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Integrated environmental assessment of the location selection with fuzzy analytical network process

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Abstract Owing to the complexity of a construction project, the fuzzy ANP is helpful to deal with interdependent relationships within a multi-criteria decision-making model. This paper uses the Porter's diamond model that influences how competitive advantages, which is a matrix providing a conceptual model for the main framework, as a construct for selecting the location of a regional hospital in Taiwan to determine its effectiveness. The applicability of our proposed fuzzy ANP model is demonstrated with a case study that summarizes an intervention in which the model's framework and basic concepts were applied.

Keywords Fuzzy ANP · Diamond model · Selection of location

1 Introduction

Implementation of the National Health Insurance scheme in Taiwan since 1995 has intensified competition in the local medical sector. Given elevated living standards island wide, Taiwanese residents have become more health conscious and attach increasing importance to quality healthcare, explaining the heightened consumer demand for medical services in quality and scope. Additionally, the medical service sector has improved its organizational structure and encouraged hospitals to establish management practices that would increase

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their competitiveness. In such an intensely competitive environment, selecting the location of hospitals to be established is of priority concern. In its early stage, linear programming was used to solve location selection-related problems (Ross and Soland 1980). For instance, previous studies attempted to locate the position to establish a hospital by utilizing conventional mathematic or statistical methods. In considering where to select a location, besides legislation restrictions, policymakers and business groups seldom consider how selecting the location during the decision making process could possibly affect its competitiveness.

A healthcare program was launched in 1984 to offer medical resources throughout Taiwan proportionately. The Department of Health of the Executive Yuan divides 63 sub-regions into 17 medical areas, with each sub-region to contain a certain number of hospitals, as planned in advance in order to continuously improve healthcare services and living standards. Under the present medical ecology in Taiwan, since health insurance was implemented, the medical organization has frequently complained that it is difficult to survive. Take a look at Taiwanese market, and it seems to existence numerous particular changes: (1) the average scale of the hospital becomes large day by day; (2) the geographical positions of the hospitals do not distribute averagely; (3) there is a fierce competition between hospitals and clinics day by day; and (4) the scale of medical organization is bipolarized.

According to the Department of Health, Executive Yuan, Taiwan (DOH), the number of hospitals in Taiwan declined by 231 or 29.35%, from 787 in 1989 to 556 in 2004. Additionally, the number of public hospitals declined by 5 or 5.38%, from 93 in 1989 to 88 in 2004; correspondingly, the number of private hospitals declined by 126 or 32.56%, from 694 in 1989 to 468 in 2004 (DOH 2005). Obviously, this reduction in hospitals will negatively impact the medical sector. Additionally, the global aging phenomenon is no exception in Taiwan, with the island officially becoming a rapidly aging society in 1993 according to the World Health Organization definition. Therefore, from a market demand perspective, Taiwan has enormous growth potential, as evidenced by the establishment of many hospitals and the increasing competitiveness in the medical care sector. Given the over saturated and fiercely competitive medical service sector, selecting the wrong location for a new hospital could significantly raise operational costs and stymie future growth. Selecting the location for a hospital in terms of competitiveness involves the various hospital types in Taiwan, devising appropriate evaluation criteria and categorizing hospitals according to those evaluation criteria.

Location theory has been extensively studied (Current et al. 1990). Kiran and John (2005) research an exploratory investigation into location strategies. Despite the considerable attention paid to selecting a location for medical care facilities, establishing a hospital must strictly comply with governmental regulations, often causing decision makers to overlook the importance of selecting a location. The criteria for developing this model are determined from an exhaustive literature review and use of the modified Delphi method. Additionally, a general consensus among experts can be reached to develop an evaluation framework and consider dependence. The purpose of this study is to solve the selection of location problem by using fuzzy ANP.

In this study, we adopted ANP for solving the selection of location problem based on the following motivations (Saaty 2000), include (1) ANP procedures to deal with the problem of the subsystems interdependence and feedback; (2) ANP has a systematic approach to set priorities and trade off among goals and criteria; (3) criteria weights or priorities established by ANP are based on the use of a ratio scale by human judgment instead of arbitrary scales; (4) ANP can measure all tangible and intangible criteria in the model; (5) ANP is a relatively simple, intuitive approach that can be accepted by managers and other decision-makers; (6) ANP can easily be used to solve multi-criteria decision problems involving group decision making; (7) ANP enables a better communication, leading to a clearer understanding and consensus among actors so that they will commit to the selected alternative more likely. In addition, because human judgment on the importance of requirements is always imprecise and vague, this work concentrates on a fuzzy ANP approach in which triangular fuzzy numbers are used to improve the hospital administrators and decision maker in establishing a standardized means of selecting the location of new facilities. Therefore, we also illustrate a numerical example to show the steps of the proposed method. On the basis of the results, we can conclude that the weights play a key for the selection of location analysis. The proposed method can provide the more informative and accurate results than the conventional fuzzy AHP of location analysis. The fuzzy ANP based decision-making method can provide decision makers a valuable reference for selecting the location of a regional hospital in Taiwan to determine its effectiveness.

2 Literature review

This study adopts the renowned diamond model introduced in Porter's *The Competitive Advantage of Nations* (1990) that influences how competitive advantages, especially with respect to developing and evaluating the objectives of location selection, are related in order to devise a standardized operational procedure.

2.1 Porter's diamond model

Porter's diamond model, consisting of six elements as shown in Fig. 1, conceptualizes how a nation can achieve success in a particular industry. While the elements work independently an advantage in one element can produce, or improve, an advantage in another. However, an advantage in all of the elements is not necessary for industry success. Individually and as a system, the determinants create the context within which the nation's firms are created and compete (Porter 1990).

Porter's diamond model comprises six elements: four country-specific determinants and two external variables, i.e., chance and government. Porter's four determinants and two

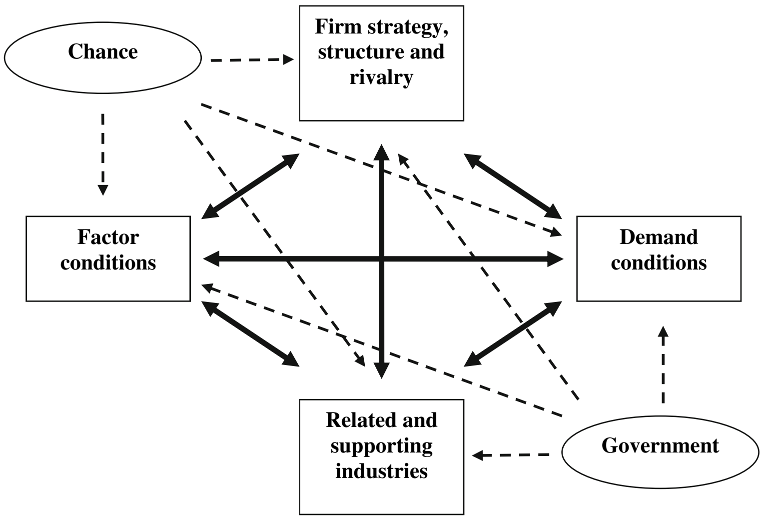


Fig. 1 Porter's diamond model showing interdependent variables that determine industrial competitiveness

outside forces interact in the diamond of competitive advantage, with the global competitiveness of a country depending on the type and quality of these interactions. According to Porter, the four determinants for a nation "... shape the environment in which local firms compete and promote or impede the creation of competitive conditions (Porter 1990)." The four determinants are

1. Factor conditions: production-related factors of a nation, including natural resources and created factors, e.g., infrastructure and skilled labor.
2. Demand conditions: domestic demand for certain products or services.
3. Firm strategy, structure and rivalry: rivalry among domestic firms and the conditions influencing how companies are created, organized and managed.
4. Related and supporting industries: the presence or absence of supplier and related industries that are globally competitive.

Porter's two external forces, i.e., chance and government, offer contrasting approaches. Government obviously influences the competitiveness of a nation. For instance, a government can penalize foreign firms either through tariffs as a direct entry barrier or through subsidies as an indirect strategy—both of which provide domestic firms with short-term competitive advantages. Whereas such discriminatory governmental measures shelter domestic firms, doing so prevents the development of sustainable (long-run) competitive advantages.

While certain components of Porter's diamond model are unoriginal, the model accurately focuses on the strategies of firms rather than those of countries. Porter states, "... firms, not nations, compete in international markets." In terms of creating firm-specific linkages between the four determinants and the two external forces, Porter's model is useful and, potentially, an accurate predictor of future trends. However, Porter's policy recommendations restrict a government's industrial and strategic trade policies instead of opening markets to foreign investment without arbitrary restrictions.

