The Study of Criteria Weight for Taiwan National Quality Award by Fuzzy Hierarchical Analysis

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Abstract

In this paper, fuzzy hierarchical analysis (FHA) is used to explore the process by which the criteria weights of the Taiwan National Quality Award (TNQA) are assigned by TNQA committee members. Each member is allowed to employ fuzzy scales in place of exact scales. Each pairwise comparison of criteria is made through a questionnaire from each TNQA committee member. The membership function of trapezoidal fuzzy numbers is introduced to specify TNQA committee members' intentions. After FHA, the reasonable range of each criterion weight of TNQA is determined. The current criteria weights of TNQA are properly verified.

Key Words: TQM, National Quality Award, Fuzzy Hierarchical Analysis

1. Introduction

In recent years, there have been many national quality awards (NQAs) established in different countries around the world. One important common reason for establishing such NQAs is to build up a business model of excellence based on total quality management (TQM) to provide better products or services, but at a lower price than those of competitors. For each country involved, the NQA is a critical systematic approach to enhancing national competitiveness. The establishment of the Deming Award in 1950 played an important role in the creation of the Japanese economic miracle. It encouraged Japanese quality and facilitated Japan becoming a significant nation in global economics, to the extent that it became a threat to the economic power of several leading industrial countries, including the United States and European countries. As a result, an increasing number of countries have established NQAs to improve their own competitiveness in terms of quality.

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In most countries, professional institutes, some of which are under partial government control, are in charge of the NQAs. To provide credibility and ensure justice in the awarding of NQAs, recognized quality experts are usually invited to design the criteria for the awards and to evaluate the quality improvement of businesses involved. Criteria are designed to provide for a high standard of quality for those organizations that are keen to pursue the highest levels of performance in TQM. For example, the criteria of the Malcolm Baldrige National Quality Award (MBNQA) (NIST, 2001) are designed to help organizations use an aligned approach to organizational performance management that results in the delivery of ever-improving value to customers, contributes to marketplace success, improves overall organizational effectiveness and capabilities, and enhances organizational and personal learning. Similarly, the criteria of Taiwan National Quality Award (TNQA) are based on following premises (CSD, 2001):

1. *Generality*: the criteria are designed to cover as many kinds of organizations as possible.
2. *Prospective*: the criteria recognize the trends of the modern age and encourage prospective thinking within organizations.
3. *Integration*: the criteria cover the main concepts, content, processes, and performance evaluations of TQM, and pursue excellence of performance in terms of integration. The seven categories of the TNQA are correlated with each other and are inseparable.
4. *Internationalism*: In 2001, the criteria of TNQA were modified, based on the 2000 Malcolm Baldrige Award (MBNQA), the 1998 Deming Award, the 1999 European Quality Award (EQA), and ISO 9000-2000. They not only meet domestic requirements, but also keep pace with global trends in TQM.
5. *Operational*: The criteria of TNQA are focused on increasing efficiency and effectiveness, and on improving productivity and performance. Taken together, they represent a practical benchmark for organizations engaged in the pursuit of excellence.

In summary, the NQA criteria specify all the conditions required to attain quality excellence, and are coherently interrelated.

The TNQA has been successfully conducted for fourteen years since it was established in 1990. In response to the advent of e-commence and the knowledge economy, the criteria of TNQA have been modified, involving a reduction from nine categories to seven in 2001. The seven categories are listed in Table 1.

As can be seen in Table 1, each category is assigned a weight to stress its importance. The question of the weighting value assigned to each category is interesting. Are the weightings reasonable as an adequate evaluation system for those organizations interested in competing for the TNQA? Although it is not possible to know exactly how committee members of the TNQA came to assign the weightings, the adequacy of such weightings can be verified through questionnaire investigation. The present study employs the fuzzy hierarchical analysis (FHA) to ascertain, via a questionnaire, a reasonable range of weights for the TNQA criteria for each category according to the perspective of committee members of the TNQA.

