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# Locating Post Offices Using Fuzzy Goal Programming and Geographical Information System (GIS)

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## ABSTRACT

This paper deals with the problem of locating new post offices in a megacity. To do so, a combination of geographical information system (GIS) and fuzzy goal programming (FGP) is used. In order to locate new offices, first six types of service facilities with high levels of interactions with post offices are defined. Then, aspiration level of proximity for each service facility is determined. Based on these values, a fuzzy goal programming model is constructed to find potential locations of facilities. In order to determine the optimal locations among potential facilities, a maximal covering location problem (MCLP) is solved and results are reported. Results show that although the current state is near-optimal, for future expansions of the network, the government should spend money on central and southern parts of this megacity.

### Keywords

Facility location, GIS, Covering location problem, Fuzzy goal programming, Post office.

## INTRODUCTION

Facility Location (FL) has been a significant problem in urban planning around the world. It is a strategic issue with applications ranging from locating distribution centers to hospitals, hotels, landfills and even medical applications. In any facility location problem, various parameters should be considered such as social, economical, and legal parameters. FL is a critical problem in both public and private sectors. While a bank is located to attract more customers, a plant is located somewhere with a fair amount of access to workforce and resources.

One of the traditional location problems, which has been well studied since the very beginning of location science is the covering location problem. In a covering location problem, one seeks a solution to cover a subset of nodes considering one or more objectives. The covering location problem is often categorized as two distinct problems: location set covering problem (LSCP) and maximal covering location problem (MCLP). In a standard maximal covering location problem (MCLP), the goal is to locate a number of facilities on a network in such a way that the covered population is maximized. A population is covered if at least one facility is located within a pre-defined distance of it. This pre-defined distance is often called coverage radius. The choice of this distance has a vital role and affects the optimal solution of the problem to a great extent. MCLP is of paramount importance in practice to locate many service facilities such as schools, parks, hospitals and emergency units. The problem was first introduced by Church and ReVelle (1974) on a network and since then, various extensions to the original problem have been made. Normally, MCLP is considered whenever there are insufficient resources or budget to cover the demand of all the nodes. Therefore, the decision maker determines a fixed budget/resource to cover the demands as much as possible.

The ability to model real-world problems has been dramatically improved since the emergence of computers. Nowadays, many complex problems are solvable using computer applications such as geographical information system (GIS). The last decade has observed an upsurge in the use of GIS-based accessibility analysis for business planning (Rtesima and de Jong, 1999). While operations research-based approaches have been widely used in many location problems, they are not user-friendly. Accordingly, in many location problems, GIS may be used to find location of facilities. GIS combines spatial and non-spatial data to construct visualized information that can be easily analyzed by decision makers (Cheng et al, 2007).

Considering a free market condition, entrepreneurs interested in entering private sector services face a great challenge in finding optimal locations in order to get higher market shares. The same challenge exists for governments to satisfy more and more citizens by providing sufficient service levels. This paper appears considering the need to scientifically locate post offices and to propose the future development plans for the current network of post offices in Tehran, Iran. Tehran, as a megacity is the capital city of Iran and is among the 30 largest cities around the world. Its population is more than 8 million and is center of many industrial, educational, and social activities. With the rapid increase in Tehran's population, there is a need to locate new service facilities such as hospitals, sport centers, and post offices. The problem of this paper is to propose locations for new post offices and to examine the performance of the current state. To do so, various considerations should be taken into account ranging from proximity of facilities to demand centers to the equity in distribution of facilities. The main problem in locating post offices is the need to model the decision maker's state of mind about the acceptable levels of problem parameters. In order to tackle this problem, fuzzy logic has been used. This paper brings an innovation in the literature by proposal of using a fuzzy logic-embedded GIS to locate post offices in Tehran. The master plan proposed in this paper could be followed further in order to define the optimal locations of post offices more accurately.

The rest of this paper is organized as follows: First, a literature review of publications in MCLP will be given. Then, brief introductions of GIS and fuzzy logic are presented. The proposed GIS-based approach is presented in the next section. Finally, concluding remarks are given and some extensions are proposed as avenues for future studies.

## LITERATURE REVIEW

The literature of covering models is too diverse to be completely studied in this paper. We will focus on some interesting publications in the last decade. To get acquaintance with the current challenges in the literature of covering location problem, one may refer to the valuable review by Berman et al. (2010).

