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# Fuzzy AHP Approach to TQM Strategy Evaluation

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**Abstract.** In recent years, many electronics producing firms have looked upon total quality management (TQM) strategy as a means by which they could maintain competitive advantage. This empirical research evaluates TQM strategic factors in order to determine the critical success factors in environmental uncertainty. Fuzzy analytic hierarchy process (FAHP) is the proposed research methodology to discuss and tackle the different decision criteria like effective leadership, people management, customer focus, strategic plan and process management, being involved in identifying the TQM strategic critical success factors with uncertainty. The result shows that effective leadership is the most critical success factor in TQM strategy.

**Keywords:** Total Quality Management, Fuzzy Analytical Hierarchy Process.

## 1. INTRODUCTION

The printed circuit board (PCB) industry in Taiwan plays a significant role in local electronic component manufacturing industries and in world market. The large volume production capability, quick response to demands, good quality products, on time deliveries and competitive pricing of Taiwan PCB manufacturers make them a viable supplier in the international market; industry output for PCBs totaled USD 48.7 billion, a strong performance which reflects the ability of the industry to handle rising prices of energy and raw materials. Thirty years of development and growth has made this industry rise to a manufacturing system from raw materials, equipment supply and manufacturing to end product assembly.

The PCB industry is expected to perform well in year 2006. However, competitiveness in the market appears to be a product of the adoption of a total quality management (TQM) strategy. Generally, TQM refers to a philosophy that aims to achieve customer satisfaction through strategic planning, effective leadership, people management, process management and customer focus in the organization (Samson and Terziovski, 1999; Fuentes-Fuents, Albacete-Sae, and Llorens-Montes, 2004; Jung and Wang, 2006). Some recent studies suggest beneficial results from TQM implementation (Flynn, Salakibara and Schroeder, 1995; Forza and Filippini, 1998; Kaynak, 2003). Consequently, several approaches and models propose the introduction of TQM strategy (Dale, 1999; Prajogo and Sohal, 2006). However, the uncertainty and intensive competition in the issue of imperative factors of TQM criteria and attributes remains a challenge to the management.

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The analytic hierarchy process (AHP) is widely used for tackling multi-criteria decision-making (MCDM) problems (Saaty, 1980). Despite its popularity and simplicity in concept, this method is often criticized for its inability to adequately handle the inherent uncertainty and imprecision associated in quantifying the decision-maker's perception. In the traditional formulation of the AHP, human's judgments are represented as exact numbers. Yet, in many practical cases the human preference model is uncertain and decision makers might be reluctant or unable to assign exact numerical values to the comparison judgments. Since some of the evaluation criteria are subjective and qualitative in nature, it is very difficult for the decision maker to express the preferences using exact numerical values and to provide exact pairwise comparison judgments. Therefore, it is more desirable for the researchers to use interval or fuzzy evaluations.

To improve the AHP method and to facilitate TQM criteria selection process, this paper introduces a fuzzy AHP (FAHP) approach using triangular fuzzy numbers to represent the comparison judgments of decision makers (Chang, 1996; Kang and Lee, 2006). The fuzzy set theory resembles human reasoning in its use of approximate information and uncertainty to generate decisions. It has the advantage of mathematically representing uncertainty and vagueness and providing formalized tools for dealing with the imprecision intrinsic to many problems. The proposed FAHP uses the triangular fuzzy numbers as a pairwise comparison scale for deriving the priorities of different TQM strategic criteria and attributes.

The priority weights of the each TQM strategic criteria are calculated and are based on the expert opinion from the PCB companies. In particular, the developed approach can adequately handle the inherent uncertainty and imprecision of the human decision making process and provide the flexibility and robustness needed for the decision maker to understand the decision priorities. These merits of the proposed method would facilitate its use in real-life situations for making effective decisions. This study attempts to identify the critical criteria and attributes in TQM strategy for PCB producing firms using FAHP. This study aims to build up and expound a hierarchical model to aid in the prioritization of TQM strategic criteria and attributes, and to identify the TQM strategic critical success factor as benchmark for all PCB producing firms.

## 2. RELATED LITERATURE

### 2.1 Fuzzy AHP

Researchers propose various FAHP methods, which are systematic approaches to alternatives selection and choice justification. Van Laarhoven and Pedrycz (1983) provide the earliest work on FAHP, comparing fuzzy ratios described by triangular membership functions. On the other hand, Buckley (1985) determines fuzzy priorities of comparison ratios with trapezoidal membership functions. The study of Stam *et al.* (1996) explores how recently developed artificial intelligence techniques can be used to determine or approximate the preference ratings in AHP and proves that the feed-forward neural network formulation appears to be a powerful tool for analyzing discrete alternative MCDM problems with imprecise or fuzzy ratio-scale preference judgments. Chang (1996) introduces a new approach for handling FAHP with the use of triangular fuzzy numbers for pairwise comparison scale and the use of the extent analysis method for the synthetic extent values of the pairwise comparisons. Weck, *et al.* (1997) presents a method to evaluate different production cycle alternatives, adding the mathematics of fuzzy logic to the classical AHP. Any production cycle evaluated in this manner yields a fuzzy set. The outcome of the analysis can finally be defuzziffied by forming the surface center of gravity of any fuzzy set, and the investigated alternative production cycles can be ranked in order in terms of the main objective set.

