Supplier selection for hospital medical equipment using fuzzy multicriteria decision making approach

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Abstract. Medical equipment is important in the healthcare service system and plays a major role in global markets. Meanwhile, selection of suitable medical equipment supplier is also essential because medical equipment relates to the patient’s life. Moreover, there are several qualitative and quantitative evaluation factors that may be conflicting in nature while assessing optimum supplier among several alternatives. This study has objectives to discover the criteria for selection of appropriate medical equipment suppliers and to illustrate methods for selection of a suitable medical equipment supplier. The ROC (Rank Order Centroid) method was applied to determine the weight of each criterion. Fuzzy TOPSIS (Fuzzy Technique for Order Preference by Similarity to Ideal Solution) was used to select the optimal supplier. A case study was chosen concerning a hospital in the northeast of Thailand. Findings indicated the main criteria for consideration of supplier selection as quality, price, reliability, agility, compliance, service, benefits/bargaining, and transport/delivery and the results showed that out of five candidates, supplier A was the optimal choice.

1. Introduction

Today, technological advances in medical devices and equipment play a huge role in health service systems which are constantly adapting and changing to keep pace with new scientific discoveries. Good, reliable equipment can increase human life quality. On the other hand, if the medical devices are not dependable or safe, this may cause problems in health economy and society.

In 2016, 131 medical supplies and equipment companies were registered in Thailand which made the country a major importer and exporter of medical equipment in the ASEAN region [1]. The medical equipment market in Thailand is continuously growing. In 2015, Thailand exported medical materials, supplies and equipment worth more than ten billion baht. Figure 1 shows the budget for the Thailand Ministry of Public Health 2007–2018 which has been increasing every year [2]. In a similar vein, the global medical devices and equipment market is becoming increasingly important. Value of the worldwide market is expected to reach US$409.5 billion by 2023, while projected CAGR (Compound Annual Growth Rate) is 4.5% from 2018 to 2023 [3]. Therefore, medical equipment is extremely important in healthcare.

Although medical devices and equipment markets both in Thailand and worldwide show strong growth, research concerning the selection of medical equipment suppliers is limited. This study aims to investigate the important factors that affect selection of medical equipment suppliers and illustrate the methods for selection of an appropriate medical equipment supplier.
2. Literature review

Limited academic research exists concerning selection of medical equipment suppliers. K Diaconu et al. [4] stated that 40%-70% of the medical equipment in low- and middle-income countries is unfit for purpose or unused. Misuse of devices leads to incomplete costing and insufficient maintenance services. Therefore, procurement officials should prioritize devices by experience and needs-based methods to reach optimal purchase decisions. P. Ghadimi et al. [5] selected suppliers in the medical device manufacturing industry using a Fuzzy Inference System (FIS). Decision criteria consisted of environmental, economic and social dimensions to achieve sustainability. I. Ivlev [6] combined health technology assessment (HTA) and multiple-criteria decision analysis (MCDA) in the assessment of medical devices. The analytic hierarchy process (AHP) and Delphi method were applied to select a magnetic resonance imaging (MRI) system in the Czech Republic. C. Hajdau, and A. M. Spiridonica [7] used AHP to select PET-CT equipment. They concluded that AHP can be used to avoid inconsistency in decision-making preferences when the choice involves conflicting qualitative and quantitative criteria.

3. Methodology

The ROC (rank order centroid) method was used to weight criteria and fuzzy technique for order preference by similarity to the ideal solution (Fuzzy TOPSIS method) for multicriteria decision-making.