Using various heuristics and metaheuristics for MCLP has been considered in some papers, such as Aytug and Saydam (2002) which is a comparative study on the performance of genetic algorithms and other heuristic approaches on large-scale maximum expected coverage problems, using lagrangian relaxation heuristics by Espejo et al. (2003) and Barbas and Marin (2004), comparing the lagrangian and surrogate relaxations by Galvao et al. (2000), using simulated annealing by Canbolat and von Massow (2009) are some of the contributions to literature of MCLP in the last decade.

Moreover, the traditional MCLP model has been extended by various scholars, such as the partial coverage concept (Berman and Krass, 2002), coverage by inclined parallelograms (Younies and Wesolowsky, 2004), considering demands on nodes and arcs (Erdemir et al., 2008), anti-covering model (Berman and Huang, 2008). Additionally, a recent interesting publication by O'Hanley and Church (2011) presented a location-interdiction model to maximize the combination of initial coverage by facilities and the minimum coverage level caused by the loss of critical facilities.

Case studies of MCLP could be found in Ratick et al. (2009) in Kohat district of Pakistan, Curtin et al. (2007) in Dallas, and Murawski and Church (2009) in Ghana, to name a few.

Besides, the uncertain version of MCLP has been addressed a couple of times, such as Correa et al. (2009), Batanovic et al. (2009) and Berman and Wang (2011). Interested readers may refer to these sources and references therein to get more acquaintance with these contributions.

To summarize the literature review, the marriage of operations research and GIS is still immature and deserves much attention, for sure. Moreover, our study revealed that there is still a gap to analyze the usefulness of MCLP in real-world case studies. In this paper, we try to fill these two gaps by introducing a three-phase methodology to locate post offices in Tehran.

## GEOGRAPHICAL INFORMATION SYSTEM (GIS)

The GIS technology is appropriate for a variety of applications including resource management, land surveying, and business planning (Cheng et al, 2007). By definition, a GIS is a computer system capable of assembling, storing, manipulating, analyzing, and displaying geographically referenced information (i.e. data identified according to their locations). GIS presents data in two different formats: Vector and Raster. While a vector is used to represent objects using points, lines and polygons, a raster is composed of a matrix of cells called pixels, each containing values. In a raster representation, the value of each pixel determines its color. GIS have been used in literature to locate many facilities such as bioenergy facilities (Panicelli and Gnansounou, 2008), taxicab stands (Ocalir et al, 2010), sewage treatment plants (Zhao et al, 2009), etc.

## FUZZY LOGIC

Fuzzy sets provide a mathematical way to represent the vagueness and imprecision underlying systems and also a way to treat linguistic variables. Fuzzy logic's robustness and ability to interpret real problems makes fuzzy logic so popular and useful in varying fields of science such as transportation, medicine, robotics, psychology, decision making, economics, risk analysis, pattern recognition, scheduling, etc. Fuzzy logic is based on the theory of fuzzy sets, which relates to classes of objects with unsharp boundaries, in which membership is a matter of degree (Ocalir, 2010). Therefore, Fuzzy logic is a useful tool to model the aspiration levels of decision maker(s) for the problem of this paper.

## PROBLEM DESCRIPTION AND SOLUTION ALGORITHM

The proposed solution procedure is comprised of three steps as definition of aspiration levels, finding candidate locations, and reaching the optimal locations. While the first step is conducted using brainstorming techniques, for the second step, a combination of fuzzy goal programming and GIS should be used. Finally, using the outputs of the second step, the optimal locations are found using an MCLP model. These steps are elaborated further in the following sections of the paper. It is worth mentioning that using this approach to locate post offices should be considered as one of the many possible applications. The proposed procedure could be used in locating various facilities such as recreational centers, medical facilities, etc.

The base map in this study is the Tehran map which has been updated using other parameters such as various demand zones. These parameters were overlaid onto the base map as layers. All projections were set to UTM (Universal Transverse Mercator) and WGS1984 reference systems. The procedure to find candidate locations is divided in two consecutive segments. First, ArcGIS 9.2 has been used to overlay parameters and to get a rough understanding of the current state. Then, the ILVIS software has been used to analyze the problem as a multi-criteria decision making. The scale of capture for the topographic data is 1:200000 and all the data are represented using raster data.

Figure 1 shows the as-is state of the Tehran district and its post offices. Obviously, the as-is state shows that a large area in north and west of Tehran lack enough post offices. This can be attributed to that fact that most of the demand arises in the central and southern sections of Tehran. However, since the trend of changing demands in the future is not certain, our model gives plans to be used in case of future changes in the city population or demand pattern.

