Prioritising critical success factors of TQM in Malaysia aerospace industry using fuzzy AHP

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Abstract. Malaysia has set a target to become the first aerospace nation in South East Asia by 2030. In efforts to ensure industry players are able to achieve the target, the critical success factors (CSFs) that affecting the successful implementation of total quality management (TQM) in aerospace industry, especially in Malaysia, need to be identified and ranked. Ranking CSFs is a sensitive task that requires extra attention. Self-judgment, previous experiences and references by industry experts, including the existence of uncertainty in decision making, results in inaccurate ranking. Therefore, this study aims to prioritise (identify and rank) the CSFs for successful implementation of TQM in Malaysia aerospace industry (manufacturing sector). Through an in-depth review of the literature, 11 CSFs were identified and categorised into four main criteria. These criteria were analysed empirically using Fuzzy Analytic Hierarchy Process (FAHP) approach to rank the CSFs based on their relative importance weights. FAHP approach was used since the judgments from industry experts have been taken into account as recommended by National Aerospace Industry Coordinating Office (NAICO). The results showed that the main criterion for successful TQM implementation is culture and people with the highest weight of 0.434, followed by organising (0.296), systems and technique (0.151), and measurement and feedback (0.119). Therefore, the top management and decision makers need to give more attention on culture and people factors before implementing TQM which include employee involvement and role of quality department. However, the relationship between CSFs and the performance of TQM implementation need to be analysed further.

1. Introduction

The idea of critical success factors (CSFs) was first presented by D. Ronald Daniel in 1960s [1]. It was then built on and popularized a decade later by John F. Rockart, of MIT’s Sloan School of Management, and has since been used extensively to help businesses implement their strategies and projects. CSFs, also known as Key Results Areas (KRAs), are the essential areas of activity that must be performed well if you are to achieve the mission, objectives or goals for your business or project. By identifying your CSFs, you can create a common point of reference to help you direct and measure the success of your business or project; i.e., CSFs help everyone in the team to know exactly what’s most important, and this helps people perform their own work in the right context and so pull together towards the same overall aims. CSFs can consequently give serious positive or negative effects to organisation depending on how they implement and handle the factors.
TQM is a structured approach to overall organisational management. The focus is to continuously improve the quality of outputs through continual improvement of internal practices to achieve high customer satisfaction. Generally, all departments of an organization need to execute TQM. According to Hamzah and Ho [2], execution of TQM in all departments allows communications within groups of different specialties from different departments to work as a team. Besides being known as a factor that can improve quality, TQM is also a holistic approach used in all organizations in accessing continuous improvement [3]. According to Talib et al. [4], TQM is considered as an important parameter and benchmark to develop manufacturing frameworks. Most manufacturing companies prefer TQM approach in improving and managing the quality of products [5].

The importance of ranking the CSFs prior to implementing TQM is associated with the reduction in cost and the ability to avoid failure, and resulting in the improvement of success rate of a firm [6]. The knowledge of CSFs should be totally understood by management to ensure successful implementation of TQM. Hence, diligent efforts and activities need to be done in ensuring the proper implementation of TQM and identifying CSFs that affect its implementation. According to Kalra and Pant [7], the failure of TQM implementation is due to ignorance of quality measures in monitoring customer satisfaction, lack of management leadership, product quality and employee morale.

The main objective of this study is to identify and rank the CSFs for successful TQM implementation in Malaysia aerospace industry (manufacturing sector) using Fuzzy Analytic Hierarchy Process (FAHP). The results from this study would give additional information to Government’s agencies in creating more initiatives to improve the growth of aerospace industry.

2. Malaysia aerospace Industry
Aerospace industry in Malaysia is a fast growing industry with high-income contribution to the nation’s economy. This is largely due to regional dynamics triggered by the rapidly growing commercial aviation sector in South East Asia. Additionally, the many opportunities offered for advanced technology transfer in engineering, electronics, composite materials, system integration, and research and technology industries have pushed the government to view the aerospace as a critical industry. The five main focus areas of Malaysia aerospace industry are aero manufacturing, engineering and design, MRO (maintenance, repair and overhaul), systems integration, and education and training, supported by research and technology activity [8]. Aero structures, avionics equipment, engines and airframe equipment are examples of products offered by aero manufacturing sector.

