Hierarchies Consistency Analysis for Quality Performance Assessment: A study of the criterion weights

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Abstract

The aim of this paper is to identify and prioritize the most important indicators of quality management practices using a multiple-criteria decision making (MCDM) approach. Analytic Hierarchy Process (AHP) is applied as a systematic methodology for constructing the hierarchy structures evaluation the model of study. This paper also utilizes the Hierarchies Consistency Analysis (HCA) theory for calculating of the criterion relative weights, rating the measures and obtaining quality performance score. The study has gone through set of steps for structuring the AHP model, collecting data, and determining the normalized priority weights of criterion. Results of consistency analysis showed the leadership and management commitment as top criteria for quality management assessment that will help organizations to investigate their current quality management practices by organizations. Ranking of the proposed criteria derived from this study will provide a better understanding of organizations on the direction and targets for improving organizational performance.

Keywords
Organizational Performance, Self-assessment, Hierarchies Consistency Analysis, Analytic Hierarchy Process, Quality Practices.

1. Introduction

Quality management as a multidimensional concept has been widely adopted by various organizations for many years. In response to this, a variety of quality management approaches have been proposed as the prime driver for enhanced organizational performance. Organizations around the globe adopted quality management approach as one of the most important means for achieving competitive advantage.

The history of quality management philosophy began initially with a narrow focus on a systematic approach known as a vehicle to understand variation and to develop strategies for improvement based on philosophical, scientific and statistical foundation (Juran, 1995).This concept later became known as the philosophical foundations of continuous improvement process under the term Total Quality Management (Dahlgaard-Park *et al.*, 2001). In order to improve organizational performance, companies have utilized self-assessment approach aim at long-term success through continuous quality improvement. The origin and key concept of self-assessment is referred to the initiation of national and international quality assessment models/frameworks (Doulatabadi & Yusof, 2015). These models provide guidelines to organizations for effective self-assessment. Quality assessment models are mainly developed to measure organiztional performance through leadership, innovation and continuous improvement.

This study aims to identify and prioritize the most important indicators of quality management practices by using Analytic Hierarchy Process (AHP) as a multiple-criteria decision making (MCDM) approach. The Hierarchies Consistency Analysis (HCA) theory is also applied for calculating of the criterion relative weights, rating the measures and obtaining quality performance score. This paper presents the results of consistency analysis of main criteria for quality management assessment. Results of this study will contribute to better understanding of organizations on the direction and targets for improving quality management practices.

2. Literature Review

2.1 Quality Management Practices

Quality management has been regarded as one of the most important factors for achieving competitive advantage. The quality management movement could be seen as referring to a set of ideas and principles which have been adopted in organizations under a variety of names. Throughout several decades, a series of major events have occurred and led to quality management concept developed continuously from practical focus to an integrated approach to managing quality in an organization (Feigenbaum, 1961). The concept of 'total quality management' (TQM) as the fourth level of quality movement became one of the most widespread quality approach for businesses almost four decades (van der Wiele et al., 1997).

The main difference between quality management practice and TQM is that the former entails adopting a number of easily implementable practices whose effects are relatively easy to evaluate. The practices chosen by a particular firm will be determined by the firm's technology, history, environment (predominantly customers, suppliers and regulators) and the availability of managerial skill. According to Besterfield (2012) TQM domain is usually referred to several sufficient principles, practices, and techniques have been developed by scholars and professionals. On the whole, the TQM principles provide general guidelines, which are implemented through practices that are supported by techniques (Dean & Bowen 1994).

In particular human resource practices including leadership, customer satisfaction, employee involvement, and continuous improvement are identified as those that constitute the 'principle and practices' aspect of TQM. On the other hand, 'tools and techniques' of TQM practices grouped into two aspects namely 'non-quantitative' aspect and 'quantitative' what is known as core aspect of TQM. In this respect, approaches such as ISO 9000, and benchmarking are classified as 'non-quantitative', while specific operational tools like Statistical Process Control (SPC), and Taguchi's Quality Engineering are considered as 'quantitative' aspect of TQM. Self-assessment process is generally grouped 'non-quantitative' aspect of TQM practice (Doulatabadi *et al.,* 2014).

