Developing Shape Analysis Tools To Assist Complex Spatial Decision Making (U)

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DEVELOPING SHAPE ANALYSIS TOOLS TO ASSIST COMPLEX SPATIAL DECISION MAKING

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ABSTRACT

The objective of this research was to develop and implement a shape identification measure within a geographic information system (GIS), specifically one that incorporates analytical modeling for site location planning. The application that was developed incorporated a location model within a raster-based GIS, which helped address critical performance issues for the decision support system. Binary matrices, which approximate the object's geometrical form, are passed over the grided data structure and allow identification of irregular and regularly shaped objects. Lastly, the issue of shape rotation is addressed and is resolved by constructing unique matrices corresponding to the object s orientation.

KEY WORDS: spatial decision support systems, shape analysis, cartographic modeling, land use planning, geo-analytical algorithms

INTRODUCTION

The task of finding a suitable location for businesses, goods and services, utilities, and other facilities is an issue that is faced by both government and commercial real estate planners. Poorly made locational decisions can often be attributed to several factors, most common of which is uninformed land use planning (O'Hare, et al., 1983). This locational decision making process may be organized and structured utilizing recent advances in geographic information systems (GIS) theory, in particular that of spatial decision support systems (Densham, 1991).

The research reported here includes the design, prototyping, evaluation, refinement, and implementation of a user-friendly site selection system for use by research scientists and land-use planners at the Savannah River Site (SRS). In addition, a unique and innovative function was built into the system to allow the user to automatically search for potential locations that require specific shape criteria (e.g., a facility's footprint). Shape analysis methods have been discussed in the literature, however most pertain to analysis of existing shapes (Davis, 1986; Moellering and Rayner, 1982). The unique type of shape analysis that was applicable in this research involves searching for locations where a particular shape may fit, not analysis of existing objects. The site selection module discussed here plays an integral role in the advancement of spatial decision support systems (SDSS) development at the Savannah River Site.

The Savannah River Site lies along the border of the states of South Carolina and Georgia and is one of fourteen Department of Energy (DOE) nuclear industrial sites located within the United States. Construction of the site began in the 1950s with its primary mission being the refinement and production of tritium and plutonium-239, radioactive materials for use in nuclear weapons. While the handling of nuclear materials for national defense purposes remains a key initiative of the site, SRS is shifting towards a new focus of waste management and environmental restoration and protection. Most recently, SRS and other DOE facilities have been presented with the task of siting a wide variety of facilities within their boundaries (WSRC, 1992). These include the siting of landfills, ;waste disposal sites, power facilities, and at a much grander scale, facilities such as the Superconducting Super Collider (Siderelis, 1992).

The immediate goals of the environmental monitoring program at SRS include the identification and quantification of the effect of site activities on the environment using state-of-the-art techniques (WSRC, 1992). Currently, SRS researchers and scientists are applying remote sensing and geographic information systems techniques to a variety of site related tasks that are spatial in nature (Jensen, 1986; Cowen et al., 1995a). Among the most current and well established applications of geographic information systems (GIS) are complex forms of spatial analysis such as facility planning, site selection, and land use planning (Tomlin and Johnston, 1988; Tomlinson, 1987). While the use of GIS and automated mapping sciences have been used in previous DOE site planning investigations (WSRC, 1992; Siderelis, 1992; Jensen, 1986), hands-on access to the technology remains mostly limited to a small group of trained and technically capable users.

Over the past two years, the Environmental Impact Data Analysis and Retrieval System was developed as a cooperative effort between the University of South Carolina and Westinghouse Savannah River Company (Cowen, et al., 1995a). The goals of the project were to integrate into a centralized computer database a diverse array of non-standard digital geographic data layers, airborne video, and bibliographic information for use within a multimedia geographic information viewing system (Cowen, et al., 1995a; Bresnahan, et al., 1994a). The system was developed in an effort to provide SRS researchers with the necessary tools to increase efficiency in their everyday geographic decision making. Throughout development of the electronic atlas, a variety of data and media formats were integrated into the site-wide system. These included USGS Digital Line Graph (DLG) Data, CAD drawings, non-spatial databases, satellite imagery, and environmental and engineering-based GIS layers. An integral component of the system was the provision of a user friendly geographic data browsing system that is standard (i.e., operates and looks the same) across all platforms (Macintosh, UNIX, OS/2, Windows) and can seamlessly access the central data bank using native information transfer protocols (Bresnahan, et al., 1994a; Bresnahan, et al., 1994b). Bibliographic information query and search may be accessed either spatially or aspatially using a document search system (Cowen, et al., 1995a; 1995b). In addition, airborne digital video was directly incorporated into the system by means of a geographical tag or "hot link", allowing spatial referencing and point-and-click launching of digital movies.

The first phase of development of the Environmental Impact Data Analysis and Retrieval System was completed in the Fall of 1994. This phase focused on the initial design and implementation of digital data integration and the spatial browsing system. The next phase of the project was concerned with actual data analysis and application development, in particular the design and implementation of a user-friendly site selection system. As initially indicated, key features of the proposed system include ease of use and flexibility in terms of being able to handle a wide variety of siting tasks. By examining both past and present siting problems at SRS, a generic site selection model has been developed. Of the more recent siting tasks within SRS, two stand out as excellent examples of site evaluation procedures.

The siting of the New Sanitary Landfill and the Replacement Power Facility at the Savannah River Site both employ similar methodology. This methodology includes a decision making process that embodies the objectives of all parties involved, including knowledgeable subject experts. Both site selection processes involved the implementation of several exclusionary criteria that specifically eliminate certain types of geographic features based on regulations or mandates (WSRC, 1992). Examples of exclusionary criteria include the location of wetlands, 100-year flood plain, and sensitive areas such as threatened and endangered species. Once these areas were eliminated from the pool of potential site locations, the site selection team was able to identify areas that are suitable for further analysis. The resulting potential site locations are then assigned a score based on their suitability to the remaining non-exclusionary, or inclusionary factors (WSRC, 1992). A site's individual score or rating is calculated by summing criteria ratings found at each potential site location.

Preliminary siting studies of facilities at the SRS serve as a guide in the prototyping and development of an automated site selection model. The site requirements of facilities included both primary, essential criteria and secondary, less critical criteria.

