpha/2),(n-1)}]^{1/2}\}$. The confidence interval for δ and γ then is calculated, with the lower and upper limits being respectively represented as $[L_\delta, U_\delta]$, $[L_\gamma, U_\gamma]$. According to the transformation $\delta = (y-x)/(x+y)$, $\gamma = 2/[3(x+y)]$, these four confidence interval values can be drawn using four straight lines to form the rectangular region in the SCPAC. The equations of these four straight lines are:

$$(y-x)/(x+y) = L_\delta,$$

$$(y-x)/(x+y) = U_\delta,$$

$$2/(x+y) = 3L_\gamma,$$

$$2/(x+y) = 3U_\gamma.$$

This rectangular region is termed the capability rectangle (see Fig. 2) The coordinates of cross points

$$a = [(1-L_\delta)/(3U_\gamma), \quad (1+L_\delta)/(3U_\gamma)],$$

$$b = [(1-U_\delta)/(3U_\gamma), \quad (1+U_\delta)/(3U_\gamma)],$$

$$c = [(1-U_\delta)/(3L_\gamma), \quad (1+U_\delta)/(3L_\gamma)],$$

$$d = [(1-L_\delta)/(3L_\gamma), \quad (1+L_\delta)/(3L_\gamma)]$$

are also achieved. If the entire capability rectangle lies outside the $C_{pp} = 0.81$ contour region, then the process is classified as non-capable, and when the whole capability rectangle lies inside the $C_{pp} = 0.81$ contour region, then the process is classified as capable. Using the confidence intervals to estimate the parameters δ and γ and using the location of the capability rectangle for supplier on SCPAC to measure the quality level are more reliable approaches that reduce mistaken decisions caused by sampling error.

Furthermore, to respond rapidly to customer needs, many enterprises already adopt supply chain management. The relationship between seller (supplier) and buyer (manufacturer) has become a long-term partnership. Hurmelinna et al. (2002) stated that utilizing the interaction between the buyer and the supplier, a company may not only achieve higher supplier performance but it also creates new business opportunities in the field of research and development. Apparently, the supplier's process in the areas of quality, technology and cost is closely related to the final product produced by the manufacturer. In some cases, suppliers wish to make the best possible quality products, and the resulting cost is extremely high. However in current situations, buyers may not want the highest quality products, and instead may prefer products with acceptable quality that are priced lower. The supplier and buyer thus require a very good communication channel for exchanging information or technology efficiency and improving on their processes in the meantime so that both can make profits. In terms of quality improvement, SCPAC provides the following information to improve the relationship between suppliers and buyers:

1. The confidence rectangle of supplier E is located inside the "super" capability region. This

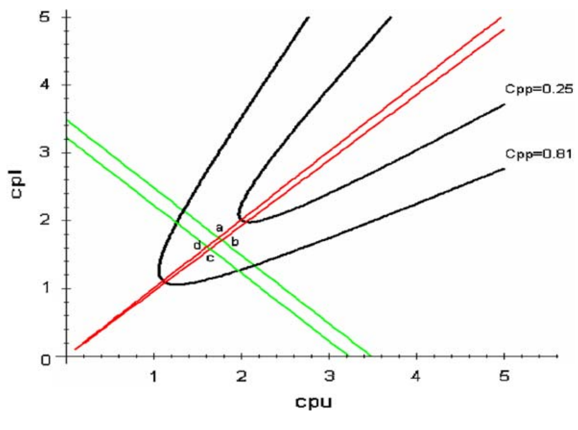

Fig. 2. The capability rectangle on SCPAC.

location indicates the superior process quality standard. Using this component can be quite helpful in making the final product. However, supplier E also wants to make the same high-standard products and invests considerably in labors and materials. The resulting cost is relatively high and so is the price. Unfortunately, buyers will give up doing business with supplier E owing to the higher than preset price level. SCPAC will request that supplier E reduces its cost. However, low cost may be associated with low quality. Additionally, if quality standard is low but still reasonable, as displayed in Fig. 3, the manufacturers will remain happy to do business with that supplier. Furthermore, since the supplier E has good quality technology, the manufacturer may even collaborate with supplier E to develop new technologies and products to improve their competitive advantage.

