Location Selection – A Fuzzy Clustering Approach

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Abstract

This paper uses the well-established Fuzzy C-Means Clustering Algorithm for suggesting a heuristic that effectively zeroes down upon a set of viable locations out of several alternatives. Besides the list of desirable location candidates, the methodology also provides a list of totally inappropriate alternatives that must be weeded out from the process of selection. The paper also proposes a self-devised scoring mechanism that is used to rank the short-listed locations. The proposed methodology is validated on three problems, and an example is presented.

Keywords: ***Fuzzy C-Means Clustering, Location Selection.***

1. Introduction

Location Selection is a seemingly innocuous but critical decision having far reaching consequences. It usually entails a one-time investment having a direct and lasting impact on material expenses, operating costs and revenues generated by the unit. Location Selection is a problem faced not only by entrepreneurs but also by designers, city-planners & administrators for locating say, a place for a new component on an IC, or a hospital or a library in a city, a new classroom in a university campus, and so on.

The Location Selection decision has been treated as a three-stage process in literature where: Stage One deals with selection of a geographical region or state. Stage Two deals with the selection of a particular community or locality within the selected region. Stage Three deals with the selection of the final site in the locality on which the new facility is to be built. Thus, Location Selection is a multi-stage, multi-decision problem where the choice of location in each stage is made such that it guides the final decision of location to be either equal to or as close to the global optimum as possible.

It is believed that a large number of criteria could possibly be considered for investigating real-world problems of Location Selection. Although no list can be considered exhaustive, Moore's [1] enunciation of criteria still appears pertinent and can be considered as a fundamental basis for selection. Table 1 encapsulates some common criteria for selection.

Table 1. Common Criteria used for Selection.

Criteria	Territory Selection	Region Selection	Site Selection
Market	*		
Raw Material	*		
Transportation	*		*
Power	*	*	*
Labour and wages	*	*	*
Laws and Taxation	*	*	
Climate and Fuel	*	*	
Community Service and Attitude	*	*	*
Water and Waste		*	*

The problem becomes further complex because in each of the three stages listed above, a different set of criteria may need to be considered, as can be seen from Table 1.

Location Selection has attracted many researchers including geographers, economists, town planners etc. Table 2 lists prominent papers in this field and also depicts the gradual shift from quantitative models to qualitative models and eventually to fuzzy based models used for Location Selection.

2. Fuzzy Set Theory

Lotfi A. Zadeh demonstrated in 1965 a method of dealing with vague & approximate situations. He identified classes of objects, which may not be compartmentalized into watertight sections. Zadeh [18] called such sets 'Fuzzy'; and defined them as those sets *"...which have a continuum of grades of membership* (μ) *ranging between zero and one."* Interestingly, relaxing the constraint of Membership Coefficient for any object - from the two element set {0, 1} in the case of 'Crisp' sets; to any value from the unit interval [0, 1] in Fuzzy Sets - provides us with an effective means of modelling situations which are known approximately and possess an inherent vagueness.

A. *Fuzzy Clustering*

Clustering can be considered as an unsupervised learning algorithm where the goal is to determine the intrinsic grouping in the set of unlabeled data i.e., given

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Manuscript received 15 Dec. 2007; revised 31 May 2008

a finite set of data X, the problem of clustering in X is to find several cluster centers that can properly characterize relevant classes of X (George and Y. Bo [19]). Fuzzy Clustering accepts the fact that real world data are usually not well separated into 'hard' classes or clusters; rather they belong to more than one cluster with possibly a non-unique grade of membership in each. So the Fuzzy Clustering procedure assigns a value from interval [0, 1] for every datum for each cluster as a grade of membership or Membership Coefficient (μ). The sum of membership coefficients for a particular datum in all clusters is equal to 1.

Clustering Algorithms are ideally suited for locating similarity in large and unmanageable data, particularly in absence of prior information about data. Also, Fuzzy Clustering is found to be a better tool for dealing with incompleteness and ambiguity in data (Kaufman and Rousseeuw [20], Jain and Dubes [21]), which is an acceptably common case in the problem of Location Selection.

