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# A study on applying FMEA to improving ERP introduction

## An example of semiconductor related industries in Taiwan

Ching-Chow Yang
*Department of Industrial Engineering, Chung-Yuan Christian University, Taiwan, ROC, and*
Wen-Tsaan Lin, Ming-Yi Lin and Jui-Tang Huang
*Department of Industrial Engineering and Management, National Chin-Yi Institute of Technology, Taiwan, ROC*

**Abstract**

**Purpose** – Facing the competition pressure of internationalization and diversification, the semiconductor industry of Taiwan has to increase the activation/utilization rate of machines, enhance flow speed and values, cut down delivery and reduce costs in an efficient way in reaction to a shortening product life cycle and the global market requirements. As a result, introduction of ERP has become a critical factor of enhancing competitiveness. The purpose of this study is establish a systematic evaluation and improvement mechanism to locate the risk priority number (RPN) of implementation items via failure mode and effects analysis (FMEA) for semiconductor related industries in Taiwan while introducing ERP.

**Design/methodology/approach** – A standardized system introduced performance matrix based on the performance evaluation matrix (PEM) will be established in accordance with the locations of severity (S), occurrence (O) and detection (D) and the three RPN indices, in the PEM. Performance levels will be assessed and the performance improvement strategy introduced by the system will be formulated. Finally, items falling within the non-appropriate performance zone will be specified through the quality function development (QFD) method.

**Findings** – From the results of the case study, the proposed systematic evaluation and improvement on the performance of introducing ERP for the semiconductor industry in Taiwan can be conducted in an efficient way.

**Practical implications** – All that the management needs to do is to correspond to the positions of these RPN indices of implementation items on the performance matrix. Performance levels will be assessed and the performance improvement strategy introduced by the system will be formulated.

**Originality/value** – The PEM is demonstrated to be suitable to define the best countermeasure can be sought to serve as a reference for the semiconductor related industries in Taiwan to introduce ERP.

**Keywords** Manufacturing resource planning, Failure modes and effects analysis, Performance management, Quality function deployment, Semiconductors, Taiwan

**Paper type** Research paper

## 1. Introduction

ERP, an abbreviation of enterprise resource planning has been promoted by the American Production and Inventory Control Society (APICS) since 1970. After the development of several decades, the operation system of MRP has extended to marketing, finance and personnel. Meanwhile, it also turned out to be a production

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control system adopted by the manufacturing industry both in America and Taiwan. However, as product-directed market has been transformed to a customer-oriented one along with the popularity of the internet, the channel among enterprises, customers and suppliers is reinforced and the traditional cooperative relationship between enterprises and suppliers has also been changed. As the enterprises recognize that the life cycle of products is getting shorter, customers' requirements are diversifying and the demand for service quality is increasing, they are in a hurry to throw away the old information system and ERP is developed accordingly.

The overall resources of an enterprise can be planned, managed and integrated through ERP. In generally, ERP can be applied to finance, human resources, manufacturing and logistics, supply chain management and data analysis. Currently, overseas and domestic ERP supplies include SAP, People-Soft, Baan, Oracle, J.D. Edwards, Data Systems Consulting Co., Ltd. (DSC), FAST Technologies Inc. and Proyoung Business Information System Co. Ltd., etc. ERP application modules vary with system suppliers. A comparison among SAP, Oracle and several domestic ERP system suppliers indicates that ERP modules can be divided into logistics module of marketing and distribution, quality management module, enterprise solution module, assets accounting module, material management module, plant maintenance module, work flow module, cost control module, production planning module, human resource module, project management module and financial accounting module. Concerning previous research documents on ERP, Motwani *et al.* (2002) explored the keys to a successful implementation of ERP and explained the implementation process via cases. Hong and Kim (2002) investigated key success factors of introducing ERP successfully from the perspective of organizational suitability.

The first transistor developed in Bell Lab in 1947 was a new page in the history of electronic products because that was the beginning of a new century of lighter, thinner and smaller electronic products has begun. The first integrated circuit (IC) was successfully developed by Texas Instruments in 1958, which replaced the leading role played by the transistor in the semiconductor industry. At the same time, IC also became a major critical component part to a wide range of electronic product applications. By 1986, the semiconductor industry system around the world was based on the manufacturing trade, including design/layout, manufacturing, testing, packaging and marketing. The importance and necessity of introducing ERP are undeniable and the semiconductor industry has occupied a large market share and advantages in Taiwan for the past few years. Nevertheless, they also have to confront keen competitions among a number of large-scaled enterprises. The application of FMEA to ERP introduction not only helps increase in overall operation performance and external effects, but also promotes substantial effect for semiconductor related industries in Taiwan.

To conclude, the main points of developing ERP consist of initial planning suitability and adaptability of personnel and organization, system appropriateness, education training, support system, consulting company, adjustment of each ERP module and after-sales service. Consequently, satisfaction and difficulty of ERP action items will be explored here in accordance with the aforesaid major points and suggestions for improvement. Major benefits that are expected to be achieved in this research plan are:

- An objective and convenient performance matrix to facilitate the evaluation of overall performance of implementing ERP for semiconductor related industries in Taiwan.

- The utilization of three indices of FMEA to judge ERP performance level, including performance of implementing each ERP module.
- The use of QFD to determine critical ERP implementation items in addition to evaluating the strengths and weaknesses of semiconductor for the reference of semiconductors related industries in Taiwan while establishing ERP objectives. Accordingly, follow-up improvements in ERP may be adjusted and a systematic evaluation on the performance of introducing ERP can be conducted.

It is expected that the direction of the above objectives will not only help promoting the performance of implementing ERP but also provide a useful reference for domestic semiconductor related industries introducing ERP.

## 2. FMEA methodology

Thanks to the upsurge of export trade for the past few years, companies have been trying to enhance the reliability of their products to grasp such a good opportunity for business development. The one and only way is prevention and failure elimination. Therefore, failure mode and effects analysis (FMEA), was born. The so-called FMEA is a preventive technology for reliability design and analysis by applying structured systematic procedures and methods to locate the potential failure modes of products at an early stage. Causes of failures and impacts of such failures upon the subsystem and the system above are examined for adoption of proper preventive measures and improvement proposals. It is usually performed in the beginning of a product life cycle to increase the reliability of products or process and to reduce the costs for follow-up corrective and improvement actions (Sharon, 1998).