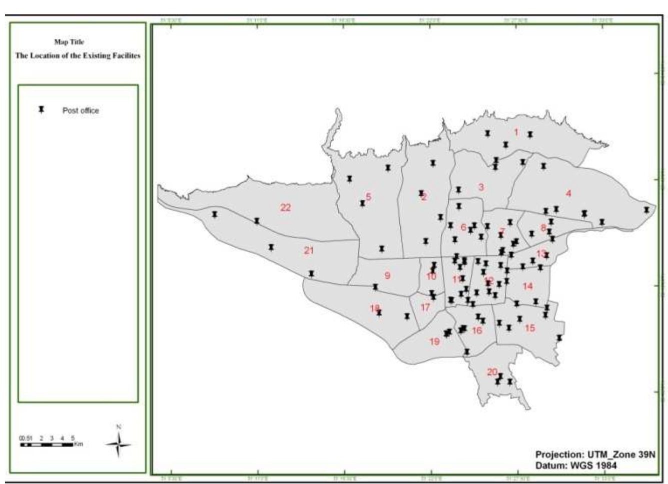


**Figure 1. The location of current post offices (the as-is state)**

A determinant factor in locating service facilities, such as post offices, is the amount of demand. In order to find various types of demands in the problem, a brainstorming group has been formed and six different types of demand zones and access points, such as bus terminals and metro stations, were found as table 1. It is to be noted that although the facilities in table 1 do not represent all the demand to the post offices, they account for a great percentage of demands. Axiomatically, service facilities such as post offices should be established near the demand zones or access points, in order to provide higher service levels. While governments and private entrepreneurs prefer to locate facilities near the zones with higher demands, customers are more interested to access service facilities in less time. This means that locating facilities in proximity of demand zones or areas with easier access is of higher value. The demand zones and access points along with their associated weight are given in table 1.

**Table 1. The demand sectors and access points and their weights**

| GIS Layer | Sub-category | Weight (1-100) |
|---|---|---|
| Service Zone | N/A | 20 |
| Transit Zone | Bus Terminal<br>Metro Station | 25 |
| Education Zone | N/A | 15 |
| Medical Zone | Medical Center<br>Medical Area | 5 |
| Industrial Zone | N/A | 10 |
| Administration Zone | N/A | 25 |

We now turn attention to the definition of aspiration levels as fuzzy membership functions. It has been considered that preference of a location follows a gradual, non-increasing trend versus the travel distance as depicted in figure 2. To define the breakpoint of preference membership functions, experts were asked to roughly determine the distance above which the membership degree is decreased from one. Although this method may need a lot of discussions between experts to reach a unanimous agreement, it is straightforward. Moreover, since it is based on the experience of experts, it is regarded as a reliable procedure which leads to practical solutions.

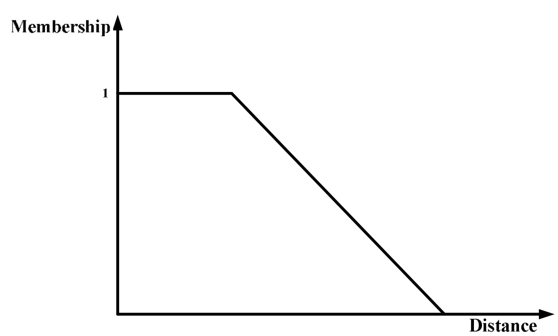


**Figure 2. Location preference against the distance to demand zones**

Expert(s) were asked to define the aspiration levels for each parameter as shown in table 2. It is known that final solution may be affected by these levels to a great extent. Thus, we tried to define them meticulously and based on a combination of expert opinions and feedbacks from questionnaires distributed between more than 500 people who uses post offices to various degrees and in various sections of the city. The questionnaire comprised of a set of multiple choice questions. Interestingly, results for all the parameters were nearly the same. Therefore, we defined the same memberships for all of the parameters. To get a better understanding of using fuzzy aspiration levels, figure 3 shows the contours drawn for each educational center. In this figure, contours are drawn assuming that the color of the circle is changed from black to white gradually based on the distance to the demand node. It should be recalled that this figure is a sample of drawing buffers around demand zones. In order to solve the problem, the same procedure must be followed for all the demand zones, overlay the layers and reach an integrated picture of the problem state.