It has been suggested that quality management practices will only produce significant benefits if it is implemented and sustained in a long-term basis (Brown, 2014; Prajogo & Sohal, 2004a; Zairi, 2002b; Shin et al., 1998). Previous studies have shown that the importance of the human related factors of quality management practices including ongoing support and commitment of top management, communication and engagement of people at all organizational levels, and organization's strategy (Brown, 2014; Araújo & Sampaio, 2014; Dahlgaard et.al., 2013; Lu, 2011; Prajogo & Sohal, 2004b; Adebanjo, 2001). In this paper, quality management practice defines as a management philosophy supporting continuous improvement in customer focus, people involvement, operational performance and competitive advantage at all levels of the organization.

2.2 Self-Assessment Concept

Self-assessment recognized as a process which enables organizations to determine where they are on their business activities and plan out the next steps. It is perceived as a key driver and one of the powerful approaches for improving performance in an organization. Self-assessment is a method of looking across an organization at a specific point in time to see where it is in relation to achieving its performance outcomes (Lee, 2002). Self-assessment in an organizational context it is about learning and improving the organizations strengths and weaknesses. Self-assessment answers the fundamental question including, where an organization is now, where they want to be, how they can get there, and how close they are to the world class destination. In the initial stages, self-assessment can be used as a 'health check' a starting point for focusing attention and action.

The primary purpose of self-assessment is to identify organizations strengths and areas for improvement and to develop action plans to improve performance (EFQM 2012). By identifying strengths and weaknesses, an organization can develop and implement an improvement strategy by analyzing the current situation (Samuelsson & Nilsson, 2002). According to Mann and Grigg (2004) organizations around the world adopt self-assessment for several reasons as follows:

i. The provision of a mechanism for selecting high performing organizations for national awards;
ii. Providing feedback on performance for award applicants, and
iii. To promote and encourage organizational self-assessment, benchmarking and general management education and development.

For many organizations conducting self-assessment towards achieving business performance is strategically and tactically vital for gaining a competitive advantage. Irrespective of what types of approach is used, there are general steps and procedures for conducting a self-assessment as illustrated in Figure 1.

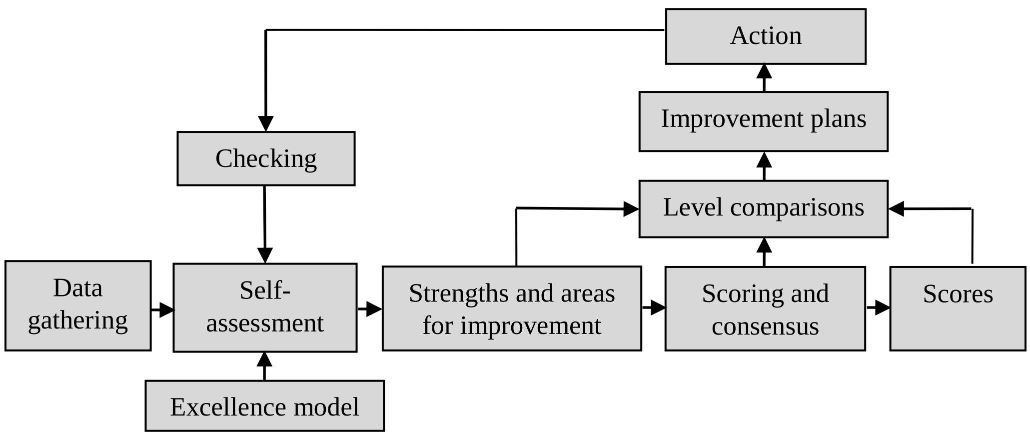

Figure 1.Self-asessment process (Source: adopted from EFQM, 2014, p. 41).

The major outcome of the self-assessment is to distinguish clearly what an organization has been achieved and what needs to be done for improvement actions against an award model (Hillman, 1994). The primary purpose of self-assessment is to identify organizations strengths and areas for improvement and to develop action plans to improve performance (EFQM, 2012). By identifying strengths and weaknesses, an organization can develop and implement an improvement strategy by analyzing the current situation (Samuelsson & Nilsson, 2002).

