

SOFTWARE TOOL FOR MODEL AND SOLVE THE MAXIMUM COVERAGE LOCATION PROBLEM, A CASE STUDY: LOCATIONS POLICE OFFICERS

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ABSTRACT

The location of facilities (antennas, ambulances, police patrols, etc.) has been widely study in the literature. The maximal covering location problem aims at locating the facilities in such positions that maximizes certain notion of coverage. The model of the MCLP and the solutions obtained as a result of applying metaheuristics are difficult to understand for non-expert users in the areas of optimization. In this sense, this paper aims to propose the development of software to model and solve the problem MCLP, as well as data management and visualization of the solutions obtained following the application of metaheuristics algorithms implemented with the BiCIAM framework. For the management of the problem data we used combinations based on GIS.

KEY WORDS: metaheuristics, maximal coverage location problem, GIS.

MSC: 90C70

RESUMEN

La ubicación de instalaciones (antenas, ambulancias, patrullas policiales, etc.) ha sido ampliamente estudiada en la literatura. El problema de localización de máxima cobertura tiene como objetivo ubicar las instalaciones en tales posiciones que maximiza cierto valor de cobertura. El modelo del MCLP y las soluciones obtenidas como resultado de la aplicación de las metaheurísticas son difíciles de entender para los usuarios no expertos en las áreas de optimización. En este sentido, este trabajo tiene como objetivo proponer el desarrollo de software para modelar y resolver el problema MCLP, así como la gestión de datos y la visualización de las soluciones obtenidas tras la aplicación de algoritmos metaheurísticos implementados con el framework BiCIAM. Para la gestión de los datos del problema se utilizan combinaciones de puntos geográficos basados en el Sistema de Información Geográfica (GIS, por sus siglas en inglés).

1. INTRODUCTION

There are now many real situations that can be modeled as optimization problems, among which are known: traveling salesman, transport vehicles routes shorter distance, location of facilities, scheduling and distribution of goods, among others. Many optimization problems identifying the man are strategic factors for the development of any society, so it is very important to implement and modeling [1]. At present, there are many centers offering services to users, from health services and food, to safety. For these centers is very important the location of its facilities to supply their services, and to cover the demand of the users is their top priority [2], therefore, the following problem arises: How do you know where to locate the facility to meet higher demand for services possible? The above problem is modeled as the location problem [2], and between localization issues are coverage problems. Coverage problems have several classifications, including known: Maximal Coverage Location Problem (MCLP) [3] y Set Coverage Location Problem (SCLP) [4]. In both variants a demand is covered if you can cover in a time / predefined distance, an installation [2]. In this paper, we focus on the MCLP.

The MCLP was first presented by Church and ReVelle [3] in 1974 and since then there have been numerous applications and theories about the MCLP model classical [2]. The problem has been studied in numerous works since its first publication and has had more than 1,550 citations in academic literature [5]. The MCLP problem has many applications in production and services, such as: police patrols stations locations [6-8], location and redistribution of ambulances or emergency units [9, 10], cell distribution networks [11, 12], location of public facilities [13], location of mobile sensors [14], location of fire stations [15] and security camera intersection in a traffic urban network [16], among others.

One of the most successful tools for solving optimization problems is the Soft Computing [33]. The components of Soft Computing are fuzzy logic, neural networks, evolutionary computation (metaheuristics

in general) and probabilistic reasoning. The model of MCLP and the solutions obtained such as result of applying metaheuristics are difficult to understand for non-expert users in the areas of optimization. In the Cuban current context they have been identified various areas where this problem can be applied. In this sense, the present work aims to propose a software for modeling, solve and visualize the MCLP data problem using a manager Geographic Information System (GIS) [17] featuring a map through different formats. To model the MCLP as an optimization problem is used the BiCIAM framework and for to solve the problem is used the metaheuristics algorithms available into this framework.

The paper is organized as follows. In Section 1 reviews the literature related to MCLP. In Section 2 we define the problem and the representation used. Section 3 describes the proposed software to model the MCLP, architecture and significant design elements. In Section 4 shows to a detailed case study about locations policing in a patrol area. Finally, we provide the conclusions of this work in Section 5.