This paper utilizes 'Fuzzy C-Means' type of clustering that was originally developed by Dunn [22] and later improved upon by Bezdek [23]. Bezdek's method is based on the minimization of the objective function (J_m) by iterative optimization as given in (1).

$$J_m(U,v) = \sum_{k=1}^{n}\sum_{i=1}^{c}(u_{ik})^m (d_{ik})^2 \quad (1)$$

d_{ik}, the distance of each point from its cluster centre, is calculated by the formula given in (2).

$$d_{ik} = \left[\sum_{k=1}^{m}\left|x_{kj} - v_{ij}\right|^2\right]^{1/2} \quad (2)$$

The cluster centre matrix v is calculated by (3).

$$v_{ij} = \sum_{k=1}^{n}(u_{ik})^m x_{kj} \Big/ \sum_{k=1}^{n}(u_{ik})^m \quad (3)$$

where U is the partition matrix, u_{ik} is the degree of membership of x_i in the cluster k, x_k is the k^{th} of d-dimensional measured data, v_j is the d-dimension centre of the cluster, n is number of data points, c is number of clusters, and m is the dimension of data.

Table 2. Some Quantitative, Qualitative and Fuzzy Methods for Location Selection.

S. No.	Methods	Approach	Remarks
QUANTITATIVE TECHNIQUES			
1.	Thunen's Theory of Least Cost Location [2]	Location was selected on the basis of price of the commodity in the market and distance from the market	Amongst the first attempts that only considered basic costs for locating decisions.
2.	Weber's Theory of Location [3]	Included cost of transportation, labour and concentration of industries. Location was decided by calculating indices for Material, Labour etc.	It excluded cost of land, depreciation etc. and was thus criticized due to it's over simplicity.
3.	Losch's Theory of Maximum Profit for Location [4]	Location was selected using a measure of profit earned rather than cost incurred.	Iinsists that the location of an establishment depends not merely on the cost of production but also on the revenue earned and losses accrued.
4.	Transportation Problem Solving Technique – Koopmans & Beckmann [5]	Used the OR technique of 'Assignment' of plants to locations and included cost of transportation between plants to consider the allocation of indivisible resources.	Uses minimization of distribution cost as the basis for selection and expresses serious concern at the oversimplification of assumptions made by other researchers.
5.	Analogue Computer Adaptation of Transportation Problem – Brink & Cani [6]	Location was selected using electric potential points to generate Iso-cost curves.	Iso-cost curves give a range of locations which are economically equal.
QUALITATIVE TECHNIQUES			
6.	Factor Weight Rating [7]	Range of methods in which some use numbers for subjective factors and others use subjective ratings.	Locations are ranked according to the scores obtained by weighing factors.
7.	Brown & Gibson's Method [8]	Factors are grouped on the basis of subjective and objective features. Critical factors are also marked.	Uses location measures to select a location.
8.	Multi-Attribute Utility Theory Model – Kirkwood [9]	A case history of nuclear power plant site selection is presented.	It gives an application of the Woodward-Clyde MAUT approach to a nuclear power plant-siting problem.
FUZZY TECHNIQUES			
9.	Weighted Goals Method - Yager [10]	Goals are represented by fuzzy sets and weights with an exponent expressing their importance	It converts a linear programming problem into a non-linear one.
10.	Delphi-based Fuzzy Rating Method - Narsimhan [11]	Fuzzy ratings were used to describe relative importance of attributes.	It provides a Delphi-based procedure to organize and evaluate imprecise information.
11.	Linguistic Descriptor Method - Mital & Karwowski [12]	Used linguistic descriptors for the subjective factors.	Simplified the process of aggregation using a fuzzy aggregator.
12.	Fuzzy MultiCriteria Decision Making Method - Liang & Wang [13]	Used fuzzy set theory with hierarchal structure analysis for aggregation of opinion of several decision-makers.	Used triangular fuzzy membership functions and ranked the location on Fuzzy Suitability Indices.
13.	Fuzzy Multi Criteria Method - Bhattacharya, Rao, Tiwari [14]	Fuzzy goal programming model for single facility in a convex region.	Triple criteria – maxmin, minmax and minisum location were used.
14.	Fuzzy-Genetic Approach - Tzeng & Chen [15]	Employed fuzzy multi objective approach with Genetic Algorithms.	It was the first paper to use Fuzzy-Genetic type of hybrid soft computing in the field of location selection.
15.	Fuzzy TOPSIS Model - Ta-Chung Chu [16]	Ratings of alternate locations are assessed in Linguistic terms.	Ranking method uses mean of ideal location to arrive at fuzzy solutions.
16.	Fuzzy Outranking Method - Kaya & Çinar [17]	Used three preference models to evaluate the nondominance set from the set of alternatives.	Used preference of alternatives with fuzzy preference relation to select location of a warehousing facility.

