An Integrated AHP-GIS-MCLP Method to Locate Bank Branches

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Abstract

One of the most crucial decision making processes in banking is optimally locating new branches. This issue is highly important especially for private banks due to vibrant competition, limited budgets and high customer expectations. This study’s objective is to provide an integrated model for selecting optimal site location using available data sources and well accepted decision models, specifically Analytic Hierarchy Process (AHP), Geographic Information System (GIS) and Maximal Covering Location Problem (MCLP). As a case study, we applied the proposed method for branch location of a private bank in the city of Rasht, Iran. The process identified the most commonly used criteria for branch location consideration. These were restricted to the most important criteria through expert judgment elicitation, yielding demographic attributes, cost, competition, transportation, flexibility, access to public facilities. Criteria and sub-criteria weights were quantified through pair-wise comparison using expert judges, via AHP. Critical geospatial criteria data for potential sites (population densities and relative distances between competitors, amongst others), were determined through ArcGIS software, yielding 10 potential sites. A MCLP model was then developed to maximize the demand coverage when there is limited budget to establish new branches. These results demonstrate the efficiency and applicability of the proposed integrated method.

Keywords
Bank Branch Location, GIS, Analytic Hierarchy Process (AHP), Maximal Covering Location Problem (MCLP)

1. Introduction

In recent years, significant changes and developments in the provision of banking services are expected to affect the structure and the organization of banks. Growing competitive pressures on the banking services result in more complex network of bank’s branches’ locations [1]. In addition, growing information technology and transferring of banking operations to online banking makes the design of a branch network a more complex, yet interest issue [2].

Hong et al., 2009 [3], demonstrated that bank branches location has a great influence on deposit amounts, and consequently on banking profits. Recent papers such as Hirtle and Stiroh, 2007 [4], Hirtle, 2007 [5], Hirtle and Metli, 2004 [6] and Spieker, 2004 [7] have examined the impact of the growth of large banks on bank performance and profitability. Boufounou, 1995 [8] introduced location feature as one of the most important factors that affects the branch performance. In addition, he identified the volume of deposits as the key element for locating new branches and also for assessing branch performance. Some other researches, such as Pratt, 1998 [9], Pollard, 1996 [10], Lord and Wright, 1981 [11], Olsen and Lord, 1979 [12] and Morrall, 1996 [13] also revealed that loss and profit of banks are deeply dependent on the locations as well as numbers of bank branches in the region.

A prior research indicates the depositors value geographic reach (having branches in many states and municipalities) and local branch density (having many branches of an institution in a given area) when selecting a depository institution [14]. Market surveys also suggest that customers place a premium on convenience when
choosing their bank, with 39 percent of bank customers surveyed in 2001 indicating that they selected their bank primarily due to its location [15]. Location selection is clearly very important for companies because it can be a very costly mistake, specifically if the decision problem is related to locating many facilities, resulting in a unnecessary moving cost, lost endeavor, lost competitive advantages and so on [16,17]. As Jain and Mahajant [18] have pointed out, “In the development of competitive strategies, prices can be matched, services can be extended and improved, but a retailer's location advantages are difficult to assail or neutralize”.

In the facility location problem literature, the bank branch location problems have been extensively considered. Geographic Information Systems (GIS), Decision Support Systems (DSS), and Maximal Coverage Location problem (MCLP) have been utilized separately and collectively. For example:

- Miliotis et al. [1] formulated the problem of determining the optimal location of bank-branches by sequentially solving two related problems. At first, they determined the minimum number of branches that are needed and then tried to locate branches with respect to minimum coverage requirements of clients. They took advantage of GIS infrastructure in their work.
- Morrison and O’Brien [19] presented a GIS-based spatial interaction model to solve the bank-branch problem which was applied in New Zealand.
- Pastor [20] used the location-allocation model for determining the location of bank branches. In his model there are two objectives: selecting the best location and allocating prospect customers to branches.
- Min [21] developed an interactive fuzzy goal programming model embedded within a decision support system for locating banks.
- Karasakal and Karasakal [22] formulated the MCLP in the presence of partial coverage and represented the impact of the proposed approach on the optimal solution by comparing it with the classical approach.
- Marianov et al. [23] addressed the problem of optimally locating service centers such as banks, under the presence of congestion and queuing.
- Fang et al. 2009 [24] proposed a model that simultaneously optimize the location of multiple-server, congestible facilities, such as banks, clinics and gas stations, in order to realize company’s maximal total captured demand.
- Xia et al. [25] proposed a model for banking facility location problem which maximizes the profit of facility network. The profit function consists of revenue and costs.
- Castillo et al. [26] provided a model for optimal location of facilities with fixed servers, stochastic demand, and congestion. As a case study, they considered the location of full service automated banking machines (ABMs) for the second largest bank in Canada.
- Zhang and Rushton [27] presented a multi-site location-allocation model for selecting locations in competitive service system with the application of locating bank branches.
- Aboolian et al. [28] presented a method for location and allocation of service units on a congested network with the application of locating bank branches where the number of teller stations at each branch is an important decision variable and the location of ATM machines where at each location one or more ATMs are built.
- Alexandris and Giannikos [29] proposed a new model based on the notion of complementary partial coverage and exploit the capabilities of GIS in order to better represent demand.

This literature review returned no integrated method which considers the bank branch location problem as a MCDM model that utilizes GIS and MCLP. Furthermore, the proposed method can be applied to locating any other service sector industry wherein customer interactions are a critical element of the business. The remainder of this paper is as follows. The proposed mythology is presented in Section 2. A case study of its application is presented in Section 3. Section 4 presents a sensitivity analysis of the optimization model. Conclusions and future researches are presented in Section 5.

2. The Proposed Methodology

The proposed method defines the ideal location as a step-wise process: 1) AHP is implemented to obtain weights for the various criteria and sub-criteria, 2) GIS data are leveraged for potential places to establish new branches, and 3) MCLP is implemented towards optimal branch location.

Step 1: Analytic Hierarchy Process

The relative importance of criteria and sub-criteria are determined utilizing pair-wise comparison questionnaires and AHP technique (Saaty, 1988 [30]). The AHP modeling process involves four phases: 1) structuring the decision problem, 2) measurement and data collection, 3) determination of normalized weights, and 4)
synthesis-finding solution to the problem [31]. The AHP method is used mainly because of its inherent capability to handle qualitative and quantitative criteria and sub-criteria. Furthermore, it can be easily understood and applied by managers [32,33,34]. The hierarchical structure used in formulating the AHP model can enable all members of the decision making team to visualize the problem systematically in terms of relevant criteria and sub-criteria. The team can also provide input to revise the hierarchical structure, if necessary, with additional criteria.

**Step 2: GIS data extraction**

After obtaining the weights of criteria, the needed information layers would be attained. GPS tool might be used in this step. Weights are assigned to layers and the layers would be combined in order to obtain the potential locations to establish new branches in ArcGIS software.

**Step 3: MCLP**

The MCLP mathematical model is solved in order to maximize demand coverage of the region and determine final suitable points. For this, MCLP maximizes the number of demand points covered within a specified critical distance or time by a fixed number of facilities [22]. The MCLP, introduced by Church and ReVelle, 1974 [35] and its numerous extensions, such as Daskin et al., 1988 [36] and Schilling et al., 1993 [37], compose an important class of problems in location literature, such as banking network, chain stores, and wireless stores. Recently, Fazel Zarandi et al., 2011 [38] proposed a model for the large scale maximal covering location problem.

These three steps are depicted in Figure 1.

3. Case study: applying proposed integrated AHP-GIS-MCLP method to locate a private bank branches in Rasht city, Iran

3.1 Obtaining weights of criteria and sub-criteria

Firstly, the criteria and sub-criteria for the selection decision were identified through the studies of the literature, specifically [1], [8], [16], [21], [39,43], as well as discussion with bank managers in different areas. Seven initial criteria and 22 sub-criteria were obtained (Table 1). The Likert Scale questionnaire was used to obtain 30 expert’s idea about the importance of criteria and sub-criteria. Utilizing one-sample T-test in this stage, 14 sub-criteria in 6 categories were selected as relevant to the study.