Several approaches have been proposed to help organizations in conducting a self-assessment. They include survey questionnaire; pro forma; workshop; the matrix chart; and award simulation. These techniques vary in terms of their top down versus empowered implementation. Of these approaches, however, survey questionnaires and award simulation has been widely adopted by organizations as main instrument to assess their business performance towards achieving excellence (EFQM, 2014). According to Hillman (1994) there is no universal and best method for self-assessment as each proposed approach has advantages and disadvantages.

3. AHP Approach: Basic Concept and Theory

The Analytic Hierarchy Process (AHP) is the most widely decision making methods used for formulating and analyzing decision making problems. It was originally introduced and developed by Thomas L. Saaty on the basis of a strong mathematical and logical groundwork. Basically, the AHP establishes decision weights for alternatives by organizing objectives, criteria and sub-criteria in a hierarchic structure. Decision weights and priorities are obtained from the decision maker's assessments of the way in which each item of a decision problem compares with respect to any other item at the same level of the hierarchy. Central in the AHP theory is the process of measurement, in particular measurement on a ratio scale. The theory of AHP is based on the concept of having n alternatives and their relative pairwise comparison is an approximation to the ratio of wi/wj which is the weight of alternative i to alternative j.

The AHP approach uses a multi-level hierarchical decision model involving objectives, criteria, sub-criteria, and alternatives. In a simple AHP situation, the overall goal or objective of the decision is represented at the top level of the hierarchy followed by the criteria and sub-criteria contributing to the decision which are represented at the intermediate levels. The next higher level would consist of the criteria for judging the alternatives, and the alternatives are at the bottom. Figure 2 shows the overall structure of the AHP method which typically use in conducting decision-making problems research.

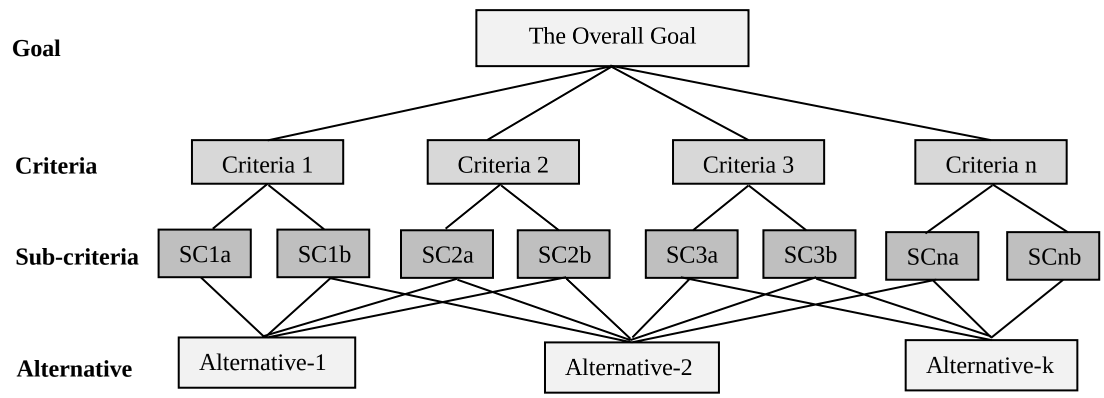

Figure 2.A simple AHP structure

4. Data Collection and Procedures

In this paper AHP methodology was applied in the developing of the model of study. In order to perform AHP method a number of steps need to conduct as recommended Ho et al. (2006). Basically, the application of AHP to a decision problem involves three main steps including; 1) hierarchy construction, 2) priority analysis, and 3) consistency verification according to Saaty (2008a). The AHP evaluation process begins with setting up an evaluation hierarchy structure for the problem based upon interrelated criteria drawn from the problem itself. Next, a matrix of pairwise comparisons of the interrelated criteria for each groups of the hierarchy is made by a decision maker. Lastly, the relative weight of criteria is obtained by utilizing the eigenvalue method. With the acquisition of the largest eigenvalue from the comparison matrix, a consistency index (CI) and consistency ratio (CR) is then constructed to measure the degree of rationality of the decision makers in making pairwise comparisons.

