2001

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An integrated spatial DSS for site selection for service organizations in developing countries

Integrating GIS and gravity models to determine locations for post offices

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ABSTRACT

An Integrated Spatial Decision Support System (ISDSS) is developed for finding locations where people can access post offices with minimum travel time between their residences and the post offices and their next destinations. Location-allocation models may be used to determine sites for these transshipment nodes. Due to the nature of traffic and unstructured zoning and all other non-predictable variables, network models may not be applied to find the optimal solution. Instead a gravity model is used to find a solution, which both minimizes the number of post offices and minimizes before-and-after travel times. The result of this system is a pattern of post offices, which can gravitate more people to these sites. A DSS is designed which utilizes GIS (ArcInfo) and Oracle DBMS to attain a flexible interactive solution with What-If and Goal seeking capabilities.

INTRODUCTION

Location-allocation models are typically used to determine optimal site locations for service industries. These models, depending on the nature of the problems, are sometimes deterministic and in some cases probabilistic. These models give users optimum or good locations for providing services to customers. In this research a variant of Gravity model is used to get a good solution.

At present there are few post offices that offer a full and comprehensive range of services (some services are offered while there are other services that are not offered in some centers). Therefore, the clients of these offices have to go to several locations if they have several needs and this causes uncontrollable traffic, increases the cost, and minimizes the clients' convenience.
A possible approach to solving this problem is to use deterministic location allocation models to find the optimum location and allocate the size of the site to accommodate the clients. However, due to the nature of traffic and unstructured zoning and the spatial nature of the problem and the behavioral nature of customers, a deterministic approach might not generate the best result. So we use a gravity model to find the best locality. We also design an integrated DSS that uses ArcInfo (a GIS tool) and Oracle DBMS to solve this problem which can be generalized to all service-providing organizations.

**PROBLEM DEFINITION AND SOLUTION CRITERIA**

The task of determining the number of post offices needed and selecting the right locations is crucial to an efficient operation. There are two opposing driving forces that exert an influence on the optimal number of sites. On one hand, cost control calls for minimizing the number of sites. The investment outlays and operating costs are inversely proportionate to the number of sites. On the other hand, the optimal service provision and the reduction of before-and-after travel time by clients call for maximizing the number of sites.

The task is thus to determine the optimal number of sites and their optimal locations. At the same time, the following principles have to be taken into account:

1. An optimal balance should be found between minimizing the number of sites, minimizing the amount of kilometers traveled, and maximizing the number of users to be served.
2. The areas served by the sites should cover the entire city of Tehran offices.
3. The prospective sites for the new post offices are tied to the locations of existing post offices.
4. The service radius of a post office is limited to N km.

Due to the special nature of the problem it was found that complex spatial models provide more insight, and they are easier to manipulate and apply when they are entered into a geographical information system (GIS). The spatial dimension of reality is explicitly modeled in a GIS. Spatial data, such as neighborhoods and roads, consist of location data (x-y coordinates) and thematic data (such as average speed on a road segment or number of residents of a neighborhood) and attenuation factors (such as dead end road and natural barrier, e.g., rivers, etc.).

These data are stored in conjunction and can be depicted on maps. The most critical advantage is that a GIS contains many analytical tools with which the spatial data can be manipulated. The GIS package ArcInfo has numerous powerful functions.

A valuable functionality of GIS is the possibility to relate spatial models with dissimilar spatial data. For instance, in this study, post office locations, number of residents of a neighborhood, and roads are integrated conjointly in the models. The transparency that many GIS models provide for the users is one of the reasons why such a model can be formulated as a decision support system (DSS). One of the main characteristics of a DSS is that it allows the input of
knowledge and expertise by the person making the decision. In this way, objective models are combined with subjective valuations to create useful information that can support the decision-making process. To make the system interactive and dynamic, all data were stored in a database. The Oracle DBMS was used and integrated with GIS to provide the data needed in the Model section of the system.

HISTORICAL BACKGROUND

The SDSS concept has evolved in parallel with DSS. The development of SDSS has been associated with the need to expand the GIS capabilities for tackling complex, ill-defined, spatial decision problems (Densham & Goodchild, 1989; Malczewski, 1997).

There has been considerable growth in research, development, and applications of SDSS in the last 10 years or so (NCGIA, 1990, 1996).