Weights of criteria and sub-criteria were determined via pair-wise comparison via AHP questionnaire involving 30 managers of banks with at least 10 years of working experience in different branches of bank (Located in Rasht City, Iran). Results are presented in Table 1.
Table 1: Weights of criteria and sub-criteria

<table>
<thead>
<tr>
<th>Main criterion</th>
<th>Weight of criterion ($W$)</th>
<th>Sub-criterion</th>
<th>Weight of sub-criterion ($WS$)</th>
<th>Final weight ($W \times WS$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demographic attributes ($C_1$)</td>
<td>0.204</td>
<td>Customers’ income ($SC_1$)</td>
<td>0.652</td>
<td>0.133</td>
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<td>Dense population of the region ($SC_2$)</td>
<td>0.348</td>
<td>0.071</td>
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<tr>
<td>Cost of the location ($C_2$)</td>
<td>0.087</td>
<td>Cost of construction/purchase/rent of the site (ground) ($SC_3$)</td>
<td>0.087</td>
<td>0.087</td>
</tr>
<tr>
<td>Competition ($C_3$)</td>
<td>0.149</td>
<td>Proximity to branches of competitors ($SC_4$)</td>
<td>0.149</td>
<td>0.149</td>
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<tr>
<td>Transportation ($C_4$)</td>
<td>0.208</td>
<td>Proximity to squares, junctions ($SC_5$)</td>
<td>0.433</td>
<td>0.090</td>
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<td>Proximity to the city center ($SC_6$)</td>
<td>0.567</td>
<td>0.118</td>
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<td>Flexibility ($C_5$)</td>
<td>0.132</td>
<td>Existence of ground for development ($SC_7$)</td>
<td>0.486</td>
<td>0.064</td>
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<td>Facilities for development ($SC_8$)</td>
<td>0.514</td>
<td>0.068</td>
</tr>
<tr>
<td>Access to public facilities ($C_6$)</td>
<td>0.219</td>
<td>Proximity to public parking ($SC_9$)</td>
<td>0.070</td>
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<td>Proximity to market centers ($SC_{10}$)</td>
<td>0.256</td>
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<td>Proximity to hospitals ($SC_{11}$)</td>
<td>0.098</td>
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<td>Proximity to hotels and restaurants ($SC_{12}$)</td>
<td>0.092</td>
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<td>Proximity to local markets ($SC_{13}$)</td>
<td>0.181</td>
<td>0.040</td>
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<td>Proximity to public and private offices and companies ($SC_{14}$)</td>
<td>0.302</td>
<td>0.066</td>
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</table>

3.2 Attaining information layers and assigning weights
Each sub-criterion is required to have an information layer. These data were extracted from commercially available data via ArcGIS application, wherein GPS coordinates of potential locations were inputted, and sub-criteria relevant data extracted. For example, the layer of information about competitors and the layer of information about demographic attributes are presented in figure 2 and 3 respectively.

Figure 2: Competitors information layer
The calculated weights were assigned to layers and different layers of information were combined in ArcGIS software. The hierarchical decision making structure for location problem in this study is depicted in Figure 4. This hierarchy consists of 4 layers which are main goal, 6 criteria, 14 sub-criteria and layers.

After aforementioned analyses in ArcGIS software, 10 potential locations were identified as the top ranked considering the MCDA process. These potential branch locations are illustrated as yellow circle points in Figure 5.

3.3 Selecting optimal points from potential points with a mathematical model
For this case study, it was determined that the limited budget allowed for just two new branches in the city. In order to identify the two optimal locations, the MCLP model required constraints to be set. The Equation (2) states that the demand \( i \) cannot be covered unless at least one branch be established in standard time or distance from it. The Equation (3) specifies the total number of branches which can be established considering the limited budget. The notations of this optimization model are as follows:

- \( i \): Demand points (regions), \( i = 1,2,\ldots,n \)
- \( j \): Potential points (candidates), \( j = 1,2,\ldots,m \)
- \( l \): Set of demand points
- \( L \): Set of potential points (candidates)
- \( P \): Number of new established branches
- \( g_i \): Population in demand point \( i \)
- \( a_{ij} \): \( \begin{cases} 1, & \text{if the established branch in point } j \text{ covers demand region } i \text{ (considering maximum time or standard distance) } \\ 0, & \text{otherwise} \end{cases} \)