- **ROC.** ROC is a methodical approach which estimates weight that minimizes the maximum error of each weight by identifying the centroid of all possible weights while maintaining the rank order of objective importance [8]. Weight can be calculated using the following formula:

\[
W_j = \frac{1}{n} \sum_{j=1}^{n} \frac{1}{r_j} ; j = 1, 2, 3, ..., n
\]

Where \(W_j\) is a weight of criteria rank \(j\), \(n\) is number of criteria and \(r_j\) is a rank position of \(W_j\) then we can assume that \(W_r + W_{r+1} + W_{r+2} + ... + W_n = 1\)

- **Fuzzy TOPSIS.** Fuzzy set theory is integrated with TOPSIS to minimize the effects of hesitancy and variation in the decision makers’ preference. It is a method that determines order preference by using linguistic variables. Fuzzy TOPSIS can be applied as follows [9,10].

**Step 1:** Aggregate fuzzy ratings of the alternatives and criteria in the metrics (\(X_0\));

\[
\tilde{x}_{ij}^k = (\tilde{a}_{ij}^k, \tilde{b}_{ij}^k, \tilde{c}_{ij}^k)
\]

\[
a_{ij} = \min_k \{a_{ij}^k\} , \quad b_{ij} = \frac{1}{k} \sum_{k=1}^{K} b_{ij}^k , \quad c_{ij} = \max_k \{c_{ij}^k\}
\]

Where \(m\) is alternatives, \(n\) is criteria from decision makers, \(i\) and \(j = 1, 2, 3, ..., n\), \(r\) is number of decision makers from 1 to \(k\)
**Step 2**: Assign and compute fuzzy rating for each criterion to alternatives matrix \((\tilde{D})\) by using fuzzy preference scale as shown in Table 1.

| Linguistic value | Triangular Fuzzy number |
|------------------|------------------------|
| (1, 1, 3)        | Very Poor (VP)         |
| (1, 3, 5)        | Poor (P)               |
| (3, 5, 7)        | Fair (F)               |
| (5, 7, 9)        | Good (G)               |
| (7, 9, 9)        | Very Good (VG)         |

**Step 3**: Normalize fuzzy decision matrix \(R\) by using the following formula. Where \(i = 1, 2, 3, \ldots, m\) and \(j = 1, 2, 3, \ldots, n\) and \(\tilde{R} = [\tilde{r}_{ij}]\)

\[
\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right); \quad c_j^+ = \max_i\{c_{ij}\} \tag{4}
\]

\[
\tilde{r}_{ij} = \left(\frac{a_{ij}}{a_j^-}, \frac{b_{ij}}{a_j^-}, \frac{c_{ij}}{a_j^-}\right); \quad a_j^- = \min_i\{a_{ij}\} \tag{5}
\]

**Step 4**: Compute the weighted normalized fuzzy decision matrix \(V\) and determine the weight of each criterion to be in the range of 0-1 by following formula.

\[
\tilde{v}_{ij} = W_j \tilde{r}_{ij} \tag{6}
\]

Where \(W_j\) is weight of criteria \(C_j\) and \(\tilde{v}_{ij}\) is normalized data.

**Step 5**: Define the fuzzy positive-ideal solution \((A^*)\) and negative-ideal solution \((A^-)\) of each criterion following formula:

\[
A^* = (\tilde{v}_{1}^*, \tilde{v}_{2}^*, \ldots, \tilde{v}_{n}^*); \quad \tilde{v}_{j}^* = \max_i\{v_{ij}\} \tag{7}
\]

\[
A^- = (\tilde{v}_{1}^-, \tilde{v}_{2}^-, \ldots, \tilde{v}_{n}^-); \quad \tilde{v}_{j}^- = \min_i\{v_{ij}\} \tag{8}
\]

**Step 6**: Define the distances of fuzzy positive-ideal solution (FPIS) \(A^*\) and fuzzy negative-ideal solution (FNIS) \(A^-\) of each criterion by using the following formula:

\[
d(\bar{x}, \bar{y}) = \frac{1}{3} [(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2] \tag{9}
\]

\[
d_i^+ = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_{ij}^*) \tag{10}
\]

\[
d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_{ij}^-) \tag{11}
\]

**Step 7**: Compute the closeness coefficient \((CC_i)\) for each alternative using the following formula:

\[
CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \tag{12}
\]

**Step 8**: Rank all alternatives according to the closeness coefficient \((CC_i)\) in decreasing order. The alternative with the highest closeness to FPIS and farthest from the FNIS is the best.

