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Keiron Bailey
University of Arizona

Ted H. Grossardt
University of Kentucky, tedgrossardt@gmail.com

Ward Jewell
Wichita State University

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Keiron BAILEY; Ted GROSSARDT** & Ward JEWELL****

*Department of Geography and Regional Development, University of Arizona, Harvill Box #2, Tucson AZ 85721
**Kentucky Transportation Center, 176 Raymond Building, Lexington KY 40506
***Department of Electrical Engineering, Wichita State

1 INTRODUCTION

The North American electric transmission network was developed under the guidance of the North American Electric Reliability Council (NERC) to enhance the reliability of electricity supply. The network also allows sale and marketing of electric power by one utility to another. Electricity marketing has taken on a much more prominent role with restructuring of the electric utility industry. As a result, long-distance sales of electric power have greatly increased the loading of some transmission lines, and have led to congestion on the transmission network. Recent system failures such as the northeast blackout of 2003 have highlighted the need for increased capacity. While some upgrades of existing infrastructure will be undertaken, some of this capacity must be provided through new transmission lines.

2 TRANSMISSION LINE ROUTING: A SOCIO-TECHNICAL PERSPECTIVE

It is clear that public frustration with, and opposition to, current methods of transmission line placement have impeded grid upgrades and continue to do so. The current crisis situation is rooted in problems that have historically surrounded line placement. Few lines have been constructed in recent years. The rules for the restructured industry provide few financial incentives for building new lines. When a utility does take the financial risk of new line construction, it will often meet with significant public opposition, based on a host of environmental, aesthetic, health, safety, and other, sometimes unanticipated, issues. Such opposition can greatly increase costs and delay lines for years. Plans for several lines, which were easily justified technically and financially, have been finally abandoned due to public opposition. This problem has been brought into sharp focus for the public because of the recent regional power grid failure events. As Mr. Weisgall of MidAmerican Energy Holdings Co recently observed in the *Washington Post*; "Where would 30,000 miles of new transmission lines go? That's the problem. Nobody wants them."

A review of current best practices reveals that advanced spatial analytic methods are not widely used as part of the decision support system to optimize location (State of Alaska BLM 1998). A typical process model is as follows:

i. Utility and other involved parties define need for a new transmission line and approach public authorities.

ii. Public officials announce the intent to build the line and suggest a timeline.

iii. A set of public forums are planned. Many are held under the auspices of NEPA regulations. These include setting a "window" for input. NEPA-mandated concerns are mainly treated as physical environmental matters.

iv. Information gathered from these meetings is transcribed and summarized.

v. GIS is used by the involved parties to locate features and prospective routes.

vi. A series of "preferred options" or numbered line routings are presented to the public on maps or GIS output plots.

vii. Selection is made based on least vocal opposition to the lines shown, or no selection is made based on depth of public opposition.

While the process seeks public involvement with honest intent, key weak points include:

Segmentation of responsibilities. Under the fragmentation of public organizations over the last 30 years, in part as a response to NEPA mandates, different organizational units are in charge of different "pieces of the pie." Sometimes, there is no structured forum at which cross-cutting concerns can be voiced. This is evident in some transmission line cases in the after-the-fact reaction of certain user groups who feel excluded.

A lack of transparency about how the actual routing decisions were made. This lack reduces public support for the chosen option and erodes public confidence in the activities of the responsible parties.

The weighting of factors is not rendered explicitly. This is attributable to the lack of a formalized decision methodology that enables analytical tradeoffs to be made. Further, it is not clear the extent to which the GIS is being integrated into the analytics of the decision making. In many cases GIS is used as a display platform to automate map production of prospective routes rather than as part of an integrated spatial analytic system.

These concerns cannot be separated from the way in which technologies are embedded into this process: for example, if the GIS system used to locate and count decision elements is built and viewed by a small cadre of professionals, it is hard for other participants to use the output as an opportunity to iterate their criteria selection and weightings.

In combination these shortcomings contribute to a decision mode characterized by some public involvement practitioners as DAD or "Decide, Announce and Defend" [1] in which a small set of pre-formed options are defined by experts, out of sight, and then taken to the public. This process circumscribes or undermines discussion of relevant criteria and their weights.

In some cases, the traditional route planning process actually helped mobilize opposition groups by avoiding public involvement until well into the planning process, and then discovering (sometimes at a public meeting) that an important issue for the local community had been missed. Such opposition groups were then able to delay line construction through lawsuits and other tactics. In response, utilities have learned to provide more information about line routes to the public earlier in the planning process. They are using more sophisticated techniques to inform the public of plans, and public input is sometimes accepted on alternate routes.