Among potential examples of primary siting criteria are the following: 1) a site with a 2 kilometer radius (1.2 miles); 2) maximum elevation range of 35 meters (114.8 feet); 3) depth to groundwater of 65 meters (213.2 feet); and 4) away from existing facilities. The standard square grid data structure was selected for representation and analysis of the spatial data. This method was selected over the vector data structure due to previous research which indicates that spatial overlay and corridor analysis operations, fundamental data processing methods within any GIS, are much more efficient within a raster system (Cowen and Ehler, 1994; Star and Estes, 1990; Dangermond, 1990).

One critical aspect of any project requirement that needs to be addressed is the problem of performing shape analysis within a GIS. For exampleone shape analysis may be for a facility requiring a circular shaped site that is 2 kilometers in radius. This analysis was resolved by performing a radial search (on a cell by cell basis). While the methods discussed above work well for a simple shape such as a circle, other shapes such as hexagonal, "L", and irregularly shaped sites are not directly supported by grid cell modeling functions (Tomlin, 1990). Therefore, it was proposed that shape analysis functions be researched and implemented as an additional tool for use both within a geographic information system and specifically within the site selection model of the user-friendly site evaluation system for the Savannah River Site.

PREVIOUS RESEARCH

I. SHAPE ANALYSIS

Davis (1986) maintains that the determination of an object's shape is an extremely difficult task to measure. Perhaps this is the reason that a great abundance of shape measures have been developed and have been met with varying degrees of success. While it is certain that different objects yield unique shape measurements, it has been proven that no single shape measurement can accurately distinguish one shape from another (Davis, 1986; Lee and Sallee, 1970). As an alternative to single-value shape measures, more sophisticated methods have been developed such as Fourier Shape Functions (Davis, 1986; Moellering and Rayner, 1982).

Single-Value Measures of Shape
Many of the earliest measures of shape include single valued calculations or some index comprised of two or more calculations (Davis, 1986; Moellering and Rayner, 1979) as seen in Table 1. Some of the more successful measurements based on single value measures are those that measure an objects circularity, compactness, thinness, form, elongation, ellipticity, and curvature. As an example, FRAGSTATS, landscape ecology software for analyzing spatial patterns, is able to compute two types of shape indices, and are based on area to perimeter metrics and fractal analysis (McGarigal and Marks, 1994). The authors of the FRAGSTATS program report that these shape measurements are indicative of a shape s overall complexity. However, despite the wide range of single parameter shape measures that have been proposed, it is clear that they are generally incomplete in describing an object's shape (Moellering and Rayner, 1979).

Table 1. Single Measurement Shape Functions

P perimeter of the figure
d distance from centroid to the i-th individual

P^i perimeter of a circle with the same area as

X

the figure

d average distance between point element and edge of shape

P perimeter of ideal lemniscate

d^1 distance between point element and edge of shape

b

A area of figure

K(n)figure curvature on discrete cell grid

A area of standard shape

K^s the limit of curvature normalized to a circle

A^c area of smallest enclosing circle

x

C number of topological pieces

L longest axis

a

H number of topological holes

L secondary axis

V number of polygonal vertices
D diameter of circle of same area
S number of polygonal sides
r length from centroid to edge of the figure

i
F number of polygonal faces
w weight for the i-th individual

i

(From Moellering and Rayner, 1979)

Fourier Measures of Shape
One of the most recent and promising techniques that has been proposed for shape measurement involves Fourier analysis. In this method, a series of measurements from the object's centroid to its perimeter are taken. Given the length of these line segments (radii) and their orientation, a series of polar coordinate pairs may be extrapolated for analysis involving Fourier methods (Davis, 1986; Moellering and Rayner, 1982). Davis (1986) points out that the effect of an object's size may be removed from the analysis by dividing all radii by the average radius. One drawback of Fourier shape analysis is that a line segment from the centroid to the perimeter may only intersect the perimeter once, therefore excluding accurate measurements of extremely convoluted shapes (Davis, 1986).

Image Content Queries
As reported by Niblack and Flickner (1993), a system has been developed recently by IBM that is able to perform a visual search of a digital image based on a graphic query defined by the user. An example of a graphic query is "find all images that contain a graphic object that looks like this" (and the user would sketch or digitize the objects shape). Methods by which a computer may search for visual content of an image include neural network technology (where the system learns patterns in an image) and feature-based methods that compute the image's visual properties (including shape). The shape measures that are calculated in the Query By Image Content (QBIC) system include area, circularity, eccentricity, major-axis direction, and a set of tangent angles around the object's perimeter (Niblack and Flickner, 1993). As reported by the authors, the system is currently under testing and evaluation and has produced some extremely promising results.

Binary Shape Matrices
Shape metrics for feature recognition based on binary shape matrices were proposed by Flusser (1992). An object s shape matrix was based on the following algorithm:

1. Find the center of gravity *T = (x , y)* of object *G.*

t t

2. Find such point *M = (x , y)* that *M G* and

m m

Max d(A,T)

d(M,T) = *(A,T)*,where: *d* is Euclidean distance in R^2.

A G

3. Construct the square with the center in *T* and with the size of the side *2 * d (M, T)*. Point *M* lies in the center of one side.
4. Divide the square into *n* x *n* subsquares.
5. Denote *S* the subsquares of the constructed grid; *k, j = 1, ... , n.*

kj

6. Define the *n* x *n* binary matrix *B*:

B = 1 m(Skj Ô G) Ú m(Sk)/2

kj
0, otherwise

where: *m (F)* is the area of the planar region *F.*

(From Flusser, 1992)

As reported by Flusser, shape matrices can be utilized as the feature for recognizing objects, with high degrees of success. In addition, there is no limit to the number of shapes these matrices can identify, and the methodology can even describe shapes that contain holes. An object s rotation and scaling can also be resolved by using binary shape matrices. Lastly, the degree of similarity between the object and the target can be measured by comparing their shape matrices (Flusser, 1992). The automated binary shape techniques described above appear to be most applicable to the type of analysis required by site location planners at the Savannah River Site.

II. SPATIAL DECISION SUPPORT SYSTEMS (SDSS)

The concept of spatial decision support systems (SDSS) represents an effort to address complex spatial problem solving and assist spatial decision making. Densham (1992) argues that by providing the user with a flexible problem solving environment, the user is able to increase their awareness and understanding of the problem task, as well as refine his or her knowledge of undesirable solutions. The components of a "true" SDSS as defined by Densham include the integration of a geographic database management system with analytical modeling capabilities, a visualization component or graphical user interface (GUI), and the decision making knowledge of domain experts (Densham, 1992). In addition, the key aspect that separates SDSS from GIS are geographic information analysis (GIA) functions. These analysis components include: 1) support of analytical modeling; 2) appropriate spatial data to support the model; 3) flexible graphical (mapping) and tabular output; and 4) incorporation of flexible decision making processes. Lastly, Densham's research provides a framework for developing spatial decision support systems and outlines a theoretical design architecture.

