BIOGRAPHICAL INFORMATION

Jesse Glasgow
GTC Operations Manager
Photo Science, Inc.

Specific Responsibilities

Glasgow is responsible for oversight of the geographic information acquisition, management, and analysis functions for Georgia Transmission Corporation (GTC). While at GTC he has lead the development of business processes and custom software solutions in support of the siting, design, construction, operations, and maintenance of electric transmission facilities. Additionally, Glasgow consults with other energy and transportation clients regarding site selection methodology and software.

Past Experience

Prior to his current position, Glasgow was a Planner at the Northwest Alabama Council of Local Governments. In this position he worked on several local government initiatives. He also participated in transportation planning for a Metropolitan Planning Organization.

Education

B.S. - Professional Geography, University of North Alabama
GIS Certification - University of North Alabama

Professional Memberships

Geospatial Information and Technology Association (GITA)
Urban and Regional Information Systems Association (URISA)

SITING LINEAR FACILITIES WITH GEOGRAPHIC INFORMATION SYSTEMS

Jesse F. Glasgow
Photo Science, Inc.
2100 East Exchange Place
Tucker, GA 30085 (Atlanta Metro)
jglasgow@photoscience.com

ABSTRACT

This paper presents a methodology and software solution designed to select the best route for linear facilities such as electric transmission lines, gas pipelines, roads, and others. Georgia Transmission Corporation (Atlanta, GA) has partnered with Photo Science, Inc. (Atlanta, GA) to develop, implement, and operate a geographic information system (GIS) that automates the route selection for new linear facilities. The Electric Power Research Institute (EPRI) has conducted a research project to enhance and improve this linear siting methodology. This paper will focus on how these partners use GIS as a tool to map study areas, analyze constraints versus opportunities, and help select defendable routes for new facilities. The reader will gain an understanding of the technology available to help automate, standardize, and improve the route selection process.

INTRODUCTION

Linear facilities, including electric transmission lines, gas pipelines, roads, and others present a unique challenge for site selection experts. Often times these new facilities must span several miles impacting hundreds of people, hundreds of acres of natural resources, and costs millions of dollars in land acquisition and construction. However, as our population continues to sprawl into more rural areas and become more dispersed, there is a need to build roads and utility corridors to serve this growth.

While it is clear that there is a need for new facility construction, the public is becoming more environmentally conscious and organized in opposition to new facilities. There is a need for a system that allows utilities and departments of transportation to analyze an abundance of cultural, environmental, and engineering information so that the most suitable routes for new facilities are selected.

When selecting the location for a new facility, the goal is to locate it so that it supplies the greatest utility to the public in the most efficient manner possible while minimizing negative impacts to people and the natural environment. It is critical to consider not only how the land is being used by people, but also its natural characteristics. In order to accomplish this goal authorities analyze an abundance of location-based information in an attempt to determine the most suitable site to construct a new facility. GIS provides the means to standardize, automate, and explain the rationale involved in selecting the location of the new facility.

Corridor analysis is not a new science and has been studied by many experts over the years. In 1967 Ian McHarg defined the least cost corridor as being the area that maximizes social benefit while minimizing social cost. McHarg developed a methodology to analyze the suitability of places using of transparent map overlays (http://www.hudsal.com/gis/corridor.htm). Since that time computer programs have been developed which quantitatively analyze the suitability of places and select routes that minimize impact and cost.

“Determining the best route through an area is one of the oldest spatial problems. Meandering animal tracks evolved into a wagon trail that became a small road and ultimately a super highway. While this empirical metamorphosis has historical precedent, contemporary routing problems involve resolving complex interactions of engineering, environmental, and social concerns.