In this study several indicators were developed for evaluating quality management practices. The selected factors and their related sub-factors used for developing the AHP model of the study. As the first step, a set of factors and sub-factors were identified through review of literature. The selected factors then were validated by the panel of experts using the survey questionnaire. A survey was then conducted separately to determine the level of quality practice in selected industry. Next, all valid responds were recorded and analyzed using Expert Choice software. From the results, five indicators were placed with less important based on expert respondents' opinions. Finally, five factors with a total of 29 related sub-factors were listed and adopted in constructing the hierarchy model of the study. Pairwise comparison technique was subsequently employed to calculate the relative weight (importance), rating the measures of the proposed factors and relevant sub-factors. The overall procedure of the AHP is shown in Figure 3. The following sections are explained detailed procedures of the AHP followed by the results of consistency analysis.

4.1 Structuring and Constructing Hierarchy Model

A typical four-level hierarchical model was designed to include goal, criteria, sub-criteria, and alternatives as the first essential step. Pairwise comparison as a quantitative evaluation technique was then conducted to establish priorities of each criteria factor and its associated sub-criteria. In this approach each participant was requested to express opinion about the value of one single pairwise comparison at a time. Having derived the relative priorities, a set of comparison matrices was then constructed to prioritize and convert individual comparative judgments into ratio scale measurements. Each matrix was normalized and then the normalized priority weights of each criterion were calculated respectively.

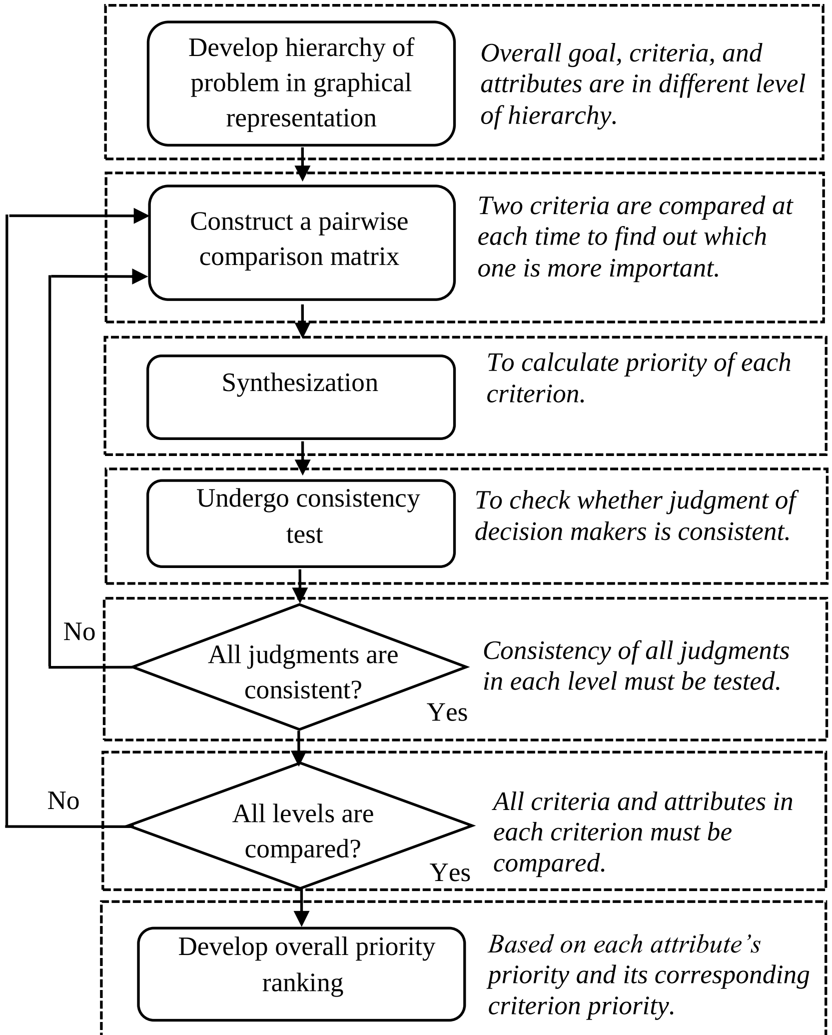

Figure 3.The flowchart of the AHP (adopted from Ho *et al.*, 2006)

According to Saaty (1977) since comparisons were carried out through personal (subjective) judgments, consistency verification is performed by computing consistency ratio (CR). It is regarded as advantage of AHP method that helps to ensure decision-making is consistent over the pairwise comparison. In order to derive a meaningful interpretation of either the difference or the consistency index, random consistency index (RCI) for different size matrices is used as suggested by Saaty (2008a). Table 1 represents the average random consistency index (RCI) for random judgments for matrices of order 1 to 10.