Kahraman *et al.* (2003) uses fuzzy objective and subjective method to obtain the weights from AHP and make a fuzzy weighted evaluation. Deng (1999) presents a fuzzy approach for tackling qualitative multi-criteria analysis problems in a straightforward and simpler manner. Lee *et al*, (1999) reviews the basic ideas behind AHP. Based on these ideas, they introduced the concept of comparison interval and proposed a methodology based on stochastic optimization to achieve global consistency and highlight the fuzzy nature of the comparison process.

Cheng *et al.* (1999) proposes a new method for evaluating weapon systems through analytical hierarchy process based on linguistic variable weight. Zhu *et al.* (1999) provides a discussion on extent analysis method and applications of FAHP. Chan *et al.* (2000) presents a technology selection algorithm to quantify both tangible and intangible benefits in uncertainty. They describe an application of the theory of fuzzy sets to hierarchical structural analysis and economic evaluations. By aggregating the hierarchy, the preferential weight of each alternative technology is found, which is called fuzzy appropriate index. The fuzzy appropriate indices of different technologies are then ranked and preferential ranking orders of technologies are established. From the economic perspective, a fuzzy cash flow analysis is employed.

Cheng *et al.* (2005) implemented the FAHP method to help telecom carriers evaluate and plan future broadband Metropolitan Area Network access strategy. Kahraman *et al.* (2004) presents four different fuzzy multi-attribute group decision-making approaches including FAHP on a facility location selection problem. Bozdağ *et al.* (2003) implemented FAHP to select best computer integrated manufacturing system by taking into account both intangible and tangible factors. Sheu (2004) presents a hybrid fuzzy-based method that integrates fuzzy AHP and fuzzy MCDM approaches for identifying global logistics strategies and applies its model to integrated circuit manufacturers in Taiwan. Kahraman *et al.* (2004) implements the FAHP to compare catering firms through customer satisfaction. Kulak and Kahraman (2005) compares the FAHP method and the fuzzy multi-attribute axiomatic design approach. This study proposes the method by Netherlands's scholar van Laarhoven and Pedrycg (1983) and Chang's extent analysis (1996), where fuzzy comparison judgment is represented by triangular fuzzy numbers.

## 2.2 Total Quality Management

In 1987, the Malcolm Baldrige National Quality Award (MBNQA) was established as a statement of national intent to provide quality leadership. Similar quality awards and frameworks were created in other industrialized countries. Other key personalities (Juran, 1989; Gale and Klavans, 1985; Heller, 1994; Wilson and Collier, 2000; Lee, Rho and Lee, 2003) in the early days made significant contributions to the development of both the conceptual and practical sides of quality management.

A number of research studies on TQM and quality awards systems have been conducted, leading to a debate about the effectiveness of such awards and of the various TQM elements. Many of these studies have been either perceptual studies or small-scale empirical works. This section examines some of the key empirical studies and their limitations. Saraph *et al*. (1989) establish eight factors, some of which are similar to those of Black and Porter (1996), and to the quality award categories. However, there is certainly not a clear agreement as to what the real factors of TQM are, and there always appear some disagreements as to how to best cut the TQM cake into factors or elements. Noting that the differences exist and are generally not major, this study uses a well established factor set, the awards framework categories. It further tests the correspondence of these factors individually and collectively with organizational performance measures, which is an additional step from Black and Porter's contribution. Black and Porter (1996) conducted factor analysis on a questionnaire administered to quality manager practitioners. They establish a list of ten factors that are considered critical to TQM. Although their approach is sound, and is similar to the proposed TQM strategic factors of this study, it, like ours, suffers from the general weakness of factor analysis that relates to the absence of prescriptive rules about how many factors are sensible in a study framework.

Samson and Terziovski (1999) examined the TQM practices and operation performance of a large number of producers in order to determine the relationships between these strategies, individually and collectively, and firm performance. The research used a large data base of 1200 Australian and New Zealand manufacturing organizations. The result shows that TQM strategy intensity explains a significant proportion of variance in performance. The categories of leadership, people management, strategic plan, process management and customer focus are the significant predictors of operational performance, similar to the results of Prajogo and Sohal (2006). Their TQM elements are based on literature reviews on historical development which satisfies content validity. Although there are always debates about how to categorize elements of a holistic process and framework such as TQM, it is necessary to decompose it to facilitate analysis. Since the most pervasive and universal method has been awards criteria, such as the MBNQA, this research follows the TQM strategic criteria and attributes from the studies of Samson and Terziovski (1999), Saraph, Benson and Schroeder (1989), Black and Porter (1996) and Evans and Lindsay (1995). The succeeding subsections discuss the TQM strategic elements considered in this study.

