A Preference-Based Approach to Fuzzy Multicriteria Decision Making Evaluation of Hospital Locations

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Abstract

This paper formulates the performance evaluation of hospital locations as a fuzzy multicriteria decision making problem, and presents a preference-based approach for obtaining an overall performance index for each hospital location. Linguistic variables approximated by fuzzy numbers are used to represent the subjective assessments of the decision maker so that the subjectiveness and imprecision inherent in the evaluation process is adequately handled in a cognitively less demanding manner. Based on the concept of the degree of optimality, the preference-based approach uses the λ-cut concept to allow the incorporation of the decision maker's attitude towards risk in approximating his/her subjective assessments**.** A hospital location evaluation problem is presented for demonstrating the applicability of the approach.

1 Introduction

People have been becoming more health conscious with their increasing focus on the quality of their health care [Wu *et al*., 2007]. As a result, there is an increasing high demand on quality medical services. To effectively meet this demand, hospital owners are developing strategies for improving the provision of medical services through the establishment of new hospitals [Brown and Barnett, 2004]. By doing so, these hospitals can achieve competitive advantages that are vital to their future growth.

In establishing new hospitals, the location and proximity of the hospital to the potential patients are the important factors for these hospitals to remain competitive and survive. This is because the largest segment of a hospital's market share comes from an area of proximity to the hospital [Brown and Barnett, 2004]. Recent surveys have shown that most hospitals located in rural areas have struggled in recent years because of the travel distance to the hospital and the lack of transportation in those rural areas [Vahidnia *et al*., 2009). As a result, evaluating the performance of hospital locations for establishing a new hospital is of priority concern for hospital owners to achieve a competitive advantage.

Evaluating the performance of hospital location alternatives, however, is complex. The complexity of the evaluation process is due to the multi-dimensional nature of the decision making process, the conflicting nature of the multiple evaluation criteria, and the presence of subjectiveness and imprecision in the decision making process [Wu *et al*., 2007]. To ensure that the hospital location evaluation process is carried out in an effective manner, a comprehensive evaluation of the hospital location's overall performance is required.

Numerous approaches have been developed for evaluating hospital locations [Wu *et al*., 2007; Lin and Tsai, 2009; Vahidnia *et al*., 2009]. Wu *et al*. [2007] apply the analytical hierarchy process (AHP) for evaluating hospital locations in Taiwan. The approach is used to determine the performance of each hospital location with respect to each criterion and the importance of the evaluation criteria pairwisely. This approach greatly reduces the decision maker's cognitive burden in the evaluation process. The pairwise comparison process, however, becomes cumbersome and the risk of inconsistencies increases when the number of alternatives and criteria increases which leads to unreliable decisions [Wibowo and Deng, 2009].

Lin and Tsai [2009] develop a hybrid approach using the analytical network process (ANP) and the technique ordered preference by similarity to the ideal solution (TOPSIS) for evaluating hospital locations. The ANP is used to obtain a set of suitable weights for the evaluation criteria involved. The TOPSIS is adopted to rank competing locations in terms of their overall performances. The underlying concept of this approach is both rational and comprehensible. The limitation of the approach is due to the computationally challenging nature of the problem solving process.

Vahidnia *et al*. [2009] present a fuzzy AHP approach to evaluate the optimum location for a new hospital in the Tehran urban area. Triangular fuzzy numbers are used for representing the decision maker's judgments. The concept of fuzzy synthetic extent analysis is applied for deciding the final priority of different decision criteria. This approach provides the flexibility and robustness needed for the decision maker in solving the decision making problem. The fuzzy AHP approach, however, is not effective in dealing with various types of fuzzy numbers used for expressing the pairwise comparison outcomes.

This paper formulates the performance evaluation of hospital locations as a fuzzy multicriteria decision making problem, and presents a preference-based approach for obtaining an overall performance index for each hospital location. Linguistic variables approximated by fuzzy numbers are used to represent the subjective assessments of the decision maker so that the subjectiveness and imprecision inherent in the evaluation process is adequately handled in a cognitively less demanding manner. Based on the concept of the degree of optimality, the λ-cut concept is used to allow the incorporation of the decision maker's attitude towards risk in approximating his/her subjective assessments. An example is presented for demonstrating the applicability of the proposed approach for effectively dealing with the evaluation problem.