Even with these techniques, however, primary responsibility for planning the line route still rests with the owner of the transmission lines and is based mainly on traditional technical and construction issues. While this answers many of the requirements, a more effective public involvement process will help resolve many of the potential objections of the public. It is possible and even desirable to have a well-planned approach to public involvement in questions regarding the planning and design of publicly-used infrastructure. Professionals who regularly work with public design issues have documented much of their experience for use in similar problems.

The solutions to these complex issues require a socio-technical perspective; that is, they should rely on technological improvements in conducting capacity to reduce required footprint and system dimensions, but at the same time, the technical system interface with the public and other stakeholders must be improved. Bureaucratic and or/non-transparent impositions of preferred routings on skeptical publics will increase mistrust and will not facilitate a long-term solution. Based on this premise it is imperative that routing methodologies consider and incorporate effective principles of public, multi-stakeholder involvement.

3 SIGNIFICANT ASPECTS OF SUCCESSFUL PUBLIC INVOLVEMENT

A set of fundamental goals defines successful public involvement in complex planning and design questions [2]. These goals reflect the experiences of community planning professionals, facilitators, architects, transportation and land-use planners. They include the following:

The public should be involved instead of marketed to Dynamic two-way communication should be established The process should be inclusive of all stakeholders and create mutual understanding Respectful communication becomes the norm Early and continuous engagement occurs The decision process is defined, structured, and transparent Agency leadership helps make process happen and provides resources to enable the process.

While these are laudable goals in the abstract, they imply a more fundamental shift in the worldview of professional planners and designers [3]. Community design professionals suggest the following principles to help guide public involvement work:

No design is too complex for the public to participate in. Users are neither in complete agreement nor complete disagreement. Participation requires time and effort. The public can be frightening to professionals. More participation is better, and always a struggle. The public can develop useful compromises.

These principles form the basis for the KTC's Structured Public Involvement (SPI) protocols [4]. SPI protocols are designed to ensure that public input into the design and planning process happens before the process is begun: that is, planners and/or designers gain a clear and documented image of public preferences as part of their initial design process. This allows professionals to avoid "guessing" about public preferences and investing much time and effort in plans and designs that are fatally flawed from the point of view of the general public. Publicly unpopular designs can occur because professionals have no useful or practical way to access public preferences. In the worst cases public involvement then becomes a chaotic, disturbing, even counterproductive moment in the planning and design process.

SPI embeds advanced technologies into iterative public involvement processes that maximize the technology's decision-support and public engagement capacities. The team has worked with virtual reality and other visualization technologies as well as decision theoretic methods and GIS in a variety of large-scale multi-stakeholder projects [5,6]. The primary methodology for this project is the team's GIS-based Analytic Minimum Impedance Surface (AMIS) that allows large numbers of diverse participants (public or professionals) to participate in the creation of a routing tool that explicitly includes all of their landscape and environmental feature and preference information in the routing decision process [7].

4 SUMMARY OF ROUTING ISSUES

It is evident that electric transmission line routing problems share many of the characteristics of other public infrastructure location questions, including landfills and other NIMBYs. The problem is always complex: it covers a large area and involves a wide range of stakeholder groups with often competing objectives. Routing demands consideration of a wide range of variables, such as current landuse and settlement patterns, environmental health considerations, locations and habitats of rare species and geomorphological phenomena relevant to construction and maintenance [8]. The problem of integrating these into an analytic system is compounded because some data are point phenomena with specific physical locations, such as structures or localized threatened and endangered species habitat, some are linear data, such as streams and rivers, while others are aggregated and/or interpolated area data, such as National Forest Lands, wetlands, areas with common demographic characteristics, or areas of technical and construction concern [9].

Given this background the aims of the project are to develop and apply a methodology that demonstrates high performance with regard to these four principles:

1. Respect. The process must respect all stakeholders by considering their input and making effective use of this information to influence line placement. It must also be seen to do so fairly by all involved parties.

2. Transparency. It must offer each stakeholder group the opportunity to see and understand the priority system of other stakeholder groups.

3. Efficiency. It should generate useful, easily-understood, transparently-derived and easily iterated preferred transmission line corridor options.

4. Analytic capacity. For user-selected corridors, it must allow detailed corridor inspection, showing meters of coverage of each landscape element and numbers or units of features covered. It must be capable of rapid sensitivity analysis, showing how preferred

corridors across the landscape are affected by varying weightings or tradeoffs of input values. It must show visual configurations of the preferred line placement and how they affect views.