In 1977, Ford Motor Company announced the operation standards of FMEA for promotion and application in the education manual (Ford, 1988), which was adopted by other motor companies one after another and further divided into Design FMEA and Process FMEA. In addition to FMEA implemented inside a company, suppliers were asked to conduct design and process FMEA for the parts they supplied. In 1985, International Electronic Commission (IEC) published FMEA standards for system reliability. IEC812 is the modified FMEA operational procedures based on MIL-STD-1629A expounding FMEA for electronic, mechanical and hydraulic equipment or parts. Besides, it also mentioned the applicability of FMEA to software and personnel reliability analyses. The failure risk evaluation method in the education manual of Ford Motor Company is the most traditional and has been generally adopted by all walks of life currently. The data of risk priority number (RPN) are based on risk assessment. The multiplied risk factor indices refer to Severity (S), the outcome of a failure, Occurrence (O), the chance of a failure and Detection (D), the chance of a failure is not detected by customers or the difficulty level of detection (Tables I-III). A scale of ten-points is served to be a comparison table for the level and grade of these three factors. RPN is the outcome of multiplying occurrence, detection and severity and can be represented as Formula 1. For the decision factor number of RPN, different decision factors and grades judgment principles can be formulated in accordance with FMEA applications.

$$\mathrm{RPN} = S \times O \times D \tag{1}$$

| Severity level | Grade |
|---|---|
| Customer may not pay attention | 1 |
| Customer is slightly troubled | 2 |
| | 3 |
| Customer is not satisfied | 4 |
| | 5 |
| | 6 |
| Customer is tremendously unsatisfied | 7 |
| | 8 |
| Life and safety of customer are affected | 9 |
| | 10 |

**Table I.**
Severity (S)

| Chance of occurrence | Grade | Probability of occurrence |
|---|---|---|
| Almost impossible | 1 | 0 |
| Very low | 2 | 1/20000 |
| | 3 | 1/10000 |
| Medium | 4 | 1/2000 |
| | 5 | 1/1000 |
| | 6 | 1/200 |
| High | 7 | 1/100 |
| | 8 | 1/20 |
| Very high | 9 | 1/10 |
| | 10 | 1/2 |

**Table II.**
Occurrence (O)

| Failure detection level | Grade | Probability of defects received by customer (%) |
|---|---|---|
| Almost impossible | 1 | 0-5 |
| Very low | 2 | 6-15 |
| | 3 | 16-25 |
| Medium | 4 | 26-35 |
| | 5 | 36-45 |
| | 6 | 46-55 |
| High | 7 | 56-65 |
| | 8 | 66-75 |
| Very high | 9 | 76-85 |
| | 10 | 86-100 |

**Table III.**
Detection (D)

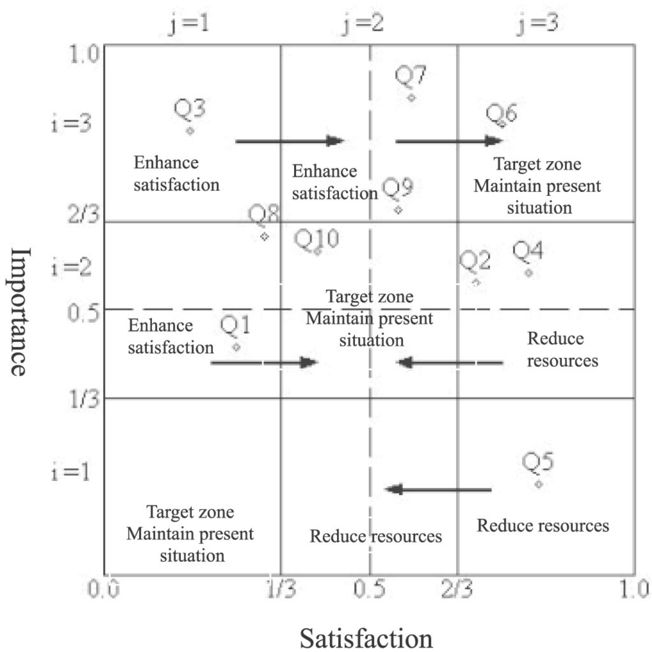
## 3. Performance evaluation matrix integrated with FMEA

### *3.1 Indices of PEM*

Parasuraman *et al.* (1985, 1991) indicated that the service quality can be assessed by customer's feelings about implementing a certain service item (importance) and actual feelings after service (satisfaction). Thus, three FMEA indices of Severity, Occurrence and Detection were applied the to failure possibility of related items while introducing ERP and their grading ranges from 1 to 10.

Lambert and Sharma (1990) proposed a performance evaluation matrix for performance improvement. Hung *et al.* (2003) modified the ideas of PEM presented by Lambert *et al.* (1990) and applied more than two indices to the performance matrix. The index of importance is plotted as a *Y*-coordinate and that of satisfaction as the *X*-coordinate. Both indices are within the range [0, 1]. Four thresholds [*0.0*, *1/3*, *2/3*, *1.0*] are adopted to define three levels of satisfaction – least satisfied [0.0, 1/3], moderately satisfied [1/3, 2/3] and most satisfied [2/3, 1.0] and three levels of importance – least important, moderately important and most important. The system-introduced performance matrix is divided into nine Performance Zones that represent the effectiveness of various system–introduced directive items. $B_{ij}(i, j = 1, 2, 3)$ is used to represent the performance zones. Critical directive items must be identified and requirements must be met with regard to cost. Therefore, a company needs to adopt the management strategy of obtaining an "appropriate performance level". Consequently, an enterprise must define the "target zone" of the system-introduced performance matrix as the "appropriate performance zone" in which satisfaction equals the importance ($i = j$) ($B_{11}$, $B_{22}$ and $B_{33}$). The satisfaction exceeds the importance ($i < j$) in zones $B_{12}$, $B_{13}$ and $B_{23}$. Applied resources then should be decreased to reduce the cost of introduction. Importance is higher than satisfaction ($i > j$) in zones $B_{31}$, $B_{32}$ and $B_{21}$. Applied resources should then be increased to enhance the performance.

The performance should be improved to the "target zones" in the direction of the arrow (see Figure 1) The strategies for improvement in each performance zone are of three types – increase resources to enhance satisfaction, decrease resources to reduce




**Source:** Modified from Huang *et al.* (2003)

**Figure 1.**
Appropriate performance zone

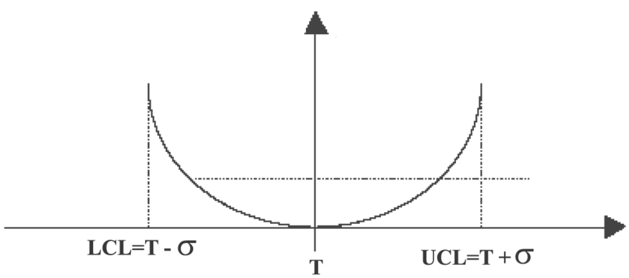
the cost of introducing the system, and maintain the present situation. The management needs only to determine the type of the performance matrix from the position of the indices of importance and satisfaction of the directive items of interest. Accordingly, the performance level of each directive item can be assessed and projects and strategies for improvement used to be formulated. Thus, the performance matrix is a simple and easy way to use graphic analysis tool and is quite helpful in evaluating the performance of introducing a system.

### *3.2 Integration of performance matrix indices and definition of performance control lines*

When coordinates in the performance matrix model presented by Hung *et al.* (2003) fall within or get very close to the appropriate performance zone (such as Q2, Q8, Q9), an objective diagnosis on performance and a judgment of required improvements can't be made merely by these coordinates. Consequently, the area of a performance evaluation matrix, Shewhart control chart (Montgomery, 2001) and the ideas of Taguchi method were integrated to set up a control boundary model. To maintain the coordinates of the indices within the appropriate performance zone, a performance control center line has to be mapped. Upper and lower performance control limits were established in accordance with the coordinates and the area. In this way, an objective diagnosis and a judgment of any improvement requirement can be made.