In what follows, a hospital location evaluation problem is first presented. Then a preference-based approach is developed for dealing with the hospital location evaluation problem. This is followed by an example for demonstrating the applicability of the proposed approach.

2 A Hospital Location Evaluation Problem

There are various factors that are considered to be critical for evaluating the comparative performance of hospital locations. Much research has been done on identifying the critical factors for evaluating the performance of hospital locations [Shen, 2003; Brown and Barnett, 2004; Lin and Wu, 2007; Wu et al., 2007; Brekke *et al*., 2008; Vahidnia *et al*., 2008; Lin and Tsai, 2009; Soltani and Marandi, 2011].

Shen [2003], for example, believes that the optimal hospital location should be of a location which provides the community with a clear awareness of the hospital's presence. Brown and Barnett [2004] show that the optimal hospital location should be able to accommodate subsequent growth of the hospital's services over time. Lin and Wu [2007] state that the availability of land for long-term expansion plays an important role in the success of the hospital. Wu *et al*. [2007] show that the population number, the density and the age profile in the area should be taken into account in evaluating the hospital location. Brekke *et al*. [2008] believe that the optimal hospital location should consider the number of existing hospitals already in the area. Vahidnia *et al*. [2008] believe that the optimal hospital location should be based on the type of medical services required by the local community. Lin and Tsai [2009] show that land cost is an important aspect in evaluating hospital locations. Soltani and Marandi [2011] state that the optimal hospital location should be based on its proximity to major commuter and public transit routes.

A comprehensive review of the related literature shows that the hospital location evaluation problem can be formulated as a fuzzy multicriteria decision making problem. Six most important criteria are identified for evaluating hospital locations in an organization including the Financial Attractiveness (C_1), Demand Potential (C_2), Organizational Strategy (C_3), Supporting Industries (C_4), Government Influence (C_5), and Marketing Dynamics (C_6). The hierarchical structure of hospital location evaluation problem is shown in Figure 1.

The Financial Attractiveness (C_1) concerns with the economical feasibility of the hospital's investment with respect to its business strategy. This is measured by the capital required for building the hospital, the labour cost of hospital personnel in the region, and the contribution of the hospital to organizational profitability usually are taken into consideration [Shen, 2003].

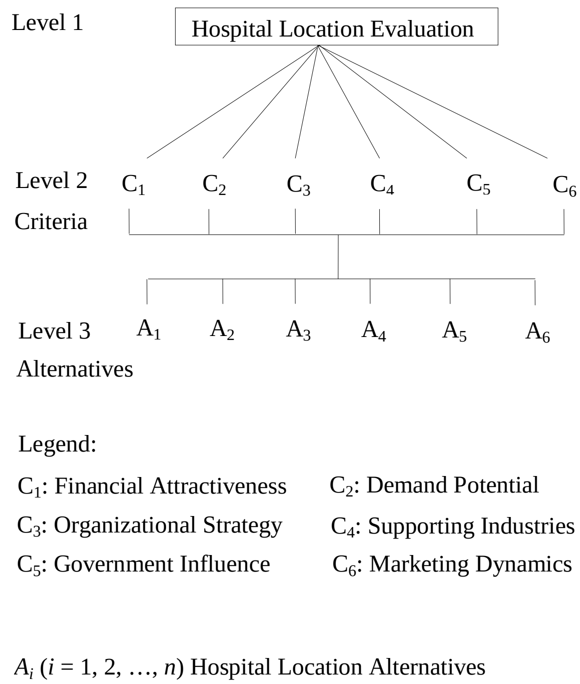

Figure 1: The Hierarchical Structure of the Hospital Location Evaluation Problem

Demand Potential (C_2) refers to the factors influencing the medical market demand. It is measured by the population number requiring medical services, the population density of the region, and the population age distribution in the region [Lin and Wu, 2007].

Organizational Strategy (C_3) concerns with the attitudes of the management towards its business practices and competitors. This is determined by the management objective for achieving a long term success, the attitude of management towards competition from other hospitals, and the policymaker's attitudes towards management's style [Brekke *et al*., 2008].

Supporting Industries (C_4) refers to the upper echelons of the medical sector and their supporting sectors. This is assessed by the support from the health sector, the medicine practice and the pharmaceutical sector including biochemistry technology and cultivation of medical personnel, and the hospital administration sector which includes management consultants and the information technology industry [Lin and Wu, 2007].

