J. Ind. Eng. Int., 6 (11), 31-38, Spring 2010
ISSN: 1735-5702

A graphical instrument for performance analysis of contractors

K. T. Yu [1] ***; C. Y. Shen*** [2] ***; D. K. Huang*** [3]

[1] *Assistant Professor, Dep. of Information Engineering and Informatics, Tzu Chi College of Technology, Hualien, Taiwan*

[2] *Assistant Professor, Dep. of Business Administrtion, Ching Yun University, Jungli, Taiwan*

[3] *Lecturer, Dep. of Industrial Management, National Taiwan University of Science and Technology, Taipei, Taiwan*

Received: 2 February 2008; Revised: 24 October 2008; Accepted: 30 December 2008

Abstract: The relationship between the manufacturer and supplier has changed from one of competition into that of greater cooperation during recent years. The selection and evaluation of suppliers are primary and important issues when an enterprise implements Supplier Relationship Management (SRM) and Total Quality Management (TQM). Much research indicates that most enterprises tend to evaluate their suppliers based largely on quality, delivery, and price performance. However, an analysis tool which can simultaneously integrate numerical decision criteria is rare, especially those suitable for evaluating various operational aspects, such as industry categories, purchase types, or production strategies. Based on this reason, an integrated model using multiple performance indices to construct a supplier performance evaluation chart (SPEC) is presented in this study. It is a graphic portrayal that can simultaneously display each supplier's performance of quality, delivery, and price through the use of a categorical symbol and its location on the SPEC. Based on the expected levels for each evaluation criteria, the manager can mark a target region on the SPEC so that an existing or new supplier's ability to achieve the preset level is effectively and conveniently indicated. Finally, an illustration is provided as a practical application.

Keywords: *Manufacturing process quality; Supplier Relationship Management (SRM); Six sigma; Supplier evaluation*

1. Introduction

Worldwide competition in global economies has posed significant challenges to companies wanting to fulfill the continuously changing requirements regarding customization, quality improvement, cost reduction, and reduced time-to-market. The relationship between a manufacturer and their suppliers is changing now from competition into cooperation. Doing so assists in responding quickly to customer needs and contributes to the profit of the whole supply chain. Supplier selection, evaluation, observation, and corrective actions thus become extremely important considerations in constructing Supplier Relationship Management (SRM) and Total Quality Management (TQM) systems.

Supplier selection and evaluation is one of the more critical activities. Selection of a wrong supplier or source could be enough to upset the company's financial and operational position. Traditionally, the supplier evaluation methods primarily focused on financial measures in the decision making process. Hirakubo and Kublin (1998) also pointed out that price is still a critical decision-making criterion, regardless of the product type. Undoubtedly, price has been the most widely used factor in practice. However, in modern management, one needs to consider many other factors with the aim of developing a long-term vendor relationship (Chou *et al*., 2007). An emphasis on manufacturing capability has gained greater importance in the supplier evaluation process. As stated by numerous scholars, including Chou (1994), Pearn and Chen (1997), Pillet *et al*. (1997), Asokan andUnnithan (1999) and Linn *et al*. (2006), process capability is considered to be the most effective method in selecting suppliers, especially those who manufacture high-quality products. Aside from requiring suppliers to provide products with a low price and high quality, an enterprise is also concerned about whether or not their suppliers can respond quickly to their dynamic needs as a means of enhancing their advantages in line with a growing emphasis on promoting just-in-time (JIT) supply-chain practices. 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 delivery performance is of "considerable importance". Chen

*Corresponding Author Email: ykt.kevin@msa.hinet.net
Tel.: +886 3 857 2158

et al. (1999, 2002, 2006) also continually developed a model for measuring the delivery performance of suppliers. In the JIT manufacturing system, delivery performance is certainly one of the more important criteria for supplier evaluation.

Overall, many literatures (Zeng, 1998; Weber *et al*., 2000, Alonso-Ayuso *et al*., 2003; Mu-Seong Lee *et al*., 2003, Talluri and Narasimhan, 2003; Chen *et al*., 2005) also indicated that quality, delivery and price are three fundamental and important factors in the processes of supplier selection and performance monitoring. It is impractical for an enterprise to consider only a single factor, such as price, in an all-round competition environment. Hence, a reliable and integrated method is essential for practitioners to measure and compare suppliers' process capabilities and delivery performance in addition to price considerations. Based on this motivation, a supplier performance evaluation chart (SPEC) is established, utilizing an integrated nonconformance index to measure the process capability of products with multiple quality characteristics, and combining with a performance index to measure the degree of delivery precision and accuracy. In addition, the researcher used symbol categorization as an indicator of a supplier's price analysis. The SPEC allows practitioners simultaneously to consider the above three importance influences.