Armstrong and Densham (1990) discuss two groups of decision making approaches that may be incorporated into SDSS: programming techniques and heuristic methods. Programming techniques tend to be computationally intensive but always yield an optimal solution. Heuristic techniques yield sub-optimal solutions, however are able to provide recommendations more efficiently by means of suggesting a range of solution alternatives (Armstrong and Densham, 1990). The authors also discuss the most commonly used databases and their applicability toward SDSS. The rectangular data model, or geographic matrix, was found to be most appropriate when only one level of spatial aggregation is to be considered. Finally, the authors conclude that a newly developed hybrid data model is most suitable to spatial decision support systems, which is based on the entity-category-relationship (ECR) approach and an extended network model (Armstrong and Densham, 1990).

Armstrong, et al. (1993) describe a SDSS that allows the analysis of school redistricting problems by education administrators. The system was designed around a geographic information system, population projection models, and a locational modeling routine. The role of GIS is to manage spatial data and produce reports and maps for use within the model. In effect, the system serves as a redistricting assistant, allowing the user to interact with the SDSS.

Peterson (1993) discusses how the problem of real estate investment can be facilitated through the use of spatial decision support systems. The real estate investment problem is an ill structured task, making it appropriate for SDSS application. Through the identification of the most important spatial tasks, the tracking of minor but important details involved in analysis, and organization of the problem space, SDSS allows the user to make well informed decisions (Peterson, 1993).

A spatial decision support system for coastal wetland permitting has been developed by Ji and Johnston (1994). The study involved customizing ARC/INFO GIS to allow resource managers to interact with permit sites and plan future permit activities. The GUI that was designed includes windows, text displays, on-line help, and functional icons. Analytical models containing knowledge-based rules were implemented pertaining to rules and regulations of wetlands permitting. The present condition of the system has yet to include mapping and report capabilities, however these functions are currently under consideration.

METHODS

I. STUDY AREA

As specified by the Savannah River Site SDSS project scope, the spatial extent of analysis for the generic site selection system at SRS included the entire site. The Savannah River Site covers approximately 300 square miles (775 km^2) of federally owned land and is located along the border of South Carolina and Georgia, including portions of Aiken, Allendale, and Barnwell counties (Figure 1). Sixteen USGS 1:24,000 quadrangles contain the boundary of SRS, which is circular in shape, and serve as the areal extent of analysis for the proposed research.

II. DATA

In addition to data compiled in the previous stages of the data atlas development, supplementary geographic information was integrated into the system for inclusion in the site selection module. The data set prior to SDSS development included digitally scanned aerial photography, multi-spectral and panchromatic SPOT imagery, wetlands and soils data, radiological contamination, DLG derived digital elevation models (DEM) and related products, and land cover. Ancillary data that was integrated during the system prototyping phase included water table information, depth to groundwater, and the location of threatened and endangered species habitat, among others. Data requirements for the site selection system were specified prior to the system design stage and was developed between WSRC technical representatives and project team personnel at the university. In all, over twenty-five data layers were required by the site's land use planners.

III. COMPUTER HARDWARE AND SOFTWARE

Computer hardware and software decisions were based on the selection of state-of-the-art technology to complement current geoscientific capabilities at the Savannah River Site and the University of South Carolina. ARC/INFO GIS Ver. 7.1 and ArcView Ver. 2.1 from Environmental Systems Research Institute (ESRI) of Redlands, California were selected as the geographic information system environments for project development. This decision was based upon the features found in both systems such as their support of high level programming languages (Arc Macro Language and Avenue), ability to be customized, ability to integrate current data sets found within the Environmental Impact Data Analysis and Retrieval System, multi-platform support, and reputation as state of the art technologies and industry standards. A Sparc 5 UNIX workstation by Sun Microsystems was acquired as the primary hardware for use in developing the site selection system. Additional hardware that was used in this research included a desktop image scanner, digitizing table, 1/4" and DAT tape drives, and various printing and plotting devices including a Hewlett-Packard Model 650 color plotter.

IV. THE DATA MODEL

Within ARC/INFO, spatial data including both locational data and attribute information is stored as a coverage for vector-based data and a grid for cell or raster-based data. Currently, data pertaining to the Savannah River Site resides in both formats. The properties of each data model must be taken into consideration before their incorporation into the site selection system. While a full discussion of spatial data models lies outside the scope of this paper, it is important to consider a primary goal of the site selection system -- performance. Users require quick and efficient results so that decisions may be made in a timely manner. This is a highly desirable feature found in a spatial decision support system as discussed by Densham (1992). Dangermond (1990) reports that the speed of overlay and buffer operations within a raster-based GIS greatly outperform their vector-based counterparts. Additionally, cartographic modeling techniques are currently available and are directly supported by ARC/INFO. It was for these reason that the raster data model and cell-based data processing methods were primarily utilized for this research. The level of spatial resolution of the cell-based model was 5 meters, a standard for raster data within the Environmental Impact Data Analysis and Retrieval System.

V. SDSS DEVELOPMENT

Methods of designing spatial models for site planning were first discussed over 30 years ago before the advent of automated geographic information systems. In his seminal paper McHarg (1969) mapped thematic site criteria onto mylar transparencies and, when superimposed, was able to differentiate between acceptable and unacceptable zones. The methods that were developed were applied to a variety of social, economic, and environmental problems. In effect each mylar layer served as an input to the "maximum benefit - minimum cost" model (McHarg, 1969).

Customization of the graphical user interface (GUI) and incorporation of the analytical site selection model were developed using ARC/INFO's Arc Macro Language (AML) and ArcView's Avenue scripting language. The user accesses the site selection system through ArcView 2.1, the graphical interface of the Environmental Impact Data Analysis and Retrieval System. By establishing a link between ArcView 2.1 and ARC/INFO through Avenue scripting, the user is able to access the full geo-processing functions of ARC/INFO. Within ARC/INFO, customization of the main user interface was performed by designing a series of "widgets" (interactive graphical objects), menus, and map and text-based displays. The user is allowed to set locational criteria as it pertains to a particular siting task via graphical interfaces, run this analytical model against the raster-based GIS data, and produce a series of potential site locations. Analytical processing within the GIS is totally transparent to the user, requiring no interaction with ARC/INFO's text-based command interface. This transparency is a common feature found within Spatial Decision Support Systems (Densham, 1991).