Table 1. Criteria of the Taiwan National Quality Award

Criterion	Weight
I. Leadership	0.15
II. Innovation and strategic management	0.11
III. Customer and market development	0.11
IV. Human resource and knowledge management	0.11
V. Information management	0.11
VI. Process management	0.11
VII. Business result	0.30

2. AHP and Related Works

During the past two decades, the analytical hierarchical process (AHP), which was introduced by Saaty (1980), has become one of the most widely used methods for the practical solution of multi-criteria decision-making (MCDM) problems. Generally, the AHP has been applied from daily problems to more complicated problems such as evaluating the implementation of a maintenance system (Labib *et al.*, 1998), selecting electric power plants (Akash *et al.*, 1999), and evaluating weapon systems (Cheng and Mon, 1994). The AHP enables decision-makers to structure a complex problem in the form of a simple hierarchy and to evaluate a large number of quantitative and qualitative factors in a systematic manner under conflict criteria. In the hierarchy, the overall goal is situated at the highest level; elements with similar features are grouped at the same middle level and decision variables are located at the lowest level. Then, a series of pairwise comparisons is made among the elements at the same level using the ratio scales 1, 3, 5, 7, and 9, as suggested by Saaty (1980). Judgment matrices are then formulated for all evaluation criteria, and the relative weights of the criteria are estimated by calculating the eigenvalues for the judgment matrices with these relative weights aggregated and synthesized for the final measurement of given decision alternatives.

The AHP has been extensively used in group decision-making. However, the scale of pair comparisons among criteria is restricted to those that are crisp (Chen, 1996; Hauser and Tadikamalla, 1996). In other words, the decision-makers are assumed to be precise in their minds regarding comparisons among criteria. However, in the real world, many situations are generally fuzzy rather than being clear in terms of decision-making. Examples include evaluating personality, past experience, and self-confidence. In such cases, the comparisons or measurements among criteria made by decision-makers are subjective and psychological. This creates a situation of imprecise value that drives the questions into fuzziness. The process of evaluation under these circumstances should involve fuzzy identification, and the AHP should be modified to fit this reality. To overcome these shortcomings, the principle of fuzzy logic was introduced into the AHP for MCDM (Jung and Lee, 1991; Levary and Ke, 1998). This makes it possible to adapt the AHP in an environment in which the input information, or the relations among criteria and alternatives, are uncertain or imprecise.

The earliest work in FHA appears in Van Laarhoven and Pedrycz (1983) which compared fuzzy ratios described by triangular membership functions. Logarithmic least square was used to derive the local fuzzy priorities. By modifying the Van Laarhoven and Pedrycz method, Bonder *et al.* (1989) present a more robust approach to the normalization of the local priorities. Later, using geometric mean, Buckley *et al.* (1984, 1985, 1990, 1992) determine fuzzy priorities of comparison, whose membership functions were trapezoidal. They use fuzzy numbers for the pairwise comparisons and the main problem is to compute the corresponding fuzzy weights. The direct approach, of finding fuzzy eigenvalues and fuzzy eigenvectors, was consider too computationally difficult. There are also other papers in FHA using different procedures to compute fuzzy weights. Ruoing *et al.* (1992) employed "step function" fuzzy numbers and fuzzified another procedure, which they claim is the same as Saaty's original method for crisp perfectly consistent, positive, reciprocal matrices, to calculate the fuzzy weights. However, the matrices are usually not perfectly consistent only "reasonably" consistent, so this procedure will produce different weights compared to Saaty's original method, for crisp data. The paper (Mohanty *et al.*, 1994) uses fuzzy relational equation to model the FHA problem. Their modeling gives a fuzzy hierarchical process quite different from Saaty's original HA. Salo (1996) developed a method for the interactive analysis of fuzzy pairwise comparisons in hierarchical weighting models which appears, in our opinion, far removed from Saaty's original HA. In this study, we adopt the Buckley and Csutora's approach (2001) to determine fuzzy weights for TNQA criteria because the Saaty's λ_{max} method was directly fuzzified.

3. Fuzzy Hierarchical Analysis

The general AHP procedure can be summarized as follows:

- constructing the hierarchical relationship structure for the problem;

- developing pairwise comparison matrices for the hierarchical relationship structure;
- determining the weights of criteria for each hierarchy and checking consistency among pairwise comparison matrices; and
- calculating and ranking the relative weight scores for each alternative.

In this paper, the decision process involves fuzziness for decision-makers. The FHA proposed by Buckley and Csutora (2001) is applied to the criteria of the TNQA. The procedure for exploring the criteria weight of TNQA is described as follows in four steps.

Step 1. Hierarchical structure for determining criteria weights of TNQA

To apply FHA, the opinions of TNQA committee members in determining the TNQA criteria weights have to be structured into hierarchical levels. The hierarchical structure is shown in Figure 1. In Figure 1, the goal is determining criteria weights of TNQA, and seven TNQA criteria are located in this category level.