Table 1.Average random index for corresponding matrix size (Saaty, 2008a)

Matrix size (n)	1	2	3	4	5	6	7	8	9	10
Random index (RI)	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The first row displays the order of the matrix while the second row presents the random index value. In general, the consistency value of less than 0.1 (i.e. CR $\leq$ 0.1) is considered reasonably consistent. The CR possible outcome which has been employed in AHP method is shown in Table 2. However, in Expert Choice (EC) software this ratio is called the inconsistency ratio since the larger the value, the more inconsistent the judgments. Generally, the value less than 0.1 (i.e. CR $\leq$ 0.1) confirms that the evaluation within the matrix is acceptable or indicates a good level of consistency in comparative judgments represented in that matrix. In contrast, the value of more than 0.1 (i.e. CR ≥ 0.1) shows inconsistency of judgments within that matrix. If this occurred the evaluation process should therefore be reviewed, reconsidered and improved (Saaty, 2008a).

Table 2.Consistency ratio outcomes (Expert Choice, 2012)

Value of CR	Result / Action
≥ 0.10	Pairwise judgment requires re-evaluation and improved
< 0.10	Judgment consistent and acceptable
= 0.0	Theoretical best fit judgment

4.2 Establishing of the Priority Analysis

After constructing the decision model in the hierarchical terms, the next step was to establish priorities of individual criteria and its associated sub-criteria. For this purpose, pairwise comparison technique was applied. Comparison was made at each level of the hierarchy to measure which factors and sub-factors are regarded as more important relative to others as suggested by Saaty (2008a).This particular stage involved five stages. More discussion on each stage is given in the following sections.

Determine Pair-Wise Comparisons

In order to determine how much one sub-factor is important than the other, pair-wise comparisons between all five sub-factors was conducted as an example. To reflect this comparison, a set of factors designed to determine different point of view of the experts on the importance of each sub-factor using the AHP rating scale of 1 to 9 (1= equally, 3= moderate, 5= strong, 7= very strong, 9= extreme) as suggested by Saaty. Table 3 presents the nine point scale indexes and their meanings as proposed by Saaty (2008a).

Table 3.The AHP fundamental pairwise comparison scale (Saaty, 2008a)

Numerical Value*	Verbal Scale	Explanation
1.0	Equally importance	Two elements contribute equally to the objective.
2.0	Weak or slight	-----
3.0	Moderate importance	Experience and judgment slightly favor one element over another.
4.0	Moderate plus	-----
5.0	Strong importance	Experience and judgment strongly favor one element over another.
6.0	Strong plus	-----
7.0	Very strong or demonstrated importance	An element is favored very strongly over another; its dominance demonstrated in practice.
8.0	Very, very strong	-----
9.0	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation.
1.1–1.9	If the elements are very close	May be difficult to assign the best value but when compared with other contrasting elements the size of the small numbers would not be too noticeable.

Construct Pair-Wise Comparisons Matrix

After completing the comparison table by experts, the preferences of each expert was geometrically averaged and the pairwise comparisons matrices were then constructed. In this situation, the importance of R1 considered equally to moderate over R2 (=2), equally compared to R3 (=1), moderate-to-strong compared to R4 (=4), and strong-to-very strong compared to R5 (=6). A similar interpretation is true for the rest of the sub-criteria. Figure 4 shows the numerical stated judgments for all the sub-factors as evaluated by the experts.

$$\begin{array}{cc} & \begin{array}{ccccc} R1 & R2 & R3 & R4 & R5 \end{array} \\ \begin{array}{c} R1 \\ R2 \\ R3 \\ R4 \\ R5 \end{array} & \begin{bmatrix} \mathbf{1} & 2 & 1 & 4 & 6 \\ 1/2 & \mathbf{1} & 1/3 & 2 & 4 \\ 1 & 3 & \mathbf{1} & 3 & 4 \\ 1/4 & 1/2 & 1/3 & \mathbf{1} & 2 \\ 1/6 & 1/4 & 1/4 & 1/2 & \mathbf{1} \end{bmatrix} \end{array}$$

Figure 4.Pair-wise comparison for RER matrix

All the diagonal elements of the matrix are equal to 1 as the elements are compared with themselves. The values of elements in the upper triangular matrix are obtained from the averaged preferences of pairwise comparisons. The reciprocals of these values are presented in the lower triangular matrix.

