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Performance evaluation for introducing statistical process control to the liquid crystal display industry

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Abstract

Statistical process control (SPC) is a powerful technique for monitoring, managing, analyzing and improving process performance by statistical methods. Unfortunately, LCD industry cannot control key factors in the application process, and do not invest adequately in resources. Therefore, the performance matrix is adopted to locate those objective items outside the appropriate performance zones (APZ). Fuzzy measures are then applied to locate relations and weighted values for all objective items outside the APZ. Finally, objective items outside the APZ are transformed to overall performance values when implementing the SPC system using the Choquet integral method. A larger performance value for a strategy in the implemented SPC system indicates an improvement in priority. Hence, this study presents a complete assessment model to help manufacturers identify objectives and strategies for improving the process of introducing SPC.

Keywords: Appropriate performance zone (APZ); Fuzzy measure; Choquet integral; Performance evaluation; Statistical process control (SPC)

1. Introduction

The LCD industry currently adopts highly advanced manufacturing techniques. Therefore, rapid responses to competition, and improvements in yield stability, are critical to success in this industry. Statistical process control (SPC) has been widely applied since first introduced by Shewhart in the early 1930s (Woodall and Montgomery, 1993). The primary application domain for SPC charts is in process control and improvement in manufacturing (MacCarthy and Wasusri, 2002). Many organizations regard SPC as a significant component of QS-9000. Furthermore, SPC considers variability in processes, and is fundamental for continuously enhancing product quality (Rungasamy et al., 2002; Schippers, 1998). Consequently, SPC has become a popular tool for quality improvement (Chen, 1991; Lascelles and Dale, 1988; Modarress and Ansari, 1989; Singh and Gilbreath, 2002; Wu et al., 2006). SPC is an essential management system for business, since it can improve manufacturing

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processes if applied as described in quality manuals. Unfortunately, the results of applying SPC according to manuals in businesses are worse than expected. There are three reasons for these disappointing results. First, a significant gap exists between theory and practice, both of which should be addressed to achieve effective results. Second, the requests for excessive perfection in quality documents make SPC difficult to perform in practical situations. Third, businesses cannot control key factors in the application process, and do not invest sufficiently in resources. Therefore, from the practical perspective, this study considers the application of SPC in the LCD industry, and the effective allocation of resources to control critical successful factors (CSFs) and solve product quality control problems.

This study surveys previous literature on the critical requirements of SPC implementation. The literature has been utilized to design a questionnaire survey for investigating and generalizing the potential importance objective items and challenges faced by the Taiwanese LCD industry in implementing the SPC system. The designed questionnaire was based on the theories of Parasuraman et al. (1985, 1991), who defined a performance index for measuring various objectives. Additionally, the modified performance matrix of Hung et al. (2003) was employed to develop a standardized performance evaluation matrix for system introduction. The importance and easiness of each objective item during the implementation of SPC in the LCD industry was thus known, and the performance level of every objective was clearly stated. Items that were not included in the range of the appropriate performance zone (APZ) refer to the improvement objectives, which are key for successfully introducing SPC systems in the LCD industry. Since implementing SPC process is considered to be a necessary strategy for fulfilling various objective items, correlation and weighted values of the improvement objectives were calculated by fuzzy measures. The relationship between improvement objectives and strategies was then determined using Choquet integral, and the overall performance values of various strategies were obtained. The strategy with the performance value refers to the key process of introducing SPC to the LCD industry and accreditation, besides a strategy of improving the objective. According to the above discussion, this study has the following three aims.

(1) Adopt the performance matrix to discover the key objective, namely promoting the SPC system in the Taiwanese LCD industry.
(2) Locate the correlation and weighted values of the items requiring improvement can be located by analyzing fuzzy measures.
(3) Include established priorities, such as support for the introduction of SPC system in the LCD industry, among the critical items.

Achieving the above aims for introducing and accrediting a SPC system creates a complete and efficient set of implementation procedures. Manufacturers can locate the objectives and strategies that need improvement during the introduction and verification of a SPC system from the complete evaluation model presented in this study, and thus can increase the timeliness of LCD industry when considering cost and time.

2. Performance evaluation model for system introduction

The Taiwanese LCD industry has particular advantages; including a comprehensive information industry chain ranging from IC design to system products, highly experienced engineers, and manufacturing flexibility (Chang, 2005). However, the LCD industry has the following characteristics: (i) capital and technique is intensively orientated; (ii) product yield and quality are key competitive factors, and (iii) short-term product life cycle (Lee, 1999). Therefore, the LCD industry is fiercely competitive, and must establish seamless, integrated models applicable to practical strategies. The performance matrix helps businesses distinguish between superior and inferior service elements, and optimize the usage of resources (Hung et al., 2003; Lin et al., 2005). Consequently, the performance matrix is very suitable for the LCD industry.

2.1. Performance matrix

This study applies the service quality performance matrix proposed by Hung et al. (2003), but replaces the "satisfaction" level of the X-coordinate with an "easiness" level. The easiness and the importance of each item to be introduced vary according to the industry and the business. Thus, the random variable I denotes importance, and E represents easiness. The easiness of introducing a system in a business varies according to the manpower and resources in the business. The easiness of achieving an objective is generally high in a business with strong talents or abundant resources relevant to it. A five-point scale was adopted to assess the importance and implementation easiness of each objective. The indices of importance and easiness are defined as follows:

$$P_I = \frac{\mu_I - \min}{R} \quad \text{(index of importance)}, \tag{1}$$

$$P_E = \frac{\mu_E - \min}{R} \quad \text{(index of easiness)}, \tag{2}$$

μ_I and μ_E denote the means of importance (I) and easiness (E), respectively; $\min = 1$ represents the minimum of the k scale, and $R = k-1$ is the full range of the k scale. A lower value corresponds to an objective with low importance or easiness. Clearly, these two indices are within (0, 1). For example, on a five-point scale ($k = 5$) with $R = k-1 = 4$, when the importance (or easiness) exceeds 3 (medium), the corresponding index exceeds 0.5 and the average importance (or easiness) is positive. Conversely, when the average importance (or easiness) is below 3 (medium), the indices are below 0.5 and the average importance (or easiness) is negative. Consequently, management can evaluate the effectiveness of introducing SPC from the values of the indices.