2. The confidence rectangle of supplier B is located outside the capability region. This location means the quality standard is not up to the buyers' expectation. The indices C_{ia} and C_{ip} or the location supplier B on SCPAC may provide process information required to identify the setbacks during the process. SCPAC helps clarify where and how to improve processes, provide that the process cost is within the tolerable range. Such suppliers also are considered, as shown in Fig. 3, but supplier B needs to reduce the distance between the process mean and the preset target then entering the capability region.
3. The confidence rectangle of supplier D is located inside the capability region. The process capability meets the quality standard but its price is too high to be a deal. SCPAC shows the message to lower the cost, and engineers must be sure that the process capability is as good as it was before the cost down process.

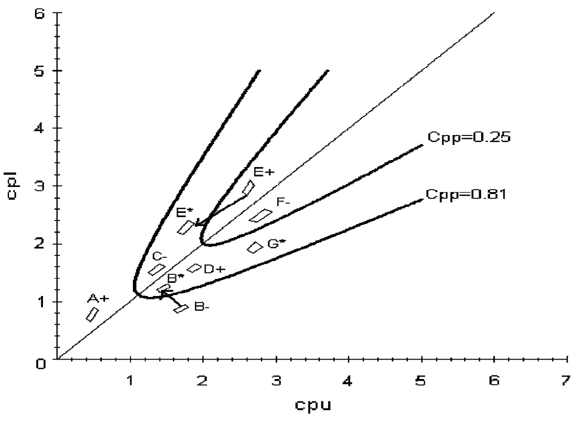

Fig. 3. The capability rectangle on SCPAC.

From the above, applying SCPAC to measure supplier performance clearly displays two key factors, namely process capability and pricing. From SCPAC, the practitioners can judge quality performance and budget pricing levels immediately and visually. Additionally, SCPAC directs the suppliers to implement their process capability and monitors this process capability to ensure it remains within the range necessary to maintain a good relationship between the suppliers and buyers. SCPAC uses confidence intervals to assess a supplier process capability and also minimizes the possibility of inaccurate sampling errors causing wrong decisions. SCPAC thus is said to be an efficient but convenient supplier evaluation tool.

5. Example of supplier selection

The example illustrates how the supplier evaluation procedure can be applied to the actual data collected from an electronics company whose main products are computer industrial and peripheral products. This company purchases numerous aluminum electrolytic capacitors from suppliers. Aluminum electrolytic capacitor is an electronic passive component generally used for electronic circuits to provide the functions of filtering, rectifying, coupling and fast charge–discharge and is applied widely in the 3C industry. In this example, considering the capacitance of the aluminum electrolytic capacitor with rated voltage 450 V, the target capacitance is 150 μF and capacitance tolerance is $\pm 20\%$; that is, the upper and lower specification limits are set to $\mathrm{USL} = 180\,\mu\mathrm{F}$ and $\mathrm{LSL} = 120\,\mu\mathrm{F}$, and the target value is set to $T = 150\,\mu\mathrm{F}$. Seven suppliers exist, from

Table 1
Sample statistics for seven suppliers

	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E	Supplier F	Supplier G
$\bar{X}$	141.0	144.2	148.2	152.2	151.2	146.0	151.7
S	9.9894	5.0210	6.1451	11.3021	5.4651	4.0360	4.2409
$\hat{C}_{pp}$	1.81	0.59	0.41	1.32	0.31	0.32	0.21
$\hat{C}_{pl}$	0.70	1.61	1.53	0.95	1.90	2.15	2.49
$\hat{C}_{pu}$	1.30	2.38	1.72	0.82	1.76	2.81	2.22
$\hat{\delta}$	−0.3	−0.193	−0.06	0.07	0.04	−0.133	0.057
(L_δ, U_δ)	(−0.3225, −0.2789)	(−0.2034, −0.1815)	(−0.0723, −0.0455)	(0.048, 0.097)	(0.02781, 0.05164)	(−0.1407, −0.1231)	(0.0483, 0.0668)
$\hat{\gamma}$	0.3330	0.1674	0.2048	0.3767	0.1822	0.1345	0.1414
(L_γ, U_γ)	(0.3182, 0.3491)	(0.1600, 0.1755)	(0.1958, 0.2148)	(0.3601, 0.3950)	(0.1741, 0.1910)	(0.1286, 0.1411)	(0.1351, 0.1482)
Price index	−0.132	−0.094	0.038	0.132	0.226	−0.019	0.358
Price symbol	−	−	+	+	+	−	+

whom 100 random samples are taken, and the above supplier assessment procedure is used to compare process capability. First, mean and process standard deviation are calculated based on the sample data for each supplier, after which the $\hat{\delta}$, $\hat{\gamma}$ and $\hat{C}_{pp}$ index can be obtained. Second, the confidence intervals of δ and γ and the price index I_p are computed. Table 1 lists the values of all estimators for each of the seven suppliers, and Fig. 4 illustrates SCPAC for seven suppliers.