Normalized Pair-Wise Comparisons Matrix

Once the comparisons matrix is established, the next step is taking average of each row of the normalized matrix to obtain the relative importance weights matrix of the factors. In order to do this, the value of each column in the matrix is divided by its corresponding sum. Figure 5 shows the normalized pair-wise 5×5 matrix to sum up to 1 for the RER factor. The values displays in the normalized pair-wise matrix are the normalized sub-factors.

$$\begin{array}{cc} & \begin{array}{ccccc} R1 & R2 & R3 & R4 & R5 \end{array} \\ \begin{array}{c} R1 \\ R2 \\ R3 \\ R4 \\ R5 \end{array} & \begin{bmatrix} 0.343 & 0.296 & 0.343 & 0.381 & 0.353 \\ 0.171 & 0.148 & 0.114 & 0.190 & 0.235 \\ 0.343 & 0.444 & 0.343 & 0.286 & 0.235 \\ 0.086 & 0.074 & 0.114 & 0.095 & 0.118 \\ 0.057 & 0.037 & 0.086 & 0.048 & 0.059 \end{bmatrix} \end{array}$$

Figure 5.Normalized pair-wise matrix

Calculate Relative Weights of Sub-Factors

After normalizing the matrix, the eigenvector of the matrix was first calculated by adding all elements in each row of the normalized matrix to obtain a row sum. The next step is dividing this sum by the number of elements in the row to give relative importance weight of each item. Table 4 represents the final relative weights of sub-factors.

Table 4.Calculation of relative weights for RER sub-factors

Item no.	R1	R2	R3	R4	R5	Sum of row	Relative weight
R1	0.343	0.296	0.343	0.381	0.353	1.716	0.3432
R2	0.171	0.148	0.114	0.190	0.235	0.858	0.1716
R3	0.343	0.444	0.343	0.286	0.235	1.651	0.3302
R4	0.086	0.074	0.114	0.095	0.118	0.487	0.0974
R5	0.057	0.037	0.086	0.048	0.059	0.287	0.0574
Sum	1	1	1	1	1	5	-

Compute Consistency Ratio (CR)

Having derived the relative weight of each sub-factor, the last step of AHP involved determining the value of consistency ratio (CR) to ensure consistency of the final comparison matrix. In this respect, first the consistency index (CI) of each sub factor was determined by multiplying the judgment matrix with relative weight matrix as shown in Figure 6.

$$\begin{bmatrix} \mathbf{1} & 2 & 1 & 4 & 6 \\ 1/2 & \mathbf{1} & 1/3 & 2 & 4 \\ 1 & 3 & \mathbf{1} & 3 & 4 \\ 1/4 & 1/2 & 1/3 & \mathbf{1} & 2 \\ 1/6 & 1/4 & 1/4 & 1/2 & \mathbf{1} \end{bmatrix} \times \begin{bmatrix} 0.3432 \\ 0.1716 \\ 0.3302 \\ 0.0974 \\ 0.0574 \end{bmatrix} = \begin{bmatrix} 1.7506 \\ 0.8776 \\ 1.7100 \\ 0.4938 \\ 0.2887 \end{bmatrix}$$

Figure 6.Calculation of pair-wise matrix with relative weight matrix

The weights of each sub-factor subsequently were obtained by dividing the resultant matrix by relative weight matrix as exhibited in Figure 7.

$$\begin{bmatrix} 1.7506 \\ 0.8776 \\ 1.7100 \\ 0.4938 \\ 0.2887 \end{bmatrix} \div \begin{bmatrix} 0.3432 \\ 0.1716 \\ 0.3302 \\ 0.0974 \\ 0.0574 \end{bmatrix} = \begin{bmatrix} 5.1008 \\ 5.1142 \\ 5.1786 \\ 5.0698 \\ 5.0296 \end{bmatrix}$$