The index of importance is plotted as a Y-coordinate, and that of easiness as the X-coordinate. A performance matrix is redefined according to various strategic requirements of business, as a tool in the performance analysis and improvement of a newly introduced system. Since indices $\hat{P}_I$ and $\hat{P}_E$ are within the range [0, 1], four thresholds [0.0, 1/3, 2/3, 1.0] are adopted to define three levels of easiness of implementation—most difficult [0.0, 1/3], moderately easiness [1/3, 2/3] and easiest [2/3, 1.0] and three levels of importance—least importance, moderately importance and most importance. Thus, $(P_E, P_I) = [0.0, 0.0]$ indicates most difficult and least importance; $(P_E, P_I) = [1.0, 1.0]$, while means the easiest and the most importance. Indices (P_E, P_I) between [1/3, 1/3] and [2/3, 2/3] indicate an implementation that is moderately easiness and moderately importance. The dotted line parallel to the y-axis in Fig. 1 ($P_E = 0.5$) indicates medium easiness. The zone to the right of the dotted line indicates that the implementation is easier than average, and that to the left of the dotted line represents that the implementation is less easy than average. The dotted line parallel to the x-axis ($P_I = 0.5$) represents medium importance. The area above the dotted line represents (higher than average importance, and the area below the dotted line represents below average importance).

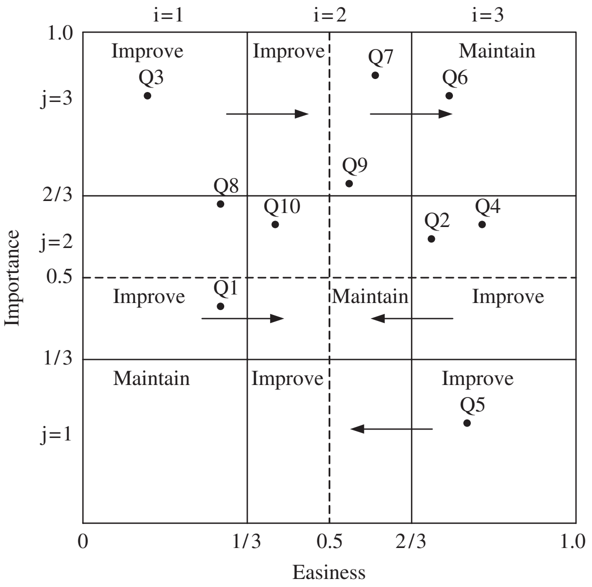


Fig. 1. Modified of the performance matrix (*Source*: Lin et al., 2005).

2.2. Appropriate performance zones of performance matrix

The proposed performance matrix is divided into nine performance zones representing the effectiveness of various system-introduced objective items (Lin, et al., 2006). $B_{ij}(i, j = 1, 2, 3)$ represents the performance zones, where, for example, B_{13} denotes the objective item with the lowest easiness of implementation and the highest importance, making it the zone that requires the most improvement. B_{31} represents the objective item with the highest easiness of implementation and the lowest importance, corresponding to highest effectiveness. The three performance zones with $i = 3$, namely B_{31}, B_{32} and B_{33} represent the easiest implementation, and are called the "highest easiness zones". The three performance zones with $i = 2$, namely B_{21}, B_{22} and B_{23}, represent moderately easy implementation, and are called the "moderate easiness zones". The three performance zones where $i = 1$, namely B_{11}, B_{12} and B_{13}, are called the "lowest easiness zones". The three performance zones with $j = 3$, namely B_{13}, B_{23} and B_{33}, represent the highest importance, and are called the "highest importance zones". The three performance zones where $j = 2$, namely B_{12}, B_{22} and B_{32}, represent moderate importance, and are called the "moderate importance zones". The three performance zones where $j = 1$, namely B_{11}, B_{21} and B_{31}, represent the lowest importance, and are called the "lowest importance zones". In the three performance zones where $i = j$, namely B_{11}, B_{22} and B_{33}, the importance equals the ease of implementation, and these zones are called the "appropriate performance zones". Although certification is an important factor for the sustainable success of a business, critical items must be identified and requirements met with regard to cost. Therefore, if a business adopts the management strategy of obtaining an appropriate performance level, then such a performance level can be maintained, reducing the cost of introducing a system. Consequently, a business must set the priority of each item. The target performance zone is that in which the importance equals the easiness ($i = j$) (B_{11}, B_{22} and B_{33}). The importance exceeds the easiness ($I<j$) in zones B_{12}, B_{13} and B_{23}. Additional resources should be to enhance performance in these zones. Importance is lower than easiness ($i>j$) in zones B_{31}, B_{32} and B_{21}. The level of resources is reduced in these zones to decrease the cost of meeting the items. The performance of each factor should reach the target zones, in the direction of the arrow in Fig. 1. The strategies for improvement in each performance zone are of three types: increasing resources to enhance effectiveness; decreasing resources to reduce the cost of introducing the items, and maintaining the status quo. For example, the performance study of SPC certification in Fig. 1 includes ten items, distributed as in Fig. 1 ($Q1 \sim Q10$). Clearly, the five items $Q1$, $Q3$, $Q7$, $Q8$ and $Q9$ are critically important for obtaining certification, since their importance is higher than their easiness of implementation ($I<j$). Therefore, these items are located in zones B_{12}, B_{13} and B_{23}, and additional resources must be applied to them to enhance performance. The three items $Q2$, $Q4$ and $Q5$ fall in zones B_{31}, B_{32} and B_{21}, in which importance is lower than easiness of implementation ($i>j$), meaning that resources must be re-allocated so that surplus resources can be applied to implement $Q1$, $Q3$, $Q7$, $Q8$ and $Q9$. Accordingly, the SPC certification can be attained without increasing the cost, and may even reduce it.

When analyzing the performance matrix of the introduction SPC, the supervisor only has to determine the type of performance matrix from the position (P_E, P_I) of the indices of importance and easiness of implementing the items. Accordingly, the performance level of each item can be assessed, and the projected improvement method and strategy can be obtained. Thus, the performance matrix is a straightforward and easy-to-use graphic analysis tool, which is quite helpful in evaluating the performance of introduction of SPC.