Government Influence (C_5) reflects on the governmental policy towards establishing hospitals in order to strengthen their competitiveness. This is assessed by qualifications of the hospital's establishment, efforts to promote a medical network, and promulgating tasks that require a hospital's assessment [Wu et al., 2007].

Marketing Dynamics (C_6) concerns with the circumstances that would negatively impact the medical care sector and possibly influence current market competition. This is measured by violent change in market demand that resulted in a decreased medical demand, dramatic fluctuations in production costs, and significant changes in the financial market and exchange rate that incur changes in the cost of medical instrumentation and pharmaceuticals [Wu *et al*., 2007].

Based on the discussion above, it can be seen that the hospital location evaluation problem is complicated due to (a) the multi-dimensional nature of the decision making process, (b) the conflicting nature of the multiple evaluation criteria, and (c) the presence of subjectiveness and imprecision in the decision making process.

To effectively evaluate the most suitable hospital location in a given situation, it is important for the decision maker to simultaneously consider the multiple evaluation criteria discussed as above. To facilitate the evaluation of the most appropriate hospital location, an effective preference-based approach is presented in the following section.

3 The Preference-Based Approach

Evaluating the comparative performance of hospital locations is always complex due to (a) the large number of hospital location alternatives available, (b) the multi-dimensional nature of the problem, (c) the presence of subjectiveness and imprecision involved in the decision making process, and (d) the need for conducting a comprehensive evaluation in a timely manner.

Evaluating the performance of hospital location alternatives usually involves in (a) discovering all the available alternatives, (b) identifying the evaluation criteria, (c) assessing the performance ratings of the hospital location alternatives and the weights of the criteria, (d) aggregating the alternative ratings and criteria weights for producing an overall performance index for hospital location alternatives across all criteria on which the final decision can be made [Wibowo and Deng, 2008].

Subjectiveness and imprecision is existent in multicriteria decision making due to (a) incomplete information, (b) abundant information, (c) conflicting evidence, (d) ambiguous information, and (e) subjective information [Yeh *et al*., 2010; Wibowo and Deng, 2012]. To adequately model the subjectiveness and imprecision in multicriteria decision making, linguistic variables approximated by triangular fuzzy numbers are often used to express the decision maker's subjective assessments. These triangular fuzzy numbers are usually used to represent the approximate distribution of these linguistic variables with values ranged between 1 and 9, denoted as (a_1, a_2, a_3) where $1 < a_1 < a_2 < a_3 < 9$. a_2 is used to represent the most possible value of the term, and a_1 and a_3 are representing the lower and upper bounds respectively used to reflect the fuzziness of the term [Chen and Hwang, 1992; Zimmermann, 2000]. Table 1 shows the linguistic variables and their corresponding triangular fuzzy number for the decision maker to make qualitative assessments about the performance rating of each alternative with respect to a given criterion.

Table 1 Linguistic Variables used by the Decision Matrix

Linguistic variables	Very Poor (VP)	Poor (P)	Fair (F)	Good (G)	Very Good (VG)
Fuzzy Numbers	(1, 1, 3)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)

To reduce the cognitive demanding on the decision maker, linguistic variables approximated by fuzzy numbers defined as in Table 2 can be used for determining the relative importance of the criteria with respect to the overall objective of the hospital location evaluation problem.

Table 2 Linguistic Variables used by the Weighting Vectors

Linguistic variables	Very Low (VL)	Low (L)	Medium (M)	High (H)	Very High (VH)
Fuzzy Numbers	(1, 1, 3)	(1, 3, 5)	(3, 5, 7)	(5, 7, 9)	(7, 9, 9)

The evaluation process starts with the determination of the performance of each hospital location alternative A_i ($i = 1, 2, \ldots, n$) with respect to each criterion C_j ($j = 1, 2, \ldots, m$). As a result, a decision matrix for all the hospital location alternatives can be obtained as follows

$$X = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1m} \\ x_{21} & x_{22} & \ldots & x_{2m} \\ \ldots & \ldots & \ldots & \ldots \\ x_{n1} & x_{n2} & \ldots & x_{nm} \end{bmatrix} \quad (1)$$