3. Approach

In this paper it is assumed that the candidate locations exist in m-dimensional space where each dimension represents some criterion/attribute for selection. The process of clustering identifies a working set of better locations and the scoring method selects the Most Suitable Location from the set.

A. *Selection Criteria*

Locations have been selected in literature using numerous evaluation criteria. Tompkins and White [24] and Spohrer and Kmak [25] suggest dividing the criteria into two distinct types – 'Objective' and 'Subjective', where Objective Criteria are those which can be expressed quantitatively. For example proximity to market, availability of raw material, cost of land etc. Subjective criteria are those that can only be defined qualitatively. This list includes community attitude, laws, and safety requirements etc., to name a few.

While the actual choice of criteria for any given Location Selection Problem is context dependent, the authors propose to have the following combination from Objective and Subjective attributes for common selection problems:

- Material Cost (Rs. in lakhs/month)
- Labour Cost (Rs. in lakhs/month)
- Community Attitude (on a scale of 0 to 1)

B. *The Logic*

Conventionally, the number of clusters to be imposed on data depends on the intrinsic nature of the problem. There could be anything from one to n possible clusters (where n is the number of datum). In here the authors propose to set the number to two clusters. The logic being that they would denote two distinct classes of locations-'Suitable' and 'Unsuitable'. The objective is achieved by using two dummy locations - Ideal Location (*IL*)[†] and Worst Location (*WL*)[‡]. *IL* is defined as that alternative (actual or fictitious) which has the best possible values for each selection criteria from the current problem set and *WL* as that alternative (actual or fictitious) which has the worst possible values. To start with, there is no selection bias towards any Location. Hence, the Initial Partitioning Matrix will contain $\mu = 1$ for all locations in cluster containing IL and $\mu = 0$ for cluster containing WL. After a Fuzzy Clustering run, those locations which cluster with the *IL*, are considered as worthy alternatives for selection and those with the *WL* are rejected.

[†] Ideal Location hereinafter abbreviated as '*IL*'

[‡] Worst Location hereinafter abbreviated as '*WL*'

C. *Scoring Mechanism*

The best location is selected by calculating the distance of each location from the *IL*, as explained earlier. This is done using (4).

$$R_i = \left[\sum_{j=1}^{m} \left(X_{kj} - X_{IL}\right)^2\right]^{1/2} \qquad (4)$$

where R_i is the matrix used for ranking locations, X_{kj} is the matrix containing the criteria values for each selected location and X_{IL} is the Ideal Location. Equation (4) uses Euclidean distance scheme to calculate the distance. The Location with the least score is selected as the Most Suitable Location

D. *Algorithm*

The algorithm proposed by the authors is as follows:

1. Identify the candidate locations, which need evaluation. Let this number be n.
2. Choose the criteria needed for the selection process. Take their number to be m.
3. Rate each candidate location with respect to all the criteria. Thus, the value for the jth criteria for the kth candidate location is given by X_{kj} where $k = 1, 2,...n$ and $j = 1, 2,...m$. This step will provide us with total $k \times j$ values.
4. Insert (or identify) an *IL* in table X_{kj} at row $(n + 1)$, having highest value for each criterion taken from X_{kj}
5. Similarly, insert a *WL* in the table X_{kj} at row $(n + 2)$, having worst possible values for all the criteria. *{This step will convert X_{kj} into a table of size $(n + 2) \times m$}*
6. Select the number of clusters. Let this number be c[§].
7. Initialize the partition matrix, U. Each step in the algorithm will be labelled r, where $r = 0, 1, 2\ldots$
8. Calculate the c cluster centres $\{v_i^{(r)}\}$ for each step.
9. Using (5) update the partition matrix for the r^{th} step, $U^{(r)}$.