Electrical transmission line siting historically required thousands of hours huddling around paper maps, sketching hundreds of possible paths, and then assessing their feasibility to narrow the list to a single preferred route. The manual approach capitalizes on expert interpretation and judgment but is often criticized as a closed process that lacks a defendable procedure and fails to engage alternative perspectives in what constitutes a preferred route." (Berry 2003)

NEED FOR A GIS APPROACH

GIS serves as a vehicle for change and resolution in addressing former inadequacies inherent in the manual siting process for linear facilities. This technology allows for comprehensive quantifiable assessment of social, engineering, and ecological impacts with the implementation of a consistent and defensible siting methodology. Consequently, organizations are armed with a tool which enables them to adhere to regulatory policies and secure appropriate permissions in an efficient manner, thereby reducing associated time and costs.

"Authority to use lands is critical for electric transmission lines. GIS siting methodology attempts to use sound science and technology to expedite approvals getting projects built on time and at lower cost. It is a state-of-the-art project management solution.

Environmental paperwork—National Environmental Policy Act (NEPA) and best management practices—constrains project siting. While the purpose of documentation is not to generate reams of excellent paperwork, but to foster excellent action, it can take years to complete and cost millions of dollars.

Documentation does not mandate particular substantive environmental results. It requires study of environmental consequences of proposed actions before action is taken. Proponents take a "hard look" at environmental consequences of alternatives. This "hard look" means examining relevant data and articulating satisfactory explanations, including rational connections between facts found and choices made.

Adopting GIS methods advances these objectives and promotes consistent, quantitative, and defensible "standards" for examining data, articulating explanations and demonstrating connections between facts and choices. GIS siting procedures can help proactive companies implement strategies that anticipate critical land use issues impacting transmission line placement.

The procedure developed aligns GIS and a NEPA-like process that solicits input from a variety of interested parties to describe both tangible and intangible "costs", and then searches for the "least cost path." That is a logical and structured result of integrating GIS technology's rigor with landscape analysis interpretations. The project team found changing the "least cost path" lexicon to "most preferred route" and "NEPA-like process" terminology to "adaptive management" was necessary in communicating with non-GIS stakeholders.

Obtaining the authority for transmission siting can be substantially advanced through GIS methodologies. It can streamline decision documentation processes that precondition land authority and expedite a more objective, consistent, and defensible "standard set of procedures" for siting. That is good news as current paperwork consumes years, costs millions of dollars, and often disenfranchises impacted parties." (Richardson 2004)

"Choosing the route for an electric power transmission line requires consideration of a number of factors. The values of these factors will usually vary across space. While the exact set of factors to be considered may change in different parts of the country, most transmission line routing will require some attention to environmental factors, such as wetlands and flood plains, community factors, such as existing neighborhoods and historic sites, and engineering factors, such as slope and access.

Historically, siting teams have relied on paper maps, aerial photographs, and field surveys to support transmission line routing decisions. Using these information sources the team would "eyeball" the best route using a straight edge and their professional experience. However, GIS is explicitly designed to manage and combine large amounts of spatially distributed data. In fact, transmission line siting can be thought of as a special case of land suitability analysis that drove much of the early development of GIS. It is only natural that the electric power industry is adopting GIS-based applications that are tailored to meet the needs of transmission line routing.

In addition to providing an efficient and effective way to handle large amounts of spatially distributed data, GIS has a number of other advantages as a platform for transmission line routing. First and foremost is consistency. A GIS application can be designed so that the same data will be treated the same way in each transmission line routing project. This creates a consistent process that can be replicated across multiple projects. Through its overlay functionality GIS provides a way to apply unique weights to different layers of information. In the manual process not all information is considered equally important, but the relative importance of each type is generally not made explicit. GIS can also use sophisticated routing algorithms to find the preferred path through a set of features. While the manual methods may find the most preferred route, a preference-maximizing algorithm has a much better chance of consistently finding the best routes. And finally,GIS enables users to drill down to find the factors that are coincident with the transmission line route. This provides the siting team and other interested stakeholders the ability to evaluate the impacts of a given alternative as a whole or at any point along the route." (French 2004)

OVERVIEW OF THE APPROACH

The EPRI Transmission Line Siting Methodology is analogous to a theoretical corridor analysis funnel into which geographic information is input and a preferred route emerges. Geographic information is calibrated and analyzed in phases with increasing resolution. Proceeding down and through the funnel, the suitability analysis process better defines the corridor(s) most suitable for transmission line construction.