3. Introduction of fuzzy measure and Choquet integral method

Zadeh (1965) first presented fuzzy logic in the 1960s to represent uncertain and imprecise information. This fuzzy theory provides approximate but effective descriptions for highly complex, ill defined, or difficult-to-analyze mathematical systems (Ko and Cheng, 2003). Fuzzy theory has been successfully applied to the numerical control of manufacturing processes (Perng et al., 2005). Other successful applications in human resource management (Ishii and Sugeno, 1985), traffic assignment (Chen and Tzeng, 2001), supplier selection (Chang et al., 2006; Amid et al., 2006) and construction technology (Perng et al., 2005). Among multiple object decision analysis, each objective is assigned a weight based on decision makers' subjective and objective views. The analytic hierarchy process (AHP) is widely used but is only applied to questions whose objectives contain independent elements. However, these objectives are in practice generally dependent on others. Therefore, AHP is not an appropriate method for analysis (Tu, 2003). Fuzzy theory can solve this problem.

This model of fuzzy measure and Choquet integral was applied to the performance evaluation model in this study. Table 1 summarizes the process of implementing SPC according to the perspectives of Rungtusanatham et al. (1997, 1999).

3.1. Fuzzy measures of objectives to be improved

For multiple attributes decision-making, independent dimensions must be presumed and added when evaluating an issue in terms of multiple dimensions (Lee and Leekwang, 1995). However, the dimensions are normally correlated with each other, which is not consistent with the additive hypothesis (Chen and Tzeng, 2001). Therefore, fuzzy measures were applied in this study to manage relations and weighted values among SPC items. Additionally,

Table 1
SPC implementing process

No.	SPC implementing process (strategy)
A1	Level of support from senior directors in implementation of SPC
A2	Senior directors oversee and announce quality policy in person
A3	Give full support of resources and budgets
A4	Establishing coordination and operation of cross functional group
A5	Choosing an independent unit in implementing the SPC
A6	Through SPC experts or consultants assistance and guidance
A7	Participation and recognition of the employees
A8	Education instructors and materials
A9	Proper education and training for quality involved employees
A10	With the combination of quality authentication system
A11	Do not combine with the quality system, two systems implemented simultaneously
A12	Combination with other quality system
A13	Productive type
A14	Level of variation according to Normal Distribution should be minimized
A15	Product defects of improved
A16	The selection of manufacturing process and the level of involvement
A17	The selection of quality attributes and the level of involvement
A18	Measuring system analysis
A19	Decision of group sampling
A20	Application of control chart
A21	The employees cooperate and audit regularly
A22	Standardization
A23	The document controls and the product quality record
A24	Automatic tool application
A25	Proper statistical software choosing and applying
A26	Application of statistical tool or quality control method
A27	Continual improvements in manufacturing process quality
A28	Performance measurement index
A29	Combination of employee performance evaluation, rewards and penalties

Choquet integral was adopted to calculate the overall evaluation value when implementing SPC.

A questionnaire was designed asking experts to determine relationships among items to be improved. Consider N experts, $E=\{E_h\}$, where $h=1, 2, 3, \ldots, N,$ who have to determine relationships among m objectives to be improved, $C=\{C_j\}$, where $j=1, 2, 3, \ldots, m$. C_{pq} represents the relationship between items p and q ($p=1, 2, 3, \ldots m-1$; $q=2, 3, 4, \ldots, m$). The relationship between items p and q are subjectively judged by expert h and the relationship is shown in C_{hpq} (where $h=1, 2, 3 \ldots N$; $p=1, 2, 3 \ldots m-1$; $q=2, 3, 4 \ldots m$; $q>p$). If $C_{hpq}=0$, this means that expert h does not think that items p and q are related. In contrast, if $C_{hpq}=1$, this means that expert h does believe that a relationship exists between items p and q. The result of the judgment is expressed by matrix Y as follows:

$$Y=[C_{hpq}]=\begin{array}{cc} & \begin{array}{ccccc} C_{12} & C_{13} & C_{pq} & \cdots & C_{(m-1)m} \end{array} \\ \begin{array}{c} 1 \\ \cdots \\ h \\ \cdots \\ N \end{array} & \begin{pmatrix} C_{112} & \cdots & C_{1pq} & \cdots & C_{1(m-1)m} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ C_{h12} & C_{h22} & C_{hq} & \cdots & C_{h(m-1)m} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ C_{N12} & C_{N22} & \cdots & \cdots & C_{N(m-1)m} \end{pmatrix} \end{array}. \tag{3}$$

In matrix Y, $\sum C_{hpq}$ represents the number of experts finding a correlation between items p and q. According to the majority principle, $\sum C_{hpq}$ must be greater than or equal to a specified value M for a common consensus, where M depends on the degree of consensus to be achieved. This study that a common consensus is achieved when two-thirds of the experts agree. Consequently, M can be obtained by the following equation:

$$M=\tfrac{2}{3}N. \tag{4}$$

An influential relationship exists for $\sum C_{pq}$ when $\sum C_{hpq}>M$ in matrix Y. If an influential relation exists for $C_{p,\ q}$ and the number is s, then a fuzzy paired judgment matrix Y'_h can be built. Any expert can then adopt C_j, C_{overall} and the calculated $C_{p'q'}$ to generate a paired fuzzy measure judgment matrix Y'_h.

$$Y'_h=[h_{ab}], \quad h_{ab}=\frac{1}{h_{ba}}, \qquad a,b=1,2 \ldots r; \quad r=m+s+1, \tag{5}$$

a, b represents set C, $C_{p'q'}$ or C_{overall} and h_{ab} refers to the measurement judged by the relationship between set a and set b.

The maximum eigenvalue and eigenvector can be obtained by the expert paired set of fuzzy judgment matrix, which results in weighted partial set. The procedures of calculating the maximum eigenvalue and the maximum eigenvector may change slightly for a matrix containing some unknown h_{ab} values.

The weight of the appropriate part recognized by expert h in judgment matrix Y_h is then measured, and expressed by W_h as

$$W_h = (W_{h1}, W_{h2}, W_{h3}, \ldots, W_{hr}), \quad r = m + s + 1, \tag{6}$$

where $r = m+s+1$. According to the weight judged by N experts, the overall weight W_{overall} can be calculated by the following equation:

$$W_{\text{overall}} = \left(\prod_{h=1}^{N} W_h\right)^{1/N}. \tag{7}$$

The *λ-fuzzy* measure presented by Sugeno (1974) can then be applied to obtain the optimal $\lambda_{\max}$. Eq. (7) can be used to find other remaining sets of fuzzy measures that the experts cannot judge.