There exists a target region marked on the SPEC representing the expected levels for each evaluation criteria. These levels are decided according to various operational aspects, such as industry categories, purchase types, or production strategies. By using the SPEC, the managers of various areas of business all can efficiently and easily distinguish the performances of each supplier and make the best decision.

In the following Section 2, the researchers will provide a detailed account of their integrated model, including that how to measure potential and performance based on each individual index and how to construct the SPEC. Section 3 demonstrates the application of the SPEC using semiconductor packaging case. Finally, Section 4 concludes the entire study.

2. Research Model

2.1. Measuring manufacturing process quality

Manufacturing process quality is still one of the primary concerns for the buyers. A supplier with high process capability can manufacture products with higher yield and lower loss. The process capability of a supplier can be measured by the quality characteristics of its products and processes. As noted by Pearn and Wu (2005), process yield is currently defined as the percentage of the processed product units passing the inspections. Units are inspected according to specification limits placed on various key product characteristics and sorted into two categories: passed (conformance) or rejected (nonconformance). Thus, the fraction of the nonconformities is convenient measuring tool and is commonly used in practice. In this study, the researcher derive three types of nonconformance indices NC^s, NC^l and NC^n to respectively measure smaller-the-better, larger-the-better and nominal-the-best quality characteristics. Their formulas can be described as:

$$\mathrm{NC^s} = \Pr(X \geq USL) = Pr\,(\frac{X-\mu}{\sigma} \geq \frac{USL-\mu}{\sigma}) = 1-\Phi(\frac{USL-\mu}{\sigma}). \quad (1)$$

$$\mathrm{NC^l} = \Pr(X \leq LSL) = Pr\,(\frac{X-\mu}{\sigma} \leq \frac{LSL-\mu}{\sigma}) = 1-\Phi(\frac{\mu-LSL}{\sigma}). \quad (2)$$

$$\begin{aligned}\mathrm{NC^n} &= 1-\Pr(LSL \leq X \leq USL)\\ &= 1-\Pr(\frac{LSL-\mu}{\sigma} \leq \frac{X-\mu}{\sigma} \leq \frac{USL-\mu}{\sigma})\\ &= 2-\Phi(\frac{USL-\mu}{\sigma})-\Phi(\frac{\mu-LSL}{\sigma}). \quad (3)\end{aligned}$$

Let X be the random number of measured characteristic and follows Normal(μ,σ^2), *USL* and *LS*L are the upper and lower specification limits, and Φ is normal cumulative distribution. Obviously, a smaller index value corresponds to a higher process capability.

As noted by Bothe (1992), Chen *et al*. (2001), and Chen *et al*. (2006), most products with multiple characteristics consist of numerous unilateral specifications and bilateral specifications. Buyers will accept products whenever all process capabilities of each characteristic satisfy preset specifications. For this reason, we further propose an integrated nonconformance index NC^T which combines smaller-the-better, larger-the-better, and nominal-the-best three indices into a single measurement.

Assume that the numbers of smaller-the-better, larger-the-better, and nominal-the-best characteristics are *s*, *l*, and *n*. Because each quality characteristic is measured independently, we will define the integrated nonconformance index for an entire product as:

$$NC^T = 1 - \prod_{i \in A} \prod_{j=1}^{i} (1 - NC_j^i), \ A = \{s, l, n\}. \quad (4)$$

Based on the Eq. (4), $\{NC_1^s, NC_2^s, ..., NC_s^s\}$ represents smaller- the- better characteristics; $\{NC_1^l, NC_2^l, ..., NC_l^l\}$ represents *l* larger-the-better characteristics; $\{NC_1^n, NC_2^n, ..., NC_n^n\}$ represents *n* nominal-the-best characteristics. NC^T is definitely higher than any of the individual nonconformance indices. In another words, when integrated process quality is preset to meet a required level, the individual quality characteristic should each be higher than the preset standard.

Due to the rapid advancement of the manufacturing capability, the common method for measuring the fraction nonconformance is often expressed in nonconformance parts per million (PPM). Table 1 summarizes the four common quality conditions based on the Six Sigma quality level established by Motorola Company.