Geographic features are organized by scale (resolution) and discipline. To rank individual features by their suitability and weight feature groups by their relative importance, internal and external stakeholder input is gathered using the Delphi process to build consensus and the analytical hierarchical process for pairwise comparison. Four separate suitability surfaces are created placing more decision making preference on: 1) minimizing natural environmental impacts, 2) minimizing built environmental impacts, 3) maximizing engineering considerations, and 4) averaging preference between all three categories.

Once the surfaces are available, Corridor Analyst™ software is used to measure the accumulative cost for every possible route connecting the end points. The accumulative cost surface is classified to delineate the top three percent of all possible routes. This results in four alternative corridors, one representing each suitability surface. Within the alternative corridors additional data is gathered, such as property lines, and routing experts define a network of alternative route segments for further evaluation.

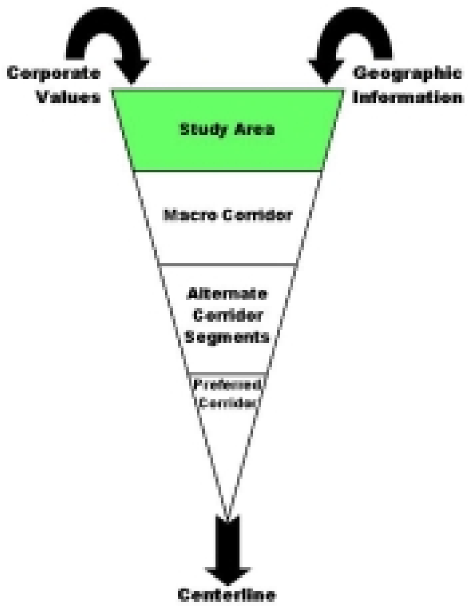
Statistics, such as acreage of wetlands impacted, number of streams crossed, number of houses within a specific proximity, etc., are automatically generated for each of the alternative route segments. Segments which have connectivity are defined, and segment statistics are summed to create alternative route statistics.

The pairwise comparison process is applied once again to assign weights to the alternative route statistics resulting in a ranking of each route alternative. The highest ranking routes are then subjected to qualitative analysis considering criteria such as risk to electrical system, aesthetics, and community concern. This analysis culminates in a preferred route corridor.

Detailed field surveys are conducted along the preferred route corridor (collecting data using GPS, photogrammetry, LiDAR, and conventional surveying techniques) to map cultural, ecological, cadastral, topographical, and physical features. Engineers then refine the final pole placements in the centerline and define associated clearing requirements based upon this information.

CORRIDOR ANALYSIS METHODOLOGY

The Corridor Analysis Funnel (below) is a conceptual diagram, which illustrates the corridor selection methodology at a high level. Geographic information is first quantified by corporate or organizational values. It is then processed through several filters with data and analysis resolution increasing as the corridor becomes more defined. The final stage of this siting methodology culminates in corridor selection, whereby a preferred route, or centerline, is selected for the proposed facility. The Corridor Analysis Funnel will be used as a reference tool throughout this paper to help the reader conceptualize the various phases in the process.



Corridor Analysis Funnel

PHASE 1: DILENEATING THE STUDY AREA

It is important to collect enough, but not too much, data for use in corridor selection. The data type and level of detail are typically determined by regulatory and reviewer requirements. Data collection can be an expensive process warranting a thorough cost/benefit analysis. While computers can be used to help organize and manage a vast amount of data, humans can realistically consider a finite amount of information. Therefore, it is critical that the organization that will construct the sited facility have a good understanding of what information is relevant in making siting decisions. This drives the data collection effort.