Decision variables in this MCLP model are as follows:

\[
x_j = \begin{cases} 1, & \text{if in potential point } j, \text{ a new branch is established } \\ 0, & \text{otherwise} \end{cases}
\]

\[
y_i = \begin{cases} 1, & \text{if the region } i \text{ is covered by at least one branch } \\ 0, & \text{otherwise} \end{cases}
\]

The Optimization model is presented as follows:

Maximize \[
\sum_{i=1}^{n} g_i y_i
\]

subject to

\[
\sum_{j=1}^{m} a_{ij} x_j \geq y_i, \quad i = 1,2,\ldots,n
\]

\[
\sum_{j} x_j = P
\]

where \( x_j \in \{0,1\}, j = 1,2,\ldots,m \) and \( y_i \in \{0,1\}, i = 1,2,\ldots,n \)

With regard to the main roads in the city, the entire city is divided into 19 regions presented in Figure 6.

![Figure 6: Nineteen regions in the city](image-url)

It must be determined that each demand region would be covered by which branch (or branches) \((a_{ij}\) matrix). It is assumed that customers choose the closest branch for receiving service. Table 2 presents the regions that can be covered by each branch and the approximate population of each region \((g_i)\). According to Table 2, for instance, region A is covered by branch number 1 and approximate population of this region is 15000. As another example, region O is covered by branches 7, 8, 10 and 12 and its approximate population is 25000.
Table 2: Covered regions by each branch and population of each region

<table>
<thead>
<tr>
<th>Demand region</th>
<th>Branch location</th>
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<th>Approximate population (in thousands)</th>
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Finally, the mathematical model of maximal coverage is written as follows. Since there are already four branches, i.e., $X_4, X_5, X_{10}, X_{12}$, in the city, the value of $X_i$ are considered equal to one as shown in Equation (25). The LINGO software is utilized to solve this model. Equation (24) represents potential branches. The mathematical model is presented as follows:

\[
\text{Maximize: } 15Y_A + 17Y_B + 10Y_C + 22Y_D + 26Y_E + 18Y_F + 22Y_G + 40Y_H + 35Y_I + 25Y_J + 30Y_K + 40Y_L + 25Y_M + 53Y_N + 25Y_O + 17Y_P + 30Y_Q + 30Y_R + 30Y_S \\
\text{s.t.}
\]

\[
X_1 \geq Y_A \\
X_1 \geq Y_B \\
X_3 \geq Y_C \\
X_2 + X_3 \geq Y_D \\
X_1 + X_2 \geq Y_E \\
X_2 + X_6 \geq Y_F \\
X_2 + X_5 + X_7 \geq Y_G \\
X_3 \geq Y_H \\
X_5 + X_6 + X_{11} \geq Y_I \\
X_3 + X_9 \geq Y_J \\
X_6 + X_7 + X_{12} \geq Y_K \\
X_7 + X_8 + X_{10} + X_{12} \geq Y_L \\
X_{10} + X_{12} \geq Y_M \\
X_9 + X_{11} \geq Y_N \\
X_8 + X_{10} + X_{11} + X_{13} \geq Y_O \\
X_{13} + X_{14} \geq Y_P \\
X_1 + X_2 + X_3 + X_5 + X_6 + X_7 + X_8 + X_{11} + X_{13} + X_{14} = 2 \\
X_4 = X_9 = X_{10} = X_{12} = 1 \quad \text{(24)} \\
X_j = \{0, 1\}, j = 1, 2, ..., 14, Y_i = \{0, 1\}, i = A, B, C, ..., S \quad \text{(25)}
\]
3.4 Results
Results obtained from LINGO software shows that among 10 potential locations to establish new branches, locations $X_1$ and $X_5$ are selected (Figure 6). Table 3 shows that branch locations should be located at points 1, 4, 5, 9, 10 and 12. Branches 1 and 5 are new ($P = 2$) and branches at 4, 9, 10 and 12 points are already existed in the city. It is also resulted that 15 regions (A, B, D, E, H, I, J, K, L, M, N, O, P, Q, R) among 19 regions of the city will be covered after establishing new branches. Six new regions (A, B, D, E, J and K) are covered by establishing 2 new branches at points 1 and 5.