Step 2. Fuzzy representation of pairwise comparison

Traditionally, in the AHP, the decision-maker judgments assigned to each criterion comparison can be represented by linguistic variables, as shown in Appendix A. In this paper, the TNQA committee members were allowed to choose crisp numbers or intervals showing their recognition of criteria comparisons to reflect the real decision situations. For example, in

Appendix A, suppose a TNQA committee member is asked to compare the importance of criterion I as compared with that of criterion II. He or she thinks that criterion I is somewhat more important than criterion II. He or she might be unsure as to whether to assign a 3, a 4, or a 5. Choosing the interval from 3 to 5 can represent his or her intention in this uncertain situation. Thus, the fuzzy ratios are introduced into pairwise comparison for this study. The present study adopts Buckley's (1985) definition of a fuzzy number as a fuzzy subset of R described by

$$(\alpha / \beta, \ \gamma / \delta)$$

where α, β, γ, and δ are real numbers and $\alpha \leq \beta \leq \gamma \leq \delta$. The graph of the membership function μ is determined by these four numbers as follows: (i) zero to the left of α; (ii) continuous and strictly increasing from (α, 0) to (β, 1); (iii) a horizontal line segment from (β, 1) to (γ, 1); (iv) continuous and strictly decreasing from (γ, 1) to (δ, 0); and (v) zero to the right of δ. In this study, the fuzzy numbers used by TNQA committee members have α, β, γ, δ, $\in S = \{0, 1, 2, \cdots, L\}$, for L a positive integer, and the graph of μ is a straight line segment over the intervals [α, β] and [γ, δ]. If two of the numbers α, β or β, γ or γ, δ are equal, the corresponding line segment does not exist. The graph of this membership function is trapezoid, as shown in Figure 2.

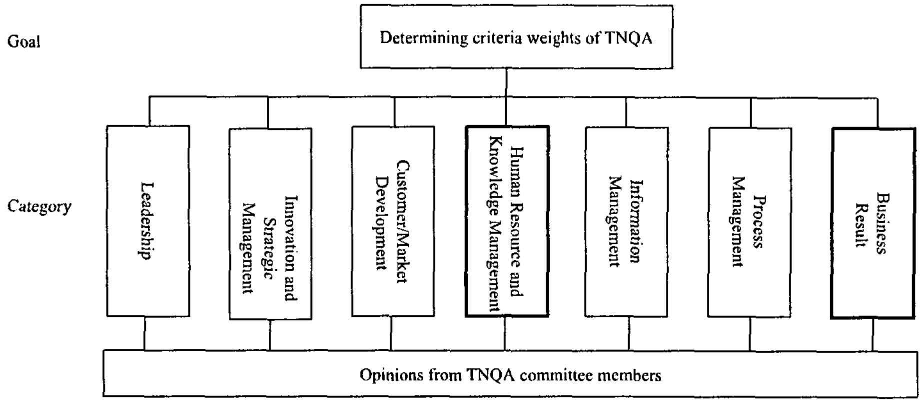

Figure 1. Membership function of a trapezoidal fuzzy number $(\alpha/\beta, \gamma/\delta)$

Step 3. Consistency check for fuzzy pairwise comparison matrix

Each committee member was allowed to make a comparison between only two criteria for each question in Appendix A. After finishing the questionnaire, a contra verdict might have occurred within pairwise comparisons. It was necessary to check the whole consistency of relative importance among criteria. Saaty (1980) suggested consistency ratio (CR) to evaluate the consistency of pairwise comparisons in a matrix among criteria, and suggested CR $\leq$ 0.1 was acceptable. However, in this study, the TNQA committee members are allowed to use fuzzy ratios in place of exact ratios. We follow the theorem proposed by Buckley (2001) which is described as following:

Theorem 1. *Let $\bar{A} = [\bar{a}_{ij}]$ be a fuzzy, positive, reciprocal matrix with $\bar{a}_{ij} = (\alpha_{ij}/\beta_{ij}, \delta_{ij}/\delta_{ij})$. Choose $\alpha_{ij} \in [\beta_{ij}, \gamma_{ij}]$ and form $A = [\alpha_{ij}]$. If A is consistent, then $\bar{A}$ is consistent.*