Figure 7.Calculation of final sub-criteria weights

Having determined the importance weights of each sub-factor, the CI value for the comparison matrix was then calculated using the following formula as defined by Saaty, where λmax represents the largest eigenvalue and n is the order of the matrix.

$$CI = \frac{(\lambda_{max} - n)}{(n-1)}$$

By taking the average of the final matrix in Figure 5.7, the value of λ max was obtained as below:

$$\lambda_{max} = \frac{(\lambda_1 + \lambda_2 + \lambda_3 + \cdots + n)}{n}$$
$$= \frac{(5.1008 + 5.1142 + 5.1786 + 5.0698 + 5.0296)}{5} = 5.0986$$

Substituting λ max (=5.0986) and n (=5) into the formula, the CI value was calculated as follows:

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} = \frac{(5.0986 - 5)}{(5-1)} = 0.0246$$

Finally with these two values in hand, the CR coefficient is obtained by taking the CI value and dividing it by Random Index (RI). The corresponding value of RI for the size of matrix five (n=5) is equal to 1.12 as defined in the Random Index. The result of this calculation is represented as below:

$$CR = \frac{CI}{RI} = \frac{0.0246}{1.120} = 0.02196 \cong 0.22$$

Based on the result, since the CR value obtained is less than 0.10 (i.e. 0.022 < 0.10), it can be concluded that the matrix is consistent over the pairwise comparison for further analysis (see Table 1). The importance of each RER sub-criteria is depicted by vertical bars. Based on the priority weights obtained, criterion R1 (i.e. Recognition and

Reward System) is considered as the most important one with the weight of 0.343, followed by criterion R3 (i.e. Recognition and Involvement) which is weighted at 0.330. The same calculations done for RER matrix was subsequently carried out for each factor and its associated sub-factors derived from pairwise comparisons matrices to obtain their priority weightings using Expert Choice (EC) software. Table 5 illustrates a summary of result for each major criteria.

Table 5: Results of consistency analysis for five main criteria

Item	Criteria	λ_{max} [a]	C.I. [b]	R.I. [c]	C.R. [d]
1	Leadership/management commitment	6.8723	0.1744	1.240	0.0910
2	Strategic quality planning	6.2325	0.0465	1.240	0.0678
3	Recognition and reward	5.0986	0.0246	1.120	0.0223
4	Communication and relationship	6.7534	0.1506	1.240	0.0913
5	Work culture and climate	6.4532	0.0906	1.240	0.0885

a: Largest eigenvalue (λ max) *c: Random Index (RI)*
b:Consistency Index (CI) *d: Consistency Ratio (CR)*

Each factor is ranked according to the CI value of major criteria as shows in the last column of the table. Based on the results, the CR values ranged from 0.0223 to 0.0913, which means that all the pairwise comparisons are perfectly consistent since the values obtained are within the acceptable level recommended by Saaty. Based on the consistency test, the entire CR of the pairwise matrix for each main criteria is calculated less than 0.10, indicating that the respondents have given their weights consistently in determining the importance weights of the each factor. The sum of the relative weights of all the factors adds up to 1. The target values for the indicators should be set.

5. Conclusion and Implications

The main purpose of this paper was to identify and prioritize the most important indicators of quality management practices using a multiple-criteria decision making (MCDM) approach. The proposed indicators were developed using Analytic Hierarchy Process (AHP) methodology. A hierarchical structure of AHP was mainly formulated to identify the necessary composition and rating them. For this purpose a set of steps were conducted in applying the AHP methodology for the purpose of identifying and rating of the indicators. The results of the study show that leadership/management commitment is the most important criterion which is followed by strategic quality planning and recognition and reward. The indicators generated through this study allow the organizations to assess their quality progress based on the proposed factors of the organizations. Through rating the current level of quality performance organizations can actually get a quick overview on where they are in their quality journey to excellence and where improvements need to be made. The proposed AHP model and its methodology will hopefully provide guidance to organizations for measuring quality and business excellence performance. The importance weights also can be used for assessing the quality performance. In this manner the indicators for each criterion must be defined with their importance weight.

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