Towards a Web-Based Spatial Decision Support System for the Multiple Capacitated Facility Location Problem

Nikolaos Ploskas[1], Jason Papathanasiou[2], Nikolaos Samaras[1]

[1] Department of Applied Informatics, School of Information Sciences, University of Macedonia, 156 Egnatia Str., 54006 Thessaloniki, Greece
[2] Department of Business Administration, School of Business Administration, University of Macedonia, 156 Egnatia Str., 54006 Thessaloniki, Greece
{ploskas, jasonp, samaras}@uom.gr

Abstract. The Multiple Capacitated Facility Location Problem (MCFLP) is a well-known and studied in the international literature optimization problem. A web-based Decision Support System (DSS) for this problem is being implemented. The geographical information data of the enterprises' locations are usually either ignored by the modeler or entered manually in these systems. In this paper, we integrate geographical data in the DSS for the MCFLP. The location of the enterprises can be added with the use of interactive maps. The DSS extracts the geographical information of the selected locations and executes a dynamic approximation algorithm for this problem. The web-based spatial DSS (WSDSS) has been implemented using jsp and Google Maps API; the system is still under development, but initial results are promising.

Keywords: Decision Support System, Capacitated Facility Location Problem, Geographical Information System, Location Allocation Problem.

1 Introduction

The facility location (or location-allocation) problem is a well-known operations research problem. The problem consists of a number of enterprises that attempt to find the best location in a specific area in order to install their new facilities while on the same time a number of already established similar facilities exist with known locations [1 – 2]. New enterprises seek the best location from a set of candidate locations in order to maximize their share and revenue in the specific market. The new enterprises cooperate with each other in order to avoid any overlapping between the market segments they will serve. The facility location problem has many practical applications in different fields [3 – 6].

The international research community offered many variants and extensions of the problem over the years; in this paper, we consider a particular type of the problem, called the Multiple Capacitated Facility Location Problem (MCFLP). In this version of the problem, the market requires a specific quantity/level of a product/service in a determined time period. A set of existing enterprises operate in a specific market producing/offering certain products/services. A set of new cooperating enterprises aim to enter the market and seek the best location from the available candidate locations. The goal of the new enterprises is to obtain the largest possible share of the specific, saturated by the present supply, market by avoiding on the same time any overlapping between the market segments that they will serve. The enterprises should be economically viable in order to enter the market. As such, the production of a new enterprise should be higher than a specified sales threshold level [7]. Existing enterprises should also ensure to be economically viable; if they fail to reach their production thresholds after the entering of the new enterprises, they will be taken off the map [8].

Only few software packages exist for the solution of this problem exclusively. The geographical information of the enterprises' locations are usually either ignored or entered manually in these systems. Geographical information systems (GIS) can assist decision makers to analyze spatial information. GIS technologies have attracted significant attention from researchers. There are a few papers proposed integration of GIS technologies on DSS for location problems [9 – 10]. Google Maps API provides access to read data associated with roads and supplies travel times for each road based on the speed limits. The Google Maps API is a promising technology for implementing a web-based DSS for the facility location problem.

This paper is an extension of the work of Papathanasiou et al. [11], in which we presented a web-based DSS that can assist policy makers find the best locations for their enterprises. Two algorithms were integrated in the DSS: (i) an algorithm that finds the exact solution of the problem so long as this exists, and (ii) a dynamic approximation algorithm that can calculate an approximation solution in an acceptable time interval. These algorithms have been proposed by Papathanasiou and Manos [12]. The innovation of this paper is that we integrate geographical information data in the DSS for the MCLP. The coordinates of the locations are not entered manually in imaginary vague market, but they are added with the use of an interactive map. Then, the DSS extracts the coordinates of these locations and builds a market surface, which is simulated by a network with existing facilities nodes, demand nodes and candidate nodes. The DSS was implemented using jsp and Google Maps API and is still under heavy development and testing.

2 Model Specification and Algorithms

The mathematical form of the problem described in Section 1 can be formulated as follows [11]:

$$\max \sum_i \sum_p DP_{ip} X_i \tag{1}$$

or

$$\max \sum_i \sum_p aDP_{ip} Q_{ip} X_i \tag{2}$$

s.t.