### 2.2.1 Leadership

Leadership is considered as the major driver of TQM strategy which examines senior executives' management style and personal involvement in setting strategic directions and building and maintaining an effective system that facilitates high organizational performance, individual development, and organizational learning (Waldman, 1994). TQM emphasizes the activities of senior leadership, much like the transformational leadership theory (Bass, 1985). The core issues in effective leadership construct include the creation of unity of purpose, organizational development, organizational structure, change of organization, continuous improvement, employee participation and environmental protection (Wilson and Collier, 2000).

### 2.2.2 People Management

People management tackles how well human resource practices are aligned with the strategic directions of an organization. This measure comes down to a simple test: the voice of the people (Garvin, 1991). This research focuses on understanding of employees, education and training of employees, communication channel with all employees, health and safety, employee development and employee involvement in quality (Prajogo and Sohal, 2006). The pairwise questions are of importance in people management because they capture the combined impact of TQM strategies. Commonly heard statements by management such as "people are really everything" and "people are our critical resource" lead to the inclusion of this variable in TQM strategy.

### 2.2.3 Customer Focus

Customer focus identifies current and emerging customer requirements and expectations, provides effective customer relationship management, and determines customer satisfaction in the organization (Evans and Lindsay, 1995; Ahire, Golhar and Waller, 1996). This research measures the extent to which customer related information is acquired through customer complaint resolution, customer demand recognition, quick response to customer, customer's preference incorporation in product design and measured customer satisfaction (Prajogo and Sohal, 2006; Chong and Rundus, 2004).

### 2.2.4 Strategic Planning

Strategic planning focuses on the organizational strategic and business planning and deployment of plans while at the same time considering customer and operational performance requirements in the organization (Evans and Lindsay, 1995). The emphasis is on customer-driven quality and operational performance excellence as key strategic business issues that need to be an integral part of overall business planning. It is appropriate to distinguish between the TQM perspective of strategy and corporate strategy. The former deals extensively with business unit strategy, that is, 'how to compete for a set of customers.' The latter deals with choosing target customers. The extent of a defined central purpose and mission in the organization is also a part of this construct (Wilson and Collier, 2000).

### 2.2.5 Process Management

TQM strategy concerns organization designs, introduces products and services, integrates production and delivery requirements and manages performance of suppliers (Evans and Lindsay, 1995). TQM principles finds basis on the interconnections among organizational processes, and that improvement of these processes is the foundation of performance improvement (Deming, 1986).

Deming (1986) defines sets of interlinked processes as systems, and his treatment of organizational systems is generally consistent with the use of this term in management theory. The intellectual turf represented by this category has been abandoned by management theorists and is currently occupied by industrial engineers (Dean and Bowen, 1994). The measurement of this element is supplier closed to product development, bilateral fluent processes from close corporation, self quality control of suppliers, well-established mechanism for product quality and clear operating procedures.

This study contributes to the knowledge about "What works?" This entails using measurement criteria similar to those of Saraph *et al*. (1989) and Samson and Terziovski, (1999). The method is based on the MCDM of critical success factors from the view point of TQM professionals due to the reliability of TQM strategic criteria and attributes evaluated in studies Figure 1.

## 3. RESEARCH METHOD

This study proposes a systematic FAHP. Considering the uncertainty and simulation analysis, the algorithm of fuzzy AHP takes basis on relative research (Cheng and Mon, 1994). Synthesizing experts' opinions complies