The total investment in Malaysia aerospace industry in 2015 worth RM5 billion with four approved projects (99% domestic) [9]. In 2016, the total investment had decreased to RM1.6 billion with nine approved projects (56.9% foreign and 43.1% domestic). However, the foreign investment had greatly increased from RM30.6 million in 2015 to RM889.4 million in 2016. The exports value in this industry in 2015 worth RM4.17 billion. In 2016, it had recorded the highest value at RM5.5 billion. Malaysia aerospace industry had recorded USD2.88 billion of total revenue in 2016 and the main contributor was from aero manufacturing. The positive trends and the abundant opportunities await in the future have driven Malaysian stakeholders to agree on the shared vision and the main focus areas.

The impressive growth of the aerospace industry in the past two decades has driven the government to put in several strategies to ensure continuous growth. This has been portrayed in the Malaysian Aerospace Industry Blueprint 2030 [8]. This document is the main reference for long term industry planning beyond 2020, forming the common development basis for the next 15 years. It is used as the guideline to position Malaysia as the region’s leading aerospace hub by 2030. The targeted annual revenue in 2030 is RM55.2 billion with more than 32,000 high-income jobs. The aero manufacturing sector is targeted to take the lead for aerospace parts and components sourcing in South East Asia.

Thus, improving the industry growth is very crucial. Industry players must build comprehensive strategies to sustain their capability in providing high quality products to fulfill the targets stated in the blueprint. Management approach such as TQM plays its role in ensuring long-term sustainability. Generally, all members of an organisation will contribute towards TQM efforts. However, TQM implementation is incomplete without assessing the CSFs that influence the execution of TQM.
3. Multi-criteria decision making

A suitable multi-criteria decision making (MCDM) approach can be used to rank the CSFs [10]. Decision making, ranking and selection processes can be complicated mainly when the determination of multiple alternatives is considered based on incommensurate and conflicting criteria. MCDM consists of two types; multiple objective decision making (MODM) and multiple attributes decision making (MADM). Analytic Hierarchy Process (AHP) is an example of MCDM. However, this study implemented FAHP to handle the unstable mode in structuring human judgments [11].

AHP was first developed by Thomas Saaty in 1980. It is a structured technique for organising and analysing complex decisions [12]. AHP is a general theory to set priorities to qualitative and quantitative decision making by determining the relative weights of a set of options against a set of criteria in perceptive manner [13]. This approach allows the conversion of pairwise comparisons into a set of numbers that represent the relative priorities of all criteria. Unfortunately, there are few shortcomings exhibit by AHP. For instance, the directly use of crisp-information decisions that leads to unstable mode of respondents which caused the judgments to be imprecise. Therefore, a fuzzy sets theory developed by Zadeh [14] must be applied to eliminate biasness in handling experts’ opinion.

Selection problems that practice the combination of fuzzy set theory concept and hierarchical structure analysis can be solved systematically using FAHP. It is an extension method from AHP to fuzzy domain. The calculation for FAHP involves fuzzy numbers instead of real numbers, and the pairwise comparisons matrices for criteria and alternatives are performed through linguistic variables.

4. Methodology

The complexity in implementing TQM increases with the number of factors. Even though AHP is the most appropriate for composite decision problems [11], this study uses FAHP because of its ability to consider the mode of vagueness and uncertainty to human judgments. The FAHP employed by Yadav and Desai [15] was considered. The methodology is divided into two phases; identifying and ranking CSFs. It is crucial to ensure that all CSFs are included. The ranking of CSFs is evaluated using FAHP.

4.1. Phase 1: Identifying critical success factors (CSFs) of TQM implementation

The CSFs that affect TQM implementation in aerospace manufacturing sector are identified based on previous studies. However, the CSFs for other sectors in aerospace industry as well as other industries were also considered. The CSFs are categorized into a number of main criteria (of factors).

4.1.1. Construct questionnaire based on CSFs

A questionnaire is constructed based on CSFs and adapted from Chin et al. [16]. The respondents are experienced individuals (expert panels) from well-established aero manufacturing companies in Malaysia, as recommended by National Aerospace Industry Coordinating Office (NAICO).

The questionnaire consists of three sections. Section A consists of description of all main criteria and their factors (CSFs). Section B retrieves respondent’s demographic information such as gender, age, current position and number of years, and experience in aero manufacturing. In Section C, the respondents will rank the main criteria and their factors using Saaty’s nine-point scale as in Table 1.

4.1.2. Define main criteria and factors to construct hierarchal structure of CSFs

The identified CSFs are categorized according to main criteria to build a hierarchal structure of CSFs. The first level is the objective of this study, the second level consists of the main criteria of all identified factors, and the third level comprises all factors grouped under the respective main criteria.