From Fig. 4, the supplier evaluations for seven suppliers are discussed below:

1. The whole capability rectangles of suppliers A and D are within the non-capability region, namely, $C_{pp} \leqslant 0.81$. This location means their process capability does not meet the preset quality criteria. Suppliers A and D thus can be eliminated from consideration immediately.
2. The capability rectangle of supplier G is located inside the $C_{pp} = 0.25$ contour region, meaning the process capability of supplier G is "super" quality condition. However, the price index is denoted as "+", $I_p > 0$, meaning the components are satisfactory in quality terms but not in price terms. Suppliers thus are not good choices for practitioners. Nevertheless, supplier G can be a suitable collaborative partner in terms of

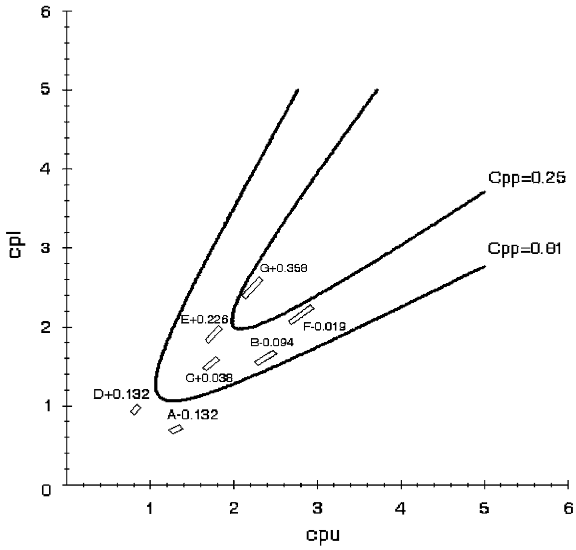

Fig. 4. SCPAC for seven suppliers.

his well quality technology, which can be useful for new technology and product development. Obviously, cost reduction is the first priority for supplier G. Monitoring with SCPAC enables the supplier and buyer to establish long-term relationships, and is very important for businesses in the current environment of global competition.

3. The capability rectangles of suppliers B, C, E and F are located within the $C_{pp} = 0.81$ contour and the $C_{pp} = 0.25$ contour region, meaning that the components related to these four suppliers satisfy the Motorola quality demand of the buyer. Considering price index I_p, the price index of suppliers C and E is denoted as "+", indicating the higher price level, so suppliers C and E are ranked last in order of preference. Apparently, suppliers B and F both provide satisfactory quality and price, making them good potential partners. According to the value of the price index, supplier B is the better choice in terms of price. Meanwhile, the process capability of supplier F can become a "super" condition that just needs to reduce the distance between the process mean and the preset target, thus enhancing process accuracy. If a buyer can assist supplier F to improve process accuracy and maintain low cost, supplier F thus is a better collaboration partner than supplier G.

6. Conclusions

Process capability indices provide single-number assessments of process potential and performance and have been widely applied in diverse manufacturing industries. This study applies the C_{pp} index to evaluate supplier process performance, and proposes using the price index I_p to measure the difference between the budget and the component price offered by the supplier. Moreover, the suppliers capability and price analysis chart (SCPAC) is established, based on the C_{pp} index and price index I_p, to provide practitioners with a powerful tool for evaluating suppliers. First, SCPAC allows practitioners simultaneously to consider the two key influences—quality and price. Second, SCPAC facilitates visual distinguishing of the process quality performance of each supplier, as well as adequate price level, and thus simplifies supplier evaluation. Finally, SCPAC also provides guidance for achieving quality improvement for all processes, and strengthening the partnership between buyers and suppliers because good quality performance benefits both sides. SCPAC thus is efficient, reliable and easy to use, and its use for supplier evaluation should be encouraged.