2.2 Location theory for hospitals

As a naturalist from US, Grinnell first addressed the location in 1904. That study assumed that two groups depend on a certain affinity for food in the same location, but cannot continue balance for keeps in amount. The number of individuals in one group is more than the other, given that these two groups compete with each for the same assets. Location's concept construct of community. Many members of a population share assets are related in the community. Location refers to the functions and roles that the population plays in the community. Correspondingly, the theory of location necessitates that scientists use a finite list of assets based on an array of answers so that groups can compete and live with each other naturally. As location selection theory emerged, Weber (1909) proposed the position problems of a factory. Early location theory focused mainly on the production of raw materials and selling to markets in order to determine a factory's optimal position by minimizing transportation costs.

The hospital sector is unique since it includes private, non-profit and governmental-owned facilities, occasionally competing for the same patients. Selection of locations in the hospital sector reflects the need to develop models that are specific to this unique sector. Empirical evidence suggests that some location dimensions normally considered in analyzing organizations are not relevant in analyzing hospitals while others explain a considerable amount of detail. For instance, unemployment rate and per capita income of the local population are significant predictors of hospital closure (Longo et al. 1996). Pertinent literature generally regards selection of location as a disadvantage for hospitals, but provides limited empirical evidence to support this claim. The potential market size in areas may pose an impediment because some hospitals are located in sparsely populated areas, not only so affects the hospital to choose the position the factor also to have very many. Exactly how hospital location, strategy, operational decisions and performance are related has seldom been addressed. In contrast, these variables have frequently been adapted to study manufacturing operations. For instance, Swamidass and Newell (1987) used the uncertain of location aspect to accurately predict elements of operations strategy, which are subsequently used to forecast business performance. Similarly, Ward et al. (1995) demonstrate the ability of selection of location factors to accurately predict the operations strategy used by successful manufacturing firms. According to their results, high and low performing firms differ in strategies in the same environment, supporting their hypothesis that high performers develop strategies that more effectively respond to selection of location demands.

Location and proximity to markets profoundly impact service organizations and hospitals in particular. Specifically, having established a location is an important selection factor for hospitals. Hospitals in locations have struggled in recent years, with their survival possibly depending on developing appropriate strategies for their location (Hudson 1995). Hospital location is important because the largest segment of the market share for a hospital comes from an area close to the hospital (Robinson and Luft 1985). Goldstein et al. (2002) investigated how hospital management adopts strategy to respond to the location factor of urban or rural locations. While hospital strategies have been extensively studied, the relation between decision-related factors to select a hospital location has seldom been addressed. Lamont et al. (1993) also found that hospitals perform better by modifying their strategy to achieve a better fit with its location. These important results demonstrate that hospitals can use their strategies to respond to location conditions. Nath and Sudharshan(1994) addressed the location relative to other hospitals as part of a hospital's business strategy. In sum, previous literature has identified strategic groups in the hospital sector and began to link strategies to decision-making and performance. Further empirical evidence is required to determine the location or organizational factors that prompt such strategies. Additionally, the role of technology investments in strategic decision-making must be evaluated. Finally, assessment of location strategies should be linked with hospital performance.

While anticipating a strong demand for healthcare, more hospitals have been constructed (Chang et al. 2004). Between 1944 and 1950, the number of hospital beds per 1,000 individuals nearly doubled (Roth et al. 1955). Meanwhile, the strategic location of a hospital results in enhanced medical treatment. In the topographical size of ground in Taiwan that saturation of influencing 23 million populations. The role of location selection strategy, under the restrictions of governmental policies and regulations, significantly influences the selection of future hospital locations.

Above investigations confirm that regardless of whether in the structure strategy, market demand or governmental regulations significantly impact decisions regarding selection of hospital location. Correct decisions regarding location selection not only enable hospitals to reduce operational costs and increase profits, but also enhance their competitive advantage, ultimately spurring future growth.

3 Methodology

The criteria for the evaluation decision model are derived an exhaustive literature review and the modified Delphi method. After interview of experts construct the evaluation criteria hierarchy. Finally, we calculate the criteria weights and rank of importance by applying fuzzy ANP method.

3.1 Modified Delphi method

The Delphi method accumulates and analyzes the results of anonymous experts that communicate in written, discussion and feedback formats on a particular topic. Anonymous experts share knowledge skills, expertise and opinions until a mutual consensus is achieved (Sung 2001). The Delphi method consists of five procedures: (1) select the anonymous experts; (2) conduct the first round of a survey; (3) conduct the second round of a questionnaire survey; (4) conduct the third round of a questionnaire survey; and (5) integrate expert opinions and to reach a consensus. Steps (3) and (4) are normally repeated until a consensus is reached on a particular topic (Sung 2001). Results of the literature review and expert interviews can be used to identify synthesize all common views expressed in the survey. Moreover, step (2) is simplified to replace the conventionally adopted open style survey; doing so is commonly referred to as the modified Delphi method (Sung 2001). Therefore, this study develops quality evaluation criteria for silicon wafer slicing manufacturing by using the modified Delphi method, as well as by conducting interviews with anonymous experts, and survey of outcome direct to focusing in our research subject.

The Delphi Technique is a conventionally adopted qualitative forecasting method (Anderson et al. 2001), which involves the systematic solicitation and collation of experts on a particular topic through a set of carefully designed sequential questionnaires interspersed with summarized information and feedback of opinions derived from earlier responses (Delbecq et al. 1975). Originally developed by a research group at the Rand Corporation, Delphi attempts to forecast current trends through a group consensus. Moreover, experts are anonymous and do not meet in person. The decision making group probably should not be too large, i.e., a minimum of five to a maximum of about 50 (Robbins 1994). Murry and Hammons (1995) suggested that the modified Delphi method must summarize expert opinions on a range from 10 to 30. Therefore, in this study, seventeen experts participated in the modified Delphi method-based decision group. To ensure non-interference, opinions of the expert group are accumulated, followed by synthesis of those opinions among the hospital's administrators and directors experts to identify the major factors for consideration in the quality evaluation criteria of hospital's location selection.

3.2 Fuzzy analytic network process methodology

AHP is a theory of measurement concerned with deriving dominance priorities from paired comparisons of homogeneous elements with respect to a common criterion or attribute (Saaty 1994). Saaty (1980) first developed AHP, which helps to establish decision models through a process that contains both qualitative and quantitative components. Qualitatively, it helps to decompose a decision problem from the top overall goal to a set of manageable clusters, sub-clusters, and so on down to the bottom level that usually contains scenarios or alternatives. The clusters or sub-clusters can be forces, attributes, criteria, activities, objectives, etc. Quantitatively, it uses pair-wise comparison to assign weights to the elements at the cluster and sub-cluster levels and finally calculates "global" weights for assessment taking place at the bottom level. Each pair-wise comparison measures the relative importance or strength of the elements within a cluster level by using a ratio scale. One of the main functions of AHP is to calculate the consistency ratio to ascertain that the matrices are appropriate for analysis (Saaty 1980). Nevertheless, AHP models assume that there are uni-directional relationships between elements of different decision levels along the hierarchy and uncorrelated elements within each cluster as well as between clusters. It is not appropriate for models that specify interdependent relationships in AHP. ANP is then developed for filling this gap.

ANP is the generic form of AHP and allows for more complex interdependent relationships among elements (Saaty 1996). It is also known as the systems-with-feedback approach (Meade and Sarkis 1998). By incorporating interdependencies (i.e., addition of the feedback loops in the model), a supermatrix will be created. The super-matrix adjusts the relative weights in individual matrices to form a new overall matrix with the eigenvectors of the adjusted relative weights (Meade and Sarkis 1998). In fact, ANP uses a network without a need to specify levels as in a hierarchy. The main reason for choosing the ANP as our methodology for selecting the location operations is due to its suitability in offering solutions in a complex multi-criteria decision environment. Some of the fundamental ideas in support of ANP are (Saaty 1999):

- ANP is built on the widely used AHP;
- By allowing for dependence, the ANP goes beyond the AHP by including independence and hence also the AHP as a special case;
- The ANP deals with dependence within a set of elements (inner dependence), and among different sets of elements (outer dependence);
- The looser network structure of the ANP makes possible the representation of any decision problem without concern for what comes first and what comes next as in a hierarchy;
- ANP is a non-linear structure that deals with sources, cycles and sinks having a hierarchy of linear form with goals in the top level and the alternatives in the bottom level;
- ANP portrays a real world representation of the problem under consideration by prioritizing not only just the elements but also groups or clusters of elements as is often necessary;
- The ANP utilizes the idea of a control hierarchy or a control network to deal with different criteria, eventually leading to the analysis of benefits, opportunities, costs, and risks. By relying on control elements, the ANP parallels what the human brain does in combining different sense data as for example does the thalamus.

The structural difference between a hierarchy and a network is depicted in Fig. 2. The elements in a node may influence some or all the elements of any other node. In a network, there can be source nodes, intermediate nodes and sink nodes. Relationships in a network are represented by arcs, and the directions of arcs signify dependence (Saaty 1996). Interdependency between two nodes, termed outer dependence, is represented by a two-way arrow, and inner dependencies among elements in a node are represented by a looped arc (Sarkis 2003).