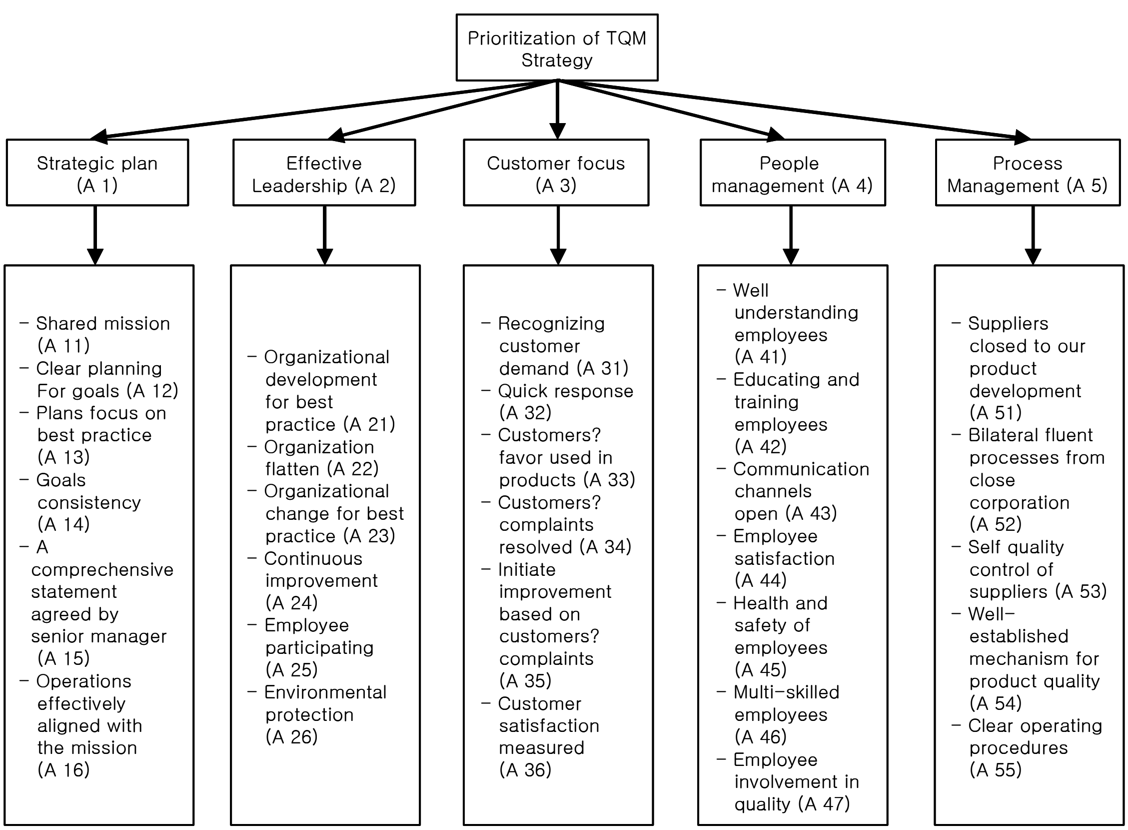


**Figure 1.** Hierarchal structure for TQM strategy

with the geometric mean method proposed by Buckley (1985). Algorithmic steps are summarized as follows:

**Step 1.** Experts in PCB industry are invited to construct the TQM hierarchy. Based on the proposed hierarchy, a questionnaire was first formulated to compare each criterion by pairs on their contribution toward achieving the goal of TQM strategy and second to compare detailed criterion by pairs in their contribution toward attaining their upper-level criterion. Five different levels of evaluation are employed, and the linguistic values used are presented in Table 1.

**Table 1.** Linguistic value table

| Fuzzy language | Quantitative Value |
|---|---|
| Absolute importance | 9 |
| Demonstrated importance | 7 |
| Strong importance | 5 |
| Weak importance | 3 |
| Equal importance | 1 |
| Intermediate values between the two adjacent judgments | 2, 4, 6, 8 |

**Step 2.** Set up fuzzy numbers in the all hierarchies. Triangular fuzzy membership function is presented in the Eq. (1).

$$\mu(x)=\begin{cases}0 & x<a\\ (x-a)/(b-a) & a\le x\le b\\ (c-x)/(c-b) & b\le x\le c\\ 0 & c\le x\end{cases} \tag{1}$$

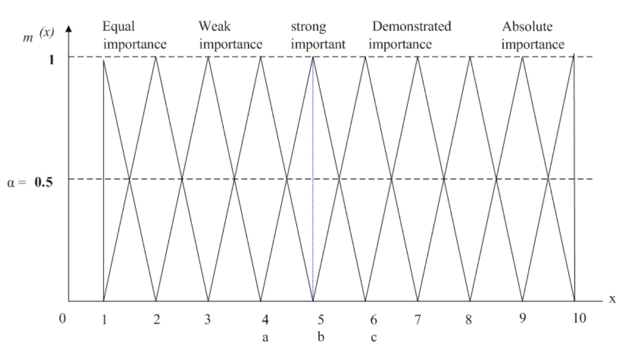


**Figure 2.** Triangular fuzzy numbers

Triangular fuzzy number was adopted, defined by Eq. (2) and illustrated in Figure 2.

$$\left[a^{\alpha}, c^{\alpha}\right]=\left[(b-a)\alpha+a, -(c-b)\alpha+c\right], \quad \alpha\in[0,1] \tag{2}$$

**Step 3.** Synthesize experts' opinions and establish fuzzy matrices. The geometric mean method, in Eq. (3), was employed to generalize experts' opinions.

$$a_{pq}=\left(\prod_{k=1}^{s} a_{pqk}\right)^{1/s} \quad \forall k=1,2,3,4,\cdots s. \tag{3}$$