2. LITERATURE REVIEW

Since the first publication of MCLP in 1974 by Church and ReVelle [3] this has been studied in numerous works, where there have been different approaches to this variant and applied methods, both exact and approximate. Furthermore, in many cases they have been linked the GIS capabilities with MCLP because the problem data may be geographically represented [5].

In 2009 Li Xia, Ming Xie et al in [18] make a comparative study between the Interchange [19], the Genetic Algorithm [19], Tabu Search [20] and Simulated Annealing [21], where the latter was the best results obtained since it always came to the optimal solution. Berman et al in that year [22] applied the algorithms Tabu search [20], Simulated Annealing [21] and the exact methods of CPLEX tool [23] to a model MCLP with some vectors of negative weight and the best results they were obtained by simulated annealing [21]. Also in [24] in that year Ratick et al make a comparative study between the hierarchical model MCLP proposed in [25] to the location of medical facilities and an application with real data, where the model was extended to include fixed and variable costs for the location and operation of facilities.

Alexandris and Giannikos in 2010 [26] proposed a new model of MCLP with the notion of complementary partial coverage and used a GIS to better represent demand. In the same year Curtin et al [8] variant MCLP applied to determine optimal areas police patrol, in this work the entire programming was applied and with the support of GIS capabilities represented the results. In 2011 Alexandris et al [27] conducted a study on the MCLP applied to the location of military units, which also integrate GIS capabilities to represent the results of the problem, using the ArcGIS manager [28]. In 2012 Azizan et al [29] use data extracted from the OpenStreetMap website MCLP to apply the model to the location of ambulances, integrating these data in ArcGIS manager [28].

In 2013, Zarandí et al [2], propose a solution or dynamic multi-period variant from the model proposed by Church and ReVelle. In solving, the problem used the Simulated Annealing algorithm and commercial tool CPLEX version 12.1, about three instances of the problem that different distributions obtained according to the data. The results of both solutions are compared in terms of the metric time and quality of the best solution found, resulting in instances larger Simulated Annealing in less time obtain a good results, because as it grows the CPLEX problem needs "much time" to reach optimal solutions.

Recently, in 2016 Murray [5] conducted research on the evolution of MCLP since its first definition to the most recent work, where issues concerning the combination of GIS capabilities with MCLP model for better representation addressed the data. Many of the works analyzed using managers GIS, as ArcGIS [28] and TransCAD [30], to display the solutions obtained from MCLP through maps, and from these visualizations have been able to perform different analyzes, depending on the scenario where the problem is being applied. With literature review, it verified that has been increasing interest in creating variants MCLP, and have been used for different applications. However, we have also checked that only few articles have addressed large-scale instances of this problem and none of them has employed hybrid metaheuristics to solve it. In addition, it can be concluded from this research that is not available software to model and solve the MCLP using the potential of GIS.

3. THE MAXIMAL COVERING LOCATION PROBLEM

In the context of location problems, we can find the so called Covering Location Problem (CLP) [3] where the aim is to cover a set of demands bearing in mind different objectives to be optimized. The two most known categories of CLPs are: Maximal Covering Location Problem (MCLP) [3] and Set Covering Location Problem (SCLP) [4]. In both categories a demand is covered if there is a facility located at a time/distance equal or lower than a predefined threshold. SCLP aims at covering all demand nodes with the least possible number of facilities, whereas MCLP aims at covering the maximum possible demand with a known number of facilities. Here we focus on MCLP.

MCLP was first introduced by Church and ReVelle in [3]. The aim of the model is to maximize the coverage of a population with limited resources. The MCLP considers a discrete set of demand nodes and a discrete set of nodes where facilities can be located. Each node has an associated demand, representing its level of importance, and some nodes can remain uncovered. The objective of the MCLP is to find the best location for a number p of facilities in order to maximize coverage of the demand.