3.2. Fuzzy measures of strategies

Because the number of strategic objectives that have been accomplished is difficult to measure, experts' judgments were utilized in this study.

$$\begin{aligned} g(X) &= g(\{x_i | i = 1, 2, 3, 4 \ldots n\}) \\ &= \sum_{i=1}^{n} g_i + \lambda \sum_{i1=1}^{n-1} \sum_{i2=2}^{n} g_{i1} g_{i2} \\ &\quad + \lambda^2 \sum_{i1=1}^{n-2} \sum_{i2=2}^{n-1} \sum_{i3=3}^{n} g_{i1} g_{i2} g_{i3} \\ &\quad + \ldots + \lambda^{n-1} g_1 g_2 g_3, \ldots, g_n \end{aligned} \tag{8}$$

with m items to be improved, each given by $\{C_j\}$, where $j = 1, 2, 3, \ldots, m$, N experts $E = \{E_h\}$, where $h = 1, 2, 3, \ldots, N$ assess the level of development strategy $A = \{A_i\}$, where $i = 1, 2, 3, \ldots, n$ accomplished. The relationship between each strategy and objective items to be improved is divided into p grades with $R = \{R_k\}$, where $k = 1, 2, 3, \ldots p$. The subjective evaluation of expert h on the correlation grade between strategy A_i and objective item C_j can then be expressed by R_{hijk} as

$$R_{jijk} = \{R_k\}, \quad \text{where} \quad k = 1, 2, 3, 4 \ldots p,$$

where R_{ijk} represents the relationship found by expert h between strategy A_i and objective item C_j. Accordingly, the overall valuation of the relation between strategy A_i and objective item C_j for N experts is given by NR_{ij} as follows:

$$NR_{ij} = \left(\prod_{h=1}^{N} R_{ijk}\right)^{1/N}. \tag{9}$$

3.3. Evaluation of strategies

Let h be a measurable function from X to [0, 1]. Assuming that $h(x_1) \geqslant h(x_2) \geqslant \ldots \geqslant h(x_n)$, then the Choquet integral is defined as follows (Sugeno, 1974; Ishii and Sugeno, 1985):

$$\begin{aligned} \int h \, \mathrm{d}g &= h(x_n) g(H_n) + [h(x_{n-1}) - h(x_n)] g(H_{n-1}) \\ &\quad + \cdots + [h(x_1) - h(x_2)] g(H_1) \\ &= h(x_n)[g(H_n) - g(H_{n-1})] \\ &\quad + h(x_{n-1})[g(H_{n-1}) - g(H_{n-2})] \\ &\quad + \cdots + h(x_1) g(H_1), \end{aligned} \tag{10}$$

where $H_1 = \{x_1\}$, $H_2 = \{x_1, x_2\}$, …, $H_n = \{x_1, x_2, \ldots, x_n\} = X$.

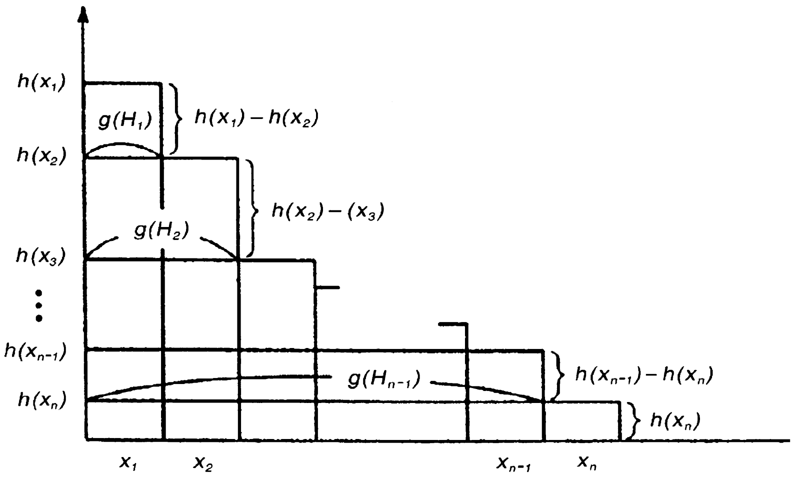


Fig. 2. The basic concept for Choquet integral (*Source*: Chen and Tzeng, 2001).

The basic concept of Eq. (10) can be illustrated as shown in Fig. 2 (Chen and Tzeng, 2001).

The aforementioned calculated fuzzy measure and overall fuzzy valuation NR_{ij} can be utilized to calculate the performance value of a certain strategy using the Choquet integral method. This flow-chart of evaluation process includes six major steps in Fig. 3. Consequently, the overall performance values of strategies are determined by the Choquet integral method above, and then sorted, resulting in strategic sorting of the SPC system.

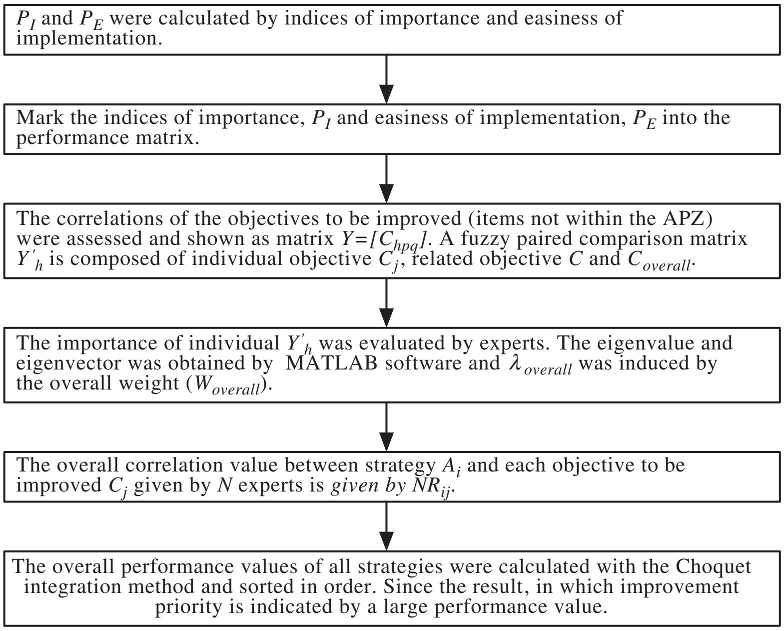
4. Empirical analysis

Academic literature concerning the implementation-critical requirements of SPC was surveyed (Antony, 2000; Dale, 1994; Oakland, 1999; Owen, 1989; Rungtusanatham et al., 1999). Based on these literatures, a questionnaire survey was designed for investigate and determine the potential importance and difficulties faced by the Taiwanese LCD industry in the SPC system. The twelve objective items required for SPC accreditation were considered as the objectives in this study, and are shown in Table 2.

