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HOSPITAL LOCATION SELECTION WITH ARAS-G

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Abstract: The facility location selection is one of the most important decisions for investors and entrepreneurs. It is a strategic issue besides often decides the fate of such a facility. In this kind of strategic decisions, decision makers should take into account various objectives and criteria and the process of location selection is inherently complicated. Hospital location selection problem is an important issue in terms of location selection problem. Hospital location selection plays a vital role in the hospital construction and management. From aspect of the government, appropriate hospital location selection will help optimize the allocation of medical resources, matching the provision of health care with the social and economic demands, coordinating the urban and rural health service development, and easing social contradictions. From aspect of the citizen, proper hospital location selection will improve access to the health care, reduce the time of rescue, satisfy people's medical needs as well as enhance the quality of life. From the aspect of the investors and operators of the hospital, optimum hospital location selection will definitely be cost saving on capital strategy. This paper considers the hospital location selection for a new public hospital by using an additive ratio assessment method with gray values (ARAS-G). Analysis of the locations by ARAS-G method allows determining value of locations' in compared with the optimal location. As a result, the closest location to the optimal location was selected using this method.

Keywords: Location selection, multi criteria decision making, additive ratio assessment method, grey values

Introduction

The general public's demand for health is rising promptly with the improvement of the living standard. Hospitals are one of the most important infrastructural objects. The increasing population, especially in developing countries, amplifies the demand for new hospitals. Hospitals are usually funded by the public sectors, by profit or nonprofit health organizations, charities, insurance companies or even religious orders. No matter who provides the answer, where to locate a new hospital is an important question to ask. Hospital site selection plays a vital role in the hospital construction and management. From aspect of the government, appropriate hospital site selection will help optimize the allocation of medical resources, matching the provision of health care with the social and economic demands, coordinating the urban and rural health service development, and easing social contradictions. From aspect of the citizen, proper hospital site selection will improve access to the health care, reduce the time of rescue, satisfy people's medical needs as well as enhance the quality of life. From the aspect of the investors and operators of the hospital, optimum hospital site selection will definitely be cost saving on capital strategy. It is an inevitable trend for hospitals to adopt cost accounting in order to adapt to the development of the market economy. Besides, better hospital site selection will promote the strategy of brand, marketing, differentiation and human resource, and enhance the competitiveness (Zhou et al., 2012). Hospital site selection is related to various aspects of the society. Mixed views and debates on which criteria are most important would confuse even health care experts. Previous studies were mainly classified into three categories based on the hospital type and scale as shown below:

- General hospital: Capture rate of population, current and projected population density, travel time, proximity to major commuter and public transit routes, distance from arterials, distance from other hospitals, anticipated impact on existed hospitals, land cost, contamination, socio-demographics of service area.
- Children hospital: Conformity to surrounding region, incremental operating costs, site purchase cost, travel time, proximity to public transport, traffic routes, site ownership, site shape, site gradient, ground conditions

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(soils/rock), access, ease of patient flow and staff movement, existing infrastructure and availability of services, perimeter buffer zone, environmental considerations, future population and prominence.

- Professional medicine and cure hospital: proximity to future expansion space, consistency with city zoning/policies, compatibility with surrounding uses, character and scale, cost of site control, helicopter access, local community preferences, accessibility, centrality, environment, land ownership, size and future population and prominence (Ali et al., 2011).

Schuurman et al. (2006) tried to define rational hospital catchments for non-urban areas based on travel-time and considered general travel time; population density; socio-demographics of service area. Wu et al. (2007) used the Delphi method, the AHP and the sensitivity analysis to develop an evaluation method for selecting the optimal location of a regional hospital in Taiwan and determining its effectiveness and considered population number, density and age profile; firm strategy, structure and rivalry; related and supporting industries; governmental policy; capital, labor and land. Vahidnia et al. (2008) used Fuzzy AHP, tried to select the optimum site for a hospital in Tehran using a GIS, while at the same time considering the uncertainty issue and considered population density; travel time; distance from arterials; land cost; contamination. Fuzzy AHP was used in similar research conducted to solve the problem of a new hospital location determination in Ankara by Aydin (2009). Soltani et al. (2011) tried to select hospital site by using two stage fuzzy multi-criteria decision making process and considered distance to arterials and major roads; distance to other medical service centers; population density; parcel size for site screening and for site selection three main criteria; traffic, parcel characteristics, land use considerations.