The parameters and variables that define the MCLP are:

- i, I : the index and set of demand nodes.
- j, J : the index and set of eligible facility locations.
- a_i : population or demand for the node i .
- d_{ij} : the shortest distance (or time) from demand node i to the facility j .
- p : number of facilities to be located.
- S : coverage distance. It is the minimum distance (or time) between a demand node and facility to be considered as covered.
- $N_i: \{j | d_{ij} \leq S\}$ set of potential facilities that can cover the demand generated in i .
- $X_j: \{0; 1\}$ a binary variable which equals 1 if the facility is placed at node j , 0 otherwise.
- $Y_i: \{0; 1\}$ a binary variable which equals 1 if the demand node i is covered by one or more facilities located within a distance of S , 0 otherwise.

The objective function of the problem is defined as:

$$\text{Maximize } Z = \sum_{i=1}^I a_i Y_i \quad (1)$$

Subject to:

$$Y_i \leq \sum_{j \in N_i} X_j \quad i \in I \quad (2)$$

$$\sum_{j \in J} X_j = p \quad (3)$$

Constraint 2 states that a demand node is covered only when one or more facilities are located within a distance S from this node. Constraint 3 ensures that the number of facilities to be located is p .

The Figure 1 shows an example of solution, which is a binary string where the amount of 1 matches the number of facilities open. You can see how the facilities opened are the following nodes: 1, 3, 6, 7 and 8, where $p = 5$.

Facilities								
node 1	node 2	node 3	node 4	node 5	node 6	node 7	node 8	node 9
1	0	1	0	0	1	1	1	0

Figure 1: Representation of a solution. A '1' appears if the facility is available. In this example $p = 5$.

4. SOFTWARE FOR MCLP MODELING: MCLP-TOOLS

In the following section, the top-level design or architectural design and the proposed software to solve the MCLP model presented. It aims to describe the structure of software at a high level of abstraction, main pieces that make up, relationships and forms of interaction, with special emphasis on its subcomponents and design decisions made for each of them.

4.1 Architecture Overview

The layered structure diagram is a tool that contains the packages, subsystems and interfaces that make up the architecture structured in layers, with different levels depending on the functionality. The software architecture proposed MCLP-Tools shown in Figure 2, and is based on the reuse approach [31].

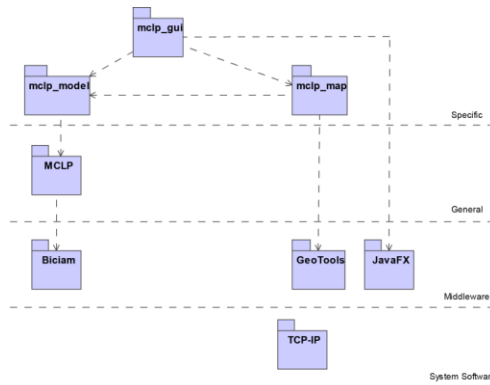


Figure 2: View software architecture, using the approach of reuse.

The architecture is structured in four layers. Specific layer contains packages that are specific to the software: interfaces and data management and maps, in the General layer contain package reusable and the implementation of the problem MCLP. The Middleware layer has class libraries used by the software and the system software layer, contain the software need and available on the Operative System.

4.2 Significant elements of the design and implementation of software

For the design of this software exist several technologies available, and manageable in Java environments, were taken into account to produce good quality and flexibility in implementation. For the implementation of MCLP problem and to solve the problem, the available algorithms used in BiCIAM [32]. The GeoTools library [33] was used to make use of GIS, which provides management and manipulation of the maps are essential for data visualization and problem solutions MCLP. For the design of graphical interfaces visual the components that provides the JavaFX library [32], which improves the visual quality of the windows and contains dynamic elements that make using the software were used.

4.3 MCLP-Tools software

MCLP-tools software is divides into two main modules: data management and the module experimenting with metaheuristics algorithms, automatically or manually, respectively. From the main screen of the application, you have access to these two modules.

4.3.1 Data management module

Then shows the data management module. Nodes demands and facilities inserted pointing on the map and filling in the blanks corresponding to your data, and then displayed on the map and in the table, since that table may choose a facility or demand to be modified or remove. The display in question is shown below in Figure 3.