Although ANP has resolved the problem in AHP, many decision-making and problem-solving tasks are too complex to be understood quantitatively. However, fuzzy multiple attribute decision-making (FMADM) methods have been developed owing to the imprecision in assessing the relative importance of attributes and the performance ratings of alternatives with respect to attributes. Imprecision may arise from a variety of reasons: unquantifiable information, incomplete information, unobtainable information and partial ignorance. Conventional MADM methods cannot effectively handle problems with such imprecise information. To resolve this difficulty, fuzzy set theory, first introduced by Zadeh, has been used and is adopted herein. Fuzzy set theory attempts to select, prioritize or rank a finite number of courses of action by evaluating a group of predetermined criteria. Solving this problem thus requires constructing an evaluation procedure to rate and rank, in order of preference, the set of alternatives. Therefore, this study combines this advantage using fuzzy ANP. The process of fuzzy ANP as follows:

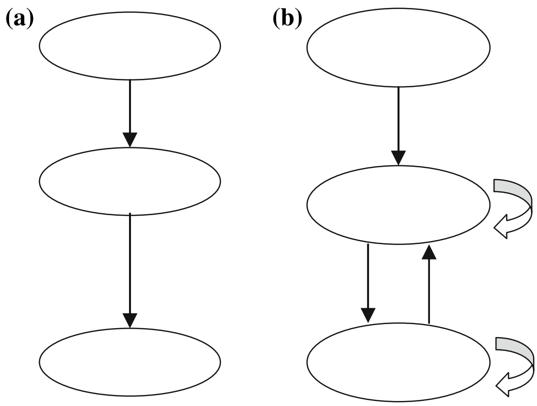


Fig. 2 Structural difference between a hierarchy and a network (**a**) a hierarchy; (**b**) a network

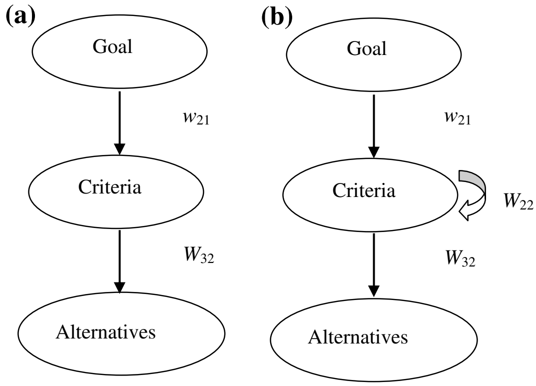


Fig. 3 Hierarchy and network (**a**) a hierarchy; (**b**) a network

(I) Model construction and problem structuring

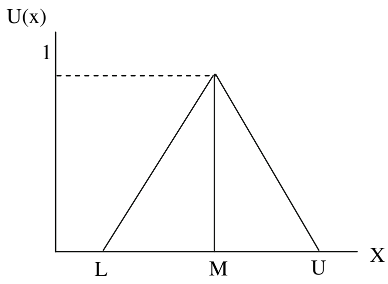
The problem should be stated clearly and decomposed into a rational system like a network. The structure can be obtained by the opinion of decision makers through brainstorming or other appropriate methods. An example of the format of a network is as shown in Fig. 3b.

(II) Establishment of triangular fuzzy numbers

Saaty (1980) contended that the geometric mean accurately represents the consensus of experts and is the most widely used in practical applications. Here, geometric mean is used as the model for triangular fuzzy numbers. Zadeh (1965) introduced the fuzzy set theory to deal with the uncertainty due to imprecision and vagueness. A major contribution of fuzzy set theory was its capability of representing vague data. The theory also allowed mathematical operators and programming to apply to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership function, which assigns to each object a grade of membership ranging between zero and one. A triangular fuzzy number (TFN) is shown in Fig. 4. A TFN is denoted simply as (L, M, U). The parameters L, M and U, respectively, denote the smallest possible value, the most promising value and the largest possible value that describe a fuzzy event.

Since each number in the pair-wise comparison matrix represents the subjective opinion of decision makers and is an ambiguous concept, fuzzy numbers work best to consolidate fragmented expert opinions. The triangular fuzzy numbers $\tilde{u}_{ij}$ are established as follows:

Fig. 4 Triangular fuzzy numbers



$$\tilde{u}_{ij=}(L_{ij}, M_{ij}, U_{ij}), \quad L_{ij} \leq M_{ij} \leq U_{ij} \text{ and } L_{ij},\ M_{ij},\ U_{ij} \in [1/9, 1] \cup [1, 9], \tag{1}$$

$$L_{ij} = \min(B_{ijk}), \tag{2}$$

$$M_{ij} = \sqrt[n]{\prod_{k=1}^{n} B_{ijk}}, \tag{3}$$

$$U_{ij} = \max(B_{ijk}), \tag{4}$$

where B_{ijk} represents a judgment of expert k for the relative importance of two criteria $C_i - C_j$.

(III) Establishment of fuzzy positive reciprocal matrix

$$\tilde{A} = \left[\tilde{a}_{ij}\right] = \begin{matrix} \\ C_1 \\ C_2 \\ \vdots \\ C_n \end{matrix} \begin{matrix} \begin{matrix} C_1 & C_2 & \ldots & C_n \end{matrix} \\ \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix} \end{matrix}, \tag{5}$$

where $\tilde{a}_{12}$ denotes a triangular fuzzy matrix for the relative importance of two criteria C_1 and C_2. Meanwhile, $\left[\tilde{a}_{ij}\right]$ represents the triangular fuzzy numbers by the formulae (1)–(4).

(IV) Defuzzification

Various defuzzication methods are available, and the method adopted herein was derived from Liou and Wang (1992) and Wu et al. (2007). As shown in formula (6), this method can clearly express fuzzy perception. Owing to the ability of this method to explicitly display the preference (α) and risk tolerance (β) of decision makers, decision makers can more thoroughly understand the risks they face in different circumstances.

Notably, α can be viewed as a stable or fluctuating condition. The range of uncertainty is the greatest when $\alpha = 0$. Meanwhile, the decision making environment stabilizes when increasing α while, simultaneously, the variance for decision making decreases. Additionally, α can be any number between 0 and 1, and analysis is normally set as the following 10 numbers, 0.1, 0.2, …, 1 for uncertainty emulation. Besides, while $\alpha = 0$ represents the upper-bound U_{ij} and lower-bound L_{ij} of triangular fuzzy numbers, and while, $\alpha = 1$ represents the geometric mean M_{ij} in triangular fuzzy numbers, β can be viewed as the degree of a decision maker's pessimism (Hsu and Yang 2000). When $\beta = 0$, the decision maker is more optimistic and, thus, the expert consensus is upper-bound U_{ij} of the triangular fuzzy number. Conversely, when $\beta = 1$, the decision maker is pessimistic, and the number ranges from 0 to 1; however, five numbers 0.1, 0.3, 0.5, 0.7, and 0.9, are used to emulate the state of mind of decision makers.

$$g_{\alpha,\beta}(a_{ij}) = [\beta \cdot f_\alpha\left(L_{ij}\right) + (1-\beta) \cdot f_\alpha\left(U_{ij}\right)], \quad 0 \leq \alpha \leq 1, \quad 0 \leq \beta \leq 1 \tag{6}$$

where $f_\alpha\left(L_{ij}\right) = (M_{ij} - L_{ij}) \cdot \alpha + L_{ij}$, represents the left-end value of α-cup for $a_{i,}$ $f_\alpha\left(U_{ij}\right) = U_{ij} - (U_{ij} - M_{ij}) \cdot \alpha$, represents the right-end value of α-cup for a_{ij}.

The single pair-ware comparison matrix is expressed in formula (8).

$$\text{(V)} \quad g_{\alpha,\beta}(A) = g_{\alpha,\beta}\left(\left[a_{ij}\right]\right) = \begin{matrix} C1 \\ C2 \\ \vdots \\ Cn \end{matrix} \begin{bmatrix} 1 & g_{\alpha,\beta}(a_{12}) & \cdots & g_{\alpha,\beta}(a_{1n}) \\ g_{\alpha,\beta}(a_{21}) & 1 & \cdots & g_{\alpha,\beta}(a_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ g_{\alpha,\beta}(a_{n12}) & g_{\alpha,\beta}(a_{n2}) & \cdots & 1 \end{bmatrix} \tag{7}$$

Calculation of eigenvalue and eigenvector

Notably, $\lambda_{\max}$ is defined to be the eigenvalue of the single pair-ware comparison matrix $g_{\alpha,\beta}(A)$.

$$g_{\alpha,\beta}(A) \cdot W = \lambda_{\max} W \tag{8}$$

and

$$[(g_{\alpha,\beta}(A) - \lambda_{\max} I]W = 0, \tag{9}$$

where W denotes the eigenvector of $g_{\alpha,\beta}(A)$, $0 \leq \beta \leq 1$, $0 \leq \alpha \leq 1$. Comparing formulae (1) and (7), the traditional AHP only uses a specific figure geometric mean to represent the expert opinions for the pair-ware comparison matrix. However, the fuzzy ANP are used to present the fuzzy opinions and expert consensus. Meanwhile, both approaches use the eigenvector method for weight calculation.