A fuzzy matrix with α-cuts is as follows:

$$A^k=\begin{bmatrix}(a^{\alpha}_{11l}, a^{\alpha}_{11u}) & (a^{\alpha}_{12l}, a^{\alpha}_{12u}) & \cdots & (a^{\alpha}_{1nl}, a^{\alpha}_{1nu})\\ (a^{\alpha}_{21l}, a^{\alpha}_{21u}) & (a^{\alpha}_{22l}, a^{\alpha}_{22u}) & \cdots & (a^{\alpha}_{2nl}, a^{\alpha}_{2nu})\\ \vdots & (a^{\alpha}_{ijl}, a^{\alpha}_{iju}) & \ddots & \vdots\\ \vdots & & \ddots & \vdots\\ (a^{\alpha}_{n1l}, a^{\alpha}_{n1u}) & (a^{\alpha}_{n2l}, a^{\alpha}_{n2u}) & \cdots & (a^{\alpha}_{nnl}, a^{\alpha}_{nnu})\end{bmatrix}$$

**Step 4.** Kwong and Bai [43] said that μ can be used to measure certain degree for experts to judge $\widetilde{A}$, known as index of optimism. That is, μ can be a parameter in α-cut fixed. It is follows in Eq. (4):

$$a^{\alpha}_{ij}=u a^{\alpha}_{iju}+(1-\mu)a^{\alpha}_{ijl}, \quad \forall\mu\in[0,1] \tag{4}$$

**Step 5.** Use different α-cuts and μ indexes of optimism to obtain a de-fuzzified matrix, as presented in Eq. (5).

$$\widetilde{A}=\begin{bmatrix}a^{\alpha\mu}_{11} & & a^{\alpha\mu}_{1n}\\ a^{\alpha\mu}_{21} & a^{\alpha\mu}_{pq} & a^{\alpha\mu}_{2n}\\ & & \\ a^{\alpha\mu}_{n1} & & a^{\alpha\mu}_{nn}\end{bmatrix} \tag{5}$$

**Step 6.** Decompose fuzzy eigen values for eigenvector. Set λ as a set of fuzzy eigen values, $\forall\lambda\in$ real numbers. $\widetilde{A}$ is a fuzzy matrix with n × n dimensions. $\widetilde{x}$ is a non-zero fuzzy eigen vector reported as:

$$\tilde{x} = \begin{bmatrix} x_1 \\ x_2 \\ .. \\ .. \\ x_{n-1} \\ x_n \end{bmatrix}$$

Decomposing λ obtains max ($\lambda_1$, $\lambda_2$, ⋯, $\lambda_n$), reported in Eq. (6).

$$\tilde{A}\tilde{x} = \lambda\tilde{x} \tag{6}$$

**Step 7.** Adding $\lambda_{max}$ in Eq. (6) results to eigenvector $\tilde{x}$ .

**Step 8.** After eigenvector decomposition, the priority weights in the same hierarchy are computed through normalization, shown by Eq. (7):

$$W = (x_1, x_2, \cdots\cdots, x_n)^T \tag{7}$$

where, W is a non-fuzzy number.

The triangular fuzzy conversion scale at α-cut equal to 0.5, given in Table 2, is used in the evaluation of fuzzy experts' opinion, following Saaty (1980).

**Table 2.** Triangular fuzzy conversion scale

| Linguistic scale | Triangular fuzzy scale | Triangular fuzzy reciprocal scale |
|---|---|---|
| Just equal | (1, 1, 1) | (1, 1, 1) |
| Equally important | (1/2, 1, 3/2) | (2/3, 1, 2) |
| Weakly important | (1, 3/2, 2) | (1/2, 2/3, 1) |
| Strongly more important | (3/2, 2, 5/2) | (2/5, 1/2, 2/3) |
| Very strongly more important | (2, 5/2, 3) | (1/3, 2/5, 1/2) |
| Absolutely more important | (5/2, 3, 7/2) | (2/7, 1/3, 2/5) |

*Source: Saaty (1980).*

The authors suggested the use of integrated TQM strategy to produce low cost and high quality products. This strategy encompasses not only appropriate high technology, but also includes a wide range of attributes. Its detailed design is further identified through a hierarchical structure model approach from the strategic level to operational levels in order to implement it.

**Table 3.** First expert's fuzzy linguistic value with α = 0.5

| | A1 | A2 | A3 | A4 | A5 |
|---|---|---|---|---|---|
| A1 | (1, 1, 1) | (2/17, 1/8, 2/15) | (2/15, 1/7, 2/13) | (2/15, 1/7, 2/13) | (15/2, 8, 17/2) |
| A2 | (15/2, 8, 17/2) | (1, 1, 1) | (15/2, 8, 17/2) | (13/2, 7, 15/2) | (15/2, 8, 17/2) |
| A3 | (13/2, 7, 15/2) | (2/17, 1/8, 2/15) | (1, 1, 1) | (2/17, 1/8, 2/15) | (11/2, 6, 13/2) |
| A4 | (13/2, 7, 15/2) | (2/15, 1/7, 2/13) | (15/2, 8, 17/2) | (1, 1, 1) | (15/2, 8, 17/2) |
| A5 | (2/17, 1/8, 2/15) | (2/17, 1/8, 2/15) | (2/13, 1/6, 2/11) | (2/17, 1/8, 2/15) | (1, 1, 1) |