It was determined from the user requirements study that users have different needs. For example, some users required quick and timely decisions. Others were concerned with the most accurate results. The most important issue was a simple and easy to understand and learn interface. Based on these needs, the project team designed a flexible interface within ArcView. The GUI allows the user to modify the spatial resolution from 20 to 150 meters, providing either highly accurate results at the cost of longer processing time, or a highly efficient processing speed at the cost of spatial resolution and accuracy (Figure 2).

A "Model Builder" tool was designed to allow the user to interactively build a site selection model in real time (Figure 2). As the user builds the model, the appropriate ARC/INFO commands are written to an executable batch file, allowing the user to concentrate on model design, not technical GIS functions and their syntax. In addition, current siting techniques in use at the Savannah River Site have been integrated into the interface. This is a process of weightings, which are assigned to each layer based on their relative importance within the model. Categorical weights are assigned to broad categories of themes (e.g., geology, ecology, or engineering). Criteria weightings are assigned to each individual theme and may vary within a category based on importance. The final weight that is applied to each layer is based on the product of the categorical weight and the criteria weight.

The Model Builder tool utilizes three types of cell-based spatial operations:

1) BUFFER - A form of proximity analysis where zones of a given distance are generated around a theme's features (points, lines, or polygons). The resulting buffer zones form polygons, which are inside of the user specified buffer distance. These zones are used for siting analysis. Example: The site must be within 800 meters of a road.

2) BUFFER EXCLUDE - A form of proximity analysis where zones of a given distance are generated around a theme's features (points, lines, or polygons). The resulting buffer zones form polygons, which are outside of the user specified buffer distance. These zones are used for siting analysis. Example: The site must be at least 1000 meters away from existing facilities.

3) RESELECT - The feature reselect tool allows the user to extract map features from a layer based on it's attribute values. The resulting zones are used within the siting analysis. Example: The site must be located at an elevation range between 300 and 375 feet - OR - the site can not be located on wetlands.

The user selects each criteria, applies the appropriate weightings and spatial operations, and adds this criteria to the overall site location model. Upon completion of building the model, each layer (or criteria) is combined by means of spatial overlay, or map algebra (Tomlin, 1990), resulting in a final site ranking layer.

Immediately following grid processing of the model, a new theme is automatically added to the active ArcView "View". This theme is uniquely classified with a color ramp ranging from yellow (least desirable site locations) to red (most desirable). Each polygonal area has its own individual numerical score based on the summed criteria weights (Figure 3). These values may be geographically queried by point-and-click with the "get information" tool.

VI. DEVELOPMENT OF SHAPE ANALYSIS FUNCTION

Many of the shape analysis measurements found in the literature are not pertinent to this research because the goal of this system is to search for locations within a study area where a shape may fit. While it has been proven that circular shaped objects (or sites) are of minor difficulty to place on an automated map, other more complex shapes introduce new difficulties. As an example, consider the locating process of a rectangular site. Within a grid system, this process would involve performing a rectangular neighborhood search (with the filter's dimensions equal to the dimensions of the site) on a cell by cell basis. This method works, however, an object's rotation also needs to be considered. For example, using the object's cetroid as a pivoting point, an infinite number of orientations may be possible (Figure 4). In effect, what needs to be modeled is a roving, spinning filter that will examine every cell and its neighborhood (based on filter orientation). This will accomplish the goal of "fitting" an object of given shape within the grid (Figure 5). It is important to note that ARC/INFO allows the user to define irregularly shaped focal functions (filters) that can model the shape of an object (ESRI, 1994), however the software does not directly support rotational searches.

Following Flusser s (1992) binary shape matrix methodology, analytical shape metrics were introduced as a functional component of the system. As with the site modeling function, the shape identification tool was developed using both Avenue and AML code. The binary matrices are constructed by geometrically constructing vector-based shapes (of selected objects, see Figure 6) within ARC/EDIT, converting them to GRID (raster) format, and exporting these shape matrices using the *GRIDASCII* function. The *GRIDASCII* function produces analogous binary shape matrices as proposed by Flusser s research.

An object s rotation is accounted for by rotating each shape in the eight cardinal directions (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) (Figure 7). This is the same methodology utilized by Podolsky within FullPixelSearch, commercial software developed to perform pattern searching on image-based data including shape metrics (Podolsky, 1996; Norr, 1995; Seiter, 1995). Given these techniques, a maximum of eight matrices (or kernels) may be produced for each individual shape-based target. For example, a square need be rotated only through the first two cardinal directions, as 0°, 90°, 180°, and 270° have the same geometrical properties and orientation, as do 45°, 135°, 225°, and 315°. At the other extreme, a star shaped object or an L shaped object must be rotated throughout the complete 360° cycle in each of the cardinal directions. This is because with each rotational increment, the shape s geometrical properties and orientation are uniquely different.

The user interacts with the shape analysis GUI in much the same manner as the model builder tool. A customized ArcView icon links the appropriate scripts and menus to perform the shape searches. After the user selects the appropriate search shape and enters the appropriate dimensions of the shape, the binary kernels are constructed and applied to the final site ranking layer. Each kernel is passed over the layer on a cell-by-cell basis, producing an output layer denoting target shape identification. Up to eight output shape layers may be produced, which are combined using map algebra to produce a final shape identification layer. The unique numerical values for each cell location denote the successful angle of rotation of the object s shape (Figure 8).

SYSTEM EVALUATION

A differentiation between qualitative and quantitative geographic information system evaluations is made by Goodchild and Rizzo (1987). The authors discuss that a qualitative evaluation is based on the system's ability to satisfactorily perform the required functions as set forth by initial user requirements and the evaluation team. A quantitative evaluation addresses the ability of the system to perform the task at hand within the constraints of personnel working time, CPU processing speeds, and data storage limits.