**Table 2. The aspiration levels of criteria**

| GIS Layer | Sub Category | Suitable | Not Suitable |
|---|---|---|---|
| Distance to Service Zone | N/A | <1000 | >1500 |
| Distance to Transit Zone | Bus Terminal<br>Metro Station | <1000 | >1500 |
| Distance to Education Distance to Zone | N/A | <1000 | >1500 |
| Distance to Medical Zone | Medical Center<br>Medical Area | <1000 | >1500 |
| Distance to Industrial Zone | N/A | <1000 | >1500 |
| Distance to Administration Zone | N/A | <1000 | >1500 |

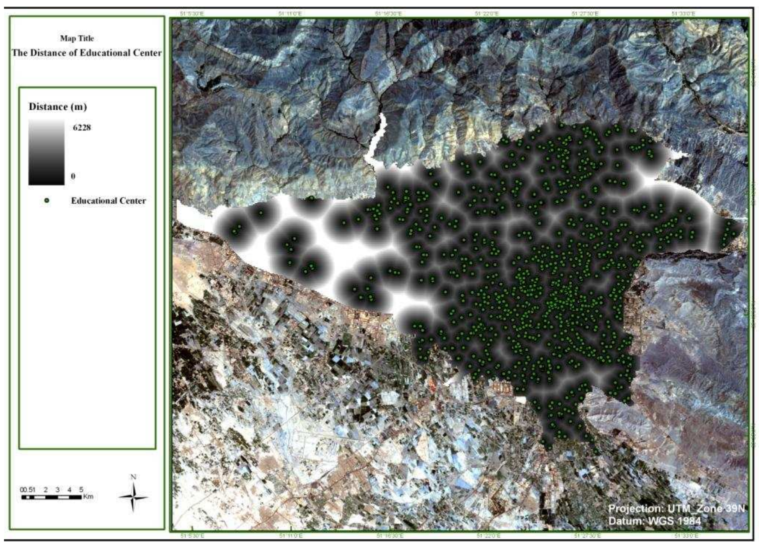


**Figure 3. Defining buffers around educational centers**

Figure 4 depicts the output of the GIS sub-problem. A close examination of results shows that the central and southern parts of Tehran are the best locations to be selected as locations to establish new facilities and the current state seems near-optimal without considering equity considerations.

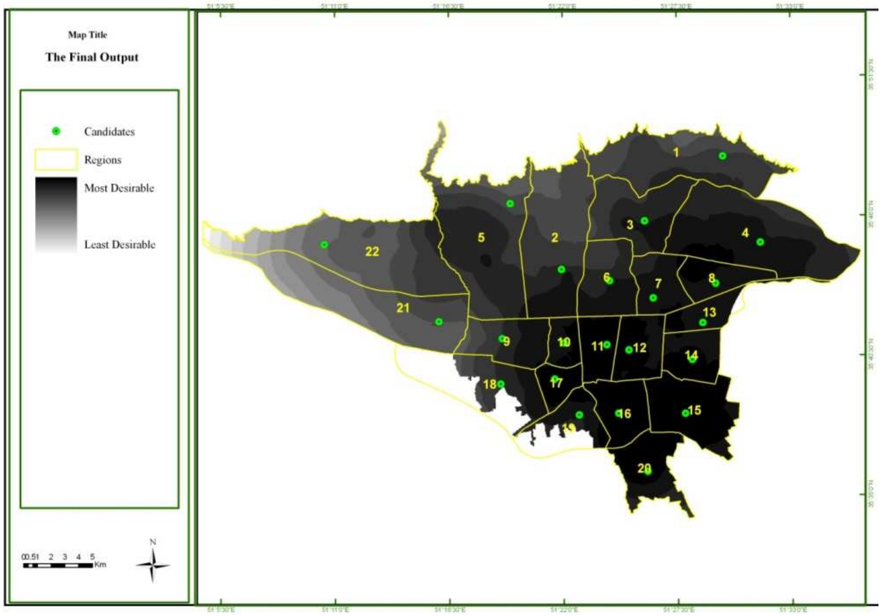


**Figure 4. The final output of the second steps**

Figure 4 clearly shows that candidate locations in districts 10, 11, 12, 14, 15, 16, 17, 19, and 20 are more desirable locations to locate facilities. Now, in order to find the optimal locations of facilities, these locations were selected to be the set of candidate locations. Then, a MCLP model is used to find the optimal locations of facilities. Before introducing the results, let's define the MCLP model, its variables and parameters and also its structure. It is assumed that a node could be covered whenever there is at least one facility within a pre-defined distance of it. Furthermore, each node could host a facility. In other words, the set of nodes and the set of potential facilities are identical. Also, it is assumed that each node has a specific amount of demand to be met. Besides, it is assumed that proximity of population to these facilities is desirable. In addition, an exogenous version of MCLP is considered. Hereby, the mathematical program of MCLP is given. First, let's define problem parameters and variables as discussed in ReVelle et al. (2008).