$$\mu_{ik}^{(r+1)} = \left[\sum_{j=1}^{c}\left(\frac{d_{ik}^{(r)}}{d_{jk}^{(r)}}\right)^{\frac{2}{(m'-1)}}\right]^{-1} \qquad (5)$$

for $I_k = \Phi$ or $\mu_{ik}^{(r+1)} = 0$ for all classes i

where $i \in I_k$, $I_k = \{i \mid 2 \le c < n; d_{ik}^{(r)} = 0\}$

and $\tilde{I}_k = \{1, 2, \ldots, c\} - I_k$, $\sum \mu_{ik}^{(r+1)} = 1$.

10. If $\|U^{(r+1)} - U^{(r)}\| \ge \varepsilon$ set r = r+1 and return to step 8
11. The candidate locations having membership above $\varepsilon = 0.5$ (termination criterion) in the cluster containing Worst Location are rejected.
12. Calculate the distance of locations that have membership coefficient values more than or equal

[§] In this paper $c = 2$, as explained.

to ε = 0.7 in the cluster containing *IL* from Ideal Location itself by using (4). This distance serves as the score for ranking locations.

13. The locations in R are now ranked according to the increasing order of distance from *IL*. The location with the least distance from *IL* (or the one that is closest to *IL*) is declared to be the Most Suitable Location.

4. Validation

The methodology was applied to three existing problems of Location Selection: Liang and Wang [13], Kapoor and Tak [26], and Telsang [27]. Liang et al. have used Fuzzy Multi Criteria Decision Making for the selection process. Kapoor et al. have dealt with a real world problem of locating a new Handicraft Manufacturing Unit using a Fuzzy heuristic. Telsang has used a conventional crisp method in which Rate of Return on Investment is used for ranking. The comparative results are listed in Tables 3, 4 and 5 respectively.

Table 3. Comparison of Results for the Problem in Liang and Wang [13].

Alternative	Solution by Liang & Wang		Solution by Authors		
	Rank	Suitability Index	Rank	Score	Membership Coefficient
A1	Third	0.416	Third	0.289	0.2159
A2	**First**	**0.476**	**First**	**0.247**	**0.7237**
A3	Second	0.469	Second	0.274	0.6120

Table 4. Comparison of Results for the Problem in Kapoor and Tak [26].

Alternative	Solution by Kapoor & Tak		Solution by Authors		
	Rank	Suitability Index	Rank	Score	Membership Coefficient
A1	**First**	**0.456**	**First**	**0.000**	**0.9959**
A2	Second	0.353	Second	0.463	0.5183
A3	Third	0.222	Third	0.887	0.0034

Table 5. Comparison of Results for the Problem in Telsang [27].

Alternative	Solution by Telsang		Solution by Authors		
	Rank	Rate of Return	Rank	Score	Membership Coefficient
A1	Second	82.4%	Second	131.14	0.0876
A2	**First**	**87.6%**	**First**	**10.00**	**0.999**
A3	Third	66.29%	Third	169.08	0.0174

As can be seen from the results the proposed method gives identical choices for selecting all the alternatives in each of the three problems.

5. Example

Consider a situation where a new facility is to be established. After a preliminary screening, assume that the experts have short listed 10 locations ($n = 10$). Let the criteria used for selection be: Material Cost, Labour Cost, and Community Attitude ($m = 3$). Let each location be rated for each criterion as reported in Table 6.

Table 6. Attribute values for ten hypothetical locations.

Location No.	Material Cost (lakhs/month)	Labour (lakhs/month)	Community Attitude
1	50	40	0.3
2	57	30	0.0
3	51	32	1.0
4	60	37	0.5
5	59	35	0.8
6	55	39	0.5
7	54	35	0.8
8	55	32	1.0
9	59	37	0.5
10	60	39	0.3
11 (*IL*)	50	30	1.0
12 (*WL*)	60	40	0.0

Let the dummy locations *IL* and *WL* be inserted; value of c duly initialized, and the Fuzzy C Means clustering be carried out. Let the Membership Coefficient of each location in the two clusters after the clustering run be as reported in Table 7.