This theorem was also proven in Buckley's paper (1985). According to Buckley, the pair-wise comparison matrix involves fuzzy ratios, so it is not perfectly but reasonably consistent. What this means is that each has an A, constructed as in this theorem, which is reasonably consistent. In other words, a fuzzy, positive, reciprocal matrix $\bar{A} = [\bar{a}_{ij}]$ is defined to be consistent when $\bar{\alpha}_{ik} \cdot \bar{\alpha}_{kj} \approx \bar{\alpha}_{ij}$ for all i, j, k. For example, let $[\beta_{13}, \gamma_{13}] = 1/2$, $[\beta_{12}, \gamma_{12}] = [1/5, 1/3]$ and $[\beta_{13}, \gamma_{13}] = 3$ and $1/2 \notin [3/5, 1]$. But since 1/2 is "reasonably" close to 3/5, we conclude that $\bar{\alpha}_{12} \cdot \bar{\alpha}_{23}$ is "reasonably" close to $\bar{\alpha}_{13}$. In $\bar{A}$ we find that $\bar{\alpha}_{ik} \cdot \bar{\alpha}_{kj}$ is "reasonably" close to $\bar{\alpha}_{ij}$ for all i, j, k and we conclude that $\bar{A}$ is "reasonably" consistent.

Step 4. Determining fuzzy weight for a fuzzy, positive, reciprocal matrix $\bar{A}$

In this study, we place a "bar" over a letter to denote a fuzzy set. All our fuzzy sets will be fuzzy subsets of the real numbers. So $\bar{a}_{ij}$, $\bar{w}_{ij}$, $\bar{b}$, $\bar{c}$,… are all fuzzy subsets of $\Re$. If $\bar{a}$ is a fuzzy set, then $\bar{a}(x)$ is the value of the membership function at $x \in \Re$. An α-cut of $\bar{a}$, written as $\bar{a}[\alpha]$, is defined as $\{x \mid \bar{a}(x) \geq \alpha\}$ for $0 < \alpha \leq 1$. The support of $\bar{a}$, written as $\bar{a}[0]$, is the closure of the union of $\bar{a}[\alpha]$, $0 < \alpha \leq 1$. The type of trapezoidal fuzzy numbers that can be used in pairwise comparisons are described by $\bar{a}_{ij} = (\alpha/\beta,\gamma/\delta)$ when α, β, γ, $\delta \in S$ then $\bar{a}_{ij}^{-1} = (\delta^{-1}/,\gamma^{-1},\beta^{-1}/\alpha^{-1})$ and $\bar{a}_{ij} = 1$ for all i in this study. However, $\bar{a}_{ij}^{-1}$ is not exactly a trapezoidal fuzzy number, but we will use the same notation $(\delta^{-1}/,\gamma^{-1},\beta^{-1}/\alpha^{-1})$ for $\bar{a}_{ij}^{-1}$. Now define $A_{\alpha l}$ and $A_{\alpha u}$ and $\lambda_{\alpha l}$, $\lambda_{\alpha u}$ are their corresponding dominant, positive eigenvalues. $\bar{\lambda}\max$ is the trapezoidal-shaped fuzzy number defined by the α-cuts $[\lambda_{\alpha l}, \lambda_{\alpha u}]$ and $w_{\alpha l}(w_{\alpha u})$ are the unique, positive, normalized eigenvectors corresponding to $\lambda_{\alpha l}(\lambda_{\alpha u})$. Again, define, for an n×n matrix $X = [x_{iim}]$, $x_{ijm} = (\beta+\gamma)/2$ if $\bar{a}_{ij} = (\alpha/\beta,\gamma/\delta)$, $x_{ijm} = (\gamma^{-1}+\beta^{-1})/2$ when $\bar{a}_{ij} = (\delta^{-1}/,\gamma^{-1},\beta^{-1}/\alpha^{-1})$ and $x_{iim} = 1$ for all i.

Let λ_m be the dominant, postivtive eigenvalue of X and w_m its corresponding postitive, normalized eigenvector. Choose the α_i in [0,1] with $0 = \alpha_n < \alpha_{n-1} < \cdots < \alpha_1 = 1$, adopt following procedure proposed by Buckley (2001) to determine fuzzy weight for $\bar{A}$.