Table 1: Four quality conditions and the corresponding process capability level with the fraction of nonconformance (PPM).

Process capability levels	Nonconformance (PPM)	Quality conditions
3σ	66810	Inadequate
4σ	6210	Capable
5σ	233	Satisfactory
6σ	3.4	Excellent

2.2. Measuring delivery performance

Beyond the quality requirement for the supplier's product, delivery performance is of considerable importance, especially in the specialized labor division of supply chain management. If a supplier's delivery is not timely, it may impact the entire supply chain performance. For instance, if a delivery is delayed, it might possibly suspend work that is waiting for materials, press for an urgent transfer, or require working overtime, etc. In contrast, a supplier delivering at too early a time might create a fund backlog, or cost increases due to overstock management. Although delivery performance is important, studies that have evaluated delivery performance are relatively limited. A primary reason for this is that many suppliers determine their delivery schedules based on production capability and by reason of the experience principle. In fact, delivery precision and accuracy are the critical points for enterprises competing in the JIT globalization management system.

In order to measure delivery efficiency, our model proposes the use of a delivery performance index (DPI) that can adequately represent the non-achievement fraction. It is expressed as follows:

$$DPI = 1 - Pr\,(T - DE \le Y \le T + DL). \quad (5)$$

Where Y is the variable representing delivery time, T is the optimal time from making the order to obtaining the goods, and DE and DL are the allowed error times for early delivery and late delivery, respectively. If the allowed error time is relaxed in order to avoid over-restricting the delivery schedule, an enterprise will increase the unused rate of equipment and the cost of manufacturing, thus lowering its competitive ability. Contrarily, if they are set too small, the product will not deliver on time. At this moment, the factory must accelerate the production by working overtime or outsourcing so that increase the cost of production. Hence, the allowed error times DE and DL should be decided reasonably by business both sides together.

Similarly, it is easy to find that a smaller DPI value corresponds to a higher delivery performance. Assume that delivery time obeys the Normal distribution with mean μ, variance σ^2, then:

$$DPI = 2 - \Phi\left(\frac{T + DL - \mu}{\sigma}\right) - \Phi\left(\frac{\mu - T + DE}{\sigma}\right). \quad (6)$$

We also express the levels of delivery, according to the Six Sigma established by Motorola Company and summarize four delivery performance conditions as Table 1.

2.3. Price analysis

In practice, price information receives strong emphasis. To clarify the relationship between the price offered by the supplier (P_s) and the price that the buyer expects to pay (P_b), our model classifies suppliers as high-priced, target range, and low-priced by the categorical method and assigns ▲, ◆, and▼ for each level, respectively.

"▲"means $P_s > (1 + x\%)P_b$.

"◆"means $(1 - x\%)P_b \le P_s \le (1 + x\%)P_b$.

"▼"means $P_s < (1 - x\%)P_b$, where $x\%$ denotes the price tolerance.

Practitioners can use these symbols as a chart indicator of a supplier's price performance.

2.4. Constructing the supplier performance evaluation chart (SPEC)

In order to assure that the integrated performance of a supplier achieves the claimed level, the managers need a convenient and effective tool to constantly monitor the supplier's performance. In this study, we construct a SPEC, which not only displays the status of the quality and delivery performances, but also analysis the relative price in the market using a categorical method. The SPEC can help the manager to monitor the performances of each supplier based upon the supplier's location and categorical symbol. Thus, the manager can quickly determine whether to continue cooperation with an existing supplier or divert to a better supplier.

The SPEC is composed of three indicators. Fist, we use the NC^T to evaluate the integrated quality performances of the suppliers by inspecting their products. Then, the results of performance evaluations are plotted on the X-axis, which has been scaled using the classifications of inadequate, capable, satisfactory, and excellent; based on the four quality conditions shown in Table 1.

Secondly, we plot the results of DPIs on the Y-axis to represent the delivery performances of the suppliers. The Y-axis is likewise divided into the four classifications according to Table 1.

Thirdly, with regard to price analysis, suppliers are classified as high-priced, target range, and low-priced by the categorical method, and assigned ▲, ◆, and▼ for each level, respectively. Then, we make mark the target region with bold lines on the SPEC to enable plotting how well the suppliers' performances satisfy the preset level. A sample of the SPEC layout is in Fig. 1, where the target region is preset at 5σ level for the performances of quality and delivery individually.