The field has now grown to the point that it is made up of many threads with different, but related names, such as collaborative SDSS, group SDSS, environmental DSS, spatial knowledge based and expert systems (Malczewski, 1997).

A GIS has various analytical functions that can help in the selection of centers. A survey of literature revealed that a variety of spatial DSS and GIS are being used in location-allocation problems (Hillsman, 1984; Jong, Ritsema van Eck, Toppen, 1991; Maat & Visser, 1996).

An easy way to gain insight into the potential of various locations is the so-called circle theory. This is the method used by the Dutch Railways to determine where to put stations. This theory is based on the assumption that the passenger potential is determined by the number of people living in an area and by the distance to the station. As the number of people living in an area around a station increases, the higher the passenger potential will be. The greater the distance to the station, the smaller the passenger potential. This method is easy to apply by using buffer analysis.

But this method is also flawed. It is assumed that passengers are evenly distributed in all directions. And it is assumed that the road connections are equally good in all directions. In fact, both assumptions are seldom true.

With GIS, however, it is also possible to take account of the road network and the distribution of inhabitants in the area. To that end, for each point of origin (terminal), we calculate the sum total of destination points within a previously defined distance across the network. Meanwhile, we add up the number of residents. Jong et al. (1991) programmed this "proximity count" in the GIS package known as Genamap. In ArcInfo, this method can be applied with the aid of ALLOCATE.

Like the circle method, the proximity count gives insight in the gradient from good to bad locations, as judged from the perspective of concentrations of clients. But this does not mean that the selection of good locations will always lead to an optimal distribution of terminals. The reason is that a number of good locations may be close to each other, while elsewhere large unserved areas may arise.
GRAVITATIONAL LOCATION-ALLOCATION MODELS

We previously identified the main criteria for the selection of post office locations. The selection entails finding an optimum between minimizing the number of locations and minimizing before and after travel time while retaining the virtually complete coverage of the area under study. A family of models that support that selection procedure is known as location-allocation models. These have recently been incorporated in ArcInfo under the name LOCATEALLOCATE.

Location-allocation models are developed to find the optimal location of services such that the service provided will be accessible to the users in the most efficient way possible. The models optimize the relation between the potential services (location) and the users assigned to it (allocation).

In ArcInfo, the family of location-allocation models consists of three types. Each one is designed to optimize the location of facilities on the basis of a given criterion. The optimization may concern the minimization of the number of transport kilometers, the maximization of the number of users, or the optimal coverage of the area within a specified maximum distance.

In the context of this study, the most significant criterion is minimization of the travel time. The MINDISTANCE model determines the location of a given number of terminals in such a manner that the total weighted distance traveled is minimized.

Starting at each site, the distance to all areas (hexagons) is calculated along the shortest (or fastest) route. Then, each hexagon is linked to the closest potential location for a site. With the help of the weighted distance — that is, distance multiplied by the number of residents — an attempt is made to find the optimal set of site locations.

The process works as follows. The algorithm takes a "starting solution" as its point of departure. It subsequently runs a routine over and over again. At every pass through this continuous loop, one location is eliminated, namely the location that gravitates the least number of people (generates the smallest increase in the total weighted distance). The one that causes the greatest reduction in the total weighted distance replaces the eliminated location. The substitution process continues until no further reduction in the total weighted distance is possible.

The algorithm applied here is a so-called heuristic. Algorithms of this type work according to logical assumptions and experiential observations. A heuristic only examines the most promising locations and combinations. In this way, the calculations can be performed much faster than would be possible with an analytical model. It cannot be proven that the solutions found through a heuristic are actually the most optimal ones. Nevertheless, they do come very close to the optimum.

The aim of "minimizing travel time" is considered to be the most important criterion. Nevertheless, it is instructive to calculate two other desirable measures as well. These are "maximizing the number of users" and "optimal coverage of the area with a minimum number of post offices."

The MAXATTEND model is employed to situate the post office close to the population
concentrations (gravity model). In this model, client density takes priority over distance reduction. The model seeks the desired density of its clientele within a given radius (20 km). In doing so, the model assumes that the chance of interaction between sites and clients declines in a linear fashion as the distance increases. For that reason, the MAXATTEND model would be preferable in calculating where to build post offices.

