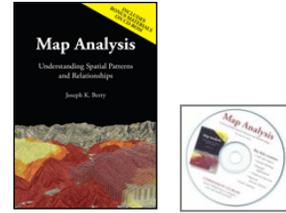


Topic 8 – Spatial Modeling Example



[Map Analysis](#) book/CD

[A Three-Step Process Identifies Preferred Routes](#) — describes the basic steps in Least Cost Path analysis

[Consider Multi-Criteria When Routing](#) — discusses the construction of a discrete “cost/avoidance” map and optimal path corridors

[A Recipe for Calibrating and Weighting GIS Model Criteria](#) — identifies procedures for calibrating and weighting map layers in GIS models

[Think with Maps to Evaluate Alternative Routes](#) — describes procedures for comparing routes

[Further Reading](#) — seven additional sections

[Click here](#) for a printer-friendly version of this topic (.pdf).

[Back to the Table of Contents](#)

A Three-Step Process Identifies Preferred Routes

(GeoWorld, July 2003)

[\(return to top of Topic\)](#)

Suppose you needed to locate the best route for a proposed highway, or pipeline or electric transmission line. What factors ought to be considered? How would the criteria be evaluated? Which factors would be more important than others? How would you be able to determine the most preferred route considering the myriad of complex spatial interactions?

GIS data can set the stage by displaying individual maps of decision criteria but visual assessment of a bunch of maps taped to the wall is overwhelming. Swiveling your head back and forth rarely provides the detailed coincidence information needed to locate the best route. Map overlay can be used to combine the maps for viewing but manual delineation of the route still lacks the objective, quantitative and exhaustive approach provided by map analysis.

For example, you might be interested identifying the most preferred route for a power line that minimizes its visual exposure to houses. The first step, as shown in figure 1, involves deriving

an exposure map that indicates how many houses are visually connected to each map location. From previous discussion (see Author’s Note 1) you might recall that visual exposure is calculated by evaluating a series of “tangent waves” that emanate from a viewer location over an elevation surface.

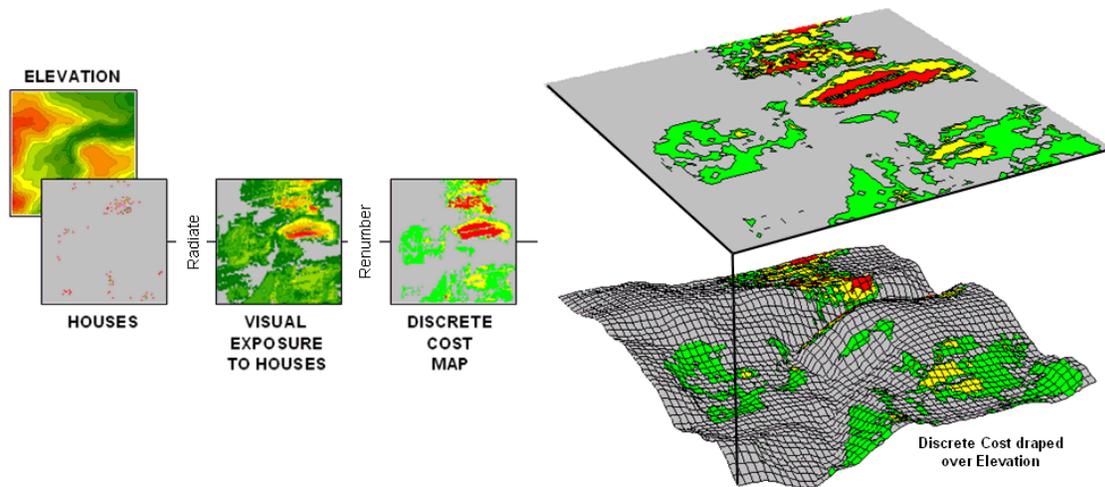


Figure 1. (Step 1) Visual Exposure levels (0-40 times seen) are translated into values indicating relative cost (1=low as grey to 9=high as red) for siting a transmission line at every location in the project area.

This process is analogous to a searchlight rotating on top of a house and marking the map locations that are illuminated. When all of the viewer locations have been evaluated a map of Visual Exposure to houses is generated like the one depicted in the left inset. The specific MapCalc command (see Author’s Notes 2) for generating the exposure map is *RADIATE Houses over Elevation completely For VisualExposure*.

In turn, the exposure map is calibrated into relative preference for siting a power line— from a cost of 1 = low exposure (0 -8 times seen) = most preferred to a cost of 9 = high exposure (>20 times seen) = least preferred. The specific command to derive the Discrete Cost map is *RENUMBER VisualExposure assigning 1 to 0 through 8 assigning 3 to 8 through 12 assigning 6 to 12 through 20 assigning 9 to 20 through 1000 for DiscreteCost*.