The outcome of a successful protocol will be higher satisfaction with the process and outcomes. A more inclusive, explicitly analytical method that renders transparent the optimization process, using criteria defined and weighted by both relevant expert groups and community input, and which offers iterative feedback opportunities, is the basis for this result. To that end, several evaluation and assessment measures are proposed. These will investigate the degree to which this protocol achieves its aims and to pinpoint areas where it may be improved [10].

5 PRINCIPLES OF THE DECISION LANDSCAPE

The *decision landscape* consists of a surface representing a decision criterion, such as *cost* or *desirability*. It is generated by specifying and quantifying a decision criterion for a wide variety of physical, environmental and socioeconomic attributes and then assigning them a location. Physical attributes include features of the built environment, such as airports, cemeteries and archaeological sites. Environmental attributes include not only the location of endangered species, but also their range and habitat. These also include air and water quality indices and ecosystem evaluations. Socioeconomic attributes are modeled in the form of social and community impacts. The decision landscape is computed and displayed by means of a raster-based GIS.

The decision landscape is a powerful and flexible means of assessing social and environmental factors in a dynamic context. It provides a graphical summary of all development features that facilitates comment and feedback at public meetings and other forums. It offers a powerful analytic tool that can be used in a number of ways to examine any type of development and its impact. Various operations can be performed on this decision landscape: such as point-to-point route “cost” minimization, buffer zone impact minimization, net environmental health hazard mitigation and so on. Because the methodology is quantitative the benefits of specific locational strategies may be analyzed closely and compared with a strong degree of confidence. Moreover, distance-decay spatial effects can be modeled accurately using origin points and mathematical functions.

5.1 AMIS: The Design Process

A State Highway Agency (SHA) requested an analytic methodology for highway corridor comparison. The problems identified and the requirements specified were analogous to those encountered in the electric transmission line problem. A decision criterion termed *impedance* was the core of AMIS [7]. In its simplest interpretation, impedance represented a reluctance to pave. This criterion recognized complexity in decision making. Instead of assuming that for financiers impedance was directly proportional to the cost of routing the Interstate over that feature or attribute, or that for engineers it represented difficulty of construction and so on, it allowed each participant to sum their judgments across diverse, competing criteria. The acronym AMIS was derived from the conjunction of the A - *analytic* hierarchy method - with the MIS - *minimum impedance surface* logic.

AMIS was designed from the ground up to incorporate input from as many sources as possible. In its prototype form, this represented input from a variety of federal (FHWA) and SHA representatives, including Engineers, Planners and Environmental specialists. This process took place over a period of approximately six months, with sets of meetings being held to move through the design stages. Facilitation methodologies were employed at each of these meetings to maximize stakeholder input.

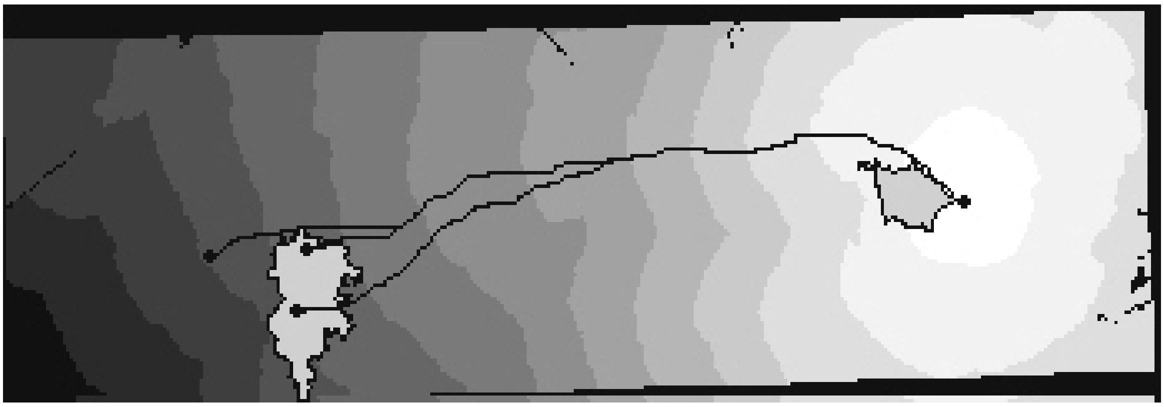
AMIS was built by specifying the multicriteria priority model and weighting its factors and then integrating this data into the GIS to create the impedance surface. The multicriteria model was comprised of a three-layer information hierarchy of surface data elements (originally 69 of these), affinity groupings of the 69 data elements (5 total) and FHWA Purpose & Need categories (8 total). The multicriteria model was designed to determine a final impedance score for each of the elements that could be assigned to a specific feature in Arc/Info.