4.2. Phase 2: Ranking CSFs using fuzzy AHP approach

4.2.1. Construct pairwise comparison matrix and fuzzy pairwise comparison matrix

The comparison matrix for each expert (s) is as follows; the entries $r_{ij}$ are ranked by $s$ industry experts based on the nine-point scale as described in Table 1.
Table 1. Saaty’s nine-point Scale

| Scale | Intensity of importance | Explanation |
|-------|-------------------------|-------------|
| 1     | Equally important       | Two activities contribute equally to the objective |
| 3     | Moderately important    | Experience and judgment slightly favour one activity over another |
| 5     | Strongly important      | Experience and judgment strongly favour one activity over another |
| 7     | Very strongly important | An activity is favoured very strongly over another |
| 9     | Extremely important     | Evidence favouring one activity over another is of the highest order |
| 2, 4, 6, 8 | Intermediate values between two adjacent judgments | When compromise is needed |

Reciprocal of above nonzero numbers when compared with i, then j has the reciprocal value when compared with i. A reasonable assumption.

\[
A_s = \begin{bmatrix}
    r_{11} & r_{12} & \cdots & r_{1j} \\
    r_{21} & r_{22} & \cdots & r_{2j} \\
    \vdots & \vdots & \ddots & \vdots \\
    r_{i1} & r_{i2} & \cdots & r_{ij}
\end{bmatrix}, \text{ where } r_{ij} = \text{scale of factor } i \text{ by factor } j.
\]

The decisions about TQM implementation are attributable to many uncertainties. In this situation, decision makers should rely on experts’ knowledge. Therefore, using the Fuzzy Logic concept [14], decision makers could enhance precision when dealing with imprecise and uncertain data. A vague input data is denoted by a fuzzy number which is represented by its membership grade ranging from 0 to 1. The scale for fuzzy pairwise comparison is shown in Table 2.

Table 2. Scale of relative importance for fuzzy pairwise comparison

| Description              | Allotted fuzzy number | Defined membership function |
|--------------------------|-----------------------|----------------------------|
| Equally important        | 1                     | (1, 1, 1)                  |
| Weakly important         | 3                     | (1, 3, 5)                  |
| Strongly important       | 5                     | (3, 5, 7)                  |
| Very strongly important  | 7                     | (5, 7, 9)                  |
| Extremely important      | 9                     | (7, 9, 11)                 |

A triangular fuzzy number (TFN) is symbolized as \((a, b, c)\) or \((a/b, b/c)\); \(a\) represents the largest value, \(b\) is the most promising and \(c\) is the smallest. The TFN comparison matrix for each expert \(s\) is

\[
\tilde{A}_s = \begin{bmatrix}
    \tilde{r}_{11} & \tilde{r}_{12} & \cdots & \tilde{r}_{1j} \\
    \tilde{r}_{21} & \tilde{r}_{22} & \cdots & \tilde{r}_{2j} \\
    \vdots & \vdots & \ddots & \vdots \\
    \tilde{r}_{i1} & \tilde{r}_{i2} & \cdots & \tilde{r}_{ij}
\end{bmatrix} = \begin{bmatrix}
    (\tilde{a}_{11}, \tilde{b}_{11}, \tilde{c}_{11}) & (\tilde{a}_{12}, \tilde{b}_{12}, \tilde{c}_{12}) & \cdots & (\tilde{a}_{1j}, \tilde{b}_{1j}, \tilde{c}_{1j}) \\
    (\tilde{a}_{21}, \tilde{b}_{21}, \tilde{c}_{21}) & (\tilde{a}_{22}, \tilde{b}_{22}, \tilde{c}_{22}) & \cdots & (\tilde{a}_{2j}, \tilde{b}_{2j}, \tilde{c}_{2j}) \\
    \vdots & \vdots & \ddots & \vdots \\
    (\tilde{a}_{i1}, \tilde{b}_{i1}, \tilde{c}_{i1}) & (\tilde{a}_{i2}, \tilde{b}_{i2}, \tilde{c}_{i2}) & \cdots & (\tilde{a}_{ij}, \tilde{b}_{ij}, \tilde{c}_{ij})
\end{bmatrix},
\]

where \(\tilde{r}_{ij}\) = scale of factor \(i\) by factor \(j = (\tilde{a}_{ij}, \tilde{b}_{ij}, \tilde{c}_{ij})\), and \(\tilde{a}_{ij}, \tilde{b}_{ij}\) and \(\tilde{c}_{ij}\) are respectively the largest, most promising and smallest values of the scale in membership function. Right and left sides of TFN consist of linear representations and can be defined in terms of its membership function

\[
\mu(x|a, b, c) = \begin{cases} 
    (x - a)/b - a, & a \leq x \leq b \\
    (c - x)/c - b, & b \leq x \leq c \\
    0, & \text{otherwise}
\end{cases}
\]