The right-side of figure 1 shows the visual exposure cost map draped on the elevation surface. The light grey areas indicate minimal cost for locating a power line with green, yellow and red identifying areas of increasing preference to avoid. Manual delineation of a preferred route might simply stay within the light grey areas. However a meandering grey route could result in a greater total visual exposure than a more direct one that crosses higher exposure for a short stretch.

The Accumulative Cost procedure depicted in figure 2, on the other hand, uses effective distance to quantitatively evaluate all possible paths from a starting location (existing power line tap in this case) to all other locations in a project area. Recall from previous discussion that effective distance generates a series of increasing cost zones that respond to the unique spatial pattern of preferences on the discrete cost map (see Author’s Note 3).

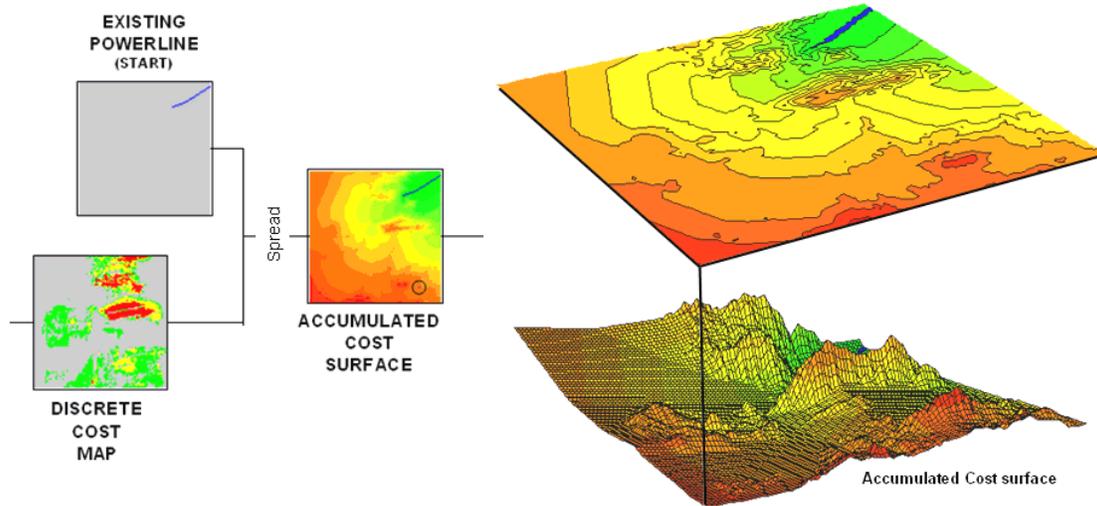


Figure 2. (Step 2) Accumulated Cost from the existing power line to all other locations is generated based on the Discrete Cost map.

This process is analogous to tossing a rock into a still pond—one away, two away, etc. With simple “as the crow flies” distance the result is a series of equally spaced rings with constantly increasing cost. However, in this instance, the distance waves interact with the pattern of visual exposure costs to form an Accumulation Cost surface indicating the total cost of routing a route from the power line tap to all other locations—from green tones of relatively low total cost through red tones of higher total cost. The specific command to derive the accumulation cost surface is *SPREAD Powerline through DiscreteCost for AccumulatedCost*.

Note the shape of the zoomed 3D display of the accumulation surface in figure 3. The lowest area on the surface is the existing power line—zero away from itself. The “valleys” of minimally increasing cost correspond to the most preferred corridors for sighting the new power line on the discrete cost map. The “mountains” of accumulated cost on the surface correspond to areas high discrete cost (definitely not preferred).