Table 7. Membership Coefficients for Two Group Cluster Analysis.

Location No.	Membership Coefficient (μ_i)	
	c = 1	c = 2
1	0.4440	0.5560
2	0.2765	0.7235
3	0.0401	0.9599
4	0.9676	0.0324
5	0.8466	0.1534
6	0.7553	0.2447
7	0.1976	0.8024
8	0.0941	0.9059
9	0.9880	0.0120
10	0.9653	0.0347
11 (*IL*)	0.0984	0.9016
12 (*WL*)	0.9389	0.0611

Since locations 4, 5, 6, 9 and 10 are found to have Membership Coefficients below 0.5 in the second cluster (that contains *WL*), let these locations be rejected. Further, since locations 2, 3, 7 and 8 are found to have Membership Coefficients greater than or equal to 0.7 in the first cluster (that contains *IL*), let these locations be selected.

Let the calculation of score for each of the selected locations be carried out as shown below and let them be reported in Table 8:

For Location 2

$$R_1 = [(57 - 50)^2 + (30 - 30)^2 + (0 - 1)^2]^{1/2} = 7.071$$

For Location 3

$$R_2 = [(51 - 50)^2 + (32 - 30)^2 + (1 - 1)^2]^{1/2} = 2.236$$

For Location 7

$R_3 = [(54 - 50)^2 + (35 - 30)^2 + (0.8 - 1)^2]^{½}$
$= 6.406$

For Location 8

$R_4 = [(55 - 50)^2 + (32 - 30)^2 + (1 - 1)^2]^{½}$
$= 5.385$

Table 8. Membership Coefficient and Score for the Selected Locations.

Location No.	Membership Coefficient (μ_i) for cluster number 2	Score	Rank
2	0.7235	7.071	Fourth
3	**0.9599**	**2.236**	**First**
7	0.8024	6.406	Third
8	0.9059	5.385	Second

Let Location 3 be declared as the Most Suitable Location since it is found to have the least score in Table 8 followed by Locations 8, 7 and 2.

6. Conclusion

In this age of globalization the decision of selecting a location has increasingly become important. Fuzzy Cluster Analysis provides a systematic and convenient solution to this problem. The method presented in this paper has the following advantages:

- It is a robust process, which can incorporate a large number of locations and criteria. With the increase in alternative locations and criteria, this model maintains its simplicity as opposed to other methods that tend to become numerically intensive.
- This method can be applied recursively in each stage for Location Selection to produce a set of locations, which work as an input for the next stage of selection.
- As the underlying procedure is fuzzy it allows the selector to include group membership which gives a broader view of the whole selection process by allowing a location under question to simultaneously belong to more than one clusters.
- It is closer to human thought process in the sense that it tries to rate the locations according to their closeness to the Ideal Location.

A. *Future Scope for Research*

While an effective methodology for Clustering based Location Selection has been proposed in this paper, there are areas that need to be further worked upon. The following areas, according to the authors need looking into:

- At many places authors have used techniques without enough supportive evidence. For instance out of many distancing schemes available, authors have used Euclidean Distance scheme. Other schemes need to be evaluated for the possible influence that they may exert on the final score.
- Also, authors have used Fuzzy C-Means Clustering due to its overlapping nature that allows a datum to be simultaneously included in the cluster that contains *IL* as well as in the one that contains *WL*. There are many other Clustering Algorithms like Fuzzy K-Medoids, Mixture of Gaussian etc., which may also be investigated for possible use in the proposed method.
- Kaufman and Rousseeuw [20], Jain and Dubes [21] have suggested weighted criteria schemes for clustering. In here the authors have considered all criteria to be of equal importance, but if some criteria are to be given more importance than others then the above scheme may also be employed.

Acknowledgment

The authors thank the referees for their helpful suggestions. Vikas Kapoor gratefully acknowledges the financial assistance and support received from Department of Science & Technology, India in connection with an SERC project under Young Scientists Scheme sanctioned during 2003-04.

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