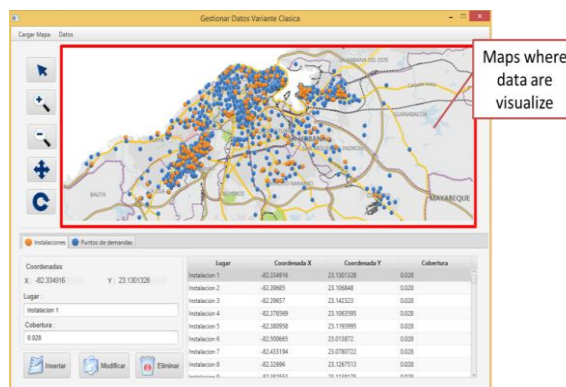


Figure 3: Screen to manage the data of the problem.

We can see that the display of data across the map, which is of vital importance for better understanding of the actual locations of facilities and nodes demands. This window enables saving and loading data of the

problem through an XML file, so the user may have stored multiple instances of the problem with which you can later make experiments.

4.3.2 Experimentation module

In the experimental software module, which has two main interfaces developed. The first interface is the Automatic Experimentation, which allows loading of data using an XML file, and then solves the problem by running of the Algorithm Portfolio [33] with 50 000 iterations. Then in Figure 5 shows where the solution of MCLP through the map, where blue lines related an active node facility with the demand node that covers. Furthermore, this solution obtained can be stored in an XML file.

The second interface is the Manual Experimentation, shown in Figure 5, which allows you to run several algorithms on the problem on user request, and set up its parameters. First data is loaded and the parameters of the available algorithms to configured. After the execution of the selected algorithms, solutions obtained shown in a table. If a solution of the table selected then displayed on the map. These solutions can be stored in an XML file.