To gather input data, the research team began with elements identified during preliminary phases. Other elements, identified as conceptually desirable, were added and data coverages were then located for the study area. The GIS data used in the AMIS prototype was taken from the public domain. Nearly 80% of the data could be assembled for analysis of a similar route within two weeks. This offered a much more rapid assessment than conventional contracting processes. The team’s original list was based on knowledge of GIS-suitable data available through organizations such as the USGS and the Area Development Districts. Much of this data was already available for download in database format from the websites of these organizations. Data that would require extensive and costly primary surveying was explicitly avoided. For these reasons the team proposes to use the same grid resolution (30 meters square) for the electric transmission line application.

5.2 Features and Output

In its prototype form AMIS was used to generate an optimum (least-effort/most productive) corridor and to inspect various corridor options for their trade-offs in total scores (Figure 1).

Figure 1: Optimum Corridors Across an AMIS Cumulative Cost/Distance Landscape



AMIS was used to explore the costs of various trade-offs against the rest of the cost surface. For example, the total offsetting costs for accomplishing a particular routing (say, near a tourist attraction) can be estimated through adjusting the attractor value assigned to the feature until the optimum route chooses that path. Alternatively, a set of required coordinates can be specified to AMIS and it will produce the optimum path that includes these specified locations. AMIS can also be used to evaluate the overall score of specified paths and determine the number and nature of features contained within a proposed corridor.

AMIS can be used in a long-range planning sense to explore the early implications of potential corridor locations, or modifications to existing corridors. Highway rehabilitations can be tested mathematically by using AMIS to summarize potential obstacles and issues near a current corridor. A third potential application is infrastructure investment options evaluation. For example, AMIS can be used to quantify more accurately and completely the landscape issues associated with various competing infrastructure investment options. It also allows context-sensitive quantitative comparisons to be made between different environmental policy strategies. The system's sensitivity analysis also satisfies "what if's" in public forums: if criteria modification is proposed, the costs and benefits can be viewed by all participants. This feature of demonstrating clearly to stakeholders how public involvement literally shapes important choices such as corridor alignments and facility locations is a critical advantage of the methodology.

5.3 Highway Project Outcome Summary

When integrated into a wide-ranging multi-stakeholder involvement process the key advantages of the AMIS methodology compared with more traditional, unstructured methods are respect, transparency, flexibility and analytic capacity. In the pilot project, for example, AMIS encouraged the explicit incorporation of specific Purpose and Need categories in the initial stages. This opened a discussion that helped clarify the goals of route planning; a result that was not anticipated by the SHA participants but one that was regarded as fruitful. Moreover, during public consultation cave locations were identified and these were later incorporated. Prior to this phase the SHA did not know of the existence of the caves, their locations, or the strength of public feeling regarding their conservation.

Second, the early integration of stakeholder groups and the formalized approach to group priority-setting reduced the potential for conflict and enhanced the consensual strength of the outcome [11]. Once shown the decision system in operation, participants showed increased enthusiasm and willingness to cooperate ([12,13] for similar results in AHP applications). Enhancing "buy-in" is clearly critical to the utility and its partners.

Third, AMIS offered a customizable framework around which specific projects can be built. Planning priorities can be customized for individual projects, or planning priorities could be mixed over different sections of the same route. So while the process would be the same for different corridors, the values chosen and the comparative priority of goals might not be.

Finally, AMIS data collection permitted the elements and values solicited from stakeholder forums to be compared directly with the values generated by transportation professionals. This allowed participants to evaluate the extent to which professionals were in step with public constituents in determining environmental and other criteria that affected highway placement.

6 SIMILARITIES AND DIFFERENCES BETWEEN THE ROUTING OF POWER TRANSMISSION LINES AND HIGHWAYS

There are parallels between the problem of routing highways and that of routing power transmission lines. In both cases, the infrastructure is generally seen as a detriment to the visual landscape, while still providing certain generalized, non-aesthetic public benefits. Also, the complete impact of the infrastructure is heavily reliant on the ultimate routing alignment, so that a "build-no build" decision is partially dependent on the routing alignment. This means that the process of deciding *whether* to build a new transmission line must involve the public in a careful consideration of *where* it might go.

Certain properties of the transmission line routing problem distinguish it from a highway routing problem, and form important aspects of the research problem. Initially, a complex process decides the need for a new transmission line. In addition to power transportation issues, a number of other issues are considered, including system reliability, security, and ancillary services [14].