| | |
|---|---|
| $i$, $I$ | The index and set of demand nodes |
| $j$, $J$ | The index and set of eligible facility sites |
| $a_i$ | The population or demand at node $i$ |
| $d_{ij}$ | The shortest distance (or time) from demand node $i$ to facility at $j$ |
| $S$ | The distance (or time) standard within which coverage is desired (Coverage radius) |
| $N_i$ | $\{ j \mid d_{ij} \le S \}$=the nodes $j$ that are within distance $S$ of node $i$ |
| $P$ | The number of facilities to be located |
| $x_j$ | a binary variable which equals 1 when a facility is sited at the node $j$ and 0 otherwise |
| $y_i$ | a binary variable which equals 1 if node $i$ is covered by one or more facilities stationed within a distance of $S$ and 0 otherwise |

$$Maximize \quad z = \sum_{i \in I} a_i y_i \tag{1}$$

$$Subject\ \text{to}: y_i \le \sum_{j \in N_i} x_j, \qquad i \in I \tag{2}$$

$$\sum_{j \in J} x_j = p \tag{3}$$

$$0 \leq y_i \leq 1 \quad \mathrm{i} \in \mathrm{I} \tag{4}$$

$$x_j \in \{0,1\} \quad \mathrm{j} \in \mathrm{J} \tag{5}$$

Definition of coverage radius has a significant role in determination of optimal locations. Thus, to find the optimal locations, the problem was solved with radii of 500, 1000, and 1500 meters and counting the total value of demand which could be covered by each facility. Figure 5 shows the buffers around each candidate node and the number of medical centers covered by each facility. Using the results of figure 5 and buffers for other facilities, the solution of the MCLP model gives the best *P* locations to establish facilities. For example, considering *P*=3 and a coverage radius of 1000 meters, locations 12, 14, and 17 are selected to locate post offices.

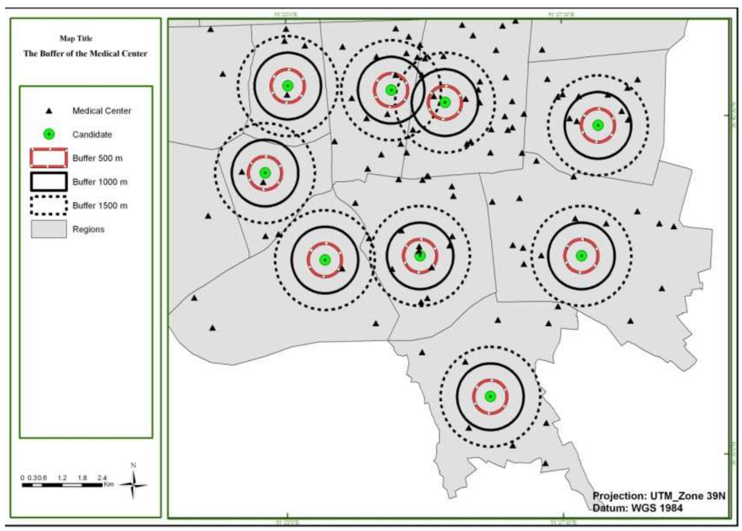


**Figure 5. Buffers of various sizes around the candidate locations**

## CONCLUDING REMARKS AND FUTURE RESEARCH PROPOSALS

This paper examined the problem of locating post offices in Tehran, using fuzzy logic and GIS in a master plan level. The proposed approach provides a flexible way to decide about future locations of post offices. Based on the results and observations, it is obvious that the current state of the city is not far from the optimal state. Anyhow, the proposed model suggests locations for future expansions of the post office network.

As some topics for future research, one may combine GIS with other solution approaches and analyze the results. Another avenue for future research could be considering type II fuzzy membership functions for aspiration levels or to consider some fuzzy variables as the problem parameters. An example of possible fuzzy variables is the travel time to reach facilities.

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