Taguchi *et al.* (1989) considered that the quality traits of products should be close to the target values as much as possible since a farther target value meant greater loss. That is a bigger cost loss area stands for higher cost loss and vice versa (see Figure 2)

Different coordinates of performance indices form different areas. First, the performance control line was defined via the Shewhart control chart and the target value was set to 0. Based on heuristics, 99.73 percent of them fell $\pm 3$ times of standard deviation, which meant a failure rate of about 0.27 percent. Whereas, 95.44 percent of them landed within the standard deviation by $\pm 2$ times with a failure rate of 4.56 percent. About 68.26 percent falls within $\pm 1$ time of standard deviation, which indicates a failure rate of about 31.74 percent. If $\pm 3$ and $\pm 2$ times of standard deviations were applied in this study, unqualified question items would not be able to locate since there were plenty of ERP items and the failure rate was extremely low. Thus, according to rule 80/20 (80 percent of the problems concentrated on 20 percent of




**Source:** Taguchi *et al.* (1989)

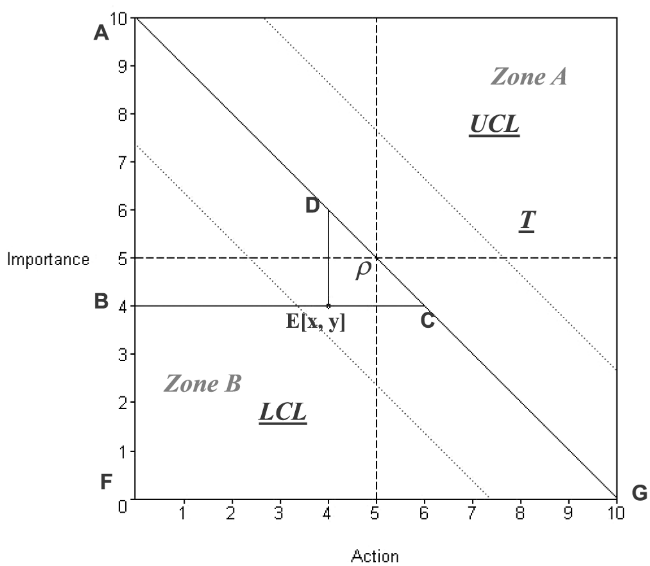
**Figure 2.**
Taguchi quality loss curve

items to be implemented), the standard deviation by $\pm 1$ time was used to establish the upper control line (UCL) and the lower control line (LCL) as follows:

- upper control line ($\text{UCL} = T + \sigma$);
- target value of center line ($T = 0$); and
- lower control line ($\text{LCL} = T - \sigma$)

The standard deviation may be adjusted in accordance with the requirements defined by the company. In Figure 3, the scoring division of FMEA indices – Severity, Occurrence and Detection is [0,10]. Therefore, the $Y$-coordinate and $X$-coordinate of the performance matrix were changed to [1,10] and a square area of $10 \times 10 = 100$ was obtained. If the target value of the diagonal center line is $T = 0$, the performance matrix can be divided into two regular triangles with an area of 50, respectively. When the coordinates fall on $E$, an isosceles triangle ($CDE$) with an area of $\rho$ can be formed by extending it to the center line $T = 0$.

According to Taguchi (1989), when the area $\rho$ of abnormal coordinates outside UCL (Zone A) is greater, it means Severity, Occurrence and Detection are extremely high and the index needs to move towards the performance control boundary for improvement. Consequently, resources to be invested need to increase in order to reduce failure factors, which will result in a positive weighted value. On the contrary, when the area $\rho$ of abnormal coordinates outside LCL (Zone B) is greater, it means severity, occurrence and detection have a very low failure. Such performance indices should move toward the performance control boundary and resources to be invested need to decrease to prevent wastage and support Zone A, which will result in a




**Source:** Rearranged in this research

**Figure 3.** Improved weighted indices

negative weighted value. The smaller these three indices, the better the results as shown in Figure 4.

Prior to calculating the area of the isosceles triangle (*CDE*), a modified value 2 was given so that the formula of (base *x* height)/2 might be transformed to base *x* height. The purpose of it was to maintain the area $\rho$ above and under the center line within $1 \sim 100$.

Area $\rho$ can be calculated from Figure 3. First, the edge length of an Area $\rho$ needs to be known. Thus, suppose the area of the isosceles triangle (*CDE*) is $\rho$:

$$\overline{BE} = x, \overline{BF} = y, \overline{CE} = z \begin{cases} x = 1 \sim 10 \\ y = 1 \sim 10 \\ z = 1 \sim 10 \end{cases}$$

As $x$ and $y$ are known, $z$ will be obtained through the equations leading to a trapezoid $BCFG = \Delta AFG - \Delta ABC$. The triangle formula as base $x$ and height $c$ will be calculated as:

$$(x + z + 10) \times y = 100 - [(x + z) \times (10 - y)]$$

$$xy + yz + 10y = 100 - [10x + 10z - xy - yz]$$

$$z = 10 - x - y$$

Suppose there are n coordinates of indices, which would result in area $\rho$ of $n$ isosceles triangles ($\Delta CDE$).

Then:

$$\rho_i = z^2 = (10 - x_i - y_j)^2 \begin{cases} \rho = 1 \sim 100 \\ i = 1 \sim n \\ j = 1 \sim n \end{cases} \quad (2)$$

Accordingly, different coordinates of performance indices form various areas. The upper control line (UCL) and the lower control line (LCL) cannot be calculated until the population mean $\mu$ and the population standard deviation $\sigma$ of all areas $\rho_i$ are known. Suppose each implementation item for an enterprise introducing a new system is subject to normal distribution, $\mu$ and $\sigma$ can be obtained as:

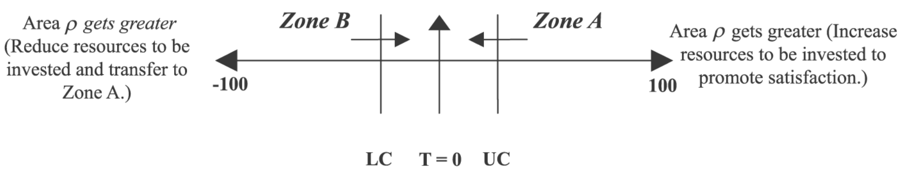



**Figure 4.**
Area $\rho$ of performance index coordinates

$$\mu = \frac{\sum_{i=1,j=1}^{n} (10 - x_i - y_j)^2}{n} \tag{3}$$

$$\sigma = \sqrt{\frac{\sum_{i=1,j=1}^{n} (10 - x_i - y_j)^4}{n} - \mu^2} \tag{4}$$