Selecting a location for a potential hospital often decides the success or the failure of such a facility. It is thus important to assess the locations from multiple dimensions before selecting the site. This paper focuses on the multi factor evaluation of hospital sites by using an additive ratio assessment method with gray values (ARAS-G).

Methods

Grey Numbers

Many systems, such as those that are social, economic, agricultural, industrial, ecological, or biological in nature, are named based on the fields and ranges to which the research subjects belong. In contrast, the name grey systems was chosen based on the colors of the subjects under investigation. For example, in control theory, the darkness of colors has been commonly used to indicate the degree of clarity of information. One of the most well accepted representations is the so-called “black box.” It stands for an object with its internal relations or structure totally unknown to the investigator. Here, we use the word “black” to represent unknown information, “white” for completely known information, and “grey” for that information which is partially known and partially unknown. Accordingly, we name systems with completely known information as white systems, systems with completely unknown information as black systems, and systems with partially known and partially unknown information as grey systems, respectively.

In our daily social, economic, and scientific research activities, we often face situations involving incomplete information. For example, in some studies of agriculture, even though all the information related to the area which is planted, the quality of seeds, fertilizers, irrigation, etc., is completely known, it is still difficult to estimate the production quantity and the consequent annual income due to various unknown or vague information related to labor quality, level of technology employed, natural environment, weather conditions, etc. (Liu et. Al., 2006).

There are four possibilities for incomplete information of systems.

1. The information of elements (or parameters) is incomplete.
2. The information on structure is incomplete.
3. The information on boundary is incomplete.
4. The behavior information of movement is incomplete

Having “incomplete information” is the fundamental meaning of being “grey”. In different circumstances and from different angles, the meaning of being “grey” can still be extended. For more details, see Table 1 (Liu et. Al., 2006).

Table 1. Comparison between black, grey and white systems

	Black	Grey	White
Information	Unknown	Incomplete	Known
Appearance	Dark	Grey	Bright
Process	New	Replace old with new	Old
Property	Chaos	Complexity	Order
Methodology	Negative	Transition	Positive
Attitude	Indulgence	Tolerance	Serenity
Conclusion	No result	Multiple solution	Unique solution

Probability and statistics, fuzzy mathematics, and grey systems theory have been the three most-often applied theories and methods employed in studies of non-deterministic systems. Even though they study objects with different uncertainties, the commonality of these theories is their ability to make meaningful sense out of incompleteness and uncertainties. The comparison of these three theories is in the following Table 2 (Liu et. Al., 2006).

Table 2. Comparison between grey systems theory, probability, statistics and fuzzy mathematics

	Grey systems theory	Probability, statistics	Fuzzy mathematics
Objects of study	Poor information Uncertainty	Stochastic Uncertainty	Cognitive Uncertainty
Basic sets	Grey hazy sets	Cantor sets	Fuzzy sets
Methods	Information coverage	Probability distribution	Function of affiliation
Procedure	Grey series generation	Frequency distribution	Marginal sampling
Requirement	Any distribution	Typical distribution	Experience
Emphasis	Intention	Intention	Extension
Objective	Laws of reality	Laws of statistics	Cognitive expression
Characteristics	Small samples	Large samples	Experience

Grey number represents that the information of the number is insufficient and incomplete, and it belongs to a range instead of crisp value. A grey number g denotes by ⊗g.

$$\otimes g = [g^-, g^+] \quad (6)$$

Where g-, g+ represent the lower and upper bound of the interval. Let ⊗g1 and ⊗g2 be two grey numbers, and be a crisp number, then the grey number arithmetic operations can be shown as follows:

$$\otimes g_1 = [{g_1}^-, {g_1}^+] \quad (7)$$

$$\otimes g_2 = [{g_2}^-, {g_2}^+] \quad (8)$$

Grey number addition

$$\otimes g_1 + \otimes g_2 = [{g_1}^-, {g_1}^+] + [{g_2}^-, {g_2}^+] = [{g_1}^- + {g_2}^-, {g_1}^+ + {g_2}^+] \quad (9)$$