The proposed SDSS will be evaluated on-site by WSRC personnel following a demonstration of the system's features and capabilities. This evaluation will primarily consist of user feedback and criticism and will be mostly qualitative in nature. In addition, a more rigorous quantitative evaluation will be proposed to WSRC technical staff. System performance will be measured by statistical comparison between hypothetical site selection results from the SDSS and those results derived from traditional manual site selection techniques (i.e., from human experts). It is hypothesized that as more criteria are introduced into the model, the accuracy of the decisions made by human site selection experts decreases while the accuracy of the SDSS remains relatively static. Lastly, an empirical study of the shape analysis and search function (query by image content) is also required in verifying the utility of the system.

CONCLUSIONS

The objectives of the research reported here was to incorporate shape metrics within the analytical modeling component of a spatial decision support system for site location. While other spatial data handling systems have analyzed the specific shapes of objects, no existing system appears to allow the user to specify a specific shape as a part of suitability analysis. In order to develop the unique type of shape analysis required for this research, it was necessary to go beyond the standard literature and search out new techniques and methodologies. Current research from the document imagining field allowed the design and prototyping of the necessary shape fitting techniques. This involved designing irregularly shaped binary kernels (filters) that approximate the form of the target in question, as proposed by Flusser (1992). In particular the system meets the following objectives:

1. The GUI provides a linkage between a vector based data browsing system and the grid module of a full featured GIS;

2. The inter-application linkage can also be supported across platforms (Windows & UNIX);

3. The system supports a full set of selection and weighting functions required for suitability analysis;

4. Conversion between vector and raster data structures are efficiently performed for the specific function;

5. The shape analysis function is totally integrated with the other functions of the system;

6. The GUI allows the user to interactively describe the desired shape and size of the object;

7. The user can select the level of spatial resolution and consequently processing speed;

8. The shape function addresses the issue of object rotation by searching the eight cardinal directions; and

9. Major performance gains are obtained by increasing cell size from 5 to 10 meters but is only marginally improved beyond 20 meters.

The research described here plays an important role in further advancing geographic information systems theory and applications. The successful design, development, and implementation of both analytical shape metrics and, from a much larger scope, the site modeling decision support system proves that sound geographic information systems theory can be applied to tackle real world issues. Perhaps with the future advancement and wide-spread application of such commercial software products such as the Heuristic Optimized Processing System (HOPS International, 1992) and ESRI s Spatial Database Engine (ESRI, 1995) we will see more efficient spatial database storage and analysis. These data processing engines will allow an unprecedented number of users to access and manipulate enormous quantities of spatial information at exceptionally responsive processing speeds. These systems signal the further advancement of traditional GIS, and will certainly allow researchers to fully develop a true SDSS . While some performance issues remain to be resolved to complete this research, it is important to note that the system has been installed at the Savannah River Site and has enjoyed a considerable amount of success -- and use.

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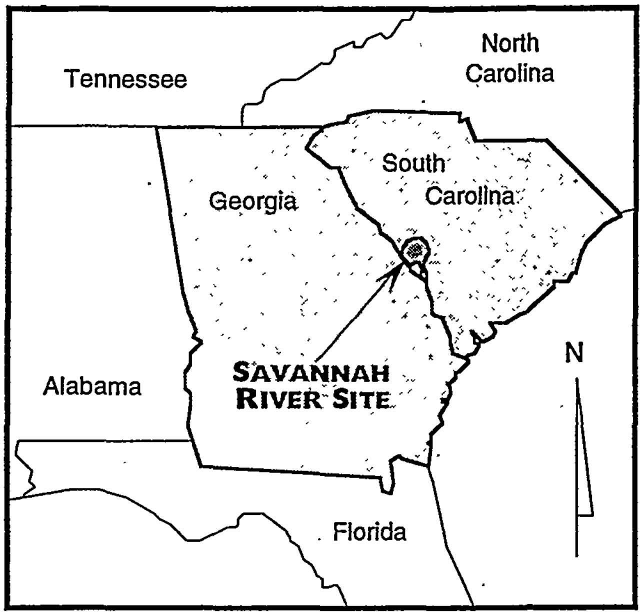