4.2.2. Calculate means of all experts to build a set of fuzzy comparison matrices (FCMs)

The means are calculated using Geometric Mean (GM). Basically, GM is not highly influenced by extreme values as in arithmetic mean, and its function is to average percentages and indexes. The geometric mean for a set of \(n\) positive real numbers can be defined as in equation (1).
Geometric Mean = GM = \sqrt[n]{(x_1)(x_2) ... (x_n)}. \quad (1)

Problems associated with fuzzy is best to use GM since it is well-defined for a set of positive real numbers. Thus, equation (1) is converted to \( \tilde{M} \) to satisfy TFN environment which enables us to calculate the scale average of all experts’ opinions for each factor to form a FCM, \( \tilde{\mathbf{A}} \). In general, \( \tilde{\mathbf{A}} \) is the \( s \)-th root of the product of \( s \) TFNs. The means \( \tilde{a}_{ij} \), \( \tilde{b}_{ij} \) and \( \tilde{c}_{ij} \) for all experts are calculated as

\[
\mathbf{A} = \begin{bmatrix}
\tilde{r}_{11} & \tilde{r}_{12} & \cdots & \tilde{r}_{1j} \\
\tilde{r}_{21} & \tilde{r}_{22} & \cdots & \tilde{r}_{2j} \\
\vdots & \vdots & \cdots & \vdots \\
\tilde{r}_{11} & \tilde{r}_{12} & \cdots & \tilde{r}_{1j}
\end{bmatrix},
\]

where \( \tilde{r}_{ij} \) = scale average for factor \( i \) by factor \( j = (\tilde{a}_{ij}, \tilde{b}_{ij}, \tilde{c}_{ij}) \), and

\[
\tilde{a}_{ij} = \frac{1}{s} \left( \prod_{i=1}^{s} \tilde{a}_{ij} \right), \tilde{b}_{ij} = \frac{1}{s} \left( \prod_{i=1}^{s} \tilde{b}_{ij} \right), \text{ and } \tilde{c}_{ij} = \frac{1}{s} \left( \prod_{i=1}^{s} \tilde{c}_{ij} \right). \quad (2)
\]

4.2.3. Shift FCM into crisp comparison matrix (CCM)

In order to define the confidence level (\( \alpha \)), the lower and upper limits of fuzzy numbers were assigned using the following equation:

\[
\forall \alpha \in [0, 1] \tilde{M}_\alpha = [\alpha^a, \alpha^c] = [(b - a)\alpha + a, -(c - b)\alpha + c] \quad (3)
\]

where \( \alpha^a \) = lower limit of fuzzy number, and \( \alpha^c \) = upper limit of fuzzy number.

The shifting of FCM (\( \tilde{\mathbf{A}} \)) to \( \alpha \)-cut comparison matrix (CCM) (\( \mathbf{A}^\alpha \)) is done using equation (3). The degree of index value (\( \mu \)) corresponds similarly to the optimism index which enabling us to find the satisfaction degree for judgment matrix by calculating \( \mu \). The \( \alpha \)-cut CCM (\( \mathbf{A}^\alpha \)) is defined as

\[
\mathbf{A}^\alpha = \begin{bmatrix}
r_{11}^\alpha & r_{12}^\alpha & \cdots & r_{1j}^\alpha \\
r_{21}^\alpha & r_{22}^\alpha & \cdots & r_{2j}^\alpha \\
\vdots & \vdots & \cdots & \vdots \\
r_{11}^\alpha & r_{12}^\alpha & \cdots & r_{1j}^\alpha
\end{bmatrix},
\]

where \( r_{ij}^\alpha = (\tilde{\mathbf{r}}_{ij}^\alpha, \tilde{\mathbf{r}}_{ij}^\alpha) \), \( \tilde{\mathbf{r}}_{ij}^\alpha \) and \( \tilde{\mathbf{r}}_{ij}^\alpha \) are respectively the lower and upper limits of a fuzzy number.