(VI) Supermatrix formation

The supermatrix concept is similar to the Markov chain process (Saaty 1996). To obtain global priorities in a system with interdependent influences, the local priority vectors are entered in the appropriate columns of a matrix, known as a supermatrix. As a result, a supermatrix is actually a partitioned matrix, where each matrix segment represents a relationship between two nodes (components or clusters) in a system (Meade and Sarkis 1999). Let the components of a decision system be C_k, $k = 1, 2, \ldots, N$, which has n_k elements denoted as $e_{k1}, e_{k2}, \ldots, e_{kn_k}$. The local priority vectors obtained in Step 2 are grouped and located in appropriate positions in a supermatrix based on the flow of influence from a component to another component, or from a component to itself as in the loop. A standard form of a supermatrix is as in formulae (11) (Saaty 1996).

$$
\begin{array}{cc}
 & \begin{array}{ccccccccccc} & C_1 & & \cdots & & C_k & & \cdots & & C_N & \\ e_{11} & \cdots & e_{1n_1} & \cdots & e_{k1} & \cdots & e_{kn_k} & \cdots & e_{N1} & \cdots & e_{Nn_N} \end{array} \\
W = \begin{array}{cc} & e_{11} \\ C_1 & \vdots \\ & e_{1n_1} \\ \vdots & \vdots \\ & e_{k1} \\ C_k & \vdots \\ & e_{kn_k} \\ \vdots & \vdots \\ & e_{N1} \\ C_N & \vdots \\ & e_{Nn_N} \end{array} & \begin{bmatrix} W_{11} & \cdots & W_{1k} & \cdots & W_{1N} \\ \vdots & & \vdots & \ddots & \vdots \\ W_{k1} & \cdots & W_{kk} & \cdots & W_{kN} \\ \vdots & & \vdots & \ddots & \vdots \\ W_{N1} & \cdots & W_{Nk} & \cdots & W_{NN} \end{bmatrix}
\end{array}, \tag{10}
$$

As an example, the supermatrix representation of a hierarchy with three levels as shown in Fig. 3a is as follows (Saaty 1996):

$$
W_h = \begin{bmatrix} 0 & 0 & 0 \\ w_{21} & 0 & 0 \\ 0 & w_{32} & I \end{bmatrix}, \tag{11}
$$

where W_{21} is a vector that represents the impact of the goal on the criteria, W_{32} is a matrix that represents the impact of criteria on each of the alternatives, I is the identity matrix, and entries of zeros corresponding to those elements that have no influence.

For the above example, if the criteria are interrelated among themselves, the hierarchy is replaced by a network as shown in Fig. 3b. The (2, 2) entry of W_n given by W_{22} would indicate the interdependency, and the supermatrix would be (Saaty 1996)

$$
W_n = \begin{bmatrix} 0 & 0 & 0 \\ w_{21} & w_{22} & 0 \\ 0 & w_{32} & I \end{bmatrix}. \tag{12}
$$

Note that any zero in the supermatrix can be replaced by a matrix if there is an interrelationship of the elements in a component or between two components. Since there usually is interdependence among clusters in a network, the columns of a supermatrix usually sum to more than one. The supermatrix must be transformed first to make it stochastic, that is, each column of the matrix sums to unity. A recommended approach by Saaty (1996) is to determine the relative importance of the clusters in the supermatrix with the column cluster (block) as the controlling component (Meade and Sarkis 1999). That is, the row components with non-zero entries for their blocks in that column block are compared according to their impact on the component of that column block (Saaty 1996). With pair-wise comparison matrix of the row components with respect to the column component, an eigenvector can be obtained. This process gives rise to an eigenvector for each column block. For each column block, the first entry of the respective eigenvector is multiplied by all the elements in the first block of that column, the second by all the elements in the second block of that column and so on. In this way, the block in each column of the supermatrix is weighted, and the result is known as the weighted supermatrix, which is stochastic.

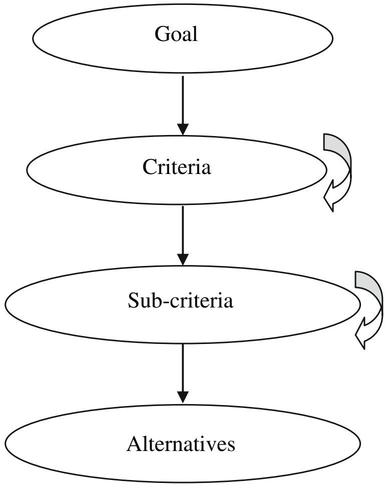


Fig. 5 Network form for this paper

Raising a matrix to powers gives the long-term relative influences of the elements on each other. To achieve a convergence on the importance weights, the weighted supermatrix is raised to the power of $2k + 1$, where k is an arbitrarily large number, and this new matrix is called the limit supermatrix (Saaty 1996). The limit supermatrix has the same form as the weighted supermatrix, but all the columns of the limit supermatrix are the same. By normalizing each block of this supermatrix, the final priorities of all the elements in the matrix can be obtained.
(VI) Selection of best alternatives

If the supermatrix formed in Step "supermatrix formation" covers the whole network, the priority weights of alternatives can be found in the column of alternatives in the normalized supermatrix. On the other hand, if a supermatrix only comprises of components that are interrelated, additional calculation must be made to obtain the overall priorities of the alternatives. The alternative with the largest overall priority should be the one selected. In this paper, the first method is applied, and a supermatrix that covers the whole network as shown by the bracket in Fig. 5, is formed.

According to the aforesaid fuzzy ANP is a multi-attribute, decision-making approach based on the reasoning, knowledge and experience of the experts in the field. fuzzy ANP can act as a valuable aid for decision making involving both tangible as well as intangible attributes that are associated with the model under study. Fuzzy ANP relies on the process of eliciting managerial inputs, thus allowing for a structured communication among decision makers. Thus, it can act as a qualitative tool for strategic decision-making problems. Mohanty et al. (2005) proposes an application of fuzzy ANP along with fuzzy cost analysis in selecting R&D projects. Kahraman et al. (2006) use the fuzzy ANP model for QFD planning process, which proposes an application in a Turkish Company producing PVC window and door systems. Because fuzzy ANP can produce a comprehensive analytic framework for solving societal, governmental, and corporate decision problems. Yet, there is a lack of published papers in the hospital's selection of location demonstrating the method with illustrative examples. In the current paper, it is suggested that fuzzy ANP is appropriate for hospital's location selection.

4 Applying fuzzy ANP to select the location of hospitals to ensure a competitive advantage

By reviewing the evaluations of the location selection of hospitals, this study has constructed indicators to evaluate the location selection. The modified Delphi method is then adopted to summarize the expert opinions in order to construct an evaluation model to assess the location selection of hospitals. Based on factors to evaluate the location selection of hospitals, i.e., factor conditions, demand conditions, firm strategy, structure and rivalry, related and supporting industries, government and chance. Fuzzy ANP is used to illustrate the problems and combine the six factors to establish the hierarchy and network structure for performance evaluation in this study.

Finally, regional hospitals in Taiwan are taken as the research object in this study. According to governmental data, of these three geographical positions, The Eastern district of Taichung City is an economically developed area with a lively metropolis. Taiping City is the largest land area while the largest population is in Dali City. When Eastern district of Taichung City, Taiping City and Dali City are considered as locations to establish a hospital, the wrap enters constructs under the construction evaluation pattern, thus confirming that the generated results correspond to the present location of the Eastern district of Taichung City. According to Fig. 6, the selective regions for establishing hospital can be considered Eastern district of Taichung City, Taiping City and Dali City.

The proposed fuzzy ANP evaluation model attempt to selecting the location of regional hospitals in Taiwan with respect to competitive advantage comprises the following steps.