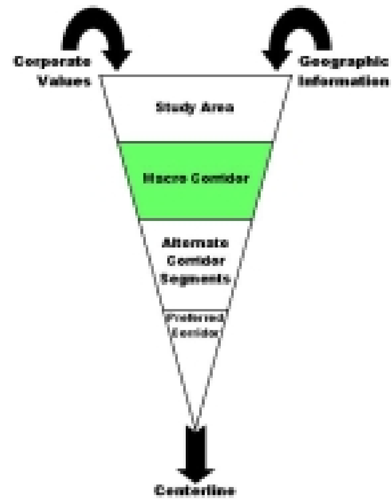
In delineating a study area for routing a linear facility users must consider several factors:

1) The distance between end points (i.e. source – destination)
2) The natural and man-made physical barriers (i.e. major rivers or interstates)
3) The administrative barriers (i.e. military bases or wilderness preserves), and
4) The budget/schedule for data collection (which are proportional to the size of study area).

Fortunately, existing electronic GIS maps typically provide sufficient supporting information for most organization’s study area delineation purposes.

PHASE 2: ESTABLISHING MACRO CORRIDORS

The second phase of route selection is the identification of Macro Corridors. These corridors utilize combinations of opportunity and sensitivity/constraint areas to make the desired connections between end points. The corridors may have a width of as much as a mile or greater, for segments that have substantial length through areas with negligible constraints. In developed areas, narrow corridors are often defined, but they should still have enough width to provide flexibility for engineering considerations in final routing of the line. Frequently existing linear facilities, especially of a similar type as the facility being sited, oriented in appropriate directions, are substantial opportunities for co-locating a proposed facility and may be identified as macro corridors.



Once the macro corridors are defined, all subsequent detailed data collection efforts are narrowed to focus only on these areas (as opposed to the entire study area). In support of defining macro corridors, organizations compile pertinent lower resolution geographic information and perform suitability analysis. Landsat Thematic Mapper 30-meter resolution satellite imagery is used as a source to create a land use/land cover classification. Other information such as conservation lands and terrain are also considered in this phase.

The user assigns suitability values to each class of land use and land cover. For example, open pastureland may be preferred over a forested wetland. Using a range of 1 – 9, with 1 being the most suitable and 9 the least suitable place for the new facility, the places that contain open pastureland are assigned values of 1 and the places that contain forested wetlands are assigned values of 9. A single suitability grid is generated combining all relevant weighted information.

Once the suitability grid is generated, a least cost path algorithm is run to assign "cost" or friction values to each cell in the study area. A cell's cost is determined not only by the suitability value assigned for the land use, but also by considering the distance away from the route end points.

The least-cost-path (LCP) procedure is a fundamental component of spatial analyses. In the context of grid data sets, algorithms calculate the least-accumulative cost distance over a cost surface. This is similar to calculating the direct distance between two points, "but instead of calculating the actual distance from one point to another, [the algorithms] determine the shortest cost distance (or accumulated travel cost) from each cell to the nearest cell in the set of source cells", according to Environmental Systems Research Institute (ESRI[*]).

A cost surface (cost grid) assigns a value to each cell representing the cost associated with crossing through any particular cell. The cost measurement systems usually represent things such as travel time, dollars, or a defined preference. In this case the defined preference is the relative suitability of each cell of land to host the new facility.