LCD manufacturers strive to be SPC certified improve the internal and external quality of their systems. The twelve items in the questionnaire were measured by Likert's five-point scale. Point 1 represents very difficult or very unimportant, while point 5 represents very easy or very important. The questionnaire was divided into two parts. The first part was to evaluate the importance of these 12 items. The second part was targeted at SPC-certified manufacturers to improve the ease of implementing each item. The questionnaires were mailed out to 100 randomly selected manufacturers and consultants, and 68 questionnaires were returned. A reliability analysis of the questionnaire indicated that the overall reliability coefficient was 0.8896. According to Gay (1992), a reliability coefficient

Table 2
Implementation requirement for SPC system

No	Quality requirement (objective)
1	Training and education
2	Commitment and support from senior directors
3	Measurement system evaluation (MSE)
4	Appropriate use of control charts
5	Identification and measurement of critical quality attributes
6	Teamwork
7	Use of pilot study
8	Organizational culture change
9	Process prioritization and definition
10	Use of computer and SPC software packages
11	Use of SPC facilitators
12	Documentation and up dare of knowledge of processes



P_I and P_E were calculated by indices of importance and easiness of implementation.

Mark the indices of importance, P_I and easiness of implementation, P_E into the performance matrix.

The correlations of the objectives to be improved (items not within the APZ) were assessed and shown as matrix $Y=[C_{hpq}]$. A fuzzy paired comparison matrix Y'_h is composed of individual objective C_j, related objective C and $C_{overall}$.

The importance of individual Y'_h was evaluated by experts. The eigenvalue and eigenvector was obtained by MATLAB software and $\lambda_{overall}$ was induced by the overall weight ($W_{overall}$).

The overall correlation value between strategy A_i and each objective to be improved C_j given by N experts is *given by* NR_{ij}.

The overall performance values of all strategies were calculated with the Choquet integration method and sorted in order. Since the result, in which improvement priority is indicated by a large performance value.

Fig. 3. Flow chart of evaluative process.

above 0.8 for any test or scale is acceptable. The reliability coefficient of this questionnaire survey was thus satisfactory. Assessment comprises the following steps.

(1) The means and indices P_I and P_E for the importance and easiness of implementation items were calculated by Eqs. (1) and (2). Table 3 shows the calculation results.
(2) The importance index P_I and the performance easiness index P_I of each item were input into the system introduction performance matrix. Fig. 4 shows the calculation results. The items not within the APZ represent the objectives to be improved in this study.
(3) The correlations of the objectives to be improved (items not within the APZ) were assessed through Eqs. (3) and (4), and shown as matrix $Y=[C_{hpq}]$, where, $C_{hpq}>M$ indicates objective p is correlated with objective q, which is represented by C. A fuzzy paired comparison matrix Y'_h consists of individual objective C_j, related objective C and C_{overall}.
(4) Experts measured the importance of individual Y'_h. The eigenvalue and eigenvector was obtained by MATLAB software, and λ_{overall} was induced by the overall weight (W_{overall}).
(5) The process of implementing SPC was then adopted as an accreditation strategy. The relationship between a strategy and an objective is difficult to measure. Therefore, N experts determined the correlation between each strategy $A=\{A_i\}$, where $i=1, 2, 3, \ldots, 24$ and every objective $C=\{C_j\}$, where $j=1, 2, 3, \ldots, 6$. Each correlation R_{hijk} was assigned a score in the range 1–10. The overall correlation value between strategy A_i and each objective to be improved C_j given by N experts is given by NR_{ij}.
(6) The overall performance values of all strategies were calculated by the Choquet integral method, and sorted in order. Because the strategy defined here is the process of implementing SPC, a larger performance value indicates the implementation of SPC in the LCD industry is the most crucial phase.

According to Fig. 4, objectives not within the APZ are:

- *Objective* 2 (x_1): Commitment and support from senior directors.
- *Objective* 5 (x_2): Identification and measurement of critical quality attributes.

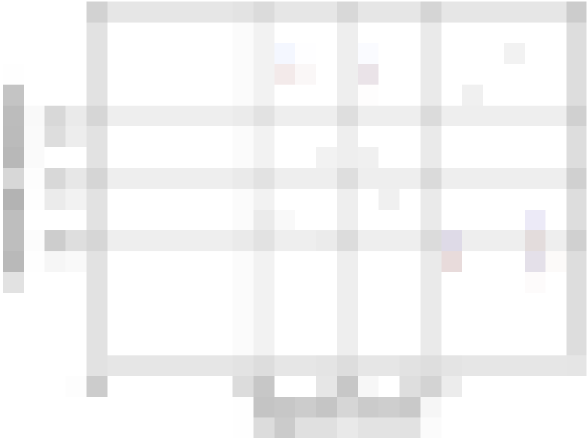


Fig. 4. Appropriate performance zones of introducing SPC system.

Table 3
Importance and easiness values of introducing objective items in SPC

Objective items	Importance	Easiness	P_I	P_E
1. Training and education	3.25	3.22	0.562	0.555
2. Commitment and support from senior directors	2.55	4.32	0.388	0.830
3. Measurement system evaluation (MSE)	2.50	2.50	0.375	0.375
4. Appropriate use of control charts	3.33	2.95	0.583	0.489
5. Identification and measurement of critical quality attributes	4.13	3.22	0.783	0.555
6. Team work	4.33	2.76	0.833	0.441
7. Use of pilot study	2.86	3.33	0.466	0.583
8. Organizational culture change	4.33	4.13	0.833	0.783
9. Process prioritization and definition	2.22	4.45	0.305	0.864
10.Use of computer and SPC software packages	2.33	3.94	0.333	0.736
11.Use of SPC facilitators.	2.55	3.00	0.341	0.500
12.Documentation and up dare of knowledge of processes	4.00	4.00	0.750	0.750

- *O*bjective 6 (x_3): Teamwork.
- *Objective* 9 (x_4): Process prioritization and definition.
- *Objective* 10 (x_5): Use of computer and SPC software packages.