1. Let $\alpha_1 = 1$, find w_{il} and w_{iu}.
2. Determine $K_{1l} = \min\{\frac{w_{im}}{w_{1il}} \mid 1 \leq i \leq n\}$ and $K_{1u} = \max\{\frac{w_{im}}{w_{1iu}} \mid 1 \leq i \leq n\}$
3. Compute $w_{1l}^{*} = K_{1l}\ w_{1l}$ and $w_{1u}^{*} = K_{1u}\ w_{1u}$
4. Repeat step 2 to determine $K_{\alpha_2 l} = \min\{\frac{w_{\alpha_1 il}^{*}}{w_{\alpha_2 il}} \mid 1 \leq i \leq \text{n}\}$ and

$$K_{\alpha_2 u} = \max\{\frac{w_{\alpha_1 iu}^{*}}{w_{\alpha_2 iu}} \mid 1 \leq i \leq \text{n}\}$$

5. Compute $w_{\alpha_2 l}^{*} = K_{\alpha_2 l} \cdot w_{\alpha_2 l}$ and $w_{\alpha_2 u}^{*} = K_{\alpha_2 u} \cdot w_{\alpha_2 u}$
6. Iterate the steps 4 and 5 with changing α_i, $i = 1, 2, 3, \cdots$, n, each time until to obtain w_{0l}^{*} and w_{0u}^{*}.

According to procedure, the fuzzy weight for pairwise comparison matrix $\bar{A}$ can be expressed as $(w_{0l}^{*}/w_{1l}^{*},\ w_{1u}^{*}/w_{0u}^{*})$

4. Implementation

The implementation of FHA for TNQA criteria is described by the following procedure (as described above).

4.1 Developing an Hierarchical Structure for Determining Criteria Weights of TNQA

The present study focuses on determining the fuzzy criteria weights of the TNQA from the perspective of committee members. Thus, first of all, an hierarchical structure for determining criteria weights of TNQA is established, as shown in Figure 1.

4.2 Constructing Fuzzy Comparison Matrices

The Corporate Synergy Development (CSD) Center is in charge of the TNQA and has 13 TNQA committee members' profiles for 2001 on hand. With the cooperation of the CSD, all 13 TNQA committee members were asked to fill in questionnaires by mail. Of these 13 requests, 10 surveys were returned. Using the questionnaires listed in Appendix A, each TNQA committee member answers were collected and translated by linguistic variables into either 'crisp numbers' or 'intervals' for each comparison between two criteria. In order to have consensus for criteria comparisons among committee members, the Delphi method (Saaty, 1980) was adopted. The rule for consensus judgement is described as follows:

Let $h_{ijk} = [s_{ijk}, t_{ijk}]$ *be the comparison for criterion* i, *and* j *by the committee member* M_k, $k = 1,2,\cdots,10$. *For any* k, $l = 1,2,\cdots,10$, $k \neq l$, *if* $h_{ijk} \cap h_{ijl} \neq \varnothing$, *means both committee members* M_k *and* M_l *have consensus for criterion i, and j.*

Fuzzy pairwise comparison matrix $\overline{A}$ among criteria was constructed for TNQA committee members as follows:

$$\begin{bmatrix} 1 & (1/2,2/2) & (1/1,2/2) & (1/2,2/2) & (1/1,1/2) & (1/1,2/2) & (2/2,2/3)^{-1} \\ (1/2,2/2)^{-1} & 1 & (1/1,2/2) & (1/2,2/2)^{-1} & (1/1,2/2)^{-1} & (1/1,1/2)^{-1} & (2/3,3/4)^{-1} \\ (1/1,2/2)^{-1} & (1/1,2/2)^{-1} & 1 & 1 & (1/1,1/2) & (1/1,2/2) & (2/3,3/3)^{-1} \\ (1/2,2/2)^{-1} & (1/2,2/2) & 1 & 1 & (1/1,1/2) & (1/1,2/2) & (2/2,3/3)^{-1} \\ (1/1,1/2)^{-1} & (1/1,2/2) & (1/1,1/2)^{-1} & (1/1,1/2)^{-1} & 1 & (1/2,2/2) & (1/2,3/4)^{-1} \\ (1/1,2/2)^{-1} & (1/1,1/2) & (1/1,2/2)^{-1} & (1/1,2/2)^{-1} & (1/2,2/2)^{-1} & 1 & (2/3,4/4)^{-1} \\ (2/2,2/3) & (2/3,3/4) & (2/3,3/3) & (2/2,3/3) & (1/2,3/4) & (2/3,4/4) & 1 \end{bmatrix}$$

4.3 Performing the Consistency Check for $\overline{A}$

According to the theorem 1 described in the step 3 of previous FHA procedure, we checked the consistency for $\overline{A}$. As expected, the result was shown reasonably consistency.