Figure 1. Location Map for the Savannah River Site

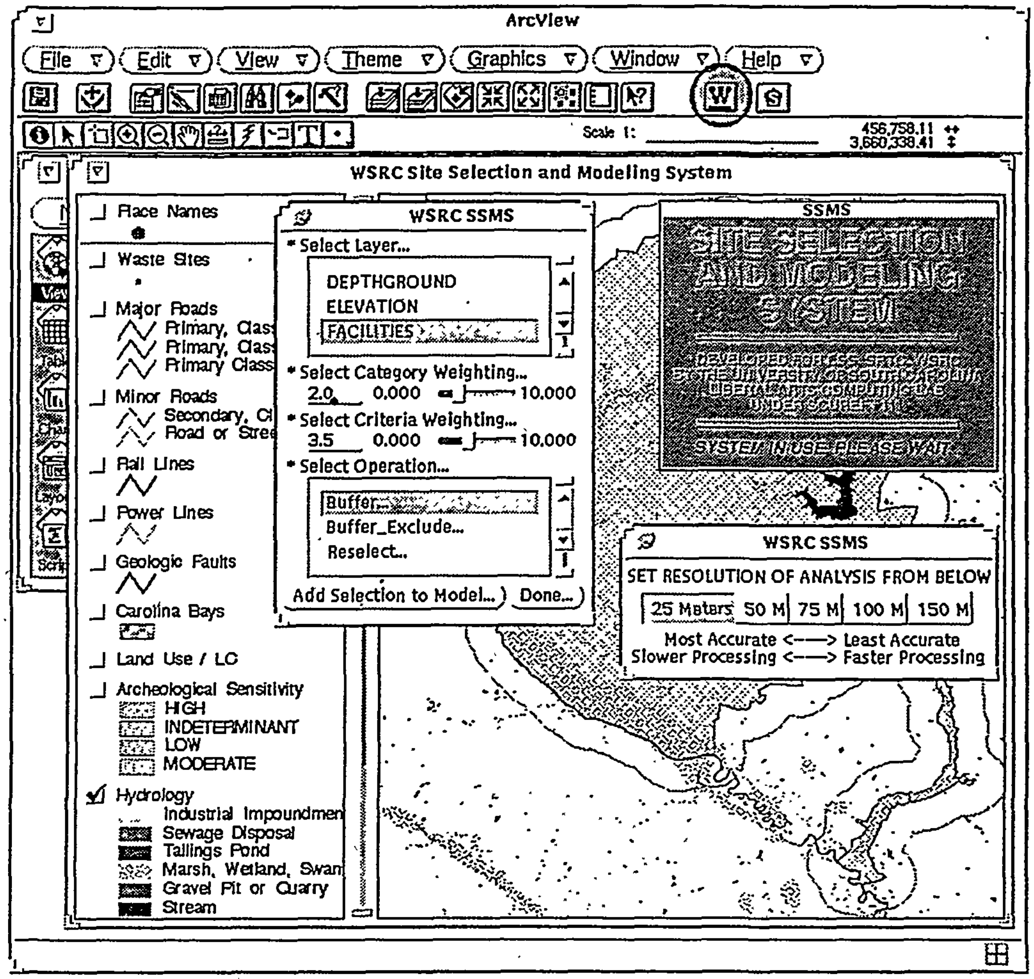

Figure 2. Site Selection and Modeling System User Interface

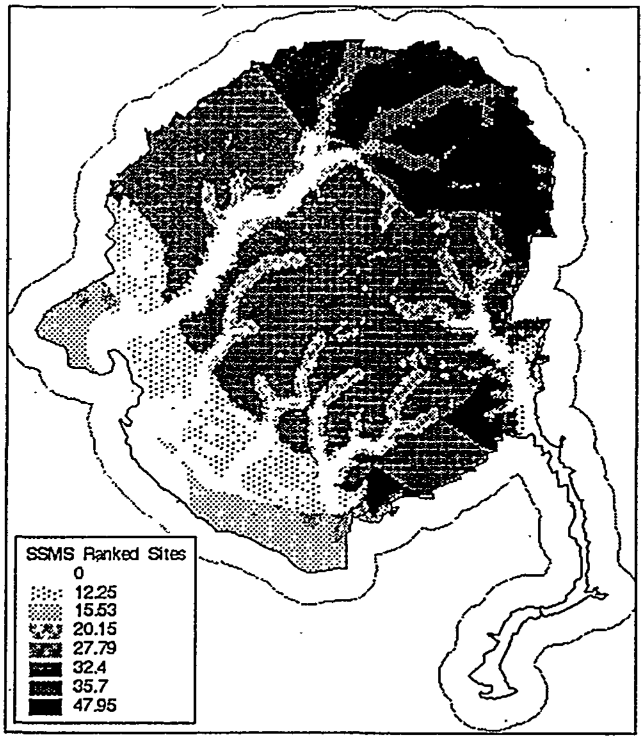

Figure 3. Grid Cell Modeling Results

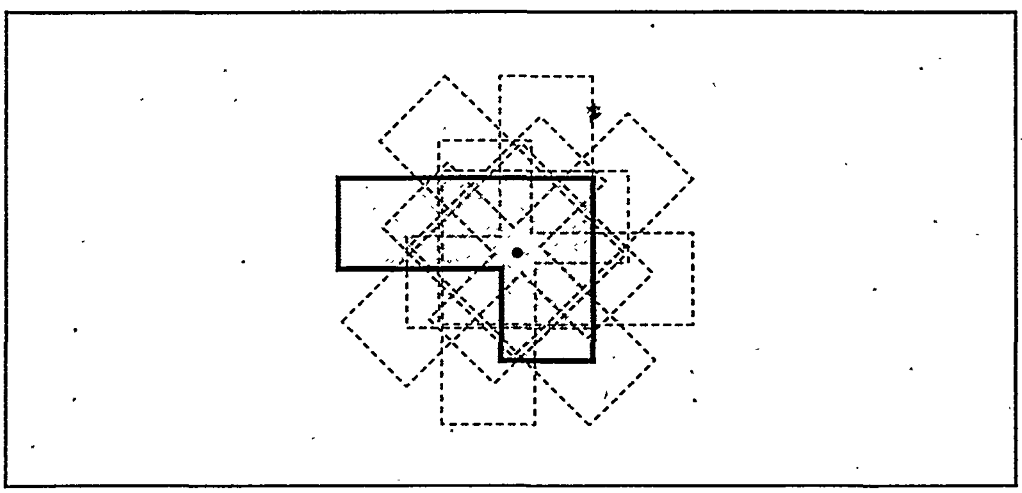