The relative importance of the evaluation criteria C_j can be assessed qualitatively using fuzzy numbers, given as

$$W = (w_1, w_2, \ldots, w_m) \quad (2)$$

The weighted fuzzy performance matrix that represents the overall performance of each alternative on each criterion can be determined by multiplying the fuzzy criteria weights (w_j) by the alternatives' fuzzy performance ratings (x_{ij}) as

$$Z = \begin{bmatrix} w_1x_{11} & w_2x_{12} & . & w_mx_{1m} \\ w_1x_{21} & w_2x_{22} & . & w_mx_{2m} \\ . & . & . & . \\ w_1x_{n1} & w_2x_{n2} & . & w_mx_{nm} \end{bmatrix} \quad (3)$$

To reflect on the decision maker's attitude towards risk in the decision making process, the idea of incorporating the risk involved in the decision maker's subjective assessments is introduced. This is beneficial towards the decision making process as the ability of the decision maker to (a) adequately deal with subjectiveness and imprecision and (b) handle the risk inherent in the decision making process will help increase the confidence of the decision maker. This will have an impact on the final outcome of the decision making process [Wibowo and Deng, 2009].

To address this issue, the concept based on $\lambda\,(0 \le \lambda \le 1)$ is introduced for reflecting the decision maker's attitude towards risk in approximating his/her subjective assessments. A larger λ value indicates that the decision maker's assessments are closer to the most possible value a_2 of the triangular fuzzy numbers (a_1, a_2, a_3). Based on this concept, the refined assessment of the decision maker in regards to his/her attitude towards risk is defined as

$$z_{ij}^{k\lambda} = (a_1 + \lambda(a_2 - a_1), a_2, a_3 - \lambda(a_3 - a_2)) \tag{4}$$

where a_1, a_2, and a_3 are the lower bound, middle bound, and upper bound of the decision maker's assessments about the performance rating of alternative A_i with respect to criterion C_j respectively.

In practical applications, λ = 1, 0.5, or 0 can be used respectively to indicate whether the decision maker involved has an optimistic, moderate, or pessimistic view in the evaluation process [Deng and Yeh, 2006]. An optimistic decision maker is apt to prefer higher values of his/her fuzzy assessments, while a pessimistic decision maker tends to favor lower values [Yeh *et al*., 2000].

Having already incorporated the decision maker's attitude towards risk as in (4), the fuzzy performance matrix can be obtained as

$$Z^{\lambda} = \begin{bmatrix} z_{11}^{\lambda} & z_{12}^{\lambda} & \dots & z_{1m}^{\lambda} \\ z_{21}^{\lambda} & z_{22}^{\lambda} & \dots & z_{2m}^{\lambda} \\ \dots & \dots & \dots & \dots \\ z_{n1}^{\lambda} & z_{n2}^{\lambda} & \dots & z_{nm}^{\lambda} \end{bmatrix} \tag{5}$$

Given the fuzzy vector of the performance matrix for criterion C_j, a fuzzy maximum ($M_{\max}^{j}$) and a fuzzy minimum ($M_{\min}^{j}$) [Chen, 1985] can be determined as in (6)-(7) which represent respectively the best and the worst fuzzy performance ratings among all the alternatives with respect to criterion C_j [Chen, 1985, Yeh *et al*., 2000].

$$\mu_{M_{\max}^{j}}(z^{\lambda}) = \begin{cases} \dfrac{z^{\lambda} - z_{\min}^{\lambda j}}{z_{\max}^{\lambda j} - z_{\min}^{\lambda j}}, \\ 0, \end{cases} \tag{6}$$

$$\mu_{M_{\min}^{j}}(z^{\lambda}) = \begin{cases} \dfrac{z_{\max}^{\lambda j} - z^{\lambda}}{z_{\max}^{\lambda j} - z_{\min}^{\lambda j}}, \\ 0, \end{cases} \tag{7}$$

where *i = 1, 2,…, n*; *j = 1, 2,…, m*.