4. **Result and Discussion**

Criteria were investigated from over 25 literature on supplier selection to classified into 23 main groups. Then, experts were asked to complete a questionnaire concerning the importance of these 23 main criteria for selection of medical equipment suppliers. Results in Table 2 show eight main criteria that impact highly on medical equipment supplier selection as quality, price, reliability, agility, compliance,
service, benefits/bargaining, and transport/delivery. Each main criterion has its own sub-criteria as shown in Table 2.

ROC was used to identify the weight of the main criteria and sub-criteria. Following equation (1), weights of the main criteria and sub-criteria are shown in Table 2.

### Table 2. Criteria and weight for medical equipment supplier selection.

| Main criteria   | Weight | Sub criteria                                      | Normalized weight |
|-----------------|--------|--------------------------------------------------|-------------------|
| Quality         | 0.34   | C1: Product quality/performance                  | 0.13              |
|                 |        | C2: Rejection rate                               | 0.02              |
|                 |        | C3: Quality certificate                          | 0.05              |
|                 |        | C4: Suitable product characteristics              | 0.13              |
| Price           | 0.22   | C5: Product price                                | 0.22              |
| Reliability     | 0.15   | C6: Performance history/History                  | 0.06              |
|                 |        | C7: Reliability                                  | 0.09              |
| Agility         | 0.11   | C8: React quickly                                | 0.03              |
|                 |        | C9: Handling and availability support by technical experts | 0.08          |
| Compliance      | 0.08   | C10: Compliance standard                         | 0.02              |
|                 |        | C11: Proper record on complaints and follow up    | 0.02              |
|                 |        | C12: Provide sample before first ordering         | 0.04              |
| Service         | 0.05   | C13: Guarantee & Warranty (GW)                    | 0.02              |
|                 |        | C14: Service rate                                | 0.01              |
|                 |        | C15: Training                                    | 0.01              |
| Benefits/Bargaining | 0.03 | C16: Quantity discount is offered by each supplier | 0.03              |
| Transport/Delivery | 0.02 | C17: On time delivery                            | 0.02              |
|                 |        | C18: Products delivered in good condition         | 0.01              |

Fuzzy TOPSIS was applied to select the optimal supplier. Each supplier was scored by the decision makers using fuzzy numbers mentioned in methodology section. By using equation (2), the aggregated fuzzy rating of each alternative supplier in relation to 18 sub-criteria obtained from decision makers is shown in Table 3. The normalize by fuzzy rating multiply with the normalized weight of each criterion according to equation (7) is shown in Table 4.

### Table 3. The aggregated fuzzy rating.

| Supplier | C1   | C2   | C3   | C4   | C5   | C6   | C7   | C8   | C9   |
|----------|------|------|------|------|------|------|------|------|------|
| A        | 5.89 | 1.13 | 5.89 | 5.89 | 5.79 | 7.99 | 7.99 | 7.99 | 5.89 |
| B        | 5.79 | 1.25 | 5.79 | 5.79 | 5.79 | 3.69 | 3.57 | 5.79 | 5.89 |
| C        | 5.89 | 1.25 | 5.89 | 3.79 | 3.57 | 5.79 | 5.79 | 5.79 | 3.69 |
| D        | 5.79 | 1.13 | 5.89 | 3.69 | 1.45 | 3.67 | 3.67 | 3.57 | 1.45 |
| E        | 5.79 | 1.13 | 5.79 | 3.69 | 3.77 | 7.99 | 5.89 | 5.79 | 3.69 |