3. Illustration

In order to illustrate how the SPEC can be used to evaluate a supplier's performance, the following example is about a semiconductor packaging company (Company S), which has cooperated with three solder-ball manufacturing suppliers (A, B, and C) in Taiwan. The solder-ball is used as a cover on the chip substrate of IC products, and an important consumable material in the Ball Grid Array (BGA) packing process. The solder-ball spheres must have accurate diameters, solidus, and high strength to ensure tight control of the BGA packing process. High quality solder-balls can make IC products with better performance. The three key quality characteristics of solder-balls include: diameter and solidus, both being nominal-the-best quality characteristics; and strength, being a larger-the-better quality characteristic.

Table 2 displays product specifications and sampling statistics of each supplier, where $\overline{X}$ and S are the natural estimators for the mean values and standard deviations. The natural estimators of the nonconformance indices can be expressed by Smaller-the-better:

$$\hat{NC}^s = 1 - \Phi(\frac{USL - \overline{X}}{S}). \quad (7)$$

Larger-the-better:

$$\hat{NC}^l = 1 - \Phi(\frac{\overline{X} - LSL}{S}). \quad (8)$$

Nominal-the-best:

$$\hat{NC}^n = 2 - \Phi(\frac{USL - \overline{X}}{S}) - \Phi(\frac{\overline{X} - LSL}{S}). \quad (9)$$

Integrated *NC* index:

$$\hat{NC}^T = 1 - \prod_{i \in A} \prod_{j=1}^{i} (1 - \hat{NC}_j^i),\ A = \{s, l, n\}. \quad (10)$$

Then, the natural estimator of integrated nonconformance index of each supplier will be plotted on the X-axis of the SPEC as shown in Fig. 2. In our example, at least 30 delivery-time samples were collected from each company to be used in generating the delivery performance index (DPI). Company S's optimal order-to-delivery time (T) is 5 days. The allowed error times for early delivery and late delivery, respectively are DE =1 day and DL = 0.5 day. They are presented in Table 3.

Likewise, $\tilde{X}$ and $\tilde{S}$ are the natural estimators for the mean values and standard deviations, and the estimators of a supplier's DPI can be expressed by:

$$\tilde{DPI} = 2 - \Phi(\frac{T + DL - \tilde{X}}{\tilde{S}}) - \Phi(\frac{\tilde{X} - T + DE}{\tilde{S}}) \quad (11)$$

Finally, each supplier's $\tilde{DPI}$ will be plotted on the Y-axis of the SPEC as shown in Fig. 2.

In price analysis, the target price (P_b) of solder-ball that Company S wishes to pay is \$100, and 5% is the price tolerance. So, the upper and lower bounds of the price are \$105 and \$95.

In addition, suppliers A, B, and C have quoted \$110, \$93, and \$102, respectively. It is obvious that the supplier A (110>105) should be classified as too high-priced, using the symbol "▲"; supplier B (93<95) is classified as low-priced, using the symbol "▼"; and supplier C (95<102<105) is classified as in target range, using the symbol "□". As for the evaluation policy of Company S, they require that the suppliers can provide high quality products and delivery performance prioritized to lower price.

They have set the target region at the 5σ level to achieve this goal. Based on the conditions established in our example, the SPEC plot is shown in Fig. 2. A glance at the SPEC shows that no supplier meets all of the desired attributes. However, according the location and symbol of each supplier, some useful information is provided to guide the manager's decision, as described below:

1. Supplier A is the only one located inside the "satisfactory" target region. It means that only supplier A achieved the claimed 5σ level in quality and delivery performances. However, the price of supplier A is classified as high-priced with a sign "▲", meaning its price is higher than the upper bound (5%) of the budget. Obviously, cost reduction is the first priority for supplier A. Company S also should provide some cooperative plans benefiting both sides in an effort to lower the purchase price, for example: increase orders, share technological research and development burdens, cost-reductions, and so on.

2. Supplier B is not located inside the "satisfactory" target region because their delivery performance didn't achieve the 5σ level. Commendably, supplier B both provides satisfactory quality and price. If supplier B can improve delivery performance, while still maintaining a low price and high quality, it would be an excellent collaboration partner.