At the same time, the transmission lines' benefit to residents is certainly more spatially abstract and less immediately obvious to those in its proximity than is a highway. Because of their immediate physical presence in the landscape, highways have a greater total potential for creating barriers and hazards. Thus, habitat interruption and destruction are more extensive in the right of way for a highway than a power transmission line, and the nature of highway proximity drawbacks (noise, privacy loss, pollutants, and trash) are different than power lines (electromagnetic fields, interrupted views). Conversely, a highway offers the potential for immediate direct benefit to many people located near its right of way (depending on the access properties of the road). The benefits of a highway are also clear to those who will use it. Power transmission lines may not offer the promise of the same direct local benefit. Even if they do, the benefits are more difficult for a layperson to understand, especially if electric service is already reliable and reasonably priced. Transmission lines thus may take on more of the properties of a pure Locally Undesirable Land Use (LULU).

Thus the judgment of the public regarding the intersection of landscape features and transmission lines is likely to be qualitatively and quantitatively different than the highway problem. Because the process is flexible and accommodative, the differences should yield a new and interesting view of how the public views the transmission line routing problem. AMIS anticipates and accommodates this process by encouraging participants to provide the landscape features and the values to be attached to those features for purposes of the routing problem. By soliciting, gathering, and documenting this information, professionals can show how their process of route planning explicitly includes the public's input and wishes. Thus the public, through use of this process, becomes part of the solution process instead of fracturing into contending parties over competing alignments.

While both highway and power transmission line routing strive to discover the shortest practical route, the cost of distance in the highway problem is more or less directly proportional to distance. In the power line routing case, cost is a non-linear function: increasing distance may result in the need to shift the design specifications of the entire line once it exceeds certain critical distance parameters, and the need for a new line may not be an exact specification. For example, two neighboring utilities may agree that a new interconnect is needed to allow the sale of excess capacity from one to the other, and to improve reliability on both systems. There may be a number of points, which can be specified by the utilities, at which the two could be interconnected to achieve the goals. However, complex line routing, with excessive curves or turns in the line, adds to the line length. Increased length will add to the cost of the line simply because of the additional materials and construction needed for the increased length. Sophisticated construction techniques and components needed for complex routes will also increase costs above those of straighter routes.

The route, however, will affect the line's electrical properties as well. The primary electrical characteristics of a line are its thermal and stability limits, and its resistive losses. Thermal and stability limits determine how much power the line can carry. Thermal limits vary with ambient temperature and are a function of the size of conductors used. Stability limits depend on the size and configuration of conductors. Resistive losses are the power lost to heat during transmission, and they also depend on the conductor size. Thus, after a certain increase in length, larger conductors and more complex configurations, which may increase costs, will be needed. At some point the line will no longer be feasible. These issues and costs must be assessed in the routing process and will be considered in the proposed project.

While highway investment decisions are partly fiscal and partly political, the feasibility of an electric transmission line will largely be a financial decision, but it is a complicated process that is evolving as the industry restructures. Monetary values can be placed on future sales, on ancillary services, and on the cost of the line. Reliability and security issues are more difficult to price, but must be considered. Utilities should be able to give some guidelines at the start of the design/routing process for the route to remain within in order to be feasible. Guidelines might include defining a fairly large geographical corridor, and a maximum line length, and possibly other criteria. Such guidelines will put limits on the routing process up front, and constitute legitimate aspects of the overall research question.

Because highways must accommodate moving vehicles, the geometries of the horizontal and vertical curvature, width, and slope of the roadway must meet certain minimum requirements. As the capacity of the roadway increases, it must be straighter, wider, and flatter. However, the overall footprint of a power transmission line may be less closely linked to the capacity requirements of the line, and may allow more flexibility in the horizontal and vertical curvature properties of the final route. This may allow more innovative routing solutions to be devised.

Similarly, the engineering problems of crossing rough landscape may be significantly different, in that bridging problems are quite different between highways and power transmission lines. A highway, except for bridges, is continuously in contact with the land. A transmission line only has towers located periodically along its length, and their location can be designated to accommodate rough landscape.

Finally, because of the difficulty of acquiring right-of-way for publicly-used infrastructure, there may be an argument for shared right-of-way between highways and power transmission lines. The impact of widening existing roadway right-of-way versus acquiring dedicated right-of-way elsewhere may be a important consideration for the routing process.

The impact of these differences may well have significant impacts on how the decision surface is generated and how it is employed to address the power transmission line routing problem. Thus, while the fundamentals of the technical and process questions have been piloted in the AMIS highway pilot, significant questions remain to be answered to bring the engineering requirements and impedance landscape properties together into a satisfactory electric transmission line routing solution. Moreover, the project proposes the integration of advanced electronic polling technology to gather stakeholder input, allowing more participants to give their values per unit of research team time.

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