Given two source locations (two source grid cells), an accumulative cost of traveling to each neighboring cell of the source cells is calculated. The lowest cost cells are chosen and an accumulative cost is then calculated for *its* neighboring grid cells. This iterative process continues until the two sets of grid cells share a grid cell, connecting the two original cells together through a path representing the least accumulative cost associated with crossing the grid surface. All other possible grid-cells that could be routed through have their accumulative costs calculated and are used to determine alternate routes. <u>Authors' Notes</u>: For more information on Routing and Optimal Path procedures see Beyond Mapping columns in GeoWorld, July through October, 2003, compiled online

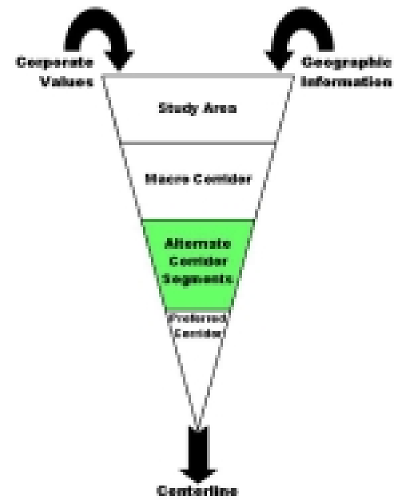
[*] ArcInfo On-line help

at www.innovativegis.com/basis/MapAnalysis/, select Topic 19. Links to further discussion of Delphi and AHP in Calibrating and Weighting GIS Model Criteria are included.

Macro corridors are generated by selecting a top percentage, say 3%, of the values in the cost grid. Detail data, such as high-resolution aerial photography and cadastral maps, are then collected to support the generation of alternate corridor segments, or alternate routes.

PHASE 3: ALTERNATE CORRIDOR SEGMENTS

The weighted overlay process occurs again once the micro database is available. The steps to create the suitability grid are similar using the macro or micro data. However, the detailed data is processed using a smaller grid cell size, or resolution. This requires more time to process, but is necessary in order to benefit from the more detailed data set.



After the suitability grid is created, least "cost" path analysis is performed using a *Constrained Least Cost Path Algorithm*™. The *Constrained Least Cost Path Algorithm*™ was developed[†] by *Photo Science Incorporated* to allow the user to enter engineering, or constructibility, constraints such as maximum angles or minimum distance between angles that a route can take. The previously existing least cost path algorithms did not consider these real criteria and therefore generated routes that were not constructible.

In the macro processing phase the product of the LCP analysis was the macro corridors. However, in the micro-processing phase the product is alternative corridor segments. These corridor segments are represented by the centerline of the corridor. Therefore alternative corridor segments are modeled in the GIS by a line. The comparison of the alternative corridor segments requires a buffer of the route to create a corridor for analysis purposes. It should be noted that even though the maps depict the alternative corridor segments as a line, this should not imply that the corridor is that narrowly defined. For example, as the process moves forward and a preferred corridor is selected, the line may shift from one side of the road to another after a more rigorous analysis of the selected route.

The standard LCP algorithm produces the statistically best single path, or route, between two points based on the geographic information and suitability values entered into the model. However, alternative corridors must be reviewed during the corridor selection process. There is typically only one statistically "best" route based on one set of parameters. However, there is a sound methodology to use LCP to generate alternative corridors. By varying the parameters the model will select different routes. For example, if more importance is placed on minimizing impact to the natural resources, and less importance is assigned to minimizing impact to land use, or people; the model will generate a route that minimizes impact to natural resources, or the land. Conversely, if more importance is placed on minimizing impact to the land use, or people, and less importance is assigned to minimizing impact to natural resources; the model will generate a route which minimizes impact the land use, or people. Additionally, more importance can be placed on cost and a route that minimizes dollar cost will be selected. It is conceivably possible that a single route could minimize impact to all three of these criteria, but highly unlikely. The reality is that all siting processes require trade-offs to be made and the organization should strive for balanced route selection criteria.

In addition to varying the relative importance of groups of data (such as natural resources or land use), the siting team may decide to vary the suitability of specific features. For example, if the team

---

[†] Beta testing 4th qtr. 2003

considers it a possible opportunity to parallel an existing transmission line, the corridor adjacent to the existing line will be weighted as an opportunity. However, if the team is unsure at the time of corridor generation whether paralleling an existing line is, in fact, an opportunity, then the model can be varied to produce a route for each criterion. When the team gets further into the route selection process the total risk of paralleling an existing line may be better defined.