The results of the questionnaire conducted on the experts are shown in matrix Y of correlations among objectives as follows:

$$Y = \begin{array}{c} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{array} \begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 1 & 0 & 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 1 & 0 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \end{pmatrix},$$

$$\sum_{h=1}^{9} x_{h12} = 5, \quad \sum_{h=1}^{9} x_{h13} = 3, \quad \sum_{h=1}^{9} x_{h14} = 3, \quad \sum_{h=1}^{9} x_{h15} = 4,$$

$$\sum_{h=1}^{9} x_{h23} = 2, \quad \sum_{h=1}^{9} x_{h24} = 4, \quad \sum_{h=1}^{9} x_{h25} = 7, \quad \sum_{h=1}^{9} x_{h34} = 6,$$

$$\sum_{h=1}^{9} x_{h35} = 3, \quad \sum_{h=1}^{9} x_{h45} = 3.$$

4.1. Establishing relation objective

Based on the majority principle, this study set $M = (2/3N)$. A relationship between two objectives exists as long as two-thirds of the experts make such judgment. Consequently, recognition by at least six experts indicated a relationship. Experts judged that relationships existed between objectives x_2 and x_5, and x_3 and x_4. Most experts thus found the following relationships between objective: $(r = 2)$

$(x_2, x_5)(x_3, x_4)$.

4.2. Establishing key objective judgment matrix

According to Eq. (5), a judgment matrix of 8×8 $(r = 4+2+1)$ can be constituted by the original objective (C_j), the overall objective (C_{overall}) and two sets of objectives with a relation. The overall weight of each objective was obtained using Eq. (6). Additionally, MATLAB was adopted to compute the maximum eigenvalue as well as the maximum eigenvector shown in Table 4.

Table 4
Weight judged by experts

Expert	*Objective*							
	x_1	x_2	x_3	x_4	x_5	x_{25}	x_{34}	$x_{overall}$
	Weight							
	W1	*W2*	*W3*	*W4*	*W5*	*W6*	*W7*	*W8*
1	0.15	0.03	0.09	0.08	0.11	0.193	0.347	1
2	0.09	0.07	0.06	0.12	0.08	0.218	0.362	1
3	0.16	0.06	0.12	0.11	0.05	0.162	0.339	1
4	0.11	0.10	0.07	0.09	0.14	0.289	0.201	1
5	0.19	0.09	0.11	0.11	0.11	0.226	0.164	1
6	0.08	0.04	0.05	0.08	0.15	0.262	0.338	1
7	0.13	0.12	0.14	0.13	0.09	0.235	0.155	1
8	0.20	0.10	0.15	0.03	0.05	0.192	0.278	1
9	0.17	0.05	0.18	0.11	0.11	0.186	0.194	1
W_{overall}	0.142	0.073	0.108	0.096	0.099	0.218	0.264	1

4.3. Applying the λ-fuzzy measures

A quadric equation was obtained from fuzzy measures in Eq. (9). The optimum $\lambda_{\max}$, and fuzzy measures of other sets were obtained by this equation.

$$W6 = g\{(x_2, x_5)\} = g(x_2) + g(x_5) + \lambda_{\text{overall}} g(x_2) g(x_5)$$
$$0.3 = 0.08 + 0.12 + \lambda_{\text{overall}} \times 0.08 \times 0.12,$$

$$W7 = g\{(x_3, x_4)\} = g(x_3) + g(x_4) + \lambda_{\text{overall}} g(x_3) g(x_4),$$
$$0.27 = 0.06 + 0.08 + \lambda_{\text{overall}} \times 0.06 \times 0.0,$$

$$\begin{aligned} W8 &= g\{(x_1, x_2, x_3, x_4, x_5)\} \\ &= \sum_{i=1}^{5} g(x_{i1}) + \lambda_{\text{overall}} \sum_{i1=1}^{4} \sum_{i2=2}^{5} g(x_{i1}) g(x_{i2}) \\ &\quad + \lambda_{\text{overall}}^2 \sum_{i1=1}^{3} \sum_{i2=2}^{4} \sum_{i3=3}^{5} g(x_{i1}) g(x_{i2}) g(x_{i3}) \\ &\quad + \lambda_{\text{overall}}^3 \sum_{i1=1}^{2} \sum_{i2=2}^{3} \sum_{i3=3}^{4} \sum_{i4=4}^{5} g(x_{i1}) g(x_{i2}) g(x_{i3}) g(x_{i4}) \\ &\quad + \lambda_{\text{overall}}^4 \sum_{i4=4}^{5} g(x_1) g(x_2) g(x_3) g(x_4) g(x_5), \end{aligned}$$

$$\begin{aligned} 1 &= 0.518 + 0.106\lambda_{\text{overall}} + 0.01\lambda_{\text{overall}} \\ &\quad + 0.0004\lambda_{\text{overall}}^3 + 0.000001\lambda_{\text{overall}}^4. \end{aligned}$$

One set of quadratic equations was obtained from the four equations above. The smallest difference sum λ_{overall} was then calculated by MATLAB, resulting in $\lambda_{\text{overall}} = 3.287$. Based on the induced

λ_{overall}, the fuzzy measures of all objectives sets were obtained in Table 5.

4.4. Establishing relativity of strategy and objective

The Choquet integral method and the overall weight of fuzzy measures in Table 5, were adopted to calculate the integrated performance value when implementing SPC. Table 6 summarizes the correlation between every strategy and each objective according to expert opinions.

4.5. Establishing the performance value

An overall strategy evaluation value was obtained by integrating the opinions from nine experts. The hypothesis in this study, the overall strategy evaluation value was found to be that obtained when practicing SPC. Strategy A1 is considered below an example to further discuss the calculations of the overall evaluation value for each strategy and its correlations. Correlation estimates for five objectives are sorted as follows:

$$\begin{aligned} & x_1(\text{Objective 2}) : 8.25 > x_5(\text{Objective 10}) : 7.88 \\ & > x_3(\text{Objective 6}) : 7.28) > x_4(\text{Objective 9}) : 6.54 \\ & > x_2(\text{Objective 5}) : 4.73. \end{aligned}$$

Consequently, the overall estimate of strategy A1 was computed by the Choquet integral utilize in Eq. (10) as follows:

$$\begin{aligned} \int h\,\mathrm{d}g = {} & h(x_1)g(H1) + h(x_2)[g(H2) - g(H1)] \\ & + h(x_5)[g(H3) - g(H2)] + h(x_3)[g(H4) - g(H3)] \\ & + h(x_4)[g(H5) - g(H4)] \\ = {} & 8.25 \times 0.142 + 7.88(0.287 - 0.142) + 7.28 \\ & \times (0.496 - 0.287) + 6.54 \times (0.748 - 0.496) \\ & + 4.73 \times (1 - 0.7487) = 6.677, \end{aligned}$$

where $g(H_1) = g(\{x_1\})$, $g(H_2) = g(\{x_1, x_2\})$, $g(H_3) = g(\{x_1, x_2, x_5\})$, $g(H_4) = g(\{x_1, x_2, x_5, x_3\})$, $g(H_5) = g(\{x_1, x_2, x_5, x_3, x_4\})$.