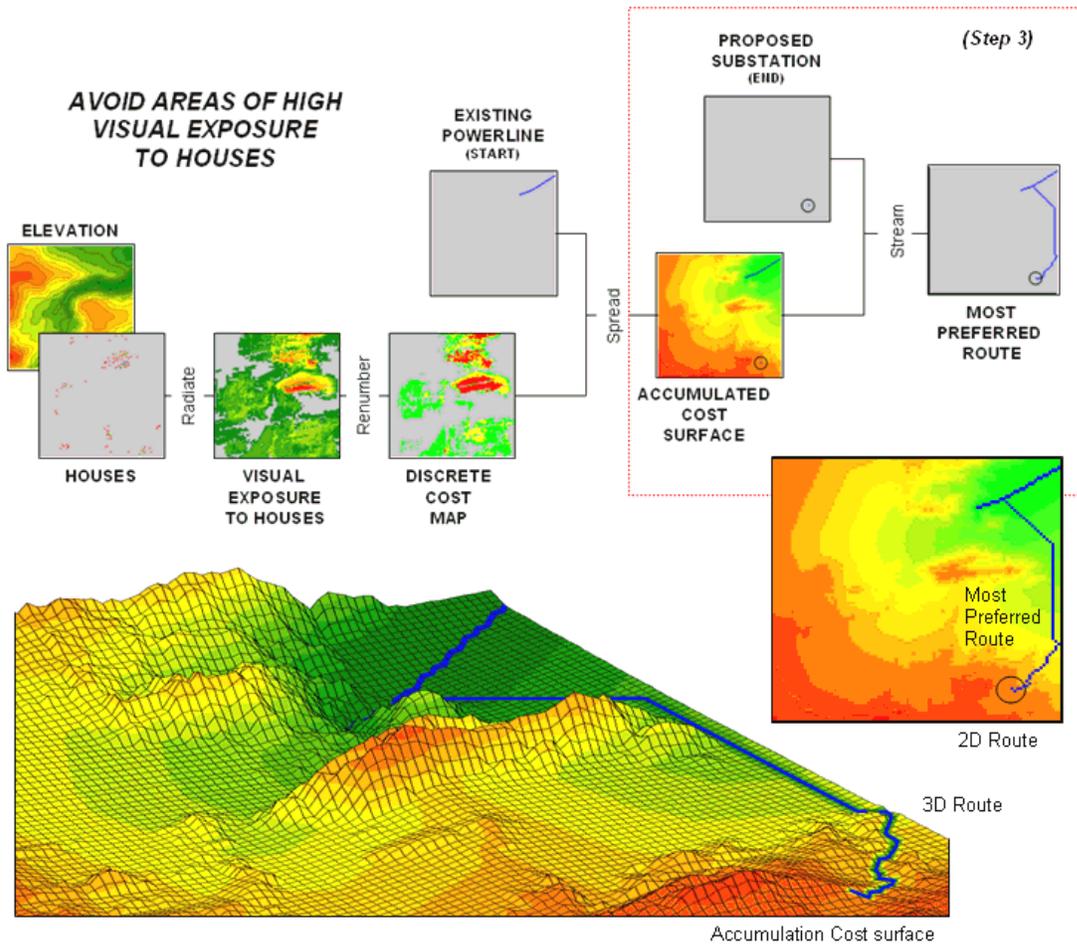


Figure 3. (Step 3) The steepest downhill path from the Substation over the Accumulated Cost surface identifies the Most Preferred Route minimizing visual exposure to houses.

The path draped on the surface identifies the most preferred route. It is generated by choosing the steepest downhill path from the substation over the accumulated cost surface using the command *STREAM Substation over AccumulatedCost for MostPreferred_Route*. Any other route connecting the substation and the existing power line would incur more visual exposure to houses.

The three step process (*step 1* Discrete Cost → *step 2* Accumulated Cost → *step 3* Steepest Path) can be used to help locate the best route in a variety of applications. The next section will expand the criteria from just visual exposure to other factors such as housing density, proximity to roads and sensitive areas. The discussion focuses on considerations in combining and weighting multiple criteria that is used to generate alternate routes.

Author's Notes: 1) See previous Topic 5, *Calculating Visual Exposure*. 2) *MapCalc Learner* (www.innovativegis.com) commands are used to illustrate the processing. The Least Cost Path procedure is available in most grid-based map analysis systems, such as ESRI's GRID, using RECLASS to calibrate the discrete cost map, Costdistance to generate the accumulation cost surface and PATHDISTANCE to identify the best path. 3) See previous Topic 4, *Calculating Effective Distance*.

Consider Multi-Criteria When Routing

(GeoWorld, August 2003)

[\(return to top of Topic\)](#)

The previous discussion described a procedure for identifying the most preferred route for an electric transmission line that minimizes visual exposure to houses. The process involves three generalized steps—discrete cost → accumulated cost → steepest path.

A map of relative visual exposure is calibrated in terms preference for power line siting (*discrete cost*) then used to simulate siting a power line from an existing tap line to everywhere in the project area (*accumulated cost*). The final step identifies the desired terminus of the proposed power line then retraces its optimal route (*steepest path*) over the accumulated surface.

While the procedure might initially seem unfamiliar and conceptually difficult, the mechanics of its solution is a piece of cake and has been successfully applied for decades. The art of the science is in the identification, calibration and weighting of appropriate routing criteria. Rarely is one factor, such as visual exposure alone, sufficient to identify an overall preferred route.

Figure 1 shows the extension of the discussion in the previous section to include additional decision criteria. The bottom row of maps characterizes the original objective of avoiding Visual Exposure. The three extra rows in the flowchart identify additional decision criteria of avoiding locations in or near Sensitive Areas, far from Roads or having high Housing Density.

Recall that *Base Maps* are field collected data such as elevation, sensitive areas, roads and houses. *Derived Maps* use computer processing to calculate information that is too difficult or even impossible to collect, such as visual exposure, proximity and density. The *Cost/Avoidance Maps* translate this information into decision criteria. The calibration forms maps that are scaled from 1 (most preferred—favor siting, grey areas) to 9 (least preferred—avoid siting, red areas) for each of the decision criteria.