Thus, \( \mathbf{A}^\alpha \) can be converted to CCM (\( \mathbf{A} \)) using \( A_{ij}^\alpha = \mu \left( \tilde{\mathbf{r}}_{ij}^\alpha \right) + (1 - \mu) \tilde{\mathbf{r}}_{ij}^\alpha \), and stated as follows:

\[
\mathbf{A} = \begin{bmatrix}
r_{11} & r_{12} & \cdots & r_{1j} \\
r_{21} & r_{22} & \cdots & r_{2j} \\
\vdots & \vdots & \cdots & \vdots \\
r_{11} & r_{12} & \cdots & r_{1j}
\end{bmatrix}, \text{ where } r_{ij} = \text{crisp value of factor } i \text{ by factor } j.
\]

4.2.4. Check consistency index and consistency ratio of all matrices

This step involves normalization of all comparison matrices. The entries for normalized comparison matrix, \( \mathbf{N} = [z_{ij}] \), ranging [0, 1], can be obtained using \( z_{ij} = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}} \).

\[
\mathbf{N} = [z_{ij}] = \begin{bmatrix}
z_{11} & z_{12} & \cdots & z_{1j} \\
z_{21} & z_{22} & \cdots & z_{2j} \\
\vdots & \vdots & \cdots & \vdots \\
z_{11} & z_{12} & \cdots & z_{1j}
\end{bmatrix}, \text{ where } z_{ij} = \text{normalized value of factor } i \text{ by factor } j.
\]

Equations to calculate the column sum of matrix \( \mathbf{A} \), \( A_j = [r_j] \), row average of normalized comparison matrix \( \mathbf{N} \), \( Z_i = [z_i] \) and \( \lambda_{\text{max}} \) are denoted as follows:

\[
A_j = [r_j] = \sum_{i=1}^{n_i} r_{ij}, \ Z_i = [z_i] = \frac{\sum_{j=1}^{n_j} z_{ij}}{n_j}, \ \lambda_{\text{max}} = A_j \times Z_i = [r_j] \times [z_i]; \quad (4)
\]

where \([r_j]\) = column sum of factor \( j \), \([z_i]\) = value of factor \( i \), \( n_i \) = total number of factor \( i \), \([z_i]\) = normalized comparison matrix of factor \( i \) by factor \( j \), \( z_i \) = normalized value of factor \( i \), and \( n_j \) = total number of factor \( j \).
The equations for consistency index (CI) and consistency ratio (CR) are \( CI = \frac{\lambda_{\text{max}} - n}{n - 1} \) and \( CR = \frac{CI}{RI} \) (\( n \) = total number of included factors). All matrices for the main criteria as well as factors must satisfy \( CR \leq 0.1 \) and \( CI \leq 0.1 \). Otherwise, the group of experts is required to revise the pairwise judgments before computing the weights. Random consistency index (RI) is shown in Table 3.

| Size \((n)\) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|-------------|---|---|---|---|---|---|---|---|
| RI          | 0 | 0 | 0.52 | 0.89 | 1.11 | 1.25 | 1.35 | 1.40 |

4.2.5. Calculate relative importance weights for all CSFs
The relative importance weights for all criteria can be calculated once the CR values for all matrices are acceptable. The row average \( A_j = [r_j] \) reflects the corresponding weight for each criterion. Hence, the relative importance weights can be simplified as \( [W_j] = [z] \).

4.2.6 Rank CSFs based on their relative importance weights
The main criteria are ranked based on their relative importance weights. The most influential critical factor of successful TQM implementation within each main criterion can be obtained by observing the weights of its factors.

5. Analysis and discussions
5.1. Critical success factors of TQM implementation in aero manufacturing
The list of CSFs stated by Chin and Pun [16] was used since it is specifically related with the successful implementation of TQM in manufacturing industry. These identified CSFs were then categorised into four main criteria to develop a hierarchy structure for FAHP, as in Table 4.

| Table 4. Main Criteria of Factors |
|----------------------------------|
| Main Criterion                   | Factor                        |
| Organising (FO)                  | Management commitment (O1)    |
|                                  | Training and Education (O2)   |
| Systems and Techniques (FST)     | Continuous Improvement (ST1)  |
|                                  | Supplier Partnership (ST2)    |
|                                  | Product/Service Design (ST3)  |
|                                  | Quality Policies (ST4)        |
| Measurement and Feedbacks (FMF)  | Quality Data and Reports (MF1)|
|                                  | Communication to Improve Quality (MF2) |
|                                  | Customer Satisfaction Orientation (MF3) |
| Culture and People (FCP)         | Role of Quality Department (CP1) |
|                                  | Employee Involvement (CP2)    |

As illustrated in Figure 1, the main objective of this study is to prioritise (identify and rank) the CSFs (Level 1). The main criteria of CSFs (Level 2) are Organizing (FO), Systems and Techniques (FST), Measurement and Feedback (FMF) and Culture and People (FCP). Finally, Level 3 consists of all 11 factors that have been clustered under the four main criteria.