The MAXCOVER model is employed to maximize the number of inhabitants living within a given radius (here too, set at 20 km). This does not require identifying the population concentrations first; it only entails trying to allocate as many residents as possible. The model is mainly of interest when it is not possible to build enough sites to cover the entire area within a radius of 20 km. The aim then becomes to reach as many clients as possible with the limited means available.

IMPLEMENTATION ISSUES

In implementing the DSS, the following issues were considered. In DSS applications the focus of the decision maker is on the decision being made. The output from the DSS is of interest only to the extent that it facilitates decision making. The DSS user wants to make use of the DSS to explore aspects of the decision. In order to do this it should not be necessary for the user to go through long sequences of commands, to enable data move between different models of the system. It is central to the design of DSS that the modeling routines can automatically extract the relevant data from the database component of the system. In a DSS the user should only need to intervene in the system to control the modeling process, not to conduct the basic operations needed for modeling. In a SDSS the models must be able to make use of the spatial database tools as appropriate. This requires that the SDSS be built with modeling tools that allow the model designer access to the database and interface components of the SDSS. In order to be used as a DSS generator, GIS software must allow easy automatic interchange of data between the GIS modules and modeling techniques operating on non-spatial elements of the data. This may entail a departure from traditional assumptions in GIS design of the user operating the system by direct manipulation of interface commands. If it is to be used as a SDSS generator then GIS software must make interface commands. If it is to be used as a SDSS generator then GIS software must make data available in a format that is appropriate for modeling techniques drawn from other disciplines. For example many types of models require that roads be modeled as a network, in the mathematical sense. GIS software may not represent roads in this way. Even where roads can be represented as networks in a GIS the network layer may not be fully integrated with the other spatial data in the problem. This lack of integration hinders comprehensive use of GIS as a SDSS generator for network based problems.

The DDM Paradigm

- the technology for a DSS must consist of three sets of capabilities in the areas of dialog, data, and modeling (Sprague & Watson, 1996).
- a well designed SDSS should have balance among the three capabilities.
The Components and Functions of IDSS

1. The DBMS Module (Spatial and Non-Spatial Data). For this module Oracle was used to manage the database. We are also in the process of implementing a Federated or Multi-Database Schema to accommodate the data capturing from several different databases. In the current version we create a heterogeneous database for the problem. With the new database approach there is no need to create a new database for the system. Current existing databases could be used instead.

2. The MBMS Module (Models). ArcInfo Modeling Capabilities were used to Model the locations. However, since the gravity model is not supported, an iterative model was used in conjunction with the DBMS Module through Spatial Data Base Engine.

3. The Dialog Management

3.1 User Interface Module (Interface)--ArcoInfo was used for user communicated report and a program was written for non-interactive updating of the data base and model iterations.

3.2 The Data Access Tool--First version of the data access tool was written in C++ to create an interface between the Oracle DBMS and ArcInfo through ODBC. The new version is going to be implemented using ESRI's and SDE module.

The Functions of ISDSS Components

<table>
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<tr>
<th>Components</th>
<th>Functions</th>
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<tbody>
<tr>
<td>Data Base Management (ORACLE DBMS)</td>
<td>manage the <em>geographic data base</em>;</td>
</tr>
<tr>
<td>Model Base Management (Gravity Model)</td>
<td>manage the <em>model base</em>;</td>
</tr>
<tr>
<td>Dialog Management</td>
<td>manage the interface between the user and the rest of the system.</td>
</tr>
<tr>
<td></td>
<td>• <em>User Interface</em></td>
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SUMMARY AND CONCLUSIONS

An Integrated Spatial DSS (ISDSS) which uses gravity location-allocation model has been developed to determine the optimal (good) location for post offices in a developing country. The optimum (good) is the point at which a service is made available to the users in the most efficient manner possible. The models optimize the relation between the potential services (location) and the identification of the users (allocation).

In ISDSS applications the focus of the decision maker is on selecting the right location decision being made). In this system the Model automatically extracts the relevant data from the database component of the system. This requires that the ISDSS be built with an interface tool that facilitates the interaction of MBMS and DBMS and allows the model designer access to the database and model base components of the ISDSS.

REFERENCE


NCGIA. (1996). Report from the specialist meeting on collaborative spatial decision making, Initiative 17, National Center for Geographic Information Analysis, UC Santa Barbara, September 17-21, 1995.