| Supplier | C10  | C11  | C12  | C13  | C14  | C15  | C16  | C17  | C18  |
|----------|------|------|------|------|------|------|------|------|------|
| A        | 7.99 | 5.89 | 7.99 | 7.99 | 5.89 | 7.99 | 5.89 | 5.89 | 5.89 |
| B        | 5.79 | 3.67 | 5.79 | 5.79 | 5.79 | 5.79 | 5.79 | 5.79 | 5.79 |
| C        | 3.67 | 5.79 | 5.79 | 5.79 | 3.67 | 3.67 | 5.79 | 3.67 | 5.79 |
| D        | 3.67 | 3.57 | 3.67 | 3.67 | 3.67 | 3.67 | 3.57 | 1.55 | 3.67 |
| E        | 5.89 | 5.79 | 5.89 | 5.89 | 5.79 | 5.89 | 5.89 | 5.79 | 5.79 |
Table 4. The normalized fuzzy.

| Supplier | C1       | C2       | C3       | C4       | C5       | C6       |
|----------|----------|----------|----------|----------|----------|----------|
| A        | 0.07,0.12,0.13 | 0.01,0.02,0.02 | 0.03,0.04,0.05 | 0.07,0.12,0.13 | 0.02,0.03,0.04 | 0.10,0.13,0.06 |
| B        | 0.07,0.10,0.13 | 0.00,0.01,0.02 | 0.03,0.04,0.05 | 0.07,0.10,0.13 | 0.02,0.03,0.04 | 0.04,0.09,0.06 |
| C        | 0.07,0.12,0.13 | 0.00,0.01,0.02 | 0.03,0.04,0.05 | 0.04,0.10,0.13 | 0.03,0.04,0.07 | 0.07,0.10,0.06 |
| D        | 0.07,0.10,0.13 | 0.01,0.02,0.02 | 0.03,0.04,0.05 | 0.04,0.09,0.13 | 0.04,0.06,0.22 | 0.04,0.04,0.04 |
| E        | 0.07,0.10,0.13 | 0.01,0.02,0.02 | 0.03,0.04,0.05 | 0.04,0.09,0.13 | 0.03,0.03,0.07 | 0.10,0.06,0.06 |

Table 5 shows the distances of FPIS and FNIS calculated by using equation (5), and $CC_i$ value of each alternative by using equation (8). The best alternative is the one with the highest $CC_i$ value. From result in the table, it can be seen that supplier A is the optimal supplier.

Table 5. Distances of the ratings of each alternative from A$^+$ and A$^-$ and supplier ranking.

| Supplier | $d^+$ | $d^-$ | $CC_i$ | Rank |
|----------|-------|-------|--------|------|
| A        | 1.866 | 3.022 | 0.618  | 1    |
| B        | 2.024 | 2.927 | 0.591  | 4    |
| C        | 1.968 | 2.902 | 0.596  | 2    |
| D        | 2.095 | 2.642 | 0.558  | 5    |
| E        | 1.979 | 2.891 | 0.594  | 3    |

The current method for selecting medical equipment supplier of a case study hospital is to use subjective judgment of decision makers which supplier A was selected. The proposed method provides a systematic evaluation process to select medical equipment supplier based on important criteria which proves that the result is acceptable as supplier A gets the highest closeness coefficient value.

5. Conclusion

Eight main criteria are important in selection of the medical equipment supplier. These are quality, price, reliability, agility, compliance, service, benefits/bargaining, and transport/delivery. Quality is the most important criterion with weight of 34%. However, product price has highest weight when considering all sub-criteria. This means that using efficient equipment is necessary for medical treatment because it relates to the patient’s life while the price is still important due to the procurement budget. Fuzzy logic was applied in the selection of supplier due to the number of qualitative criteria which each required the
opinion of the decision maker. The fuzzy TOPSIS method ranked the suppliers which helped in selecting the optimal alternative.

This study identifies criteria for supplier selection of medical equipment. Findings will be beneficial for medical equipment suppliers to evaluate and develop their products and service. Moreover, other hospitals and organizations can use the criteria and the decision-making method as guidelines to apply for selecting the optimal medical equipment supplier.

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