According to the upper and lower control lines defined above, equations 5 and 6 can be derived as follows:

Upper control line:

$$\mathrm{UCL} = \sqrt{\frac{\sum_{i=1,j=1}^{n} (10 - x_i - y_j)^4}{n} - \mu^2} \tag{5}$$

Target value of center line: $T = 0$

Lower control line:

$$\mathrm{LCL} = -\sqrt{\frac{\sum_{i=1,j=1}^{n} (10 - x_i - y_j)^4}{n} - \mu^2} \tag{6}$$

After getting the control line model, coordinates of UCL and LCL on the performance matrix can be derived in a reverse way. UCL results in a performance area $\rho$. Coordinates of UCL can be obtained through equation 4 as:

$$\mathrm{UCL} = \sqrt{\frac{\sum_{i=1,j=1}^{n} (10 - x_i - y_j)^4}{n} - \mu^2} = (10 - x_i - y_j)^2 => $$

$\therefore$

$$\left(\sqrt{\frac{\sum_{i=1,j=1}^{n}(10-x_i-y_j)^4}{n}-\mu^2}\right)^{\frac{1}{2}}=10-x_i-y_j$$

$$=>10-\left(\sqrt{\frac{\sum_{i=1,j=1}^{n}(10-x_i-y_j)^4}{n}-\mu^2}\right)^{\frac{1}{2}}=x_i+y_j$$

Based on the idea of two points forming a line, one of UCL coordinates can be derived by setting *x*-coordinate as 10 as shown in equation 7; whereas, the other UCL coordinates will be obtained by setting *y*-coordinate as 10 in equation 8.

$$\left[10,-\left(\sqrt{\frac{\sum_{i=1,j=1}^{n}(10-x_i-y_j)^4}{n}-\mu^2}\right)^{\frac{1}{2}}\right] \tag{7}$$

$$\left[-\left(\sqrt{\frac{\sum_{i=1,j=1}^{n}(10-x_i-y_j)^4}{n}-\mu^2}\right)^{\frac{1}{2}},10\right] \tag{8}$$

Likewise, LCL coordinates will be calculated in accordance with equations 9 and 10 as follows:

$$\mathrm{LCL}=-\sqrt{\frac{\sum_{i=1,j=1}^{n}(10-x_i-y_j)^4}{n}-\mu^2}=(10-x_i-y_j^2=>$$

$\therefore$

$$-\left(\sqrt{\frac{\sum_{i=1,j=1}^{n}(10-x_i-y_j)^4}{n}-\mu^2}\right)^{\frac{1}{2}}=10-x_i-y_j$$

$$=>10+\left(\sqrt{\frac{\sum_{i=1,j=1}^{n}(10-x_i-y_j)^4}{n}-\mu^2}\right)^{\frac{1}{2}}=x_i+y_j$$

$$\left[10+\left(\sqrt{\frac{\sum_{i=1,j=1}^{n}(10-x_i-y_j)^4}{n}-\mu^2}\right)^{\frac{1}{2}},0\right] \tag{9}$$

$$\left[0,10+\left(\sqrt{\frac{\sum_{i=1,j=1}^{n}(10-x_i-y_j)^4}{n}-\mu^2}\right)^{\frac{1}{2}}\right] \tag{10}$$

Upon establishing the performance control line model, map it in the performance matrix. The management only complies with the items located outside the control lines for improvement, which not only reduces time and cost but also serves to be an extremely useful tool.

*3.3 Model of integrating FMEA and performance matrix*

FMEA determines the possibility of a failure through three indices – Severity (S), Occurrence (O) and Detection (D). Accordingly, these three indices formed three performance matrices in this article. Suppose there are $n$ implementation items, which means there are $n$ different Severity, Occurrence and Detection indices for each individual item as shown in Table IV. Map the three indices of n items into the performance matrix and suppose the area of abnormal items is taken as e. If it falls in Zone A outside the performance matrix boundary, resources have to be increased to reduce the occurrence of system failures and a positive area weight ($+e$) is resulted. If it lands in Zone B outside the performance matrix boundary, resources invested need to be decreased and a negative area weight (-*e*) is given. If it falls within the boundary, an appropriate performance and a weight of 0 ($e = 0$) is resulted. Coordinates of indices are mapped in accordance with the indices (S, O, D,) of each item leading to three performance matrix charts (as shows in Figure 5). Next, the area of abnormal indices of n items in the three performance matrixes added with the total weight ($C_i$)will replace the importance weight in QFD to specify the priority of system improvement strategies. Consequently, the formula of adding the area formed by abnormal coordinates of each item (see Table V) is as follows:

$$C_i = \sum_{j=1}^{3} e_{ij} \text{ for } i = 1 \text{ to } n$$

$C_i$ = total weight of area formed by abnormal indices;

$e_{ij}$ = area of abnormal items;

$n$ = number of system implementation items.

## 4. TQFD model defined principles of improving implementation items

Quality function development (QFD) was developed in Japan in 1972 (Mizuno and Akao, 1987). It has been applied to product development and design and stressed that every stage during the production process has to take "consumers" wishes and aspirations" into consideration, which is different from other numerous quality methods. Practice of QFD increases the efficiency of product design and development process significantly, including shortening product development time, improving product quality, enhancing actions to cope with customers' requirements and real time handling of crucial problems on the production line.

Bossert (1990) claimed that QFD had to resort to House of Quality (HOQ), which consisted of customer demand, engineering technology, evaluation of competitive products, related matrixes, significance weight and absolute weight.

The extended QFD of Radharamanan and Godoy (1996) was referred to in this article; however, only customer demand, engineering properties, related matrixes, significance and absolute weights in HOQ were considered. Thus, the HOQ was modified to Table VI and the formula of calculating HOQ weight is as follows:

| Number of system implementation items *(i)* | Severity | Occurrence | Detection | Risk priority number (RPN) |
|---|---|---|---|---|
| *1* | $S_1$ | $O_1$ | $D_1$ | $RPN_1$ |
| *2* | $S_2$ | $O_2$ | $D_2$ | $RPN_2$ |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| *n* | $S_n$ | $O_n$ | $D_n$ | $RPN_n$ |