The questionnaire was sent to six industry experts. However, only four experts responded to the questionnaire, as detailed in Table 5. All respondents were male and holding related positions with more than 10 years professional experiences. The respondents are responsible to evaluate the importance of all factors from their viewpoint and experiences. The nine-point scale in Table 1 was used.
shows the main criteria FCMs from the four industry experts based on their point of view.

The nine-point scale of TFN, as shown in Table 2, was employed to construct PCM and FCM. Table 6

5.2. Ranking CSFs using fuzzy AHP approach
The FAHP adapted from Yadav and Desai [15] was employed to analyse the questionnaire data.

5.2.1. Pairwise comparison matrix (PCM) and fuzzy pairwise comparison matrix (FCM)
The nine-point scale of TFN, as shown in Table 2, was employed to construct PCM and FCM. Table 6 shows the main criteria FCMs from the four industry experts based on their point of view.

| Industry Expert 1: | Criteria | FO | FST | FMF | FCP |
|-------------------|----------|-----|-----|-----|-----|
| FO                | (1, 1, 1) | (1, 3, 5) | (1, 1, 1) | (1, 1, 1) |
| FST               | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) | (1, 1, 1) | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) |
| FMF               | (1, 1, 1) | (1, 3, 5) | (1, 1, 1) | (1, 1, 1) |
| FCP               | (1, 1, 1) | (1, 3, 5) | (1, 1, 1) | (1, 1, 1) |

| Industry Expert 2: | Criteria | FO | FST | FMF | FCP |
|-------------------|----------|-----|-----|-----|-----|
| FO                | (1, 1, 1) | (1, 3, 5) | (1, 1, 1) | (1, 1, 1) |
| FST               | (1, 1, 1) | (1, 3, 5) | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) |
| FMF               | (1, 1, 1) | (1, 3, 5) | (1, 1, 1) | (1, 1, 1) |
| FCP               | (1, 1, 1) | (1, 3, 5) | (1, 1, 1) | (1, 1, 1) |

| Industry Expert 3: | Criteria | FO | FST | FMF | FCP |
|-------------------|----------|-----|-----|-----|-----|
| FO                | (1, 1, 1) | (1, 3, 5) | (1, 1, 1) | (1, 1, 1) |
| FST               | (1, 1, 1) | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) |
| FMF               | (1, 1, 1) | (5, 7, 9) | (1, 1, 1) | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) |
| FCP               | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) | (7, 9, 11) | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) | (1, 1, 1) |

| Industry Expert 4: | Criteria | FO | FST | FMF | FCP |
|-------------------|----------|-----|-----|-----|-----|
| FO                | (1, 1, 1) | (1, 3, 5) | (1, 1, 1) | (1, 1, 1) |
| FST               | (1, 1, 1) | (1, 3, 5) | (5, 7, 9) | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) |
| FMF               | (1, 1, 1) | (5, 7, 9) | (1, 1, 1) | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) |
| FCP               | (\frac{1}{5}, \frac{3}{5}, \frac{7}{5}) | (1, 3, 5) | (7, 9, 11) | (1, 1, 1) |

5.2.2. Calculate means of FCMs of all experts using geometric mean approach
The means of all FCMs were calculated using geometric means, as stated in equation (2), for each industry expert. The new FCM, \( \tilde{A} \), is illustrated in Table 7.

| Main Criteria | FO          | FST         | FMF          | FCP          |
|---------------|-------------|-------------|--------------|--------------|
| FO            | (1.00, 1.00, 1.00) | (1.00, 1.32, 1.50) | (2.14, 2.59, 2.96) | (0.67, 1.00, 1.50) |
| FST           | (0.67, 0.76, 1.00) | (1.00, 1.00, 1.00) | (0.58, 1.00, 1.73) | (0.15, 0.22, 0.47) |
| FMF           | (0.34, 0.39, 0.47) | (0.57, 1.00, 1.73) | (1.00, 1.00, 1.00) | (0.20, 0.25, 0.29) |
| FCP           | (0.67, 1.00, 1.50) | (2.14, 4.49, 6.62) | (2.65, 3.95, 4.96) | (1.00, 1.00, 1.00) |
5.2.3. Shift FCM into crisp comparison matrix (CCM)

The value of case optimism $\mu$ was set as 0.5 to indicate the balance optimism for assessments made by experts. Table 8 shows $A^\alpha$ and $A$ for the main criteria, and Table 9 shows $A$ for each criterion.