The objective function of the model was to maximize the coverage rate of the bank branches. It resulted from LINGO that the optimal value for objective function is 430. It means 430000 people are covered by establishing 2 new branches at points 1 and 5. It also revealed that having 6 branches in total will cover 15 regions of the total number of 19 regions of the city.

5. Sensitivity Analysis
In this part, we choose different values for $P$ (or the number of branches that can be established (new branches)) to explore the regions and populations which are under coverage. The results of this analysis are presented in Table 4. The total demand in Rasht city is approximated 510000 people and in case of $P = 5$ the whole demand is covered which means if 5 new branches could be set up at points 1, 2, 3, 5, 14 the whole demand of the people would be covered. The demand coverage percentages considering various $P$ values are shown in Table 5. It can be seen that the bank can cover all 19 regions of the city with only 9 bank branches.

<table>
<thead>
<tr>
<th>$P$</th>
<th>Current branches</th>
<th>Current regions covered by bank</th>
<th>Current demand coverage</th>
<th>New branches</th>
<th>New regions covered by bank</th>
<th>New demand coverage</th>
<th>Total demand coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>4, 9, 10,12</td>
<td>H, I, L, M, N, O, P, Q, R</td>
<td>295000</td>
<td>1, 5</td>
<td>A, B, D, E, J, K</td>
<td>135000</td>
<td>430000</td>
</tr>
<tr>
<td>3</td>
<td>4, 9, 10,12</td>
<td>H, I, L, M, N, O, P, Q, R</td>
<td>295000</td>
<td>1, 5, 14</td>
<td>A, B, D, E, J, K, S</td>
<td>165000</td>
<td>460000</td>
</tr>
<tr>
<td>4</td>
<td>4, 9, 10,12</td>
<td>H, I, L, M, N, O, P, Q, R</td>
<td>295000</td>
<td>1, 5, 14, 3</td>
<td>A, B, D, E, J, K, S, F, C</td>
<td>193000</td>
<td>488000</td>
</tr>
<tr>
<td>5</td>
<td>4, 9, 10,12</td>
<td>H, I, L, M, N, O, P, Q, R</td>
<td>295000</td>
<td>1, 5, 14, 3, 2</td>
<td>A, B, D, E, J, K, S, F, C, G</td>
<td>215000</td>
<td>510000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$P$</th>
<th>Current demand coverage percentage</th>
<th>Current number of regions covered by bank</th>
<th>New demand coverage percentage</th>
<th>New number of regions covered by bank</th>
<th>Total number of branches</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>57.84%</td>
<td>9</td>
<td>84.31%</td>
<td>15</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>57.84%</td>
<td>9</td>
<td>90.19%</td>
<td>16</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>57.84%</td>
<td>9</td>
<td>95.69%</td>
<td>18</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>57.84%</td>
<td>9</td>
<td>100%</td>
<td>19</td>
<td>9</td>
</tr>
</tbody>
</table>
6. Conclusions
In this paper, a hybrid model of AHP-GIS-MCLP was proposed to determine optimal locations of new bank branches. This proposed method used AHP to find the weights of criteria and sub-criteria of locating bank branches. Criteria and sub-criteria relevant data were extracted from commercial a GIS application to obtain layers of information for different regions of the city. MCLP optimization model was used to identify optimal locations to establish new branches that maximized the amount of covered demand when there is a budget constraint.

The case study first considered 2 new branches in Rasht city in Iran. The results revealed that establishment of two branches in points 1 and 5 will cover the demand of new regions A, B, D, E, J and K with total population of 135000. It means that in addition to 295000 people who were covered by four previous branches, the aggregated number of 430000 people of the city would be covered by adding 2 new branches.

This decision was revisited via a sensitivity analysis to test the effect of changing the number of new branches to establish the number of regions under coverage and the demand to be covered. For future research, other MCDM methods such as ANP can be used to obtain the weight of criteria and sub-criteria. Furthermore, to solve the optimization problem in large scale problem, the heuristic algorithm such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) can be utilized.

References