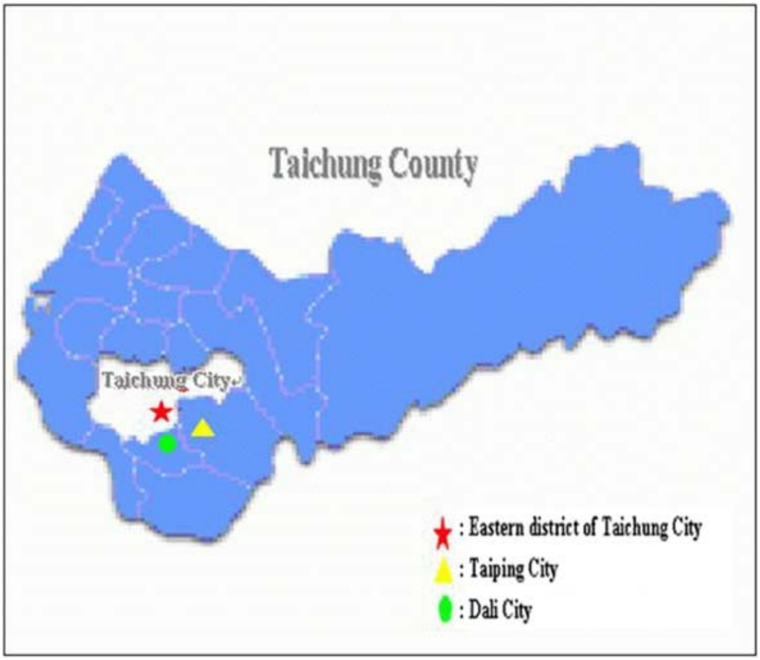


Fig. 6 Establishment of a regional hospital with consideration of locations in Eastern district of Taichung City, Taiping City and Dali City

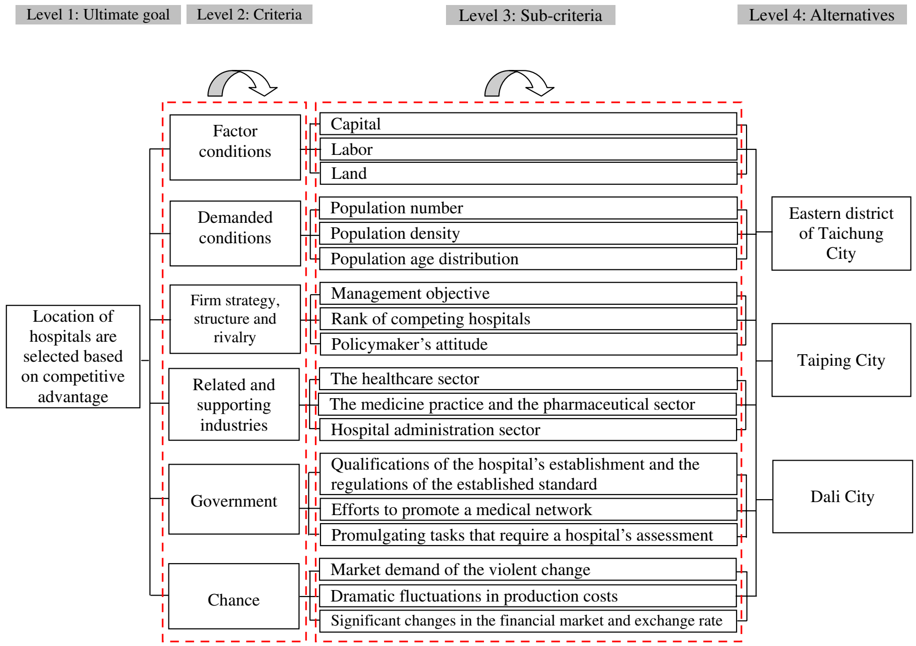


Fig. 7 Hierarchical structure to select and evaluate the location for hospitals with respect to competitive advantage

Step 1: Select and define the evaluative criteria and establish an ANP model.

Here, the modified Delphi method is applied to select and define the evaluation criteria and sub-criteria. Finally, according to 16 hospital administrators and academics confirm six evaluation criteria and 18 evaluation sub-criteria.

Based on the modified Delphi method obtain criteria. After, a general consensus among experts can be reached to establish a hierarchical structure and consider dependence. The ultimate goal of evaluating the ideal selection of location can be achieved, in Fig. 7 followed by six evaluation criteria, 18 evaluation sub-criteria and finally alternatives of a regional hospital with consideration of locations in Eastern district of Taichung City (Al_1), Taiping City (Al_2) and Dali City (Al_3).

- Factor conditions (C_1)

Factor-related conditions refer to a hospital's investment in production time, including capital (Bell 1997; Gourley 1997; Chapman and Walker 1991), labor (Bell 1997; Gourley 1997; Chapman and Walker 1991) and land (Bell 1997; Gourley 1997).

- Capital (SC_1): Funds required to construct the hospital requires capital.
- Labor (SC_2): Demand for hospital personnel, including physicians, pharmacists, health-care personnel, dieticians, registered professional nurses, medical equipment technicians, medical care talent, as well as the quality and quantity of specialized talented individuals.
- Land (SC_3): How the land obtained will affect the cost, the plan as to how the land is used and the appropriate disposition to avoid a situation in which land is unavailable when hospital expansion occurs in the future.

- Demand conditions (C_2)

Factors influencing medical market demand include population number, population density and population age distribution (Bell 1997).

- Population number (SC_4): The demand for medical services varies according to the local population. For instance, the demand for medical services is greater in metropolitan areas than in rural areas.
- Population density (SC_5): Hospital scale and rank (district hospital regional hospital and medical center) must correspond to the population density of the region, such as Taipei with a highly dense population.
- Population age distribution (SC_6): Type of illness of hospital patients (acute, chronic, faculty or synthesis) must correspond to the distribution of population age. For instance (ex, the old age population ratio low area suits to set up the women and children hospital.)

- Firm strategy, structure and rivalry (C_3)

Hospital establishment, organization, management practices and competitors all influence management objective (Porter 1990), rank of competition hospitals (Chapman and Walker 1991) and policymaker's attitudes (Gold 1991).

- Management objective (SC_7): Hospital administrators establish a mission for the hospital to continue management practices.
- Rank of competing hospitals (SC_8): Medical centers, regional hospitals and district hospitals for both Western and Chinese medicine, depending on their number and scale, affect how hospitals rank in position.
- Policymaker's attitude (SC_9): Individuals include the board of directors (administrators), consultants (including hospital management and financial personnel) and other related professionals such as architects have opinions towards management's style, such as an authoritative or a benevolent one.

- Related and supporting industries (C_4)

Developing the upper echelons of the medical sector and supporting sectors include the medicine practice and the pharmaceutical sector, hospital administration sector and the healthcare sector.

- The medicine practice and the pharmaceutical sector (SC_{10}): The medicine practice includes biochemistry technology, cultivation of medical personnel and related industrial development. The pharmaceutical sector includes medical instrumentation, pharmaceuticals and medicinal preparation, medicinal cosmetics and related industrial development.
- Hospital administration sector (SC_{11}): This area includes management consultants, the information technology industry, material flow and related industrial development.
- The healthcare sector (SC_{12}): This area involves sustaining community health, home caregivers, long-term care, residential caregivers, the insurance sector and related industrial development.

- Government (C_5)

Governmental policy towards establishing hospitals in order to strengthen their competitiveness includes qualifications of the hospital's establishment and the regulations of the established standard, efforts to promote a medical network and promulgating tasks that require a hospital's assessment (Hsiao et al. 1990).

Table 1 Fuzzy aggregate pair-wise comparison matrix for criteria of level 2

Goal	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1, 1, 1	1/5, 0.380, 1	1/8, 0.408, 2	3, 3.706, 5	1/4, 0.318, 1/2	1, 2.266, 4
C_2	1, 2.632, 5	1, 1, 1	1/3, 0.907, 3	3, 4.696, 6	0.608, 3, 5	1/3, 2, 3.061
C_3	1/2, 2.451, 8	1/3, 1.103, 3	1, 1, 1	3, 4.318, 7	1/4, 0.682, 1	2, 2.985, 4
C_4	1/5, 0.270, 1/3	1/6, 0.213, 1/3	1/7 0.232, 1/3	1, 1, 1	1/6, 0.244, 1/2	1/5, 0.305, 1/2
C_5	2, 3.145, 4	1/5, 1/3, 1.645	1, 1.466, 4	2, 4.098, 6	1, 1, 1	2, 3.378, 5
C_6	1/4, 0.441, 1	0.327, 1/2, 3	1/4, 0.335, 1/2	2, 3.279, 5	1/5, 0.296, 1/2	1, 1, 1

- Qualifications of the hospital's establishment and the regulations of the established standard (SC_{13}): This area includes establishment of the hospital. After health authorities approve the hospital, the construction license can be applied for along with related governing laws complied with.
- Efforts to promote a medical network (SC_{14}): In order to promote the medical resources balanced development, the division medical service region, and establishes the graduation medical service formulation. For example, lacking the regions to the medical resources and rewarding the folk to establish medical organizations.
- Promulgating tasks that require a hospital's assessment (SC_{15}): To strengthen the business management of hospitals and guarantee the quality of medical service, establishing a graded medical system will influence whether individuals seek a physician.

- Chance (C_6)

Hospitals and the government cannot foresee circumstances that would negatively impact the medical care sector and possibly influence current market competition or other constructs in the diamond theory, including market demand of the violent change (Porter 1990), dramatic fluctuations in production costs (Porter 1990) and significant changes in the financial market and exchange rate (Lin and Wu 2003; 2004; Wu and Lin 2004; 2007).