Figure 4. Orientation of L-Shaped Object in Eight Cardinal Directions

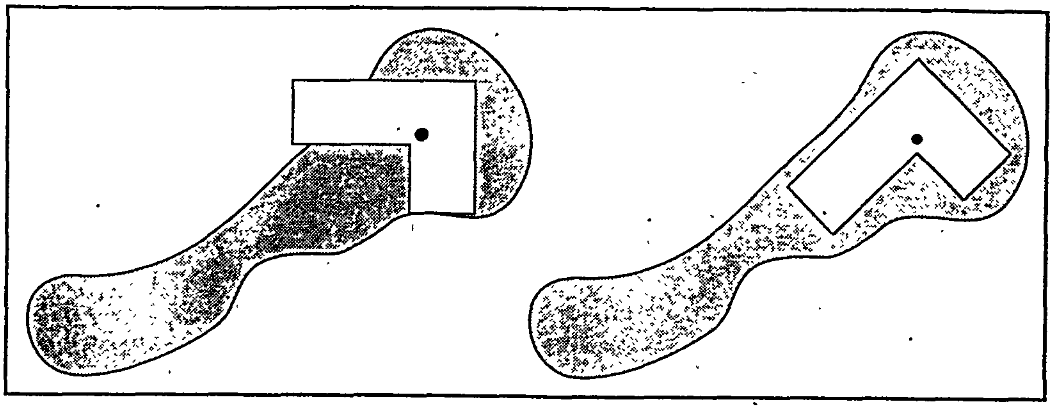

Figure 5. Feasible Orientation for L-Shaped Object Within Polygon

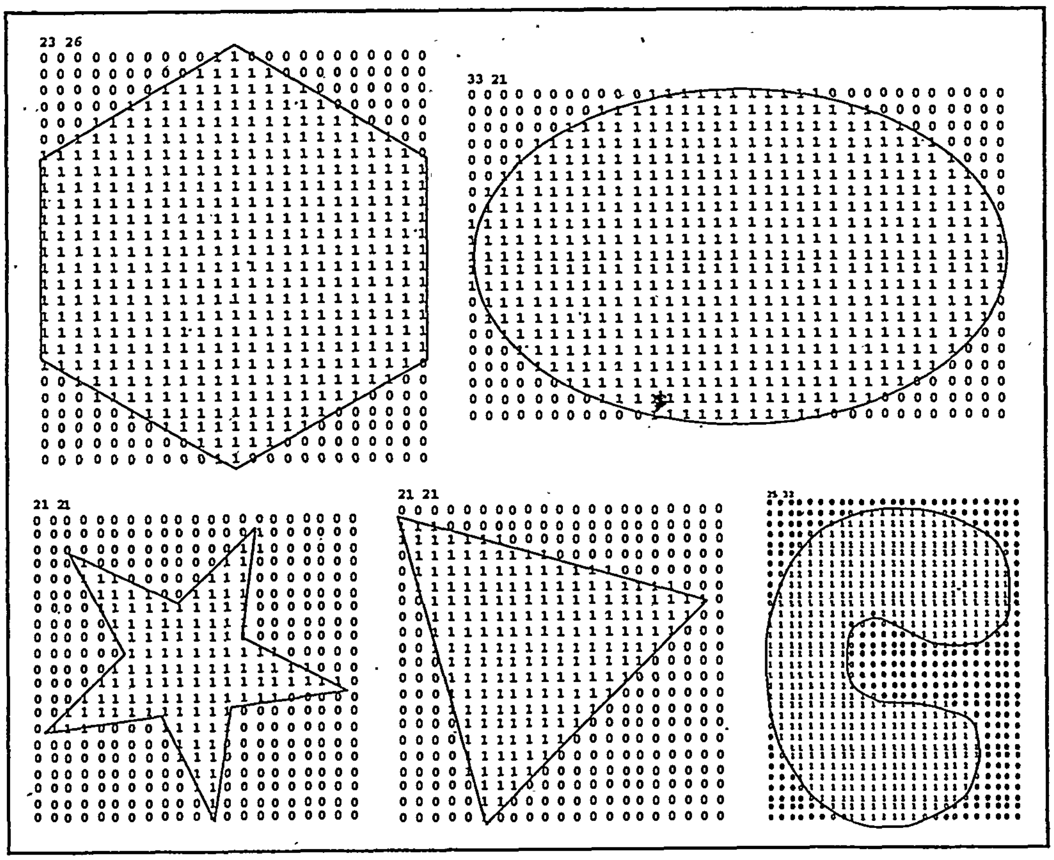

Figure 6. Binary Filters for Five Different Shapes

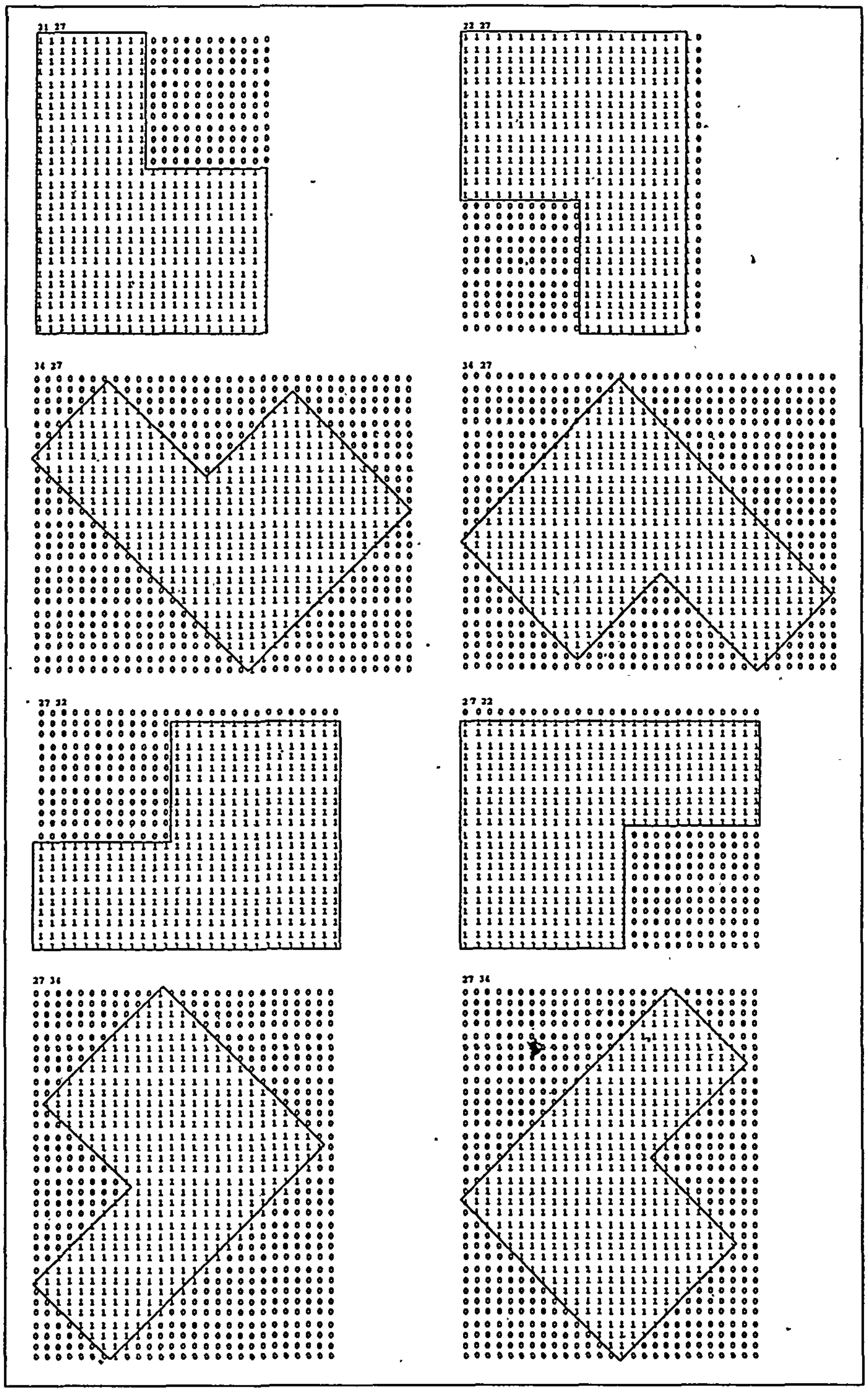