Furthermore, the delivery performance is another important criterion for selecting suppliers especially for a company with the JIT manufacturing system. The possible application can be recommended for practitioners that the delivery performance can be incorporated into SCPAC. Suppose the delivery performance of suppliers can be defined and scored, then grade the scores, transform the scores into recognized symbols, and finally attach the symbols on SCPAC. Hence, SCPAC displays three key supplier evaluation criteria, process capability, price and delivery, clearly. This possible expansion of SCPAC could be recommended and applied in the feature.

Appendix

Pearn and Chen (1997) defined six capability zones and indicated that a process is called "super" if $C_{pk} \geqslant 2.00$. In Section 3, the "super" capability zone can be obtained by transforming the index in $C_{pk} \geqslant 2.00$ to $C_{pp} \leqslant 0.25$. These transformations are explained as follows.

The index C_p, proposed by Juran et al. (1974), and the index C_{pk}, proposed by Kane (1986), are defined as

$$C_p = \frac{\text{USL} - \text{LSL}}{6\sigma} = \frac{d}{3\sigma},$$

$$C_{pk} = \min\left\{\frac{\text{USL} - \mu}{3\sigma}, \frac{\mu - \text{LSL}}{3\sigma}\right\} = \frac{d - |\mu - m|}{3\sigma},$$

where USL and LSL are upper specification limit and lower specification limit; μ denotes the process mean and σ represents the process standard deviation; $d = (\text{USL} - \text{LSL})/2$ and

$m = (\text{USL} + \text{LSL})/2$ is the midpoint of the specification interval. When the specification limits are symmetric about the target value T at the midpoint m of the specification interval, which is quite common in practical situations, the definition of index C_{pk} can be rewritten as

$$C_{pk} = \frac{d - |\mu - m|}{3\sigma} = \frac{d - |\mu - T|}{3\sigma}.$$

Process meets the "super" capability zone requirement if $C_{pk} \geqslant 2.00$, and hence we have

$$C_{pk} = \frac{d - |\mu - T|}{3\sigma} \geqslant 2,$$

$$|\mu - T| \leqslant d - 6\sigma,$$

then we have

$$\frac{|\mu - T|}{d} \leqslant 1 - \frac{6\sigma}{d}.$$

Since the Motorola standard requires 12σ of the specification interval, $d = (\text{USL} - \text{LSL})/2 = 6\sigma$; thus,

$$\begin{aligned} C_{pp} &= 9 \times (\delta^2 + \gamma^2) \\ &= 9 \times \left[\left(\frac{\mu - T}{d}\right)^2 + \left(\frac{\sigma}{d}\right)^2\right] \\ &\leqslant \left\{9 \times \left[\left(1 - \frac{6\sigma}{d}\right)^2 + \left(\frac{\sigma}{d}\right)^2\right]\right\} \\ &= \{9 \times [0 + (1/6)^2]\} = 0.25. \end{aligned}$$

Analogously, the Motorola requirement can be obtained by transforming the index in $C_{pk} \geqslant 1.5$ at index $C_p \geqslant 2.00$ to $C_{pp} \leqslant 0.81$. These transformations are explained as follows.

1. The index $C_p \geqslant 2.00$:

$$C_p = \frac{\text{USL} - \text{LSL}}{6\sigma} = \frac{d}{3\sigma} \geqslant 2;$$

thus,

$$\frac{\sigma}{d} \leqslant \frac{1}{6}.$$

2. The index $C_{pk} \geqslant 1.5$:

$$C_{pk} = \frac{d - |\mu - m|}{3\sigma} = \frac{d - |\mu - T|}{3\sigma} \geqslant 1.5,$$

$$|\mu - T| \leqslant d - 4.5\sigma;$$

then, we have

$$\frac{|\mu - T|}{d} \leqslant 1 - \frac{4.5\sigma}{d}.$$

Since the Motorola standard requires 12σ of the specification interval, $d = (\text{USL} - \text{LSL})/2 = 6\sigma$. Thus, according to illustrations 1 and 2, we have

$$\begin{aligned} C_{pp} &= 9 \times (\delta^2 + \gamma^2) \\ &= 9 \times \left[\left(\frac{\mu - T}{d}\right)^2 + \left(\frac{\sigma}{d}\right)^2\right] \\ &\leqslant 9 \times \left[\left(1 - \frac{4.5\sigma}{d}\right)^2 + \left(\frac{\sigma}{d}\right)^2\right] \\ &\leqslant \{9 \times [(1/4)^2 + (1/6)^2]\} = 0.81. \end{aligned}$$

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