**Table IV.**
Contrast table of FMEA indices

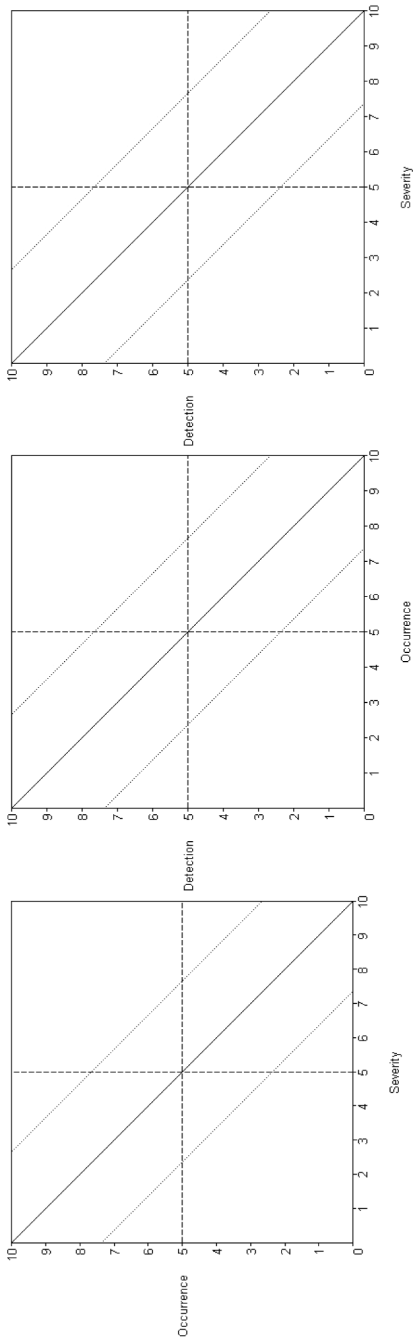



**Figure 5.**
Corresponding performance matrix charts of three indices of FMEA

| Number of system implementation item ($i$) | 1st PM severity vs occurrence 1 | 2nd PM occurrence vs detection 2 | 3rd PM severity vs detection 3 | Total weight of area of abnormal indices ($C_i$) |
|---|---|---|---|---|
| 1 | $e_{11}$ | $e_{12}$ | $e_{13}$ | $\sum_{i=1,j=1\sim3} e_{ij}$ |
| 2 | $e_{21}$ | $e_{22}$ | $e_{23}$ | $\sum_{i=2,j=1\sim3} e_{ij}$ |
| $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ |
| $n$ | $e_{n1}$ | $e_{n2}$ | $e_{n3}$ | $\sum_{i=n,j=1\sim3} e_{ij}$ |

**Table V.** Corresponding table of abnormal indices

$$T_j = \sum_{i=1}^{n} W_i C_i$$

$T_j$ = Absolute weight of column $j(j = l, \ldots, m)$;

$C_i$ = Significance weight of customer demand in row $i(i = l, \ldots, n)$;

$W_{ij}$ = Correlation weighted coefficient of related matrix $(i = l, \ldots, n, j = l, \ldots, m)$;

$m$ = Number of engineering technology developed;

$n$ = Number of customer demand.

In addition to locating area $e$ of abnormal coordinates through the performance matrix, strategic improvement in certain crucial items while introducing a new system needs to be made. Therefore, crucial implementation items were located first via the KJ method presented by Kawakita Jiro (2004). Area $e$ of abnormal coordinates located through the performance matrix would work with QFD for the development of related matrixes to define the priority of critical improvement items as well as to serve as a reference for the enterprises. The procedures of performance evaluation and definition of crucial items for the semiconductor related industries in Taiwan while introducing ERP are given in the following:

| | Significance weight | Number of engineering technology ($j$) | | | | |
|---|---|---|---|---|---|---|
| Number of customers demand ($I$) | | | 1 | 2 | ……… | $m$ |
| | $C_1$ | 1 | $W_{11}$ | $W_{12}$ | ……… | $W_{1m}$ |
| | $C_2$ | 2 | $W_{21}$ | $W_{22}$ | ……… | $W_{2m}$ |
| | $\vdots$ | $\vdots$ | $\vdots$ | $\vdots$ | $W_{ij}$ | $\vdots$ |
| | $C_n$ | $n$ | $W_{n1}$ | $W_{n2}$ | ……… | $W_{nm}$ |
| Absolute weight ($T_j$) | | | $T_1$ | $T_2$ | ……… | $T_m$ |

**Source:** Radharamanan and Godoy (1996)

**Table VI.** Table of quality function development

- *Set up crucial items for implementing ERP.* First, a documentary review and interviews were conducted for an understanding of difficulties confronted by semiconductor related industries while introducing ERP (e.g. personnel cooperation, flow planning, cooperation of the consulting company and introduction costs.) as well as potential severity, occurrence and detection of each ERP module. In addition, 22 ERP implementation items were specified, filled in Table IV and mapped in three performance matrixes defined in this article.
- *Define performance control lines.* Areas $\rho$ of 22 ERP implementation items were calculated by formula 2 and the population mean $\mu$ and the population standard deviation $\sigma$ were calculated using equations 3 and 4. Next, mean $\mu$ and standard deviation $\sigma$ were brought into equations 5 and 6 for the upper control line (UCL) and the lower control line (LCL). Coordinates of UCL in the performance matrix could be defined through formulas 7 and 8 and those of LCL via equations 9 and 10, which would be mapped into three performance matrixes.
- *Locate abnormal coordinates.* After mapping into the performance control lines, abnormal coordinates beyond UCL and LCL could be located. Each abnormal coordinate had a corresponding performance area $e$. Compare it with Figure 4 and give either a positive or negative value to each corresponding $e$, which would replace the significance/importance weight ($C_i$) in Table VI via formula 11.
- *List crucial items for implementing ERP.* Critical ERP implementation items would replace the engineering technology (item $j$) in Table VI. Critical improvement items were defined with the KJ method presented by Kawakita Jiro (2004) and a documentary review. The KJ method refers to a card classification approach; i.e. strategies and concepts in the previous documents that might affect the promotion of the ERP system were mapped into cards and classified after brainstorming and discussion with several specialists. There were 16 crucial items established that may achieve the objective successfully.
- *Build correlation matrix between ERP and critical ERP implementation items.* A correlation development between ERP implementation items and critical implementation target items was made. The opinions of experts would be utilized to set up a correlation weighted coefficient in the overlapping matrix. The correlation weighted coefficient ($W_{ij}$) was measured by a five-point scale. Point 5 stands for extremely strong correlation, 4 for strong correlation, 3 for medium correlation, 2 for weak correlation and 1 for extremely weak correlation. A higher weighted coefficient was given to a higher correlation and vice versa. After this coefficient was determined, multiply it with $e$ corresponding to the abnormal index. The absolute weight ($T_j$) of critical ERP implementation target items could be obtained via equation 12.
- *Develop the priority of critical ERP implementation items.* Upon completion of QFD, crucial ERP implementation target items can be sorted and suggestions of improving ERP performance can be made based on the absolute weight ($T_j$).

## 5. Case discussion

For evaluation of ERP implementation performance, there were 22 action items, including ten ERP implementation items and 12 ERP module implementation items.