There are still other methods used for generating alternative routes. When possible the start point of a route may vary, as in the case of routing from and existing transmission line to a substation. The siting team has flexibility in where the new line starts, or taps, the existing line. Therefore multiple start points are used to generate alternative corridors.

One some occasions a waypoint may be identified and the route is forced to pass through this point, regardless of the cost of the path. For example, if there is a potential future need for a new facility, in an intermediate location, between the current termini of the line being routed, the intermediate location may be identified as a waypoint in the model. This scenario, in essence, breaks the routing process into two parts. There is a route to go from point A - B and another route that connects point B and C. The A-B-C alternative is then compared with A-C alternatives throughout the route selection process, and again, later in the process, the total risk of each alternative is analyzed in more detail. This varying criterion methodology results in a critical need for the GIS Analyst to keep track of which criteria are used to generate specific routes.

After the route alternatives are generated using the LCP, siting experts gather in a team setting to insert the human component back into the process. Computer models are very efficient tools that allow users to analyze and abundance of data in a relatively short time frame. However, computer models are no substitute for many years of human experience siting, permitting, acquiring land, and constructing transmission lines. It is for this reason that siting teams scrutinize each of the routes generated by the LCP. During this process the team is encouraged to openly voice their opinions regarding the feasibility of the routes generated using LCP. It is critical for the GIS Analyst, or modeler, to obtain this feedback so that they can modify the model to truly represent organizational values and issues associated with facility constructability.

The siting team may choose to modify the alternative corridor segments generated through the LCP process. However, the macro corridors are used as a reference when aligning the segments. It is desirable to keep all route alternatives within the macro corridors.

PHASE 4: PREFERRED CORRIDOR

Once the project team has polished the alternative corridor segment network, the segments are combined into corridors. Overlay and proximity statistics are generated which provide a means for objectively comparing the alternatives. For example Route A may impact 10 acres of wetlands, but only come within 500’ of 5 houses. However, Route B may not impact any wetlands, but it may come within 500’ of 20 houses.

In addition to impact, monetary cost is analyzed by applying unit cost to statistical data. For example if Route A crosses 200 acres of pine trees valued at $1000 per acre, the cost for this line item is estimated to be $200,000. Many line items are cumulated to calculate the total *relative* cost of each route alternative. This data, along with the impact statistics and risk analysis are used to select the preferred corridor for the new facility.

CONCLUSION

There is a need to construct new linear facilities to transport energy, goods, and people. The goal is to locate these new facilities so that they supply the greatest utility to the public in the most efficient manner possible while minimizing negative impacts to people and the natural environment. The corridor analysis methodology has evolved over the years to take greater advantage of computers, allowing the siting teams to analyze an abundance of information efficiently. The methodology supports the entire corridor selection workflow by addressing the creation of suitability grids, the generation of alternate routes, the generation of comparative statistics and relative cost estimates. Organizations that use this methodology to select the site for their new linear facilities are empowered with information that facilitates sound decision-making.

BIBLIOGRAPHY

Berry, J., PhD., 2003, *Identifying the Most Preferred Route*, GeoWorld 2003, http://www.innovativegis.com/basis/MapAnalysis/Topic19/Topic19.htm

Glasgow, J., Berry, J., PhD., French, S., PhD., Zwick, P., PhD., Richardson, S., Kramer, E., PhD., 2004, *Finding Preferred Routes for Power Line,s* Feature article for GeoWorld, published monthly by Adams Business Media, a division of MCA Communications, LLC. April, 2004

Hudsal, J., PhD., 2001, *Corridor Analysis – A Timeline of Evolutionary Development,* http://www.husdal.com/gis/corridor.htm

Environmental Systems Research Institute, 2000, COSTDIST, ArcInfo Online Help