$$DP_{ip\min} \le DP_{ip} \le DP_{ip\max} \tag{3}$$

$$\sum_i X_i = P \quad (4)$$

$$Y_{ij} - X_i \leq 0 \quad (5)$$

$$X_i = 0,1 \quad (6)$$

$$Y_{ij} = 0,1 \quad (7)$$

$$UP_{ij} = 0,1 \quad (8)$$

$$UM_{mj} = 0,1 \quad (9)$$

$$\sum_p DP_{ip} = \sum_p \sum_i \sum_j H_{ij}^p Y_{ij} UP_{ij} \quad (10)$$

where:

|P|: the cardinality number of new enterprises

$p_n \in P = \{p_1, p_2, ..., p_k\}, n = 1, 2, ..., k$

|M|: the cardinality number of existing enterprises

$m_f \in M = \{m_1, m_2, ..., m_k\}, f = 1, 2, ..., h$

|I|: the cardinality number of candidate nodes of new enterprises

$i_s \in I = \{i_1, i_2, ..., i_q\}, s = 1, 2, ..., q$

|J|: the cardinality number of demand nodes

$j_r \in J = \{j_1, j_2, ..., j_b\}, r = 1, 2, ..., b$

T: the time within which the market demands a specific quantity of the product in question

DP_{ip}: the production capacity in time T of the new enterprise p established in node i

DP_{ipmax}: the maximum production capacity in time T of the new enterprise p established in node i

DP_{ipmin}: the minimum acceptable production capacity in time T of the new enterprise p established in node i

DM_m: the production capacity in time T of the existing enterprise m

DM_{mmax}: the maximum production capacity in time T of the existing enterprise m

DM_{mmin}: the minimum acceptable production capacity in time T of the existing enterprise m

H_j: demand in demand node j

HP_{ij}^p : the fraction of demand in node j, which is serviced by node i where the new enterprise p has been located

HM_{mj}: the fraction of demand in node j where the existing enterprise m has been located

S_{pi}: the range of new enterprise p in node i and in time T (distance units)

S_m: the range of existing enterprise m in time T (distance units)

Q_{ip}: the production cost of new enterprise p in node i.

Q_m: the production cost of existing enterprise m.

a: the profit percentage.

The total number of nodes of the network is |I|+|J|+|M|. Objective functions (1) and (2) refers to the maximization of the product that was produced, in the event that the cooperating enterprises choose the aggressive and the conservative tactic, respectively.

Constraint (3) refers to the range of prices which the quantity of production can obtain for each p_n within the given time T, while constraint (4) requires that precise |P| enterprises are established. Constraint (5) allows the service only from nodes where units have been established and constraints (6) – (9) require that the these variables are integers to the values of zero and one. Finally, constraint (10) shows that each new enterprise's entire production is consumed; otherwise surplus stock of unsold products will be created.

The multiple capacitated facility location problem is NP-hard [13] and the algorithms that have been proposed to find the optimal solution use the Lagrangean relaxation method as the core technique or transportation simplex method. Hence, the execution time of an exact algorithm is prohibited for inclusion in a web-based spatial DSS.

For the solution of the above model, two algorithms are used in this paper [11]: (i) an algorithm that finds the exact solution of the problem so long as this exists, and (ii) a dynamic approximation algorithm that can calculate an approximation solution in an acceptable time interval (for a more detailed description, see [11 – 12]).

3 Integrating Geographical Information Systems

The locations of the candidate nodes are usually entered manually. Many DSS for the facility location problem simulate the market segment as a graph and the distances between the nodes are not always corresponding to the real situation. The DSS that we presented in [10] used the same rationale (Fig. 1). The main aim of this paper is to discuss implementation issues of a web based Spatial DSS that uses freely available Google Maps to integrate GIS technologies on the MCFLP.