**Table 4.** Second expert's fuzzy linguistic value with α = 0.5

| | A1 | A2 | A3 | A4 | A5 |
|---|---|---|---|---|---|
| A1 | (1, 1, 1) | (13/2, 7, 15/2) | (11/2, 6, 13/2) | (11/2, 6, 13/2) | (2/15, 1/7, 2/13) |
| A2 | (2/15, 1/7, 2/13) | (1, 1, 1) | (2/17, 1/8, 2/15) | (2/17, 1/8, 2/15) | (2/17, 1/8, 2/15) |
| A3 | (2/13, 1/6, 2/11) | (15/2, 8, 17/2) | (1, 1, 1) | (15/2, 8, 17/2) | (2/11, 1/5, 2/9) |
| A4 | (2/13, 1/6, 2/11) | (15/2, 8, 17/2) | (2/17, 1/8, 2/15) | (1, 1, 1) | (2/13, 1/6, 2/11) |
| A5 | (13/2, 7, 15/2) | (15/2, 8, 17/2) | (9/2, 5, 11/2) | (11/2, 6, 13/2) | (1, 1, 1) |

**Table 5.** Fuzzy matrix showing the synthesized opinion of the fifteen experts

$$A_k = \begin{pmatrix} (1, 1, 1) & (1/8, 29/31, 1) & (6/7, 25/27, 1) & (6/7, 25/27, 1) & (1, 31/29, 8/7) \\ (1, 31/29, 8/7) & (1, 1, 1) & (31/33, 1, 33/31) & (7/8, 29/31, 1) & (31/33, 1, 33/31) \\ (1, 27/25, 7/6) & (31/33, 1, 33/31) & (1, 1, 1) & (31/33, 1, 33/31) & (1, 23/21, 6/5) \\ (1, 31/29, 8/7) & (1, 31/29, 8/7) & (31/33, 1, 33/31) & (1, 1, 1) & (29/27, 9/8, 46/37) \\ (7/8, 29/31, 1) & (31/33, 1, 33/31) & (5/6, 21/23, 1) & (37/46, 8/9, 27/29) & (1, 1, 1) \end{pmatrix}$$

## 4. EMPIRICAL RESULT

Essentially, the methods follow four major phases: (1) establish the present position, (2) analyze strategic requirements, (3) develop strategic improvements, and (4) formulate implementation strategy. This process is conducted by a team consisting of the general manager, manufacturing director, plant managers, engineering, quality, marketing, human resources and information system.

Pairwise comparisons for the criteria and attributes were provided by a group of fifteen (15) PCB industry experts. The accomplished questionnaires provide the evaluations. However, the group of experts came up with a consensus. Therefore, only a single evaluation was obtained to represent experts' opinion. All the weight vectors were normalized. The weight of the criteria and attributes are calculated in different $\alpha$ cuts [0, 1]. The following shows a numerical example of the steps enumerated in section 3.

After gathering expert opinion, these were evaluated for various $\alpha$ cuts. Two of fifteen experts' opinions are presented in Table 3 and Table 4, showing fuzzy matrices at $\alpha$=0.5. Following Eq. (3), experts' opinions were synthesized to establish a fuzzy matrix (Table 5). It was assumed that $\mu$ is 0.5 and the fuzzy $\alpha$-cut is also 0.5 (Step 4), following Eq. (4). Incorporating $\mu$, the resulting matrix is presented in Table 6.

**Table 6.** Defuzziffied matrix

$$\tilde{A} = \begin{bmatrix} 1 & 15/16 & 13/14 & 14/16 & 9/15 \\ 16/15 & 1 & 5/12 & 8/9 & 2/3 \\ 14/13 & 12/5 & 1 & 7/6 & 5/4 \\ 16/14 & 9/8 & 6/7 & 1 & 9/8 \\ 15/9 & 3/2 & 4/5 & 8/9 & 1 \end{bmatrix}$$