The performance evaluation matrix presented by Huang *et al.* (2003) was modified to establish a standardized system-introduced performance matrix with target line and upper and lower control lines. All that the management has to do is to calculate the area formed by coordinates of three FMEA indices (S, O, D) and the target line in the performance matrix for the evaluation of the performance level. At last, Taguchi's concept of quality loss and Shewhart control chart were integrated to define crucial ERP implementation items and draw up performance improvement strategies by developing the items within the "non-performance control boundary" through QFD. Detailed performance evaluation procedures are described as follows:

- *Set up ERP implementation items.* A total of 22 ERP action items, including ten ERP implementation items and 12 ERP module implementation items were "established" from the opinions of scholars and interviews. Severity, occurrence and detection of these 22 ERP action items were defined by experts' opinions for a reliable understanding of possible problems confronted by semiconductor related industries in Taiwan while introducing the ERP system. Next, map these three indices in Table I and mark them in the system-introduced performance matrix defined in this article (see Table VII and Figure 6)
- *Define performance control lines.* Areas $\rho$ of 22 ERP implementation items were calculated by equation 2 and the population mean$\mu$ and the population standard deviation $\sigma$ were calculated using equations 3 and 4. Next, mean $\mu$ and standard deviation $\sigma$ were brought into equations 5 and 6 for the upper control line (UCL) and the lower control line (LCL). Coordinates of UCL in the performance matrix could be defined through equations 7 and 8 and those of LCL via equations 9 and 10, which would be mapped into three performance matrixes as shown in Table VIII and Figure 6.
- *Locate abnormal coordinates.* After mapping unto the performance control lines, abnormal coordinate beyond UCL and LCL could be located. Each abnormal coordinates had a corresponding performance area *e*. Compare it with Figure 4 and give either a positive or negative value to each corresponding *e*, which would replace the significance/importance weight ($C_i$) in Table VI via formula 11 as shown in Table IX.
- *List crucial items for implementing ERP.* Critical ERP implementation items would replace the engineering technology in the House of Quality. These critical ERP implementation items were classified by a documentary review and the KJ method in Table X and divided into organization, system supplier and consulting company. Regarding the objective of the organization, it is expected to be smooth the organization are flow be enhanced and education training of the organization be promoted through organizational re-engineering for successful implementation of the ERP system. Concerning the objective of the system supplier, it is hoped that the quality and integration of the ERP system be increased for successful implementation of the ERP system. As for the objective of the consulting company, it is expected that professional service and consultation be provided by setting up critical ERP action items. There were 16 critical ERP action items, including eight sub-items for the organization, which were dominance and promotion of high-level management, adjustment of the internal special organization, establishment of ERP implementation strategies,

**Table VII.**
ERP Implementation items vs SOD indices

| System implementation item *(i)* | Severity | Occurrence | Detection | Risk priority number (RPN) |
|---|---|---|---|---|
| *ERP action item:* | | | | |
| 1. Consistency between ERP project strategy and the overall strategy of the enterprise is not specific | 8 | 2 | 6 | 96 |
| 2. Understanding of ERP introduction in each department is not consistent | 9 | 9 | 7 | 567 |
| 3. Adaptability and support of ERP for all employees are not sufficient | 5 | 8 | 3 | 120 |
| 4. Planning, leadership and problem-solving experience of ERP special team is insufficient | 7 | 5 | 3 | 105 |
| 5. Assistance and industrial flow planning experience provided by consulting company is not enough | 6 | 6 | 5 | 180 |
| 6. Integration know-how and information provided by the consulting company is insufficient | 8 | 5 | 4 | 160 |
| 7. Customized system and cross-region features provided by the system supplier is not good | 4 | 8 | 1 | 32 |
| 8. Applicable system modules provided by system the supplier not good enough | 4 | 5 | 1 | 20 |
| 9. Total cost and actual effect of ERP system are inconsistent with the company planning | 9 | 8 | 7 | 504 |
| 10. Time phase planned for ERP system is too long | 10 | 9 | 5 | 450 |
| *ERP module action item:* | | | | |
| 11. Marketing management | 10 | 8 | 7 | 560 |
| 12. Material/acquisition management | 7 | 6 | 4 | 168 |
| 13. Human resources | 3 | 2 | 4 | 24 |
| 14. Production management/planning | 10 | 9 | 7 | 630 |
| 15. Quality management | 7 | 7 | 7 | 343 |
| 16. Project management | 6 | 5 | 2 | 60 |
| 17. Cost control | 9 | 9 | 4 | 324 |
| 18. Financial accounting | 9 | 8 | 4 | 288 |
| 19. Enterprise strategy | 4 | 3 | 5 | 60 |
| 20. Applied technology | 3 | 4 | 3 | 36 |
| 21. Supply chain management | 7 | 8 | 6 | 336 |
| 22. Customer relationship management | 9 | 6 | 5 | 270 |

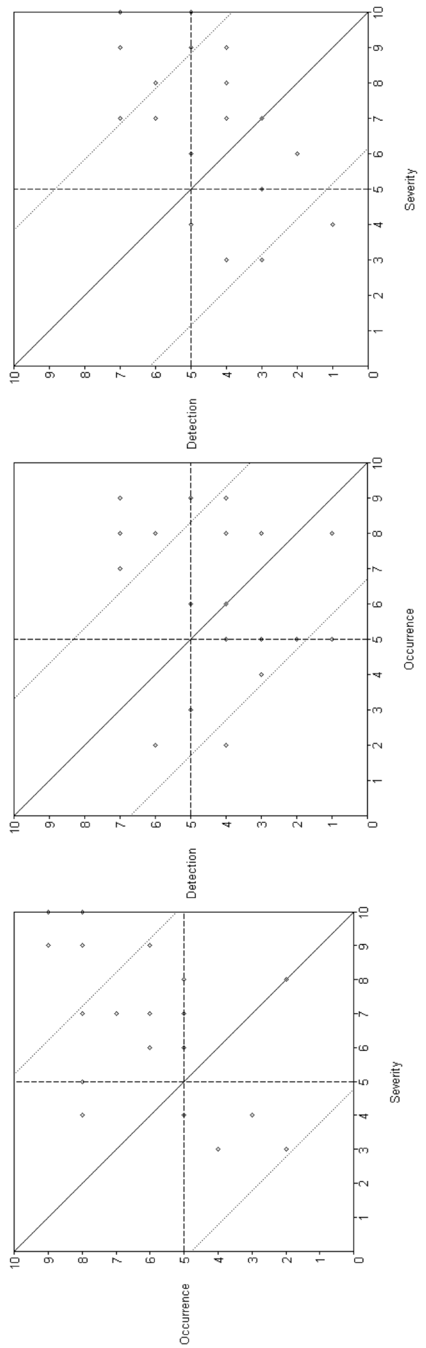



**Figure 6.**
Marked performance
matrixes

organization flow reengineering, increasing the quality of education training, examining the rationality of implementation, target management and enhancing personnel cooperation; five sub-items for the system supplier, which were enhancing system module capability and reducing cost, providing system flexibility ad expansibility, increasing compatibility between application structure and database, promoting cross-department and cross-region application and inspecting the service quality of the supplier and three sub-items for the consulting company, which were examining the professional expertise of the consulting company, communication between the consulting company and the enterprise and inspecting the service quality of the consulting company.