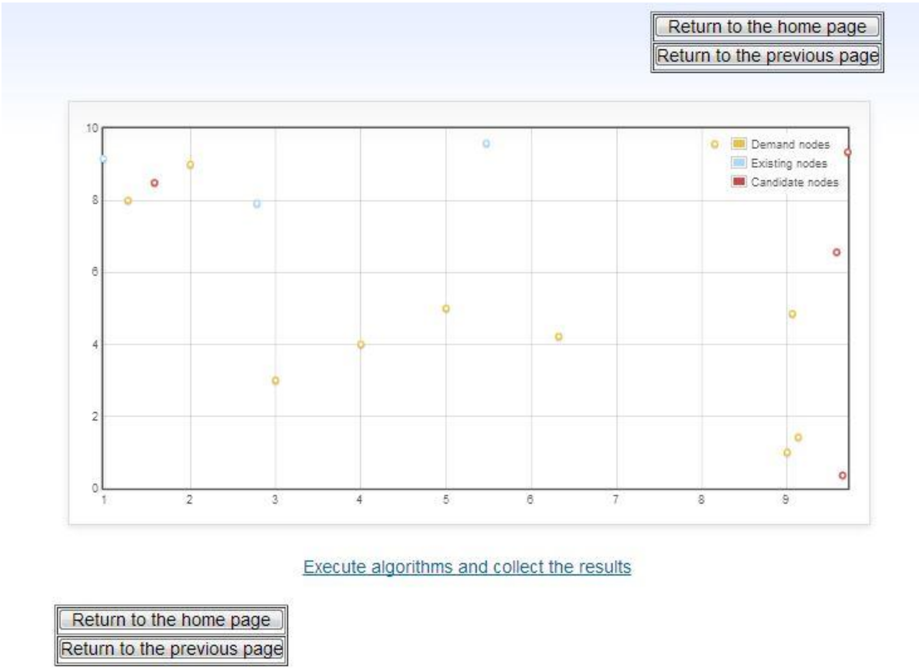

Fig. 1. Market Representation for the MCFLP

In Fig. 1, a visual representation of the WSDSS in terms of a flow chart is represented. Initially, the decision maker selects the locations of the candidate nodes and the existing enterprises via an interactive Google Map. The locations of the candidate nodes are added interactively in a Google Map, as shown in Fig. 3. Then, the other parameters of the model can be entered though user-friendly interactive forms. In the next step, the algorithms are executed and a solution is constructed. If a solution is found, then it is visually displayed through the use of a Google Map instance.

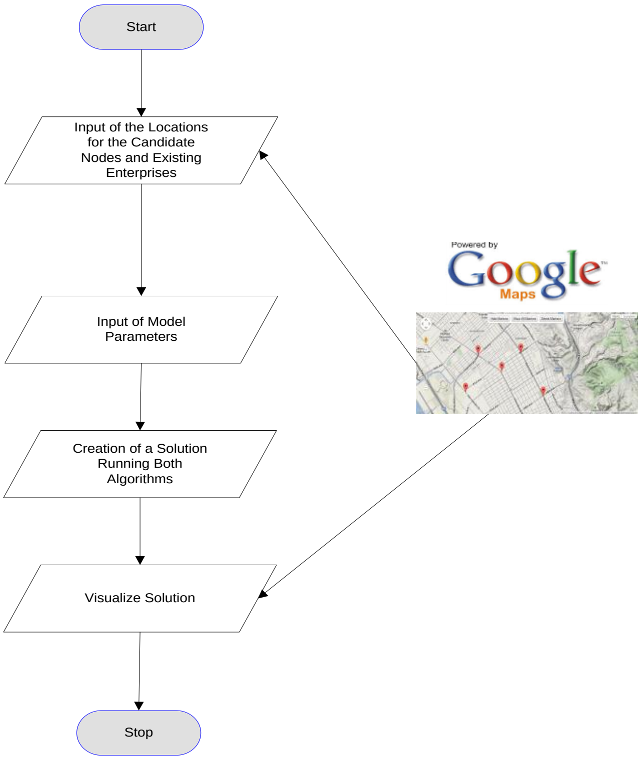

Fig. 2. Flow Chart of the WSDSS

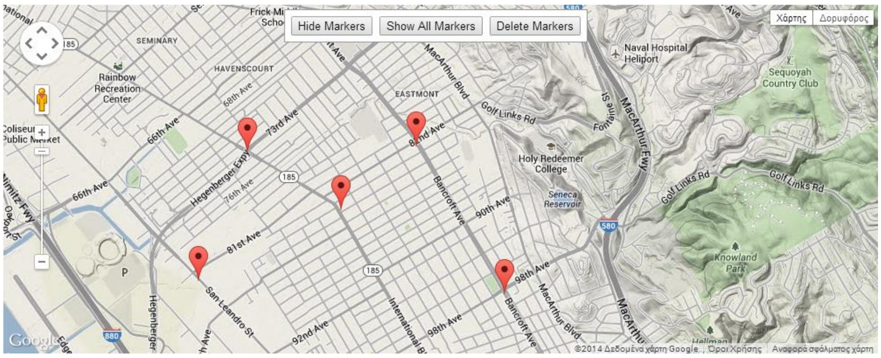

Fig. 3. Adding Locations of the Candidate Nodes via an Interactive Map

4 Conclusions

The MCFLP is a well-known operations research problem with many practical applications. GIS technologies have not yet been integrated extensively on web-based DSS for this specific problem. In this paper, we discuss implementation issues for integrating GIS technologies on a web-based spatial DSS still under development. The decision maker can easily add the candidate locations through an interactive Google Map. Then, the DSS can export the geographical coordinates and the time distances from the specified locations and execute the optimization algorithms.

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