**Table 7.** Priority weights of TQM criteria and attributes

| $\alpha$-cuts | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 |
|---|---|---|---|---|---|---|---|---|---|---|
| A1 | 0.1174 | 0.1166 | 0.1159 | 0.1159 | 0.1159 | 0.1159 | 0.1159 | 0.1159 | 0.1159 | 0.1159 |
| A11 | 0.0131 | 0.0130 | 0.0129 | 0.0129 | 0.0245 | 0.0099 | 0.0099 | 0.0099 | 0.0099 | 0.0099 |
| A12 | 0.0138 | 0.0137 | 0.0136 | 0.0135 | 0.0253 | 0.0102 | 0.0102 | 0.0102 | 0.0102 | 0.0102 |
| A13 | 0.0062 | 0.0061 | 0.0061 | 0.0107 | 0.0132 | 0.0083 | 0.0083 | 0.0083 | 0.0083 | 0.0083 |
| A14 | 0.0274 | 0.0272 | 0.0270 | 0.0284 | 0.0185 | 0.0218 | 0.0218 | 0.0218 | 0.0218 | 0.0218 |
| A15 | 0.0068 | 0.0067 | 0.0067 | 0.0068 | 0.0097 | 0.0052 | 0.0052 | 0.0052 | 0.0052 | 0.0052 |
| A16 | 0.0502 | 0.0499 | 0.0496 | 0.0437 | 0.0247 | 0.0342 | 0.0342 | 0.0342 | 0.0342 | 0.0342 |
| A2 | 0.4320 | 0.4339 | 0.4343 | 0.4343 | 0.4343 | 0.4343 | 0.4343 | 0.4343 | 0.4343 | 0.4343 |
| A21 | 0.1095 | 0.1607 | 0.1608 | 0.1607 | 0.1625 | 0.0903 | 0.1244 | 0.1244 | 0.1244 | 0.1244 |
| A22 | 0.0710 | 0.0709 | 0.0708 | 0.0707 | 0.0800 | 0.1283 | 0.0550 | 0.0550 | 0.0550 | 0.0550 |
| A23 | 0.1205 | 0.1022 | 0.1024 | 0.1025 | 0.0982 | 0.0754 | 0.0795 | 0.0795 | 0.0795 | 0.0795 |
| A24 | 0.0664 | 0.0299 | 0.0300 | 0.0301 | 0.0307 | 0.0595 | 0.0233 | 0.0233 | 0.0233 | 0.0233 |
| A25 | 0.0312 | 0.0310 | 0.0311 | 0.0311 | 0.0298 | 0.0235 | 0.0244 | 0.0244 | 0.0244 | 0.0244 |
| A26 | 0.0389 | 0.0392 | 0.0392 | 0.0393 | 0.0330 | 0.0574 | 0.0304 | 0.0304 | 0.0304 | 0.0304 |
| A3 | 0.1271 | 0.1238 | 0.1240 | 0.1240 | 0.1240 | 0.1240 | 0.1240 | 0.1240 | 0.1240 | 0.1240 |
| A31 | 0.0152 | 0.0157 | 0.0157 | 0.0157 | 0.0266 | 0.0125 | 0.0124 | 0.0124 | 0.0124 | 0.0124 |
| A32 | 0.0188 | 0.0184 | 0.0184 | 0.0184 | 0.0260 | 0.0147 | 0.0147 | 0.0147 | 0.0147 | 0.0147 |
| A33 | 0.0214 | 0.0219 | 0.0219 | 0.0219 | 0.0255 | 0.0174 | 0.0174 | 0.0174 | 0.0174 | 0.0174 |
| A34 | 0.0186 | 0.0182 | 0.0182 | 0.0182 | 0.0156 | 0.0145 | 0.0145 | 0.0145 | 0.0145 | 0.0145 |
| A35 | 0.0136 | 0.0132 | 0.0132 | 0.0132 | 0.0120 | 0.0104 | 0.0104 | 0.0104 | 0.0104 | 0.0104 |
| A36 | 0.0365 | 0.0365 | 0.0366 | 0.0366 | 0.0183 | 0.0291 | 0.0291 | 0.0291 | 0.0291 | 0.0291 |
| A4 | 0.2923 | 0.2954 | 0.2954 | 0.2954 | 0.2954 | 0.2954 | 0.2954 | 0.2954 | 0.2954 | 0.2954 |
| A41 | 0.0414 | 0.0361 | 0.0361 | 0.0360 | 0.0483 | 0.0369 | 0.0358 | 0.0358 | 0.0358 | 0.0358 |
| A42 | 0.0506 | 0.0553 | 0.0553 | 0.0553 | 0.0803 | 0.0541 | 0.0550 | 0.0550 | 0.0550 | 0.0550 |
| A43 | 0.0247 | 0.0272 | 0.0272 | 0.0272 | 0.0406 | 0.0247 | 0.0270 | 0.0270 | 0.0270 | 0.0270 |
| A44 | 0.0212 | 0.0213 | 0.0213 | 0.0213 | 0.0235 | 0.0217 | 0.0208 | 0.0208 | 0.0208 | 0.0208 |
| A45 | 0.0732 | 0.0739 | 0.0738 | 0.0738 | 0.0545 | 0.0745 | 0.0743 | 0.0743 | 0.0743 | 0.0743 |
| A46 | 0.0051 | 0.0045 | 0.0045 | 0.0045 | 0.0131 | 0.0063 | 0.0045 | 0.0045 | 0.0045 | 0.0045 |
| A47 | 0.0747 | 0.0771 | 0.0771 | 0.0772 | 0.0350 | 0.0772 | 0.0780 | 0.0780 | 0.0780 | 0.0780 |
| A5 | 0.0302 | 0.0302 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 | 0.0304 |
| A51 | 0.0064 | 0.0056 | 0.0056 | 0.0060 | 0.0089 | 0.0037 | 0.0037 | 0.0037 | 0.0037 | 0.0037 |
| A52 | 0.0038 | 0.0033 | 0.0033 | 0.0042 | 0.0045 | 0.0026 | 0.0026 | 0.0026 | 0.0026 | 0.0026 |
| A53 | 0.0075 | 0.0087 | 0.0088 | 0.0068 | 0.0084 | 0.0042 | 0.0041 | 0.0041 | 0.0041 | 0.0041 |
| A54 | 0.0049 | 0.0046 | 0.0047 | 0.0048 | 0.0034 | 0.0029 | 0.0029 | 0.0029 | 0.0029 | 0.0029 |
| A55 | 0.0085 | 0.0080 | 0.0080 | 0.0085 | 0.0051 | 0.0053 | 0.0053 | 0.0053 | 0.0053 | 0.0053 |