Grey number subtraction

$$\otimes g_1 - \otimes g_2 = [{g_1}^-, {g_1}^+] - [{g_2}^-, {g_2}^+] = [{g_1}^- - {g_2}^+, {g_1}^+ - {g_2}^-] \quad (10)$$

Grey number multiplication

$$\otimes g_1 . \otimes g_2 = [{g_1}^-, {g_1}^+][{g_2}^-, {g_2}^+]$$
$$= [\min\{{g_1}^-{g_2}^-, {g_1}^-{g_2}^+, {g_1}^+{g_2}^-, {g_1}^+{g_2}^+\}, \max\{{g_1}^-{g_2}^-, {g_1}^-{g_2}^+, {g_1}^+{g_2}^-, {g_1}^+{g_2}^+\}] \quad (11)$$

Grey number division

$$\frac{\otimes g_1}{a} = \left[\frac{{g_1}^-}{a}, \frac{{g_1}^+}{a}\right] \quad (12)$$

$$\frac{a}{\otimes g_1} = \left[\frac{a}{{g_1}^+}, \frac{a}{{g_1}^-}\right] \quad (13)$$

Where $g_1^- > 0,\ g_1^+ > 0,\ g_2^- > 0,\ g_2^+ > 0,\ a > 0.$

An Additive Ratio Assessment Method with Grey Values (ARAS-G)

ARAS method (Zavadskas and Turskis, 2010, Zavadskas et al., 2010a; Tupenaite et al., 2010) is based on the argument that phenomena of complicated world could to be understood by using simple relative comparisons. It is argued that the ratio of the sum of normalized and weighted values of criteria, which describe alternative under consideration, to the sum of the values of normalized and weighted criteria, which describes the optimal alternative, is degree of optimality, which is reached by the alternative under comparison.

According to the ARAS method a utility function value determining the complex relative efficiency of a reasonable alternative is directly proportional to the relative effect of values and weights of the main criteria considered in a project.

The first stage is grey decision-making matrix (GDMM) forming. In the GMCDM of the discrete optimization problem any problem to be solved is represented by the following DMM of preferences for m reasonable alternatives (rows) rated on n criteria (columns): where m – number of alternatives, n – number of criteria describing each alternative, $\otimes x_{ij}$ – grey value representing the performance value of the i alternative in terms of the j criterion, $\otimes x_{0j}$ – optimal value of j criterion.

$$\tilde{X} = \begin{bmatrix} \otimes x_{01} & \cdots & \otimes x_{0j} & \cdots & \otimes x_{0n} \\ \vdots & \ddots & \cdots & \ddots & \vdots \\ \otimes x_{i1} & \cdots & \otimes x_{ij} & \cdots & \otimes x_{in} \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ \otimes x_{m1} & \cdots & \otimes x_{mj} & \cdots & \otimes x_{mn} \end{bmatrix} \quad (14)$$

$$i = \overline{0,m};\ j = \overline{1,n}.$$

If optimal value of *j* criterion is unknown, then $\otimes x_{0j}$= max $\otimes x_{ij}$, if the criterion is benefit criterion; $\otimes x_{0j}$= min $\otimes x_{ij}$, if the criterion is cost criterion. The system of criteria as well as the values and initial weights of criteria are determined by experts. The information can be corrected by the interested parties by taking into account their goals and opportunities.

The second stage the initial values of all the criteria are normalized-defining values $\otimes \overline{X_{ij}}$ of normalized decision-making matrix $\otimes \overline{X}$:

$$\otimes \overline{X} = \begin{bmatrix} \otimes \bar{x}_{01} & \cdots & \otimes \bar{x}_{0j} & \cdots & \otimes \bar{x}_{0n} \\ \vdots & \ddots & \cdots & \ddots & \vdots \\ \otimes \bar{x}_{i1} & \cdots & \otimes \bar{x}_{ij} & \cdots & \otimes \bar{x}_{in} \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ \otimes \bar{x}_{m1} & \cdots & \otimes \bar{x}_{mj} & \cdots & \otimes \bar{x}_{mn} \end{bmatrix} \quad (15)$$

$$i = \overline{0,m};\ j = \overline{1,n}.$$

The criteria, whose preferable values are maxima, are normalized as follows:

$$\otimes \bar{x}_{ij} = \frac{\otimes x_{ij}}{\sum_{i=0}^{m} \otimes x_{ij}} \quad (16)$$