- Market demand of the violent change (SC_{16}): An increasing population in this region has increased both hospital bed capacity and the number of illnesses, e.g., SARS, subsequently creating a dramatic fluctuation in the demand for the local medical market.
- Dramatic fluctuations in production costs (SC_{17}): This includes the global rise in the price of steel and iron or events such as an energy crisis.
- Significant changes in the financial market and exchange rate (SC_{18}): Fluctuations in the debt–credit interest rate of banks or the influence of global currency values incur changes in the cost of medical instrumentation and pharmaceuticals.

Step 2: Establish the triangular fuzzy numbers

According to Table 1, administer the questionnaire to a sample group of 16 experts, with each respondent making a pair-wise comparison of the decision elements and then assigning those relative scores.

Step 3: Establish the pair-wise comparison matrix and determine eigenvectors

Perform defuzzification using formula (6) and establish the pair-wise comparison matrix and calculate the eigenvalue and eigenvector of each pair-wise comparison matrix using formulae (8)–(9). The weights of level 2 and level 3 are then determined for a sample group of 16 matching the above characteristics with each respondent making a pair-wise comparison

Table 2 Aggregate pair-wise comparison matrix for criteria of level 2

Goal	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	0.490	0.735	3.853	0.346	2.383
C_2	2.041	1	1.287	4.598	2.304	2.114
C_3	1.360	0.777	1	4.659	0.654	2.992
C_4	0.260	0.217	0.215	1	0.289	0.328
C_5	2.888	0.434	1.530	3.464	1	3.439
C_6	0.420	0.473	0.334	3.052	0.291	1

Table 3 Eigenvectors (weights) for level 2 and level 3

Criteria	Weights of criteria (W_{21})	Sub-criteria	Weights of sub-criteria (W_{32})
C_1	0.145	SC_1	0.460
		SC_2	0.230
		SC_3	0.310
C_2	0.238	SC_4	0.434
		SC_5	0.268
		SC_6	0.298
C_3	0.248	SC_7	0.257
		SC_8	0.319
		SC_9	0.424
C_4	0.044	SC_{10}	0.497
		SC_{11}	0.298
		SC_{12}	0.205
C_5	0.219	SC_{13}	0.602
		SC_{14}	0.206
		SC_{15}	0.193
C_6	0.106	SC_{16}	0.413
		SC_{17}	0.350
		SC_{18}	0.237

of the decision elements and assigning them relative scores. The relative scores provided by 16 experts are aggregated using the geometric mean method. Table 2 describes the aggregate pair-wise comparison matrix for the criteria. While the eigenvectors for level 2 to level 3 lists in Table 3, include the respective weights of the six evaluative criteria (W_{21}) and the respective weights of the 18 evaluative sub-criteria (W_{32}). Assume there is no interdependence among criteria and sub-criteria, which criteria and sub-criteria should emphasize more in determining their respective upper level criterion. The priorities for the criteria, W_{43}; the respective weights of the eighteen sub-criteria for level 4 are showing in Table 4.

According to Table 1, when α and $\beta = 0.5$, defuzzification is performed as follows:

$$f_{0.5}(L_{12}) = (0.38 - 1/5) \cdot 0.5 + 1/5 = 0.290$$

Table 4 Eigenvectors (weights) for level 4

Sub-criteria	W_{43} Alternatives		
	A_{11}	A_{12}	A_{13}
SC_1	0.393	0.156	0.451
SC_2	0.256	0.136	0.608
SC_3	0.618	0.116	0.266
SC_4	0.241	0.119	0.640
SC_5	0.571	0.115	0.314
SC_6	0.501	0.127	0.372
SC_7	0.238	0.125	0.637
SC_8	0.563	0.121	0.316
SC_9	0.581	0.111	0.309
SC_{10}	0.539	0.115	0.346
SC_{11}	0.577	0.116	0.307
SC_{12}	0.370	0.141	0.488
SC_{13}	0.594	0.108	0.298
SC_{14}	0.512	0.135	0.353
SC_{15}	0.383	0.145	0.472
SC_{16}	0.471	0.131	0.398
SC_{17}	0.587	0.112	0.301
SC_{18}	0.414	0.148	0.438

$$f_{0.5}\left(U_{12}\right) = 1 - (1 - 0.380) \cdot 0.5 = 0.690$$
$$g_{0.5,0.5}(a_{12}) = [0.5 \cdot 0.290 + (1 - 0.5) \cdot 0.690] = 0.490.$$

Experts can determine α-cut subjectively, depending on environmental uncertainty for evaluating the objectives of optimal location selection of hospitals. Notably, a higher α value can be selected when the decision making environment is stable and information is readily available. Conversely, when the decision marking is ambiguous, and information is lacking, a lower α value can be used to more accurately reflect reality. Furthermore, the evaluator can be based on their own judgment and furthermore, adopt a conservative or optimistic attitude when determining β value. Where $\beta = 0$ represents the most optimistic scenario, while $\beta = 1$ is the most pessimistic scenario. Following nominal group technique discussion and a consensus of opinion among the 13 experts, 0.5 was assigned as the value of β. To understand how criteria weights impact various evaluation environments, α of 0.1 to 1 were attempted to more thoroughly understand the change of ranking in the evaluation criteria. In the following analysis, when $\alpha = 1$, the fuzzy number becomes concrete, thus confirming the evaluation results where $\alpha < 1$ falls under the fuzzy concept results. The eigenvectors were calculated using formulae (8) and (9). Table 5 summarizes the results of eigenvectors for the three criteria under various α-cut when $\lambda = 0.5$.

Table 5 summarizes different α-cuts, factor conditions, demand conditions, firm strategy, structure and rivalry, related and supporting industries, government and chance according to the magnitude of environmental changes. When experts confer that uncertainty is increasingly higher, the significance of demand conditions becomes more apparent. Conversely, when experts believe uncertainty is increasingly lower, the significance of firm strategy,

Table 5 Eigenvectors (weights) of criteria under different α-cuts when $\lambda = 0.5$

α-cuts	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
C_1	0.158	0.155	0.152	0.148	0.144	0.140	0.136	0.132	0.127	0.121
C_2	0.289	0.288	0.286	0.283	0.278	0.273	0.265	0.255	0.241	0.223
C_3	0.183	0.187	0.191	0.195	0.200	0.205	0.211	0.216	0.222	0.227
C_4	0.044	0.045	0.045	0.045	0.046	0.046	0.046	0.046	0.046	0.046
C_5	0.225	0.228	0.232	0.236	0.241	0.247	0.254	0.263	0.276	0.296
C_6	0.101	0.097	0.095	0.093	0.091	0.098	0.089	0.088	0.087	0.086

Table 6 Inner dependence matrix of criteria, W_{22}

W_{22}	C_1	C_2	C_3	C_4	C_5	C_6
C_1	0.230	0.162	0.268	0.279	0.187	0.187
C_2	0.279	0.325	0.220	0.129	0.195	0.172
C_3	0.428	0.341	0.446	0.507	0.200	0.445
C_4	0.063	0.172	0.066	0.085	0.067	0.071
C_5	0	0	0	0	0.351	0
C_6	0	0	0	0	0	0.125

structure and rivalry and government rises. However, in this study, $\alpha = 0.5$ is used to express that environmental uncertainty is steady.

Step 4: Establish pair-wise comparison matrices of interdependencies

Porter's diamond model deems the inner interdependence among criteria in Fig. 1. The resulting eigenvectors obtained from pair-wise comparisons formed matrix, W_{22}; and are shown in Table 6. Note that zeros are assigned to the eigenvector weights of criteria that are independent. Based on the expert interview acquire the inner dependence among the sub-criteria is analyzed next. The schematic representation of the relationship among sub-criteria is presented in Fig. 8. The relative importance weights of the inner dependence among detailed criteria are represented by W_{33} in Table 7.

Step 5: Establish supermatrix and the limit matrix.