The overall performance values for other strategies were also calculated by these procedures. Table 7 shows the calculation results of all 29 strategies.

4.6. Discussion

As mentioned above, the first CSF is identical to other management systems. Consistent support among senior directors for SPC implementation is needed to enable the SPC application to make clear goals for all members to increase efficiency and reduce resistance (Schippers, 1998). The second CSF is "Measuring system analysis". A successful SPC system should be based on a reliable measurement system. Furthermore, statistical data should be collected according to a measuring system analysis to match manufacturing process capability. Otherwise, an unreliable measurement system reduces the effectiveness of SPC. The third CSF is "Establishing coordination and operation of the cross functional group". A cross-function team is more efficient than internal independent departments or external consulting companies in the application process, because a cross-function team not only understands the internal management process, quality guarantee system and manufacturing process, but can also coordinate tasks smoothly among other departments. The fourth CSF is

Table 5
Weights of all objectives sets

Key objective sets	Weight	Key objective sets	Weight	Key objective sets	Weight	Key objective sets	Fuzzy measure values
x_1	0.08	x_{12}	0.199	x_{123}	0.326	x_{1234}	0.549
x_2	0.08	x_{13}	0.166	x_{124}	0.368	x_{1235}	0.672
x_3	0.06	x_{14}	0.195	x_{125}	0.455	x_{1245}	0.744
x_4	0.08	x_{15}	0.254	x_{134}	0.320	x_{1345}	0.661
x_5	0.12	x_{23}	0.164	x_{135}	0.399	x_{2345}	0.655
		x_{24}	0.192	x_{145}	0.448	x_{12345}	1
		x_{25}	0.254	x_{234}	0.316		
		x_{34}	0.159	x_{235}	0.394		
		x_{35}	0.212	x_{245}	0.443		
		x_{45}	0.245	x_{345}	0.387		

Table 6
Correlations between development strategies and objectives

No. strategies	Correlations	Objectives				
		x_1	x_2	x_3	x_4	x_5
A1	Level of support from senior directors in implementation of SPC	8.25	4.73	7.28	6.54	7.88
A2	Senior directors oversee and announce quality policy in person	7.23	4.12	3.71	4.21	5.00
A3	Give full support of resources and budgets	3.74	2.21	5.01	4.64	6.54
A4	Establishing coordination and operation of cross functional group	8.87	5.18	6.38	4.29	3.77
A5	Choosing an independent unit in implementing the SPC	6.16	4.34	3.02	3.70	5.78
A6	Through SPC experts or consultants assistance and guidance	4.14	3.08	3.66	5.43	2.52
A7	Participation and recognition of the employees	5.94	4.22	4.63	3.66	6.32
A8	Education instructors and materials	4.14	6.38	6.37	5.51	5.63
A9	Proper education and training for quality involved employees	3.33	4.83	3.56	2.43	3.11
A10	With the combination of quality authentication system	2.11	3.20	6.58	5.20	2.02
A11	Do not combine with the quality system, two systems implemented simultaneously	3.65	4.73	5.49	7.03	6.22
A12	Combination with other quality system	2.51	3.69	2.87	5.38	5.49
A13	Productive type	3.92	5.69	4.03	4.26	4.73
A14	Level of variation according to Normal Distribution should be minimized	3.48	7.20	6.89	5.13	6.02
A15	Product defects of improved	3.12	6.97	3.04	2.25	5.64
A16	The selection of manufacturing process and the level of involvement	2.33	7.78	5.97	3.13	5.02
A17	The selection of quality attributes and the level of involvement	2.98	6.76	5.67	2.78	4.54
A18	Measuring system analysis	4.47	5.49	8.85	4.67	6.58
A19	Decision of group sampling	4.53	7.32	4.56	3.92	5.21
A20	Application of control chart	2.62	2.34	5.39	6.83	6.88
A21	The employees cooperate and audit regularly	1.92	2.58	5.60	6.47	4.54
A22	Standardization	2.07	3.78	2.32	4.69	4.41
A23	The document controls and the product quality record	1.62	3.28	4.63	4.42	2.98
A24	Automatic tool application	2.52	3.69	5.82	7.31	4.21
A25	Proper statistical software choosing and applying	2.62	3.92	5.32	8.42	4.58
A26	Application of statistical tool or quality control method	2.32	6.21	3.27	4.41	7.87
A27	Continual improvements in manufacturing process quality	3.98	4.92	3.523	6.79	8.45
A28	Performance measurement index	2.42	6.42	5.68	3.65	5.31
A29	Combination of employee performance evaluation, rewards and penalties	7.62	3.38	2.12	3.80	6.05

"Education instructors and materials". Instructors guide the implementation of SPC system principles, and their professional knowledge and experience in statistics provide the key for successfully applying SPC when system bottlenecks occur. The instructors and materials also support new users of the system. The fifth CSF is "Level of variation according to Normal Distribution should be minimized". The minimization of manufacturing process variation is easily ignored during the initial phase of applying SPC. Business also mistakenly considers SPC as an all-powerful tool and forgets that SPC is merely a management system. The effectiveness of SPC is reduced in situations involving significant manufacturing process variation. This study also found a low correlation between SPC system and quality assurance certification. Experts believe that this low correlation occurs because the statistical methods for quality assurance certification lack flexibility and do not match the practical work requirements of business.