Figure 7. Orientation of L-Shaped Object as a Binary Filter

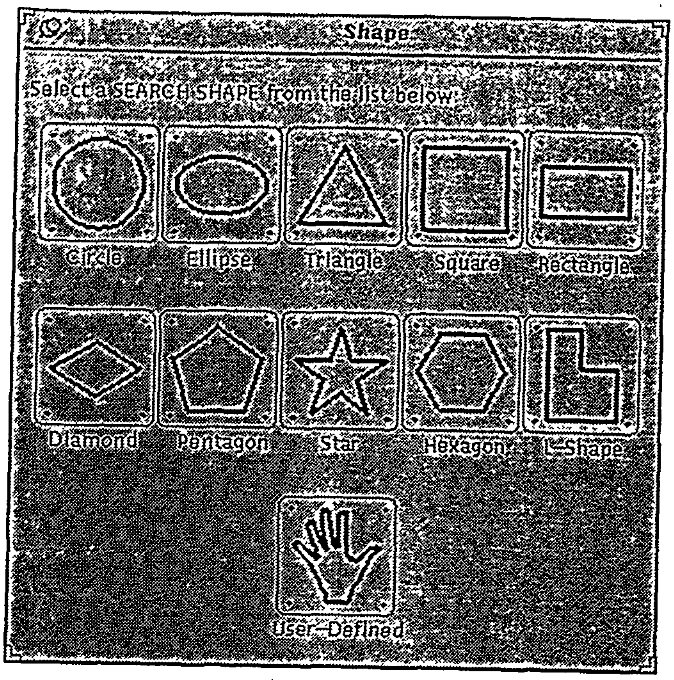

Figure 8. User Interface for Shape Analysis

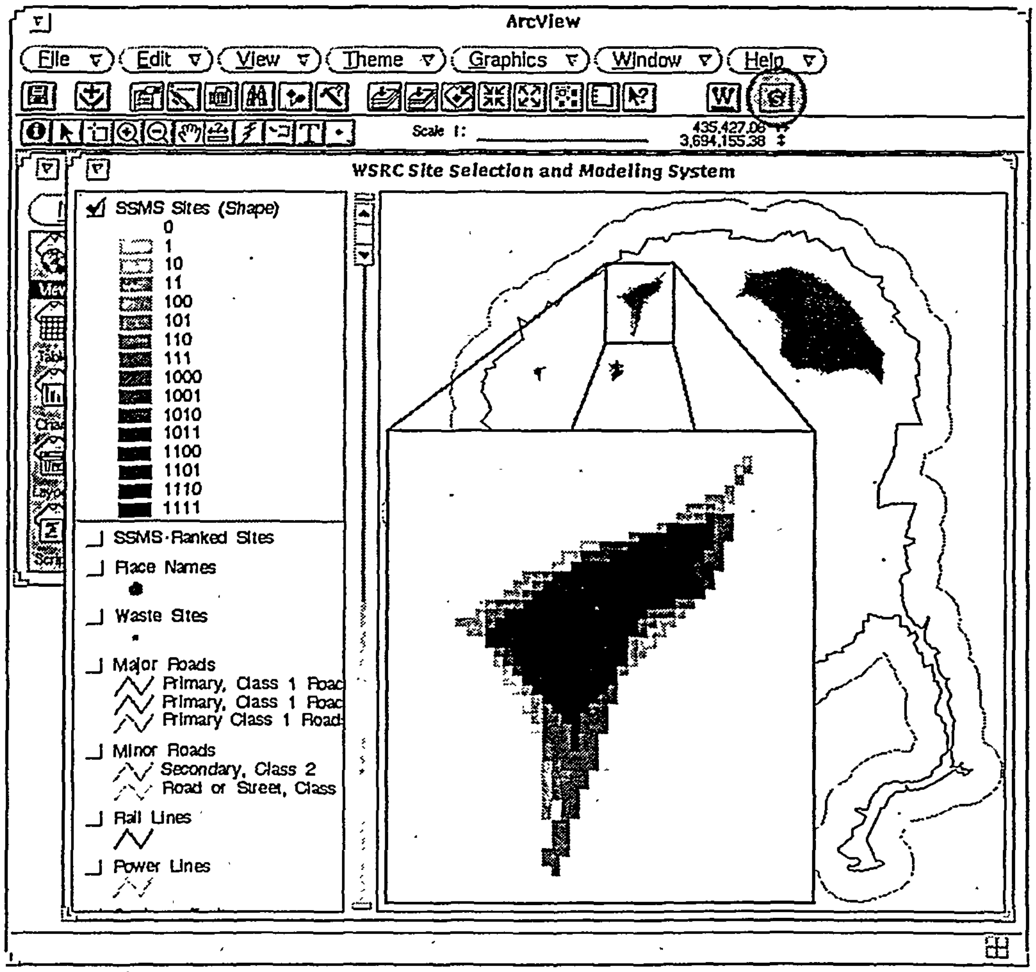

Figure 9. Results of Shape Search within GIS Environment

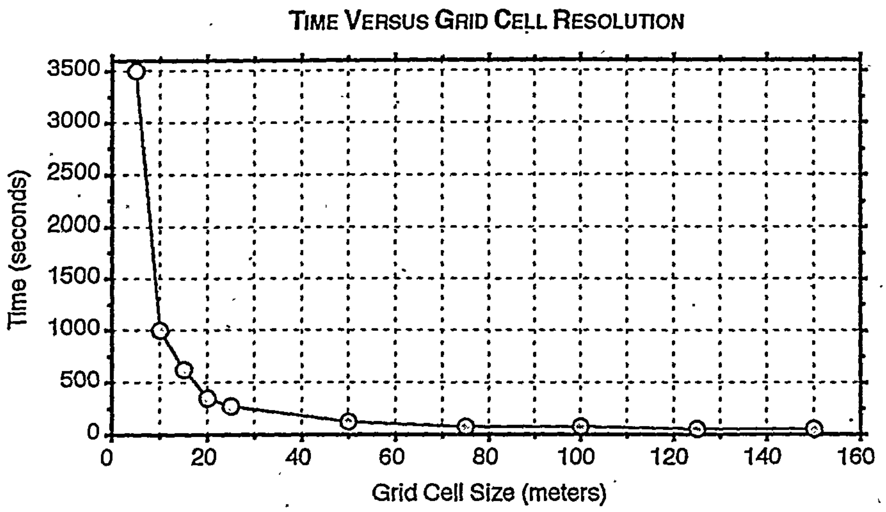

Figure 10. Performance Evaluation Results