4.4 Determining Fuzzy Weight for $\overline{A}$

Using previous FHA procedure, we found the fuzzy weight vector $\overline{w}$ for $\overline{A}$. Choose the α_i in $[0,1]$ with $0 = \alpha_7 < \alpha_6 = 0.2 < \alpha_5 = 0.4 < \alpha_4 = 0.55 < \alpha_3 = 0.7 < \alpha_2 = 0.85 < \alpha_1 = 1$. As before, we first find the w_{1il}^* and w_{1iu}^*, $1 \leq i \leq 7$. Using this values we determine $w_{\alpha_2 il}^*$, $w_{\alpha_2 iu}^*$, 1

$\leq i \leq 7$. Eventually, we work our way down to w^*_{0il}, w^*_{0iu}, $1 \leq i \leq 7$. These values determine the trapezoidal-shaped fuzzy number $\overline{w}$ for $\overline{A}$. The $\overline{w}$ for each α-cut distributions are shown in Table 2. Based on the results in Table 2, we obtained trapezoidal-shaped fuzzy criteria weight of TNQA, taking α-cuts with α = 0 and α = 1, as Table 3.

Table 2. The fuzzy criteria weight of TNQA for each α-cut distributions.

	α_7 = 0	α_6 = 0.2	α_5 = 0.4	α_4 = 0.55	α_3 = 0.7	α_2 = 0.85	α_1 = 1
$\overline{w}^*_1$	[0.0510,0.1712]	[0.0654,0.1712]	[0.0700,0.1712]	[0.1054,0.1712]	[0.1102,0.1712]	[0.1102,0.1657]	[0.1316,0.1642]
$\overline{w}^*_2$	[0.0347,0.1169]	[0.0413,0.1122]	[0.0452,0.1089]	[0.0621,0.1072]	[0.0632,0.1059]	[0.0690,0.1016]	[0.0742,0.1003]
$\overline{w}^*_3$	[0.0526,0.1305]	[0.0526,0.1282]	[0.0563,0.1262]	[0.0752,0.1248]	[0.0753,0.1233]	[0.0832,0.1233]	[0.1093,0.1156]
$\overline{w}^*_4$	[0.0465,0.1426]	[0.0575,0.1390]	[0.0630,0.1361]	[0.0861,0.1342]	[0.0877,0.1325]	[0.0985,0.1318]	[0.1008,0.1242]
$\overline{w}^*_5$	[0.0362,0.1449]	[0.0489,0.1417]	[0.0565,0.1399]	[0.0792,0.1394]	[0.0847,0.1393]	[0.0938,0.1344]	[0.1089,0.1344]
$\overline{w}^*_6$	[0.0330,0.1154]	[0.0574,0.1110]	[0.0574,0.1074]	[0.0574,0.1052]	[0.0574,0.1031]	[0.0630,0.1019]	[0.0630,0.0954]
$\overline{w}^*_7$	[0.1016,0.3318]	[0.1289,0.3289]	[0.1445,0.3258]	[0.2016,0.3235]	[0.2085,0.3210]	[0.2366,0.3073]	[0.2479,0.3028]

Table 3. The fuzzy weights of TNQA

Criterion no.	Trapezoidal-shaped fuzzy weights of TNQA
1	(0.0510 / 0.1316,0.1642 / 0.1712)
2	(0.0347 / 0.0742,0.1003 / 0.1169)
3	(0.0526 / 0.1093,0.1156 / 0.1305)
4	(0.0465 / 0.1008,0.1242 / 0.1426)
5	(0.0362 / 0.1089,0.1344 / 0.1449)
6	(0.0330 / 0.0630,0.0954 / 0.1154)
7	(0.1016 / 0.2479,0.3028 / 0.3318)

4.5 Determination of Reasonable Range of Criterion Weight

In order to minimize the fuzziness, we took α-cut with $\alpha = 1$ for each TNQA criterion so that the weight with interval value can be obtained. We called this interval value as reasonable range of weight (RRW) for each TNQA criterion in contrast to the current weight is listed in Table 4.