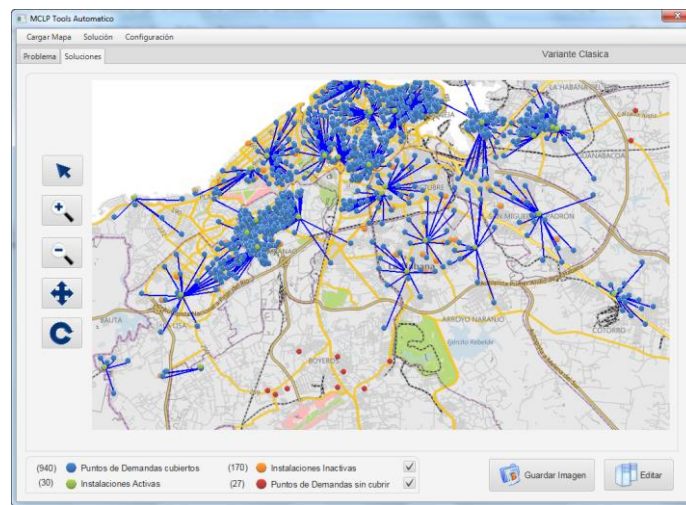


Figure 4: MCLP solution into window Automatic Experimentation

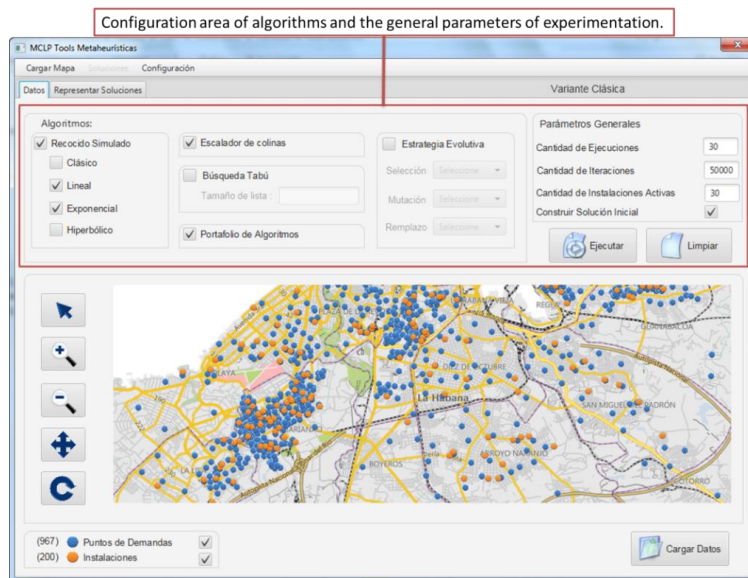


Figure 5: Set parameters and algorithms in manual experimentation

5. EXPERIMENTAL STUDY

The aim of this experimental study is firstly to measure the performance of the proposed algorithms in the software, to determine which of them has offered the best results on multiple instances of MCLP, based on

the quality of the solutions obtained. After this experiment, we analyze the application of MCLP-Tools software to a case study provided between fundamental applications of the problem MCLP.

For all experiments, we use the algorithm portfolio. In this work, the algorithm portfolio is composed by four methods. Concretely, by three Simulated Annealing methods proposed in [2], because of their good performance in this problem, and by an Evolutionary Algorithm to provide a higher diversity to the portfolio.

5.1 Case Study: Locations policemen in a patrol area

The case study: Locations police officers in a patrol area describe the procedure for distributing the police to ensure the greatest possible security in a given area. The main function of these police is to monitor areas of the city presenting the greatest crime rate or other characteristic of specific interest that need to give special priority.

For the analysis of the case study it is proposed a set of dummy data where the coordinates of the points were randomly generated, using the range of X and Y coordinates belonging to the area of Havana. These data set areas of interest, generated randomly over the same area where they were generated locations police officers. The interest level or level of importance (demand of the nodes) of each area ranges from three values: 20 (low), 50 (medium) and 100 (high). The data set consists of 522 possible locations of police (facilities) and 300 areas of interest (demand node). We analyzed for generating the locations of police that they could be located anywhere on a street. Therefore, since the model MCLP need to know the location of the facilities, we decided that the locations of police would be coincident with the intersections points between the streets.

The selected algorithm for the solution of MCLP model applied to data set of case study is the Algorithms Portfolio, with one execution with 50,000 iterations, with the same configuration parameters algorithms described in the previous section.

5.2 Analysis of results

We decided to do two experiments with two radii of coverage. The Table 1 describes in detail the experiments to be performed to analyze the case study.

Table 1: Description of the instances for the case study.

Experiments	Distance to be covered (in degrees)	Number of police available		
		Scenario 1	Scenario 2	Scenario 3
1	0.001	20	40	60
2	0.0015	20	40	60

Then, Table 2 shown the percentages of coverage over the areas of interest that obtained by applying the Algorithms Portfolio on the data of case study.

Table 2: Percentage of coverage over areas of interest.

Experiments	Percentage of coverage over areas of interest		
	Scenario 1	Scenario 2	Scenario 3
1	41,42	68,89	85,97
2	66,36	96,62	100

As we can see, for this data set, the number of police that may be placed for to have 100% surveillance over the areas of interest is 60, with a distance of 0.0015 degrees coverage. For more than 50% may be placed 40 cops with the smallest distance analyzed, 0.001 degrees. These analyzes also allow to determine what amounts of police should patrol to cover a certain percentage of surveillance.

Then the display of several of these experiments shown on the map for analysis on these results. In Figure 6 shown the result of Experiment 1 in Scenario 1.