$$z_{\max}^{\lambda j} = \sup \bigcup_{i=1}^{n} (z_{ij}^{\lambda}), \tag{8}$$

$$z_{\min}^{\lambda j} = \inf \bigcup_{i=1}^{n} (z_{ij}^{\lambda}). \tag{9}$$

The degree to which alternative A_i is the best alternative with respect to criterion C_j can then be calculated by comparing its weighted fuzzy performance (z_{ij}^{λ}) with the fuzzy maximum $(M_{\max}^{j})$, given as in (10). $u_{Rj}(i)$ represents the highest degree of approximation of alternative A_i's weighted performance on criterion C_j to the fuzzy maximum. This setting is in line with the optimal decision of Zadeh [1973] who states that "in a fuzzy environment, objective and constraints formally have the same nature and their confluence can be represented by the intersection of fuzzy sets".

$$u_{R_j}(i) = \sup\left(z_{ij}^{\lambda} \cap M_{\max}^{\lambda j}\right), \tag{10}$$

Similarly, the degree to which alternative A_i is not the worst alternative with respect to criterion C_j can be calculated by comparing the weighted fuzzy performance ($w_j x_{ij}$) of alternative A_i with the fuzzy minimum ($M_{\min}^{j}$), as

$$u_{L_j}(i) = 1 - \sup\left(z_{ij}^{\lambda} \cap M_{\min}^{\lambda j}\right), \tag{11}$$

The degree of optimality (or preferability) of alternative A_i over all other alternatives with respect to criterion C_j is thus determined by

$$r_{ij}^{\lambda} = \frac{u_{R_j}(i) + u_{L_j}(i)}{2} \tag{12}$$

A fuzzy singleton matrix [Zadeh, 1973] can be obtained from the weighted fuzzy performance matrix based on (6)-(12), given as

$$R^{\lambda} = \begin{bmatrix} r_{11}^{\lambda} & r_{12}^{\lambda} & \dots & r_{1m}^{\lambda} \\ r_{21}^{\lambda} & r_{22}^{\lambda} & \dots & r_{2m}^{\lambda} \\ \dots & \dots & \dots & \dots \\ r_{n1}^{\lambda} & r_{n2}^{\lambda} & \dots & r_{nm}^{\lambda} \end{bmatrix} \tag{13}$$

To avoid the unreliable process of comparing fuzzy numbers for determining the overall performance of each alternative across all criteria, the concept based on the ideal solution is proposed. This concept has since been widely used in developing various methodologies for solving different practical decision problems [Wibowo and Deng, 2012]. This is due to (a) its simplicity and comprehensibility in concept, (b) its computation efficiency, and (c) its ability to measure the relative performance of the decision alternatives in a simple mathematical form.

Based on the concept of the ideal solution above, the positive ideal solution $A^{\lambda+}$ and the negative ideal solution $A^{\lambda-}$ can be determined respectively from (13), shown as in (14) and (15).

$$\begin{aligned} A^{\lambda+} &= (a_1^{\lambda+},\ a_2^{\lambda+},\ \dots,\ a_m^{\lambda+}) \\ A^{\lambda-} &= (a_1^{\lambda-},\ a_2^{\lambda-},\ \dots,\ a_m^{\lambda-}) \end{aligned} \tag{14}$$

where

$$\begin{aligned} a_j^{\lambda+} &= \max\,(r_{1j}^{\lambda},\ r_{2j}^{\lambda},\ \dots,\ r_{nj}^{\lambda}) \\ a_j^{\lambda-} &= \min\,(r_{1j}^{\lambda},\ r_{2j}^{\lambda},\ \dots,\ r_{nj}^{\lambda}) \end{aligned} \tag{15}$$

Based on (14)-(15), the degree of similarity between each alternative and the positive ideal solution $S_i^{\lambda+}$ and between the alternative and the negative ideal solution $S_i^{\lambda-}$ can be respectively calculated by applying the vector matching technique as

$$S_i^{\lambda+} = \frac{A_i^{\lambda} A^{\lambda+}}{\max(A_i^{\lambda} A_i^{\lambda},\ A^{\lambda+} A^{\lambda+})} \tag{16}$$

$$S_i^{\lambda-} = \frac{A_i^{\lambda} A^{\lambda-}}{\max(A_i^{\lambda} A_i^{\lambda},\ A^{\lambda-} A^{\lambda-})} \tag{17}$$

where A_i^{λ} is the i^{th} row of the performance matrix in (13), representing the corresponding performance of alternative A_i in regard to criterion C_j. The larger the value of $S_i^{\lambda+}$ and $S_i^{\lambda-}$, the higher the degree of similarity.