Table 4. The reasonable range of weight for TNQA criteria

Criterion	Current weight	RRW
I. Leadership	0.15	0.1316~0.1642
II. Innovation and Strategic Management	0.11	0.0742~0.1003
III. Customer/Market Development	0.11	0.1093~0.1156
IV. Human Resource and Knowledge Management	0.11	0.1008~0.1242
V. Information Management	0.11	0.1089~0.1344
VI. Process Management	0.11	0.0630~0.0954
VII. Business Result	0.30	0.2479~0.3028

5. Discussion

In general, the more complicated are the problems, the more likely it is that fuzzy judgments or comparisons are required for group decision-making. In the pairwise comparisons of AHP, trapezoidal fuzzy numbers are introduced to improve the scaling scheme of Saaty method. Each TNQA committee member was allowed to express an indefinite opinion by assigning an "interval" when making a comparison between two criteria. The present study noted the responses from TNQA committee members and observed that many of the pairwise comparisons between two criteria were answered with an "interval" response. This was in accordance with expectations prior to the study. After FHA, RRW was obtained for each TNQA criterion, as shown in Table 4. It was found that the criteria were actually adjustable within a reasonable range in response to necessary changes in accordance with global or domestic economic requirements. However, we noted that not each criterion was exactly within corresponding RRW. The criterion II and VI showed slight outside of RRW. Part of the reason behind this is that the group decision for designing the TNQA criteria weights is not independent behavior. As we mentioned in the introduction section, in order to characterize the internationalism, TNQA was modified based on other NQAs such as MBNQA and EQA. Thus, the final assignment for TNQA criteria weights does not totally reflect individual intentions among committee members. The present study does not criticize the current TNQA criteria weights on the basis of whether they are the best design for a "game rule". However, the study has provided an evaluation procedure that can be used as a baseline for the designing of TNQA criteria, or for the revising of the criteria, no matter how TNQA committee members decide the criteria weights. The evaluation procedure should be used before making or revising criteria weights in future, or before a complete change in the whole framework of the TNQA.

Another interesting aspect was the backgrounds of the various TNQA committee members. The committee members in 2001 were basically from four different groups. Of all TNQA members, 41.9% were from academia, 27.9% from government sectors, 13.9% from semi-official organizations, and only 16.3% from private businesses. This distribution is perhaps not ideal. The TNQA is an excellent quality system that is mainly designed for private businesses. It provides an excellent paradigm for companies that have excellent quality performance. Therefore, the involvement of more voices and opinions from private business would be helpful in this regard in undertaking design or any fundamental reappraisal of TNQA criteria.

6. Conclusion

The TNQA has been successfully conducted for fourteen years since it was established in

1990. So far, the process of weighting the criteria of the TNQA has not been explored. In fact, it is not known how TNQA committee members first created the weightings for each criterion. However, the present study can verify that the weightings of the criteria are reasonable, as a result of analyzing the opinions of committee members through FHA. In this paper, trapezoidal fuzzy numbers were adopted to measure the relative importance of criteria from the perspective of various committee members. Each committee member was allowed to choose linguistic variables using "interval" expressions that reflected his or her subjective judgments of the relative importance of criteria. This is very close to meeting the reality of group decision-making. After the evaluation of FHA, a reasonable range of weight for each criterion was obtained.

There are two suggestions for future study with regard to the TNQA criteria. First, in this study, the sample size may be smaller to make conclusive findings from the analysis. To obtain more opinions from quality experts, the questionnaire respondents could include past and current TNQA committee members. Quality experts in private business could also be on the invitation list when seeking opinions. Secondly, the TNQA has now become a model of excellence in business performance in Taiwan. An increasing number of non-manufacturing organizations compete for the TNQA in order to increase their organizational efficiency. Therefore, the weights of TNQA criteria should be independently designed or modified to allow for the requirements and needs of different businesses.

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APPENDIX A: Questionnaire scale items

Please indicate your level of importance with a single 'number' or 'interval' in each following comparison between two criteria:

Scale Anchors: Equal Importance (1), Weak Importance (3), Essential Importance (5), Very Strong Importance (7), Absolute Importance (9), Intermediate Values (2, 4, 6, 8).

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
I																		II

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
I																		III

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
I																		IV

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
I																		V

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
I																		VI

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
I																		VII

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
II																		III

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
II																		IV

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
II																		V

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
II																		VI

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
II																		VII

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
III																		IV

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
III																		V

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
III																		VI

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
III																		VII

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
IV																		V

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
IV																		VI

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
IV																		VII

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
V																		VI

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
V																		VII

scale / criterion	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	scale / criterion
VI																		VII