| Table 8. $\alpha$-cut CCM ($A^\alpha$) and CCM ($A$) for main criteria |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Main Criteria | FO | FSF | FMF | FCP |
| FO | 1.00, 1.00 | 1.16, 1.41 | 2.37, 2.78 | 0.83, 1.25 |
| FSF | 0.71, 0.88 | 1.00, 1.00 | 0.79, 1.37 | 0.19, 0.35 |
| FMF | 0.36, 0.43 | 0.79, 1.37 | 1.00, 1.00 | 0.23, 0.27 |
| FCP | 0.83, 1.25 | 3.31, 5.55 | 3.30, 4.45 | 1.00, 1.00 |

| Table 9. CCMs ($A$) for factors under four main criteria |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Organising (FO) | Factors | O1 | O2 |
| O1 | 1.00 | 1.63 |
| O2 | 0.62 | 1.00 |
| Total | 1.62 | 2.63 |
| Systems and Techniques (FST) | Factors | ST1 | ST2 | ST3 | ST4 |
| ST1 | 1.00 | 0.62 | 1.03 | 1.34 |
| ST2 | 1.82 | 1.00 | 2.04 | 2.61 |
| ST3 | 1.03 | 0.59 | 1.00 | 2.26 |
| ST4 | 0.82 | 0.40 | 0.47 | 1.00 |
| Total | 4.67 | 2.61 | 4.55 | 7.21 |
| Measurement and Feedback (FMF) | Factors | MF1 | MF2 | MF3 |
| MF1 | 1.00 | 0.50 | 0.25 |
| MF2 | 2.04 | 1.00 | 1.10 |
| MF3 | 4.19 | 0.92 | 1.00 |
| Total | 7.23 | 2.42 | 2.35 |
| Culture and People (FCP) | Factors | CP1 | CP2 |
| CP1 | 1.00 | 0.22 |
| CP2 | 4.57 | 1.00 |
| Total | 5.57 | 1.22 |

Based on Table 8, CCM ($A$), column sums for $[A_i]$, were obtained as in Table 10. The column sums were used to normalise $A$. The normalized CCM ($A$) and its row averages are shown in Table 11.

| Table 10. Column sums of for Matrix $A$, $[A_i]$, for main criteria |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Main Criterion | FO | FSF | FMF | FCP |
| Column Sum | 3.23 | 7.79 | 8.52 | 2.56 |

| Table 11. Normalized CCM ($A$) and row averages for main criteria |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Main Criteria | FO | FSF | FMF | FCP |
| FO | 0.31 | 0.16 | 0.30 | 0.41 |
| FSF | 0.25 | 0.13 | 0.13 | 0.10 |
| FMF | 0.12 | 0.14 | 0.12 | 0.10 |
| FCP | 0.32 | 0.37 | 0.45 | 0.39 |

Hence, the row averages of matrix $N$ for main criteria are denoted as $z_i = [0.30, 0.15, 0.12, 0.43]$. Furthermore, the normalized matrices of factors ($N$) for the four main criteria are shown in Table 12.

| Table 12. Normalized matrices $N$ for factors under four main criteria |
|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Organising (FO) | Factors | O1 | O2 |
| O1 | 0.62 | 0.62 |
| O2 | 0.38 | 0.38 |
| Total | 1.00 | 1.00 |
| Systems and Techniques (FST) | Factors | ST1 | ST2 | ST3 | ST4 |
| ST1 | 0.21 | 0.24 | 0.23 | 0.19 |
| ST2 | 0.39 | 0.38 | 0.45 | 0.36 |
| ST3 | 0.22 | 0.23 | 0.22 | 0.31 |
| ST4 | 0.18 | 0.15 | 0.10 | 0.14 |
| Total | 1.00 | 1.00 | 1.00 | 1.00 |
| Measurement and Feedback (FMF) | Factors | MF1 | MF2 | MF3 |
| MF1 | 0.14 | 0.21 | 0.10 |
| MF2 | 0.28 | 0.41 | 0.47 |
| MF3 | 0.38 | 0.38 | 0.43 |
| Total | 1.00 | 1.00 | 1.00 |
| Culture and People (FCP) | Factors | CP1 | CP2 |
| CP1 | 0.18 | 0.18 |
| CP2 | 0.82 | 0.82 |
| Total | 1.00 | 1.00 |
5.2.4. Consistency index (CI) and consistency ratio (CR) of all matrices

Before calculating consistency index (CI) and consistency ratio (CR) for the main criteria matrix, $\lambda_{\text{max}}$ and random consistency index (RI) need to be determined. Table 13 shows the values of $\lambda_{\text{max}}$, CI, RI, and CR for the main criteria. Hence, the conditions CI $\leq$ 0.1 and CR $\leq$ 0.1 are both satisfied.