3. Supplier C is not located inside the "satisfactory" target region because neither the quality nor the delivery performances achieved the expected 5σ level. The price of their product, being neutral, doesn't justify an attempt to improve their performance on these issues. So, supplier C should actively enhance product process capability and delivery performance, or else be eliminated from consideration.

4. Conclusion

Supplier's performance monitoring and evaluation are critical functions within SRM construction. Thus, it is extremely necessary for an enterprise to employ an efficient and reliable tool in evaluating new or existing suppliers. Our concept involves the development of a new, integrated chart for better discrimination in evaluating supplier's performances. The SPEC is established based on suppliers' key criteria of quality, delivery, and price, and can be applied in many different business environments.

In determining quality performance, we reflect the process capability of a supplier by measuring the products with multiple quality characteristics, including smaller-the-better, larger-the-better, and nominal-the-best characteristics.

As a measure of delivery performance, we lay emphasis on delivery precision and accuracy, i.e. the achievement fraction of suppliers' deliveries within desired time frames. In price analysis, suppliers are graded as high-priced, target range, and low-priced according to the difference between the buyer's preferred price and a supplier's product price. Each of these three measures is displayed on the SPEC using a combination of location and categorical symbols. Furthermore, with consideration of the company's operational situation, a target region is generated on the SPEC to aide in determining whether or not a given supplier's performance satisfies preset levels.

We have included an example using purchasing data from a semiconductor packaging company to illustrate the implementation of this SPEC. In summary, this proposal offers an effective and easy to use SPEC to display the performances of three important criteria in the supplier selection and evaluation process.

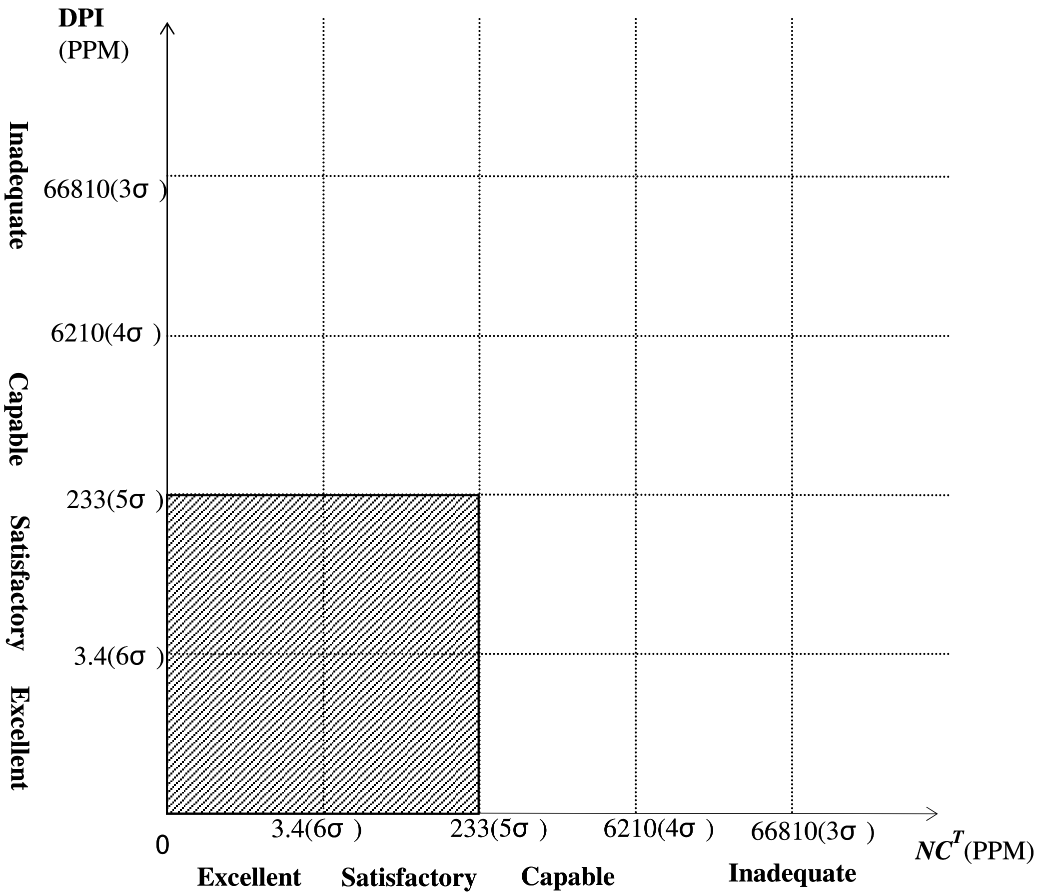

Figure 1: SPEC.