The criteria, whose preferable values are minima, are normalized by applying two stage procedure:

$$\otimes x'_{ij} = \frac{1}{\otimes x_{ij}} \quad ; \quad \otimes \bar{x}_{ij} = \frac{\otimes x'_{ij}}{\sum_{i=0}^{m} \otimes x'_{ij}} \quad (17)$$

The third stage is defining normalized-weighted matrix – $\otimes\bar{\bar{X}}$. Only well-founded weights should be used because weights are always subjective and influence the solution. The values of weight *wj* are usually determined by the expert evaluation method.

$$\sum_{j=1}^{n} w_j = 1, \tag{18}$$

$$\otimes\bar{\bar{x}}_{ij} = \otimes\bar{x}_{ij} \times w_j\,, \tag{19}$$

$$\otimes\bar{\bar{X}} = \begin{bmatrix} \otimes\bar{\bar{x}}_{01} & \cdots & \otimes\bar{\bar{x}}_{0j} & \cdots & \otimes\bar{\bar{x}}_{0n} \\ \vdots & \ddots & \cdots & \ddots & \vdots \\ \otimes\bar{\bar{x}}_{i1} & \cdots & \otimes\bar{\bar{x}}_{ij} & \cdots & \otimes\bar{\bar{x}}_{in} \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ \otimes\bar{\bar{x}}_{m1} & \cdots & \otimes\bar{\bar{x}}_{mj} & \cdots & \otimes\bar{\bar{x}}_{mn} \end{bmatrix} \tag{20}$$

$$i = \overline{0,m};\ j = \overline{1,n}.$$

The following task is determining values of optimality function:

$$\otimes S_i = \sum_{ij}^{n} \otimes x_{ij}; \quad i = \overline{0,m}, \tag{21}$$

where $\otimes S_i$ is the value of optimality function of i alternative. The biggest value is the best, and the least one is the worst. The result of grey decision making for each alternative is grey number $\otimes S_i$. There are several methods for transforming grey values to crisp values. The centre-of-area is the most practically and simple to apply:

$$S_i = \frac{1}{2}\left(S_{i\alpha} + S_{i\gamma}\right). \tag{22}$$

The degree of the alternative utility is determined by a comparison of the variant, which is analyzed, with the ideally best one S_0. The equation used for the calculation of the utility degree K_i of an alternative i is given below (Turskis and Zavadskas, 2010):

$$K_i = \frac{S_i}{S_0};\ i = \overline{0,m} \tag{23}$$

If the current method is developed for group decision making, the following equation can be used for the calculation of the utility degree Ki of an alternative i is given below:

$$K_i = \sqrt[D]{\prod_{d=1}^{D} K_i^d} \tag{24}$$

K_i^d : d is the decision maker d, i is the alternative i, D is the number of decision makers.

Results and Findings

In this case hospital location selection is problem for a public hospital. Public benefit should be maximized whereas possible regret should be minimized in this process. The decision-makers consisted by three academics and three experts from the ministry of health. Three locations have been proposed by the governorship and the municipality for hospital site selection evaluation. These location sites are shown as a_1, a_2, and a_3.

Many different criteria are considered for hospital site selection in many different researches and based on the considered situations for each research case. These criteria are integrated in the current research and classified into six criteria. These criteria are listed as:

- C_1: Site conditions and surrounding (Site size, Site preparation time, parking: Surrounding street network to accommodate adequate parking, Proximity to banking facility, Proximity to community services, and Attractive outlook)
- C_2: Accessibility and traffic (Public transport link, Bicycle, Pedestrian, and Commute time for hospital staff)
- C_3: Patient/emergency access consideration (Helicopter access and Access to road network)
- C_4: Cost (Site preparation cost, Operational cost, and Maintenance cost).
- C_5: Future considerations (Expansion ability and Represent different geographic regions).
- C_6: Nuisance (Atmosphere conditions and Noise).