Table 13. Consistency index and consistency ratio for main criteria

| $\lambda_{\text{max}}$ | CI   | RI   | CR  |
|------------------------|------|------|-----|
| 4.26                   | 0.09 | 0.89 | 0.10|

5.2.5. Relative importance weight for all factors

The row averages $A_i$ that reflect the main criteria’s corresponding weights were calculated, and the relative importance weights can be stated as $W = [\text{FO}, \text{FST}, \text{FMF}, \text{FCP}] = [0.30, 0.15, 0.12, 0.43]$.

5.2.6. Rank CSFs based on relative importance weights

The final relative importance weights for all CSFs are summarised and ranked in Table 14.

Table 14. Relative importance weights and ranking of main criteria and factors

| Main Criterion | Priority Weight | Rank | Factor | Priority Weight | Rank |
|----------------|-----------------|------|--------|-----------------|------|
| Organizing (FO) | 0.296           | 2    | Management Commitment (O1) | 0.618 | 2 |
|                 |                 |      | Training and Education (O2) | 0.382 | 6 |
| Systems and Technique (FST) | 0.151          | 3    | Continuous Improvement (ST1) | 0.216 | 8 |
|                 |                 |      | Supplier Partnership (ST2) | 0.396 | 4 |
|                 |                 |      | Product/Service Design (ST3) | 0.243 | 7 |
|                 |                 |      | Quality Policies (ST4) | 0.142 | 11 |
| Measurement & Feedback (FMF) | 0.119         | 4    | Quality Data and Reports (MF1) | 0.150 | 10 |
|                 |                 |      | Communication to Improve Quality (MF2) | 0.388 | 5 |
|                 |                 |      | Customer Satisfaction Orientation (MF3) | 0.462 | 3 |
| Culture and People (FCP) | 0.434          | 1    | Role of Quality Department (CP1) | 0.181 | 9 |
|                 |                 |      | Employee Involvement (CP2) | 0.819 | 1 |

The results indicate that Culture and People (FCP) is the most influential criterion on the successful implementation of TQM with 0.434 priority weight. Among the factors, Employee Involvement (CP2) is the most critical with 0.819 priority weight.

6. Conclusion and recommendation

The main objective of this study is to identify and rank the CSFs of TQM implementation in Malaysia aero manufacturing sector using Fuzzy AHP approach. A list of 11 CSFs for successful TQM implementation were selected from various sources and categorised into four main criteria; Organizing (FO), Systems and Technique (FST), Measurement and Feedback (FMF), and Culture and People (FCP). The collected data consist of individual’s judgments from industry experts in Malaysia aero manufacturing sector. The CSFs were analysed empirically using FAHP approach.

The results showed that Culture and People (FCP) has the highest weight of 0.434, followed by Organising (FO), Systems and Technique (FST), and Measurement and Feedback (FMF); i.e., 43.4% of successful TQM implementation is influenced by culture and people factors. This agreed with Chin et al. [16]. Thus, industry players need to put more effort and attention on the factors that associated with this criterion; employee involvement (CP1) and role of quality department (CP2). CP1 is the most critical factor within FCP with priority weight of 0.819. Thus, the top management should give more attention on employee involvement, commitments and participation in making quality decisions.

The second most influential criterion is Organising (FO) with 0.296 of priority weight; i.e., 29.6% of TQM implementation is influenced by organising. Management commitment (O1) and training and education (O2) are the factors within this criterion with 61.8% and 38.2%, respectively. The third main criterion is Systems and Technique (FST) with 0.151 priority weight; i.e., FST influences as much as
15.1% to successful TQM implementation. Within FST, supplier partnership is the most critical factor. Last but not least, Measurement and Feedback (FMF) criterion with only 0.119 priority weight. Within FMF, customer satisfaction orientation (MF3) is the most influential factor. From the first and second most influential criteria, it can be concluded that an organisational transformation is required for successful TQM implementation especially organisation structure and corporate culture.

The findings from this study suggested that a further analysis on relationship between identified CSFs with the performance of TQM implementation needs to be done to understand the behaviour on how CSFs would affect the implementation of TQM. The prioritisation of CSFs can be improved with one-to-one interview and discussion with industry experts. Furthermore, researchers and practitioners can further this study to focus on evaluation of the impact of CSFs towards financial and non-financial performances of an aerospace manufacturing company.

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