Table 2: Product specifications, sampling statistics, and estimators of the indices.

Supplier	Process characteristic	LSL	USL	$\overline{X}$	S	$\hat{NC}^{i}_{i\in\{s,l,n\}}$ (PPM)	$\hat{NC}^{T}$ (PPM)
	Diameter(mm)	0.480	0.520	0.512	0.002	31.686	
A	Solidus(˚C)	217.000	219.000	218.175	0.221	94.676	228.265
	Strength(kgf/mm)	5.340		5.470	0.035	101.919	
	Diameter(mm)	0.480	0.520	0.498	0.005	32.194	
B	Solidus(˚C)	217.000	219.000	218.237	0.212	159.727	204.660
	Strength(kgf/mm)	5.340		5.500	0.038	12.747	
	Diameter(mm)	0.480	0.520	0.502	0.006	1472.866	
C	Solidus(˚C)	217.000	219.000	217.750	0.270	2738.494	7740.419
	Strength(kgf/mm)	5.340		5.480	0.052	3548.020	

Table 3: The optimal time T, sampling statistics, and the estimators of the indices.

Supplier	T	DE	DL	$\tilde{X}$	$\tilde{S}$	$\tilde{DPI}$ (PPM)
A	5.000	1.000	0.500	4.925	0.163	209.716
B	5.000	1.000	0.500	4.883	0.241	5355.370
C	5.000	1.000	0.500	5.057	0.232	28102.463

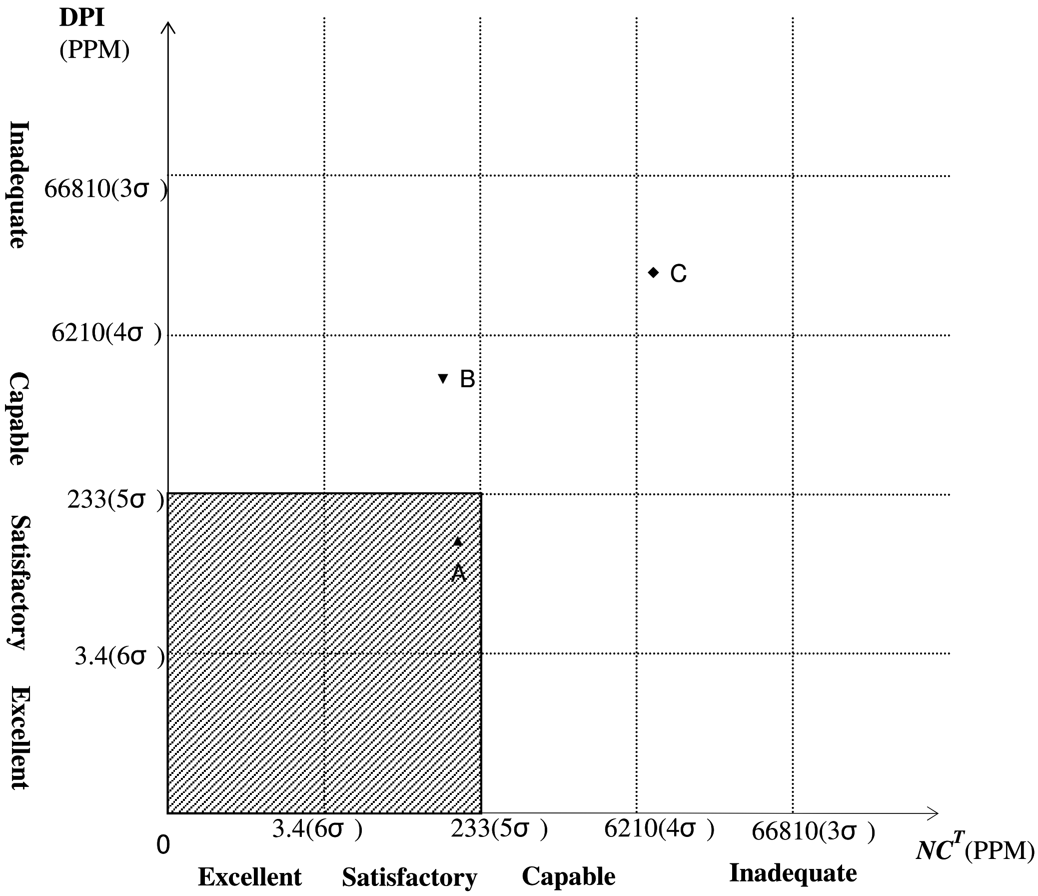

Figure 2: The SPEC of suppliers A, B, and C.