The group leader determined the weights of the criteria. After that, first step is establish the grey decision-making matrix ($\tilde{X}$) for all decision makers. Decision making matrix for decision maker 1 is as shown in Table 3. The second step, the initial values of all the criteria are normalized-defining values $\otimes \overline{X_{ij}}$ of normalized decision-making matrix $\otimes \overline{X_{ij}}$ as shown in Table 4 for decision maker 1.

Table 3. Decision maker 1 initial grey decision making matrix

Criteria	Site conditions and surrounding		Accessibility and traffic		Patient/emergency access consideration		Cost		Future considerations		Nuisance	
	C_1		**C_2**		**C_3**		**C_4**		**C_5**		**C_6**	
Optimum	**max**		**max**		**max**		**min**		**max**		**max**	
W	α	γ	α	γ	α	γ	α	γ	α	γ	α	γ
	0,2	0,2	0,2	0,2	0,15	0,15	0,25	0,25	0,1	0,1	0,1	0,1
A_0	1,0	1,0	1,0	1,0	1,0	1,0	0,4	0,4	1,0	1,0	1,0	1,0
A_1	0,8	1,0	0,4	0,6	0,4	0,6	0,4	0,6	0,6	0,8	0,4	0,6
A_2	0,6	0,8	0,6	0,8	0,6	0,8	0,6	0,8	0,4	0,6	0,4	0,6
A_3	0,8	1,0	0,4	0,6	0,6	0,8	0,4	0,6	0,8	1,0	0,6	0,8

Table 4. Decision maker 1 normalized decision-making matrix

Criteria	Site conditions and surrounding		Accessibility and traffic		Patient/emergency access consideration		Cost		Future considerations		Nuisance	
	C_1		**C_2**		**C_3**		**C_4**		**C_5**		**C_6**	
Optimum	**max**		**max**		**max**		**min**		**max**		**max**	
w	α	γ	α	γ	α	γ	α	γ	α	γ	α	γ
	0,2	0,2	0,2	0,2	0,15	0,15	0,25	0,25	0,1	0,1	0,1	0,1
A0	0.26	0.31	0.33	0.42	0.31	0.38	0.273	0.353	0.29	0.36	0.33	0.42
A_1	0.25	0.26	0.17	0.20	0.15	0.19	0.235	0.273	0.21	0.24	0.17	0.20
A2	0.19	0.21	0.25	0.27	0.23	0.25	0.176	0.182	0.14	0.18	0.17	0.20
A3	0.25	0.26	0.17	0.20	0.23	0.25	0.235	0.273	0.29	0.29	0.25	0.27

The third step is defining normalized-weighted matrix – $\otimes \bar{\bar{\mathbf{X}}}$. Then S, K_i ; are calculated. The calculated values for decision maker 1 as shown in Table 5.

Table 5. Results for decision maker 1

	S	K^1
A0	0.363	1
A1	0.243	0.670315557
A2	0.226	0.621005331
A3	0.268	0.737695576

The final step, K value for all alternatives calculated from K^i values as shown in Table 6.

Table 6. Results for all decision maker and the group

	K^1	**K^2**	**K^3**	**K^4**	**K^5**	**K^6**	**K**
A_1	0.67	0.65	0.60	0.67	0.63	0.67	0.647795998
A_2	0.62	0.66	0.59	0.61	0.61	0.62	0.617978216
A_3	0.74	0.71	0.65	0.65	0.70	0.65	0.682424635

Conclusion

Hospital location site selection problem turns into a complicated problem that one decision-maker cannot handle as amount of the investment increases. In this case, personal expertise is not enough and the subject should be examined from different angles. Therefore, the problem was handled by group decision making method as the information and experience provided by the persons would be more than one person's information and experience and this would increase the effectiveness of the decision. Location site selection is a strategical decision and a mistake would be very hard to correct. As a result of the study alternative 3 (A_3) selected because the utility degree of it is the biggest. The method was developed to include group decision-making.

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