A preferred alternative should have a higher degree of similarity to the positive ideal solution, and a lower degree of similarity to the negative ideal solution [Yeh *et al.*, 2000]. Based on this perception, an overall performance index for each alternative with the decision maker's λ degree of optimism towards risk can be calculated in a simple manner.

$$P_i^{\lambda} = \frac{S_i^{\lambda-}}{S_i^{\lambda+} + S_i^{\lambda-}} \tag{18}$$

The larger the performance index value, the better the overall hospital location alternative, relative to other alternatives.

The preference-based approach presented above is summarized as

Step 1. Obtain the fuzzy decision matrix for the decision maker as expressed in (1).
Step 2. Determine the weighting vector of the decision maker as expressed in (2).
Step 3. Obtain the weighted fuzzy performance matrix by multiplying the fuzzy decision matrix (1) and the fuzzy weighting vector (2) given as in (3).
Step 4. Introduce the λ-cut concept for reflecting the decision maker's attitude towards risk as defined in (4).
Step 5. Obtain the fuzzy performance matrix as in (5).
Step 6. Determine the fuzzy maximum and the fuzzy minimum which represent respectively the best and the worst fuzzy performance ratings among all the alternatives with respect to criterion C_j as in (10) and (11).
Step 8. Determine the degree of optimality (or preferability) of alternative A_i over all other alternatives with respect to criterion *Cj* by (12).
Step 9. Obtain the fuzzy singleton matrix given as (13).
Step 10. Determine the positive ideal solution and the negative ideal solution from (13), shown as in (14) and (15) respectively.
Step 11. Calculate the degree of similarity between each alternative and the positive ideal solution and between the alternative and the negative ideal solution by (16) and (17) respectively.
Step 12. Compute the overall performance index for each alternative by (18).
Step 13. Rank the alternatives in descending order of their performance indexes.

4 An Example

To demonstrate the applicability of the preference-based approach, an example of evaluating the performance of six available hospital locations is presented.

To start with the hospital location evaluation process, the performance ratings and the criteria weights of all available hospital locations can be determined by the decision maker using the linguistic variables defined in Table 1 and Table 2 respectively. Table 3 shows the assessment results.

Table 3: Performance Ratings and Criteria Weights of Hospital Locations

Alternatives	Criteria					
	C_1	C_2	C_3	C_4	C_5	C_6
A_1	VG	G	VG	F	G	G
A_2	G	VP	G	P	P	F
A_3	G	G	F	G	G	F
A_4	F	VG	F	F	F	G
A_5	G	F	P	G	F	G
A_6	F	P	F	P	P	F
Criteria Weights	VH	M	H	M	H	M

Based on (3)-(18), the overall performance index for for each hospital location alternative across the criteria can be calculated in a computational efficient manner. Table 5 shows that alternative hospital location A_1 has a better overall performance, relative to other alternatives when the attitudes of the decision maker towards risks is pessimistic, neutral, or optimistic.

Table 4: The Performance Index of Hospital Location Alternatives and their Rankings

	λ = 0.0		λ = 0.5		λ = 1.0	
	Index	Ranking	Index	Ranking	Index	Ranking
A_1	0.728	1	0.736	1	0.728	1
A_2	0.466	5	0.471	5	0.466	5
A_3	0.524	4	0.539	4	0.524	4
A_4	0.683	2	0.694	2	0.683	2
A_5	0.641	3	0.672	3	0.641	3
A_6	0.425	6	0.429	6	0.425	6

It is evident that the proposed preference-based approach is capable of effectively dealing with the multi-dimensional nature of the decision process, the conflicting nature of the multiple evaluation criteria and the presence of subjectiveness and imprecision in the decision making problem. With its simplicity in concept and efficiency in computation, the proposed approach is applicable for dealing with the general fuzzy multicriteria decision making problem.

5 Conclusion

The hospital location evaluation process is complex due to the multi-dimensional nature of the decision process, the conflicting nature of the multiple evaluation criteria and the subjectiveness and imprecision inherent in the human decision making process. To effectively deal with this problem, this paper has formulated the performance evaluation of hospital locations as a fuzzy multicriteria decision making problem, and presented a preference-based approach. A hospital location evaluation problem is presented that shows the proposed approach is simple and effective for dealing with the general hospital location evaluation problem.

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