5. Conclusion

SPC become QS-9000 quality system essential technique manual after the formal publication of the SPC quality system in 1994. The LCD industry was requisitioned to implement SPC requirements and accreditation, as had previously occurred in the automobile industry. Therefore, the LCD industry must apply the SPC quality system in the near future, despite possible customer objections. Failure to master the critical objectives and crucial strategies during the introduction and certification of SPC

Table 7
Overall performance values of Choquet integral

No.	Performance value	Priority
A1	6.676	1*
A2	4.566	10
A3	3.959	16
A4	5.229	3*
A5	4.209	12
A6	3.440	23
A7	4.662	8
A8	5.141	4*
A9	3.135	26
A10	3.106	27
A11	4.840	6
A12	3.403	25
A13	4.227	11
A14	4.981	5*
A15	3.417	24
A16	3.831	19
A17	3.812	20
A18	5.401	2*
A19	4.623	9
A20	4.026	14
A21	3.453	22
A22	2.901	28
A23	2.821	29
A24	3.946	17
A25	4.128	13
A26	3.795	21
A27	4.745	7
A28	3.889	18
A29	4.017	15

A larger overall performance value for a stage indicates that the LCD industry needs to pay special attention to it when implementing SPC. The top five stages with the greatest performance value are (marked with "*"):
A1: Level of support from senior directors in implementation of SPC.
A18: Measuring system analysis.
A4: Establishing coordination and operation of cross-functional groups.
A8: Education instructors and materials.
A14: Level of variation according to Normal Distribution should be minimized.

causes time and money to be wasted. Consequently, this study integrated three scientific approaches, namely the performance matrix, fuzzy measure analysis and Choquet integral. Therefore, this study categorized the critical objectives and strategies for introducing and accrediting SPC systems. SPC is a powerful technique for monitoring, managing, analyzing and improving process performance by statistical methods. Therefore, this study presented a complete assessment model for helping LCD manufacturers locate objectives and strategies for improvement when introducing and certifying of SPC, and for improving the production efficiency in terms of cost and time.

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References

Amid, A., Ghodsypour, S.H., O'Brien, C., 2006. Fuzzy multi-objective linear model for supplier selection in a supply chain. International Journal of Production Economics 104 (2), 394–407.

Antony, J., 2000. The key ingredients for making SPC successful in organizations. Measuring Business Excellence 4 (4), 7–10.

Chang, S.H., 2005. The TFT–LCD industry in Taiwan: Competitive advantages and future developments. Technology in Society 27, 199–215.

Chang, S.L., Wang, R.C., Wang, S.Y., 2006. Applying fuzzy linguistic quantifier to select supply chain partners at different phases of product life cycle. International Journal of Production Economics 100 (2), 348–359.

Chen, F.T., 1991. Quality management in the chain saw industry: A case study. International Journal of Quality and Reliability Management 8 (1), 31–39.

Chen, Y.W., Tzeng, G.H., 2001. Using fuzzy integral for evaluating subjectively perceived travel costs in a traffic assignment model. European Journal of Operational Research 130, 653–664.

Dale, D.G., 1994. Managing Quality. Prentice-Hall, Hemel Hempstead.

Gay, L.R., 1992. Educational Research Competencies for Analysis and Application. Macmillan, New York.

Hung, Y.H., Huang, M.L., Chen, K.S., 2003. Service quality evaluation by service quality performance matrix. Total Quality Management 14 (1), 79–89.

Ishii, K., Sugeno, M., 1985. A model of human evaluation process using fuzzy integral. International Journal of Machine Studies 22 (1), 19–38.

Ko, C.H., Cheng, M.Y., 2003. Hybrid use of AI techniques in developing construction management tools. Automation in Construction 12, 271–281.

Lascelles, D.M., Dale, B.G., 1988. A study of quality management methods employed in UK automotive suppliers. Quality and Reliability Engineering International 4 (3), 301–309.

Lee, H.Y., 1999. Strategic analysis of Taiwan's TFT-LCD industry with game theoretical approach. Master Thesis, Chiao-Tung University, Taiwan.

Lee, K.M., Leekwang, H., 1995. Identification of λ-fuzzy measure by genetic algorithm. Fuzzy Sets and Systems 75 (3), 301–309.

Lin, W.T., Chen, S.C., Chen, K.S., 2005. Evaluation of performance in introducing CE marking on the European market to the machinery industry in Taiwan. International Journal of Quality & Reliability Management 22 (5), 503–517.

Lin, W.T., Chen, S.C., Jang, H.F., Wu, H.H., 2006. Performance evaluation of introducing QS-9000 to the Taiwanese semiconductor industry. International Journal of Advanced Manufacturing Technology 27, 1011–1020.

MacCarthy, B.L., Wasusri, T., 2002. A review of non-standard applications of statistical process control (SPC) charts. The International Journal of Quality & Reliability Management 19 (2/3), 295–320.

Modarress, B., Ansari, A., 1989. Quality control techniques in US firms: A survey. Production and Inventory Management Journal 30 (2), 58–62.

Oakland, J.S., 1999. Statistical Process Control, fourth ed. Butterworth-Heinemann, Oxford.

Owen, M., 1989. SPC and Continues Improvement. IFS Publication, Bedford.

Parasuraman, A., Zeithaml, V.A., Berry, L.L., 1985. A conceptual model of service quality and its implications for future research. Journal of Marketing 49, 41–50.

Parasuraman, A., Zeithaml, V.A., Berry, L.L., 1991. Understanding customer expectation of service. Sloan Management Review 39–48.

Perng, Y.H., Hsueh, S.L., Yan, M.R., 2005. Evaluation of housing construction strategies in China using fuzzy-logic system. International Journal of Strategic Property Management 9, 215–232.

Rungasamy, S., Antony, J., Ghosh, S., 2002. Critical success factors for SPC implementation in UK small and medium enterprises: Some key findings from a survey. The TOM Magazine 14 (4), 217–224.

Rungtusanatham, M., Anderson, J.C., Dooley, K.J., 1997. Conceptualizing organizational implementation and practice of statistical process control. Journal of Quality Management 2 (1), 113–137.

Rungtusanatham, M., Anderson, J.C., Dooley, K.J., 1999. Towards measuring the SPC implementation/practice construct. International Journal of Quality & Reliability Management 16 (4), 301–329.

Schippers, W.A.J., 1998. Applicability of statistical process control techniques. International Journal of Production Economics 56–57 (20), 525–535.

Singh, R., Gilbreath, G., 2002. A real-time information system for multivariate statistical process control. International Journal of Production Economics 75 (1–2), 161–172.

Sugeno, M., 1974. Theory of fuzzy integral and its application. Ph.D. Thesis, Tokyo Institute of Technology.

Tu, F.K., 2003. Evaluating development strategies of resource integrate for Kaoshiung city and harbor. Master Thesis, Huafan University, Taiwan.

Woodall, W.H., Montgomery, D.C., 1993. Research issues and ideas in statistical process control. Journal of Quality Technology 31 (4), 376–386.

Wu, Z., Shamsuzzaman, M., Wang, Q., 2006. The cost minimization and manpower deployment to SPC in a multistage manufacturing system. International Journal of Production Economics, in press, Available online 22 August.

Zadeh, L.A., 1965. Fuzzy sets. Information and Control 8 (3), 338–353.