- *Build correlation matrix between ERP implementation items and critical ERP implementation items.* A correlation development between ERP implementation items and critical implementation target items was made. The opinions of experts are utilized to set up a correlation weighted coefficient in the overlapping matrix. The correlation weighted coefficient ($W_{ij}$) was measured by a five-point scale. The absolute weight of critical ERP implementation target items could be obtained via equation 12 as shown in Table XI.
- *Develop the priority of critical ERP implementation items.* Upon completion of QFD, priority can be sorted in accordance with the absolute weight in Table XI. The order is: dominance and promotion of high-level management in item 1, communication between the consulting company and the enterprise in item 15, organization flow reengineering in item 4, providing system flexibility and expansibility in item 10, establishment of ERP implementation strategies in item 3, inspecting the service quality of the consulting company in item 16, adjustment of the internal special organization in item 2, target management in item 7, examining the rationality of implementation in item 6, increasing the quality of education training in item 5, enhancing system module capability and reducing cost in item 9, promoting cross-department & cross-region application in item 12, enhancing personnel cooperation in item 8, examining the professional expertise of the consulting company in item 14, increasing compatibility between application structure and database in item 11 and inspecting the service quality of the supplier in Item 13. In the order as follows: dominance and promotion of high-level management in item 1, communication between the consulting company and the enterprise in item 15, organization flow reengineering in item 4, providing system flexibility and expansibility in item 10,

**Table VIII.** Corresponding coordinates and indices of three performance matrixes

| Index and number/coordinates of the performance matrix | $\mu$ | $\sigma$ | UCL | LCL | Coordinates of UCL | Coordinates of LCL |
|---|---|---|---|---|---|---|
| 1st performance matrix (severity vs. occurrence) | 27.36 | 27.24 | 27.24 | −27.24 | [10, −5.2193]<br>[−5.2193, 10] | [15.2193, 0]<br>[0, 15.2193] |
| 2nd performance matrix (occurrence vs. detection) | 11.36 | 10.86 | 10.86 | −10.86 | [10, −3.2949]<br>[−3.2949, 10] | [13.2949, 0]<br>[0, 13.2949] |
| 3rd performance matrix (severity vs. detection) | 16.36 | 14.74 | 14.74 | −14.74 | [10, −3.8387]<br>[−3.8387, 10] | [13.8387, 0]<br>[0, 13.8387] |

**Table IX.** Table of areas formed by abnormal indices corresponding to performance matrix

| Number of system implementation items ($i$) | 1st performance matrix severity vs occurrence | 2nd performance matrix occurrence vs detection | 3rd performance matrix severity vs detection | Total weight of abnormal index area ($C_i$) | Countermeasure |
|---|---|---|---|---|---|
| 1. Consistency between ERP project strategy and the enterprise. Overall strategy is not specific | 0 | 0 | +16 | +16 | Increase resources |
| 2. Understanding of ERP introduction in each department is not consistent | +64 | +36 | +36 | +136 | Increase resources |
| 3. Adaptability and support of ERP for all employees are not sufficient | 0 | 0 | 0 | 0 | Keep present situation |
| 4. Planning, leadership and problem-solving experience of ERP special team are insufficient | 0 | 0 | 0 | 0 | Keep present situation |
| 5. Assistance and industrial flow planning experience provided by the consulting company are not enough | 0 | 0 | 0 | 0 | Keep present situation |
| 6. Integration know-how and information provided by the consulting company are insufficient | 0 | 0 | 0 | 0 | Keep present situation |
| 7. Customized system and cross-region features provided by the system supplier are not good | 0 | 0 | −25 | −25 | Decrease resources |
| 8. Applicable system modules provided by the system supplier is not good enough | 0 | −16 | −25 | −41 | Decrease resources |
| 9. Total cost and actual effect of ERP system are inconsistent with the company planning | +49 | +25 | +36 | +110 | Increase resources |
| 10. Time phase planned for ERP system is too long | +81 | +16 | +25 | +122 | Increase resources |
| 11. Marketing management | +64 | +25 | +49 | +138 | Increase resources |
| 12. Material/acquisition management | 0 | 0 | 0 | 0 | Keep present situation |

*(continued)*

Table IX.

| Number of system implementation items ($i$) | 1st performance matrix severity vs occurrence | 2nd performance matrix occurrence vs detection | 3rd performance matrix severity vs detection | Total weight of abnormal index area ($C_i$) | Countermeasure |
|---|---|---|---|---|---|
| 13. Human resources | 0 | −16 | 0 | −16 | Decrease resources |
| 14. Production management/planning | 0 | +36 | +49 | +85 | Increase resources |
| 15. Quality management | 0 | +16 | +16 | +32 | Increase resources |
| 16. Project management | 0 | +16 | 0 | +16 | Increase resources |
| 17. Cost control | +64 | 0 | 0 | +64 | Increase resources |
| 18. Financial accounting | +49 | 0 | 0 | +49 | Increase resources |
| 19. Enterprise strategy | 0 | 0 | 0 | 0 | Keep present situation |
| 20. Applied technology | 0 | 0 | −16 | −16 | Decrease resources |
| 21. Supply chain management | 0 | 0 | 0 | 0 | Keep present situation |
| 22. Customer relationship management | 0 | 0 | +16 | +16 | Increase resources |

| Level 1 | Level 2 | Critical ERP implementation item |
|---|---|---|
| Organization | Increase overall adaptability to ERP<br>Promote a smooth flow in the organization<br>Enhance education training | Dominance and promotion of high-level management<br>Adjustment of the internal special organization<br>Establishment of ERP implementation strategies<br>Organization flow reengineering<br>Increasing the quality of education training<br>Examining the rationality of implementation<br>Target management<br>Enhancing personnel cooperation |
| Supplier | Increase quality and integration of ERP system | Enhancing system module capability and reducing cost<br>Providing system flexibility and expansibility<br>Increasing compatibility between application structure and database<br>Promoting cross-department and cross-region application<br>Inspecting the service quality of the supplier |
| Consulting company | Provide professional service and consultation | Examining the professional expertise of the consulting company<br>Communication between the consulting company and the enterprise<br>Inspecting the service quality of the consulting company |

**Table X.** Critical ERP implementation items

establishment of ERP implementation strategies in Item 3, inspecting the service quality of the consulting company in Item 16, adjustment of the internal special organization in Item 2, target management in Item 7, examining the rationality of implementation in Item 6, increasing the quality of education training in Item 5, enhancing system module capability and reducing cost in Item 9, promoting cross-department and cross-region application in Item 12, enhancing personnel cooperation in Item 8, examining the professional expertise of the consulting company in Item 14, increasing compatibility between application structure and database in Item 11 and inspecting the service quality of the supplier in Item 13.