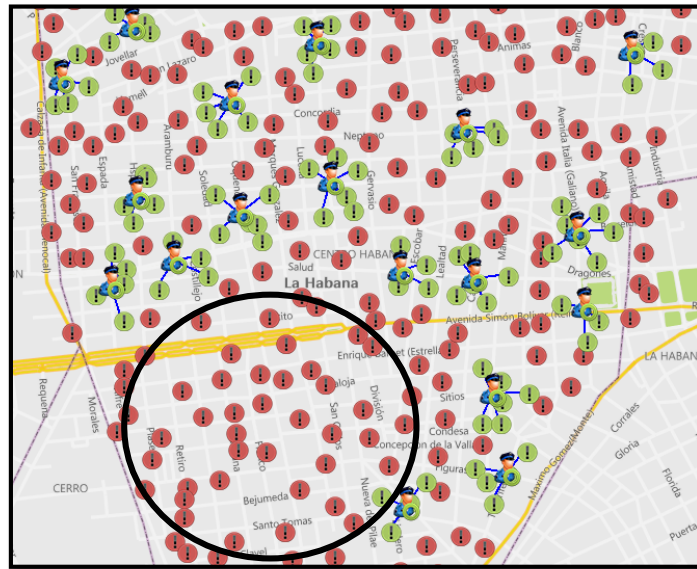


Figure 6: Display solution for Experiment 1 in Scenario 1.

From this result, you can make the following analysis:

- We can know the 20 places of more interest.
- In the selected area not is police located. This is because in that area there are very few points with a high interest level, whether it is very important to watch these points its crime levels can be modified and guide the metaheuristic for to place police in that area.
- You can also consider increasing the distance; they can cover the police to have greater coverage of the areas.

Taking into account this latest analysis, in is shown the result of Experiment 2 in Scenario 1, where, with the same number of police like the previous example, has increased the distance they can cover a police.

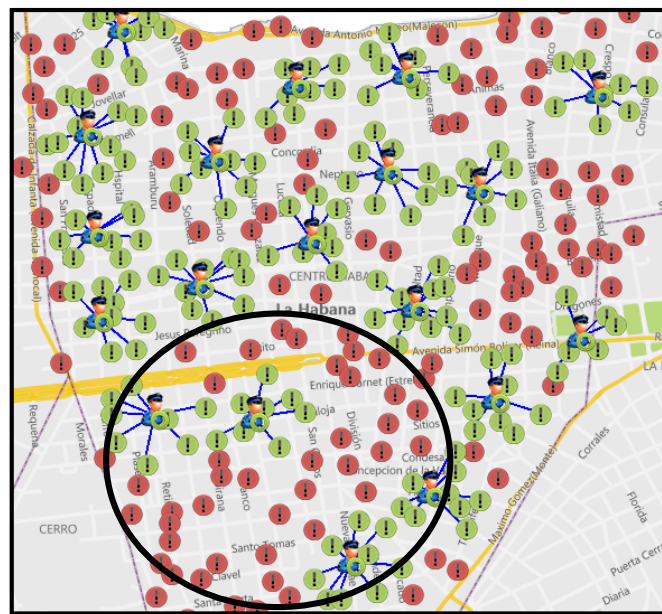


Figure 7: Display solution for Experiment 2 in Scenario 1.

From this result, you can make the following analysis:

- In the selected area that was not under surveillance by any police in Figure 6, now three police officers were located. Therefore, one can conclude that it is very important to correctly define the distance to be covered by the police for this case study, when there not is a greater availability of police to locate.
- With this change, for Experiment 2, the percentage of watched over the areas increases more than 20% compared to Experiment 1.

In general, we can to conclude:

- In both experiments, mainly in two, the police should give surveillance over many interest areas regardless of their interesting level. Therefore, the ability of police to monitor an area might be a parameter to consider in this case study.
- In the latter case, where there is a 100% coverage would be very useful to determine the minimum number of police needed to achieve this result.
- The display of model results MCLP using GIS capabilities, allows to do different analyzes related to this case study: criminal behavior in the area and places where there are more interest level, among other analyzes.

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6. CONCLUSION

In this paper, we present MCLP-Tools software to model and solve the MCLP using BiCIAM, also for to visualize your data using a GIS manager: Geotools. The software contains features that offer different ways to solve the MCLP using metaheuristics algorithms. Through the analysis of the case study we proposed apply the software to a real scenario, showing that the new proposal allows identification more than easy of application areas in the Cuban sectors. Using GIS capabilities in visualizing data MCLP and experimentation with metaheuristics through visual interfaces is improved user interaction with the model MCLP.

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