A supermatrix allows for the resolution of the effects of interdependence between the elements of the system. It is a partitioned matrix, where each sub-matrix is composed of the vectors obtained from the pair-wise comparison. As discussed in the appendix and shown by the dotted bracket in Fig. 4, the supermatrix in this paper covers all the elements in the network. The generalized form of the supermatrix is shown in Fig. 9. The supermatrix, inserted with respective vectors and matrices obtained before is shown in Table 8. Because the supermatrix includes interactions between clusters, e.g., there is inner dependence among criteria and among sub-criteria, not each of the columns sums to one. A weighted supermatrix is transformed first to be stochastic as shown in Table 9. After entering the normalized values into the supermatrix and completing the column stochastic, the supermatrix is then raised to sufficient large power until convergence occurs. The current super-matrix reached convergence and attained unique eigenvector. Table 10 provides the final limit matrix. This limit matrix is column stochastic and represents the final eigenvector. In Table 10, synthesis with respect to selection of location: Eastern district of Taichung City (0.443), Taiping City

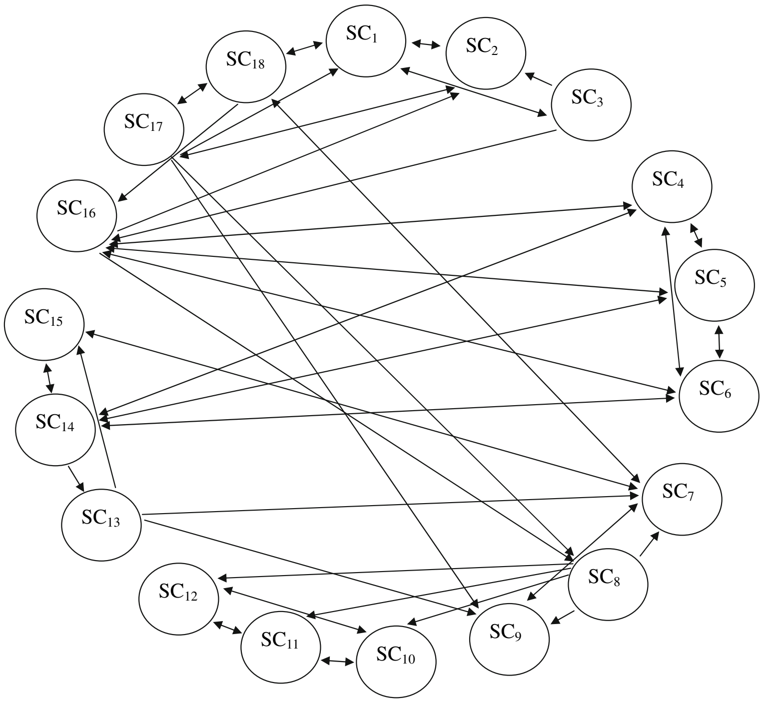


Fig. 8 Inner dependence among sub-criteria

$$
\begin{array}{c}
\\
\text{Goal} \\
\\
\text{Criteria} \\
\\
\text{Sub-Criteria} \\
\\
\text{Alternatives}
\end{array}
\begin{array}{c}
\begin{array}{cccc} \text{Goal} & \text{Criteria} & \text{Sub-Criteria} & \text{Alternatives} \end{array} \\
\left[\begin{array}{c|c|c|c}
I & & & \\
\hline
W_{21} & W_{22} & & \\
\hline
 & W_{32} & W_{33} & \\
\hline
 & & W_{43} & I
\end{array}\right]
\end{array}
$$

Fig. 9 Generalized supermatrix

Table 7 Inner dependence matrix of sub-criteria, W_{33}

W_{33}	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7	SC_8	SC_9	SC_{10}	SC_{11}	SC_{12}	SC_{13}	SC_{14}	SC_{15}	SC_{16}	SC_{17}	SC_{18}
SC_1	0.467	0.608	0.351	0	0	0	0	0	0	0	0	0	0	0	0	0	0.298	0.195
SC_2	0.167	0.139	0.146	0	0	0	0	0	0	0	0	0	0	0	0	0.159	0.129	0
SC_3	0.142	0	0.404	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_4	0	0	0	0.279	0.231	0.191	0	0	0	0	0	0	0	0.160	0	0.211	0	0
SC_5	0	0	0	0.131	0.201	0.238	0	0	0	0	0	0	0	0.180	0	0.139	0	0
SC_6	0	0	0	0.201	0.208	0.298	0	0	0	0	0	0	0	0.235	0	0.155	0	0
SC_7	0	0	0	0	0	0	0.250	0.375	0.701	0	0	0	0.219	0	0.604	0	0	0.198
SC_8	0	0	0	0	0	0	0	0.144	0	0	0	0	0	0	0	0.149	0.143	0
SC_9	0	0	0	0	0	0	0.203	0.481	0.299	0	0	0	0.363	0	0	0	0.132	0
SC_{10}	0	0	0	0	0	0	0	0	0	0.440	0.419	0.462	0	0	0	0	0	0
SC_{11}	0	0	0	0	0	0	0	0	0	0.120	0.275	0.134	0	0	0	0	0	0
SC_{12}	0	0	0	0	0	0	0	0	0	0.440	0.306	0.404	0	0	0	0	0	0
SC_{13}	0	0	0	0	0	0	0	0	0	0	0	0	0.132	0.125	0	0	0	0
SC_{14}	0	0	0	0.177	0.216	0.157	0	0	0	0	0	0	0	0.091	0.129	0	0	0
SC_{15}	0	0	0	0	0	0	0.249	0	0	0	0	0	0.286	0.209	0.267	0	0	0
SC_{16}	0	0	0.099	0.213	0.145	0.115	0	0	0	0	0	0	0	0	0	0.187	0	0.207
SC_{17}	0	0.253	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.113	0.252
SC_{18}	0.224	0	0	0	0	0	0.299	0	0	0	0	0	0	0	0	0	0.184	0.149

Table 8 The supermatrix

	Goal	C_1	C_2	C_3	C_4	C_5	C_6	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7	SC_8	SC_9	SC_{10}	SC_{11}	SC_{12}	SC_{13}	SC_{14}	SC_{15}	SC_{16}	SC_{17}	SC_{18}	Al_1	Al_2	Al_3
Goal	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_1	0.145	0.230	0.162	0.268	0.279	0.187	0.187	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_2	0.238	0.279	0.325	0.220	0.129	0.195	0.172	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_3	0.248	0.428	0.341	0.446	0.507	0.200	0.445	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_4	0.044	0.063	0.172	0.066	0.085	0.067	0.071	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_5	0.219	0	0	0	0	0.351	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_6	0.106	0	0	0	0	0	0.125	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_1	0	0.460	0	0	0	0	0	0.467	0.608	0.351	0	0	0	0	0	0	0	0	0	0	0	0	0	0.298	0.195	0	0	0
SC_2	0	0.230	0	0	0	0	0	0.167	0.139	0.146	0	0	0	0	0	0	0	0	0	0	0	0	0.159	0.129	0	0	0	0
SC_3	0	0.310	0	0	0	0	0	0.142	0	0.404	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_4	0	0	0.434	0	0	0	0	0	0	0	0.279	0.231	0.191	0	0	0	0	0	0	0	0.16	0	0.211	0	0	0	0	0
SC_5	0	0	0.268	0	0	0	0	0	0	0	0.131	0.201	0.238	0	0	0	0	0	0	0	0.18	0	0.139	0	0	0	0	0
SC_6	0	0	0.298	0	0	0	0	0	0	0	0.201	0.208	0.298	0	0	0	0	0	0	0	0.235	0	0.155	0	0	0	0	0
SC_7	0	0	0	0.257	0	0	0	0	0	0	0	0	0	0.25	0.375	0.701	0	0	0	0.219	0	0.604	0	0	0.198	0	0	0
SC_8	0	0	0	0.319	0	0	0	0	0	0	0	0	0	0	0.144	0	0	0	0	0	0	0	0.149	0.143	0	0	0	0
SC_9	0	0	0	0.424	0	0	0	0	0	0	0	0	0	0.203	0.481	0.299	0	0	0	0.363	0	0	0	0.132	0	0	0	0
SC_{10}	0	0	0	0	0.497	0	0	0	0	0	0	0	0	0	0	0	0.44	0.419	0.462	0	0	0	0	0	0	0	0	0
SC_{11}	0	0	0	0	0.298	0	0	0	0	0	0	0	0	0	0	0	0.12	0.275	0.134	0	0	0	0	0	0	0	0	0
SC_{12}	0	0	0	0	0.205	0	0	0	0	0	0	0	0	0	0	0	0.44	0.306	0.404	0	0	0	0	0	0	0	0	0
SC_{13}	0	0	0	0	0	0.602	0	0	0	0	0	0	0	0	0	0	0	0	0	0.132	0.125	0	0	0	0	0	0	0
SC_{14}	0	0	0	0	0	0.206	0	0	0	0	0.177	0.216	0.157	0	0	0	0	0	0	0	0.091	0.129	0	0	0	0	0	0
SC_{15}	0	0	0	0	0	0.193	0	0	0	0	0	0	0	0.249	0	0	0	0	0	0.286	0.209	0.267	0	0	0	0	0	0

Table 8 continued

	Goal	C_1	C_2	C_3	C_4	C_5	C_6	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7	SC_8	SC_9	SC_{10}	SC_{11}	SC_{12}	SC_{13}	SC_{14}	SC_{15}	SC_{16}	SC_{17}	SC_{18}	Al_1	Al_2	Al_3
SC_{16}	0	0	0	0	0	0	0.413	0	0	0.099	0.213	0.145	0.115	0	0	0	0	0	0	0	0	0	0.187	0	0.207	0	0	0
SC_{17}	0	0	0	0	0	0	0.350	0	0.253	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.113	0.252	0	0	0
SC_{18}	0	0	0	0	0	0	0.237	0.224	0	0	0	0	0	0.299	0	0	0	0	0	0	0	0	0	0.184	0.149	0	0	0
Al_1	0	0	0	0	0	0	0	0.393	0.256	0.618	0.241	0.571	0.501	0.238	0.563	0.581	0.539	0.577	0.370	0.594	0.512	0.383	0.471	0.587	0.414	1	0	0
Al_2	0	0	0	0	0	0	0	0.156	0.136	0.116	0.119	0.115	0.127	0.125	0.121	0.111	0.115	0.116	0.141	0.108	0.135	0.145	0.131	0.112	0.148	0	1	0
Al_3	0	0	0	0	0	0	0	0.451	0.608	0.266	0.640	0.314	0.372	0.637	0.316	0.309	0.346	0.307	0.488	0.298	0.353	0.472	0.398	0.301	0.438	0	0	1