## 6. Conclusion

The purpose of this article is to locate the risk priority number (RPN) of implementation items via FMEA for semiconductor related industries in Taiwan while introducing ERP. A standardized system-introduced performance matrix based on the performance evaluation matrix is established in accordance with the locations of the three RPN indices Severity (S), Occurrence (O) and Detection (D), in the PEM. All that the management needs to do is to correspond to the positions of these RPN indices of implementation items on the performance matrix for the assessment of performance

**Table XI.**
QFD of abnormal indexes of ERP implementation items and crucial ERP implementation items

| Abnormal index of ERP implementation item | Area corresponding to abnormal index | Critical ERP implementation item 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Consistency between ERP project strategy and the overall strategy of the enterprise is not specific | 16 | 5 | 2 | 5 | 2 | 4 | 5 | 5 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 | 4 |
| 2. Understanding of ERP for each department | 136 | 5 | 5 | 5 | 4 | 4 | 3 | 4 | 5 | 3 | 4 | 4 | 4 | 3 | 3 | 5 | 3 |
| 7. Customized system and cross-region features provided by the system supplier is not good | −25 | 1 | 3 | 4 | 2 | 4 | 4 | 2 | 1 | 4 | 5 | 4 | 5 | 4 | 3 | 3 | 3 |
| 8. Applicable system modules provided by the system supplier is not good enough | −41 | 2 | 4 | 5 | 2 | 5 | 2 | 2 | 5 | 4 | 3 | 3 | 5 | 4 | 3 | 3 | 3 |
| 9. Total cost and actual effect of ERP system | 110 | 5 | 5 | 5 | 4 | 3 | 4 | 3 | 3 | 5 | 5 | 3 | 4 | 3 | 3 | 5 | 5 |
| 10. Time phase planed for ERP system us too long | 122 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 3 |
| 11. Marketing management | 138 | 4 | 4 | 3 | 5 | 4 | 4 | 4 | 3 | 4 | 5 | 3 | 4 | 4 | 2 | 5 | 4 |
| 13. Human resources | −16 | 5 | 3 | 3 | 5 | 4 | 4 | 4 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 |
| 14. Production management/planning | 85 | 4 | 5 | 4 | 4 | 4 | 5 | 4 | 4 | 5 | 5 | 4 | 6 | 3 | 4 | 4 | 5 |
| 15. Quality management | 3 | 2 | 5 | 2 | 4 | 3 | 5 | 4 | 5 | 2 | 1 | 1 | 1 | 1 | 1 | 4 | 4 |
| 16. Project management | 16 | 5 | 5 | 5 | 5 | 2 | 5 | 4 | 4 | 1 | 2 | 2 | 3 | 2 | 4 | 4 | 5 |
| 17. Cost control | 64 | 5 | 2 | 5 | 5 | 5 | 4 | 4 | 2 | 5 | 5 | 5 | 5 | 1 | 5 | 4 | 5 |
| 18. Financial accounting | 49 | 5 | 2 | 5 | 5 | 5 | 4 | 4 | 2 | 5 | 5 | 5 | 5 | 1 | 5 | 5 | 5 |
| 20. Applied technology | −16 | 4 | 1 | 3 | 1 | 3 | 3 | 3 | 3 | 5 | 5 | 5 | 5 | 1 | 2 | 2 | 2 |
| 22. Customer relationship management | 16 | 5 | 4 | 4 | 2 | 4 | 4 | 5 | 5 | 1 | 1 | 1 | 1 | 1 | 4 | 4 | 4 |
| Absolute weight | | 3,446 | 2,874 | 2,988 | 3,079 | 2,722 | 2,823 | 2,846 | 2,530 | 2,708 | 3,014 | 2,336 | 2,700 | 1,872 | 2,433 | 3,275 | 2,908 |
| Sort absolute weight | | 1 | 7 | 5 | 3 | 10 | 9 | 8 | 13 | 11 | 4 | 15 | 12 | 16 | 14 | 2 | 8 |

**Notes:** 1: Dominance and promotion of high-level management; 2: Adjustment of the internal special organization; 3: Establishment of ERP implementation strategies; 4: Organization flow re-engineering; 5: Increasing the quality of education training; 6: Examining the rationality of implementation; 7: Target management; 8: Enhancing personnel cooperation; 9: Enhancing system module capability and reducing cost; 10: Providing system flexibility and expansibility; 11: Increasing compatibility between application structure and database; 12: Promoting cross-department and cross-region application; 13: Inspecting the service quality of the supplier; 14: Examining the professional expertise of the consulting company; 15: Communicatuion between the consulting company and the enterprise; 16: Inspecting the service quality of the consulting company. Definition of weight: Extremely strong = 5 (5.0); Strong = 4 (4.0); Medium = 3 (3.0); Weak = 2 (2.0); Extremely weak = 1 (1.0) levels and the formulation of system-introduced performance improvement strategies. Finally, the total weighted $T_i$ of individual critical ERP action items falling within the non-appropriate performance zone will be specified through the quality function development (QFD) method for the determination of the priority and strategies for improvement. According to the absolute weight $T_j$, critical ERP action items are sorted. Accordingly, a systematic evaluation and improvement on the performance of introducing ERP for the semiconductor industry in Taiwan can be conducted in an efficient way. Upon completion of performance evaluation and QFD, the following were made:

- A complete set of ERP countermeasures and a performance analysis model are required for the high-level management to comply during the process of implementing ERP. The high-level management needs to be active in dominating the whole project and holds review meetings on a regular basis to increase the overall efficiency of the plan.
- Consulting companies play an important part in introducing ERP. The enterprise and the consulting company ought to make a flow plan at the beginning of introduction. After that, both parties should discuss the problems encountered regularly to improve or solve the potential difficulties during the process.
- Customization of the module provided by the system supplier is required to cope with the demand of the enterprise, enhance the practicability of the system and to reduce the costs required for resources to be invested.
- Organization flow reengineering in an enterprise has to be based on the management capability, objectives and philosophy of the enterprise in addition to the suggestions provided by the consulting company. If a system is introduced without any justifiable reason, it is counted as a waste without any operational effect.
- After ERP is put into practice, the objective should not be merely confined to a computerized operation flow. Instead, the overall effects of ERP ought to be fully developed and applied to the operation.

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## About the authors

Ching-Chow Yang is an Associate Professor of Industrial Engineering Department at Chung-Yuan Christian University, Taiwan, ROC. He received the PhD degree in Management Science from National Chian-Tung University, Taiwan. In 1997, Dr Yang was honored the Individual Award of the ROC National Quality Awards. He is the author of six books (including *Hoshin Management, Quality is the Best Strategy for Competition, Human Resource Management, and Service Quality, etc.).* His research interests include total quality management, strategy management, service quality, and Six Sigma.

Wen-Tsaan Lin is currently an Associate Professor in the Department of Industrial Engineering and Management, National Chin-Yi Institute of Technology, Taiwan, ROC. he received the MS degree in Industrial Engineering and Management from the National Chiao-Tung University Taiwan, and now he has his PhD study in Industrial Engineering Department at Chung-Yuan Christian University ROC. His research interests are total quality management, MIS, service quality, and Six Sigma.

Ming-Yi Lin is a Master's student at the Institute of Production System Engineering and Management from the National Chin-Yi Institute of Technology, Taiwan, ROC. His research interests include ERP information systems, quality control, production management, and engineering economics.

Jui-Tang Huang is a Master's student at the Institute of Production System Engineering and Management from the National Chin-Yi Institute of Technology, Taiwan, ROC. His research interests include ERP information systems, quality control, production management, and engineering economics.