References

Asokan, M. V.; Unnithan, V. K. G., (1999), Estimation of vendor's process capability from the lots screened to meet specifications. *Quality Engineering*, 11(4), 537-540.

Alonso-Ayuso, A.; Escudero, L. F.; Garin, A.; Ortuno, M. T.; Perez, G., (2003), An approach for strategic supply chain planning under uncertainty based on stochastic 0-1 programming. *Journal of Globalization Optimization*, 26(1), 97-124.

Bothe, D. R., (1992), A capability study for an entire product. *ASQC Quality Congress Transactions*, 46, 172-178.

Chou, S. Y.; Shen, C. Y.; Chang Y. H., (2007), Vendor selection in a modified re-buy situation using a strategy-aligned fuzzy approach. *International Journal of Production Research*, 45(14), 3113-3133.

Chou, Y. M., (1994), Selecting a better supplier by testing process capability indices. *Quality Engineering*, 6(3), 427-438.

Chen, K. L.; Chen, K. S.; Li R. K., (2005), Suppliers capability and price analysis chart. *International Journal of Production Economics,* 98(3), 315-327.

Chen, K. S.; Yang, H. H., (1999), Evaluation of supplier delivery performance. *Journal of The Chinese Institute of Engineers*, 16(6), 681-688.

Chen, K. S.; Huang, M. L.; Li, R. K., (2001), Process capability analysis for an entire product. *International Journal of Production Research*, 39(17), 4077-4087.

Chen, K. S.; Chen, H. T.; Tong, L. I., (2002), Performance assessment of processing and delivery times for very large scale integration using process capability Indices. *International Journal of Advance Manufacturing Technology*, 20(7), 526-531.

Chen, K. S.; Huang, M. L.; Chang, P. L., (2006), Performance evaluation on manufacturing times. *International Journal of Advance Manufacturing Technology*, 31(3-4), 335-341.

Chen, K. S.; Yu, K. T.; Sheu, S. H., (2006), Process capability monitoring chart with an application in the silicon-filler manufacturing process. *International Journal of Production Economics*, 103(2), 565-571.

Dickson, G. W., (1966), An analysis of vendor selection systems and decisions. *Journal of Purchasing*, 2(1), 5-17.

Hirakubo, N.; Kublin, M., (1998), The relative importance of supplier selection criteria: The case of electronic components procurement in Japan. *Journal of Supply Chain Management*, 34(2), 9-24.

Linn, R. J.; Tsung, F.; Ellis, L. W. C., (2006), Supplier selection based on process capability and price analysis. *Quality Engineering*, 18(2), 123-129.

Lee, M. S.; Lee, Y. H.; Jeong, C. S., (2003), A high-quality-supplier selection model for supply chain management and ISO 9001 system. *Production Planning and Control*, 14(3), 225-232.

Pearn, W. L.; Chen, K. S., (1997-98), Multiprocess performance analysis: A case study. *Quality Engineering*, 10(1), 1-8.

Pearn, W. L.; Wu, C. W., (2005), An effective modern approach for measuring high-tech product manufacturing process quality. *Journal of the Chinese Institute of Industrial Engineers*, 22(2), 119-133.

Pillet, M.; Rochon, S.; Duclos, E., (1997-98), SPC-generalization of capability index Cpm: Case of unilateral tolerances. *Quality Engineering*, 10(1), 171-176.

Talluri, S.; Narasimhan, R., (2003), Vendor evaluation with performance variability: A max–min approach. *European Journal of Operational Research*, 146(3), 543-552.

Weber, C. A.; Current, J. R.; Benton, W. C., (1991), Vendor selection criteria and methods. *European Journal of Operational Research*, 50, 2-18.

Weber, C.A.; Current, J. R.; Desai, A., (2000), An optimization approach to determining the number of vendors to employ. *Supply Chain Management.*, 5(2), 90-98.

Zeng, A. Z., (1998), Single or multiple sourcing: An integrated optimization framework for sustaining time-based competitiveness. *Journal of Marketing Theory and Practice*, 6(4), 10-25.