Table 9 The weighted supermatrix

	Goal	C_1	C_2	C_3	C_4	C_5	C_6	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7	SC_8	SC_9	SC_{10}	SC_{11}	SC_{12}	SC_{13}	SC_{14}	SC_{15}	SC_{16}	SC_{17}	SC_{18}	Al_1	Al_2	Al_3
Goal	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_1	0.073	0.115	0.081	0.134	0.140	0.094	0.094	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_2	0.119	0.140	0.163	0.110	0.065	0.098	0.086	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_3	0.124	0.214	0.171	0.223	0.254	0.100	0.223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_4	0.022	0.032	0.086	0.033	0.043	0.034	0.036	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_5	0.110	0	0	0	0	0.176	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_6	0.053	0	0	0	0	0	0.063	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_1	0	0.230	0	0	0	0	0	0.234	0.304	0.176	0	0	0	0	0	0	0	0	0	0	0	0	0	0.149	0.098	0	0	0
SC_2	0	0.115	0	0	0	0	0	0.084	0.070	0.073	0	0	0	0	0	0	0	0	0	0	0	0	0.080	0.065	0	0	0	0
SC_3	0	0.155	0	0	0	0	0	0.071	0	0.202	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_4	0	0	0.217	0	0	0	0	0	0	0	0.140	0.116	0.096	0	0	0	0	0	0	0	0.080	0	0.106	0	0	0	0	0
SC_5	0	0	0.134	0	0	0	0	0	0	0	0.066	0.101	0.119	0	0	0	0	0	0	0	0.090	0	0.070	0	0	0	0	0
SC_6	0	0	0.149	0	0	0	0	0	0	0	0.101	0.104	0.149	0	0	0	0	0	0	0	0.118	0	0.078	0	0	0	0	0
SC_7	0	0	0	0.129	0	0	0	0	0	0	0	0	0	0.125	0.188	0.351	0	0	0	0.110	0	0.302	0	0	0.099	0	0	0
SC_8	0	0	0	0.160	0	0	0	0	0	0	0	0	0	0	0.072	0	0	0	0	0	0	0	0.075	0.072	0	0	0	0
SC_9	0	0	0	0.212	0	0	0	0	0	0	0	0	0	0.102	0.241	0.150	0	0	0	0.182	0	0	0	0.066	0	0	0	0
SC_{10}	0	0	0	0	0.249	0	0	0	0	0	0	0	0	0	0	0	0.220	0.210	0.231	0	0	0	0	0	0	0	0	0
SC_{11}	0	0	0	0	0.149	0	0	0	0	0	0	0	0	0	0	0	0.060	0.138	0.067	0	0	0	0	0	0	0	0	0
SC_{12}	0	0	0	0	0.103	0	0	0	0	0	0	0	0	0	0	0	0.220	0.153	0.202	0	0	0	0	0	0	0	0	0
SC_{13}	0	0	0	0	0	0.301	0	0	0	0	0	0	0	0	0	0	0	0	0	0.066	0.063	0	0	0	0	0	0	0
SC_{14}	0	0	0	0	0	0.103	0	0	0	0	0.089	0.108	0.079	0	0	0	0	0	0	0	0.046	0.065	0	0	0	0	0	0
SC_{15}	0	0	0	0	0	0.097	0	0	0	0	0	0	0	0.125	0	0	0	0	0	0.143	0.105	0.134	0	0	0	0	0	0

Table 9 continued

	Goal	C_1	C_2	C_3	C_4	C_5	C_6	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7	SC_8	SC_9	SC_{10}	SC_{11}	SC_{12}	SC_{13}	SC_{14}	SC_{15}	SC_{16}	SC_{17}	SC_{18}	Al_1	Al_2	Al_3
SC_{16}	0	0	0	0	0	0	0.207	0	0	0.050	0.107	0.073	0.058	0	0	0	0	0	0	0	0	0	0.094	0	0.104	0	0	0
SC_{17}	0	0	0	0	0	0	0.175	0	0.127	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.057	0.126	0	0	0
SC_{18}	0	0	0	0	0	0	0.119	0.112	0	0	0	0	0	0.150	0	0	0	0	0	0	0	0	0	0.092	0.075	0	0	0
Al_1	0	0	0	0	0	0	0	0.197	0.128	0.309	0.121	0.286	0.251	0.119	0.282	0.291	0.270	0.289	0.185	0.297	0.256	0.192	0.236	0.294	0.207	1	0	0
Al_2	0	0	0	0	0	0	0	0.078	0.068	0.058	0.060	0.058	0.064	0.063	0.061	0.056	0.058	0.058	0.071	0.054	0.068	0.073	0.066	0.056	0.074	0	1	0
Al_3	0	0	0	0	0	0	0	0.226	0.304	0.133	0.320	0.157	0.186	0.319	0.158	0.155	0.173	0.154	0.244	0.149	0.177	0.236	0.199	0.151	0.219	0	0	1

Table 10 The limit supermatrix

	Goal	C_1	C_2	C_3	C_4	C_5	C_6	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7	SC_8	SC_9	SC_{10}	SC_{11}	SC_{12}	SC_{13}	SC_{14}	SC_{15}	SC_{16}	SC_{17}	SC_{18}	Al_1	Al_2	Al_3
Goal	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
C_6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_{10}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_{11}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_{12}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_{13}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_{14}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_{15}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 10 continued

	Goal	C_1	C_2	C_3	C_4	C_5	C_6	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7	SC_8	SC_9	SC_{10}	SC_{11}	SC_{12}	SC_{13}	SC_{14}	SC_{15}	SC_{16}	SC_{17}	SC_{18}	Al_1	Al_2	Al_3
SC_{16}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_{17}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SC_{18}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Al_1	**0.443**	0.433	0.433	0.437	0.467	0.458	0.451	0.404	0.339	0.535	0.339	0.509	0.478	0.314	0.489	0.471	0.506	0.533	0.423	0.502	0.476	0.366	0.449	0.510	0.419	1	0	0
Al_2	0.126	0.133	0.124	0.124	0.125	0.125	0.128	0.149	0.139	0.126	0.122	0.120	0.126	0.129	0.122	0.118	0.120	0.120	0.133	0.117	0.131	0.138	0.128	0.123	0.141	0	1	0
Al_3	0.431	0.434	0.442	0.439	0.408	0.417	0.421	0.447	0.522	0.339	0.539	0.371	0.396	0.557	0.389	0.411	0.374	0.374	0.443	0.381	0.393	0.496	0.423	0.367	0.440	0	0	1

(0.126) and Dali City (0.431). Thus, optimal location is selected by the “Eastern district of Taichung City”.

5 Discussion and conclusion

In this paper we propose a fuzzy extension of the analytic network process (ANP) that uses uncertain human preferences as input information in the decision-making process. Instead of the classical Eigenvector prioritization method, employed in the prioritization stage of the ANP, a new fuzzy preference programming method, which obtains crisp priorities from inconsistent interval and fuzzy judgments is applied. The resulting fuzzy ANP enhances the potential of the ANP for dealing with imprecise and uncertain human comparison judgments. It allows for multiple representations of uncertain human preferences, as crisp, interval, and fuzzy judgments and can find a solution from incomplete sets of pair-wise comparisons. An important feature of the proposed method is that it measures the inconsistency of the uncertain human preferences by an appropriate consistency index. A prototype fuzzy ANP in process models decision-making realizing the proposed method is developed, and its performance is illustrated by examples.

Most hospital administrators feel that given governmental regulations and constraints, selecting the optimal location of a hospital is extremely difficult. Therefore, the proposed fuzzy ANP-based decision making model adopts the renowned diamond model from Porter’s *The Competitive Advantage of Nations* to understand the intricate relations among competitive advantages involved in selecting a hospital location. Finally, by applying fuzzy ANP in obtaining criteria weight and ranking on those results, the Eastern district of Taichung City is the preferred location. For the regional hospital considered in the case implementation of this study, while setting up the hospital, the three locations considered are taken to construct under the evaluation method. Our results correspond to those of the hospital. The proposed evaluation method can select the location for a new hospital under construction to ensure that it has a competitive advantage once established. This study develops an evaluation criterion to select the location for new hospitals to be established in Taiwan. Moreover, the proposed evaluation criterion provides policy makers and academics with recommendations for future development.

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