**Step 6.** Decompose $\lambda$ using Eq. (2) to obtain $\lambda_1$ = 5.0018, $\lambda_2$ = -0.0005 + 0.0952i, $\lambda_3$ = -0.0005 - 0.0952i, $\lambda_4$ = -0.0004 + 0.0121 i, $\lambda_5$ = -0.0004 - 0.0121 i

**Step 7.** With $\lambda_{max}$ equal to 5.0018, $\tilde{x}$ obtained equals [0.4337, 0.4465, 0.4617, 0.4726, 0.4195].

**Step 8.** The priority weights are computed through the normalized eigenvector. The result of priority weights is $w$ = [0.1941, 0.1999, 0.2067, 0.2115, 0.1878].

Table 7 shows the priority weight of TQM strategic criteria. Effective leadership (A2) is 0.4343, people management (A4) is 0.2954, customer focus (A3) is 0.1240, strategic plan (A1) is 0.1159 and process management (A5) is 0.0304 when $\alpha$ is equal to 0.5. The respective weights of attributes are also presented along with the complete result. From these, effective leadership is considered the most important criteria for TQM efficacy. Effective leadership deserves to be of significance because it plays a more imperative role with higher uncertainty to achieve TQM effectiveness.

## 5. CONCLUSION

The core element, underlying the integrated process, finds basis on the doctrine of TQM, the driving force of the company to achieve higher quality and productivity. Total quality means that everyone should be involved in quality at all levels and across all functions, ensuring that quality is achieved in everything they do according to the requirements. TQM is the most important management tool for the electronics industry. To manage it successfully, its measurement indicators must be defined and prioritized. Because of the subjective nature of the criteria and attributes used in the evaluation, AHP is the most appropriate MCDM method for this problem. However, since the experts prefer natural language expressions rather than sharp numerical values in their assessments, the classical AHP may not yield a satisfactory result. This study proposes a fuzzy AHP framework to weigh the TQM strategic criteria and attributes.

Fuzzy AHP approach ranks TQM strategic criteria and attributes for PCB producing firms to implement one of most critical success factors in environmental uncertainty. The criteria and attributes were chosen based on current business scenario and expert opinion in the said field. The large number of criteria and attributes demonstrates the complexities involved in the selection of TQM strategic factors. Each criteria and attributes affecting the TQM strategy have been analyzed and discussed. The result shows effective leadership (A2-0.4343) as the most important criterion, focusing on organizational development for best practice (A21-0.165) when $\alpha$ is in the range [0, 1]. This study identified the important criteria and paves the way to consider this in practical, relevant and interesting cases.

The proposed FAHP framework proves to be simple and less computational as compared to other existing decision-making software. The use of FAHP does not involve cumbersome mathematical operation, making it of general use for solving practical MCDM problems. The FAHP has the ability to capture the vagueness of human thinking style and effectively solve MCDM problems. The illustrative example demonstrates the flexibility, and efficiency of the proposed model to directly tap the subjectivity and preferences of the decision makers. In terms of research method, the fuzzy analytical network process and other research methods may be considered to explore its inter-effects among all constructs.

Despite the aforementioned advantages of the proposed approach for the TQM factors evaluation, this research work can be extended to add more manufacturer alternatives which encompass both domestic and international electronic manufacturers. This study provides a number of directions for future research. The possibility of developing a richer, multi-hierarchical structure that incorporates other constructs such as customer satisfaction and the like, and considers their interactive effects, appears to be attainable. Differences in the optimism or pessimism levels of the decision-maker can result to different interpretation of fuzzy results.

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