The individual cost maps are combined into a single map by averaging the individual layers. For example, if a grid location is rated 1 in each of the four cost maps, its average is 1 indicating an area strongly preferred for siting. As the average increases for other locations it increasingly encourages routing away from them. If there are areas that are impossible or illegal to cross

these locations are identified with a “null value” that instructs the computer to never traverse these locations under any circumstances.

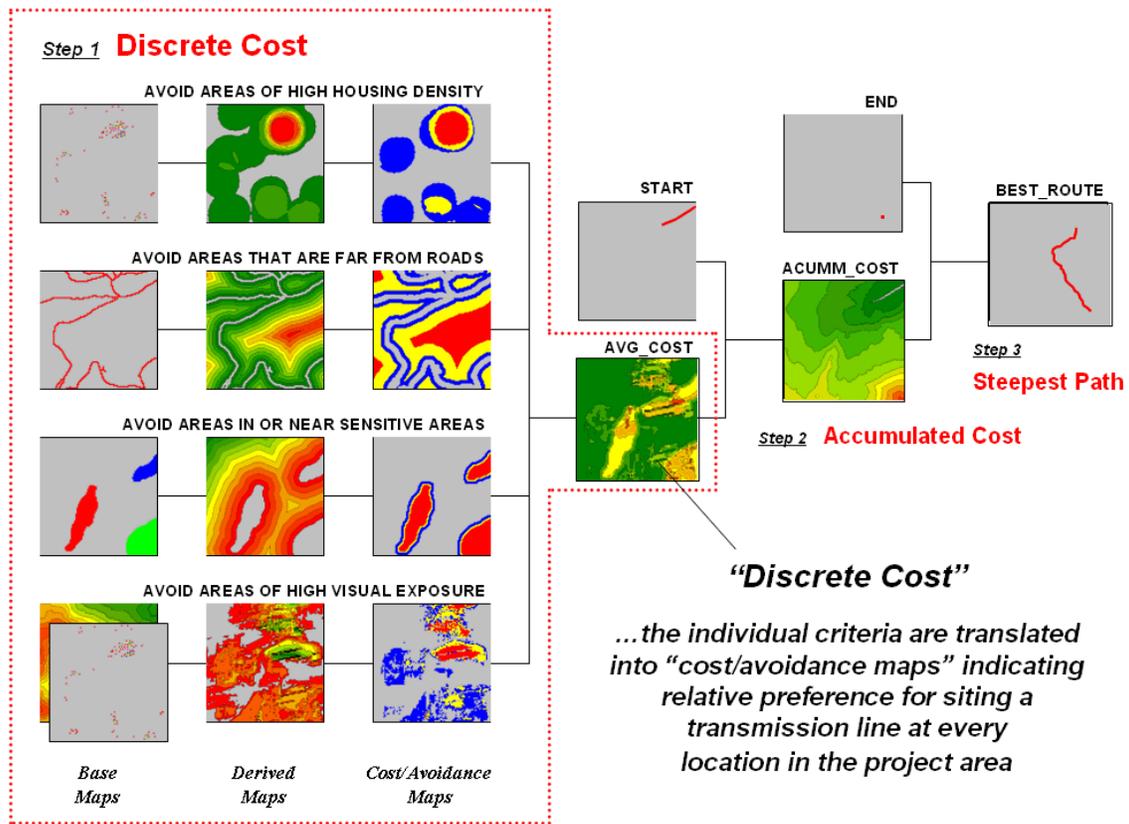


Figure 1. Discrete cost maps identify the relative preference to avoid certain conditions within a project area.

The calibration of the individual cost maps is an important and sensitive step in the siting process. Since the computer has no idea of the relative preferences this step requires human judgment. Some individuals might feel that visual exposure to one house constitutes strong avoidance (9), particularly if it is their house. Others, recognizing the necessity of a new power line, might rate “0 houses seen” as 1 (most preferred), 1 to 2 houses seen as 2 (less preferred), through more than 15 houses seen as 9 (least preferred).

In practice, the calibration of the individual criteria is developed through group discussion and consensus building. The Delphi process (see author’s note) is a structured method for developing consensus that helps eliminate bias. It involves iterative use of anonymous questionnaires and controlled feedback with statistical aggregation of group responses. The result is an established and fairly objective approach for setting preference ratings used in

deriving the individual discrete cost maps.

Once an overall *Discrete Cost* map (step 1) is calculated, the *Accumulated Cost* (step 2) and *Steepest Path* (step 3) processing are performed to identify the most preferred route for the power line (see figure 1). Figure 2 depicts a related procedure that identifies a preferred route corridor.

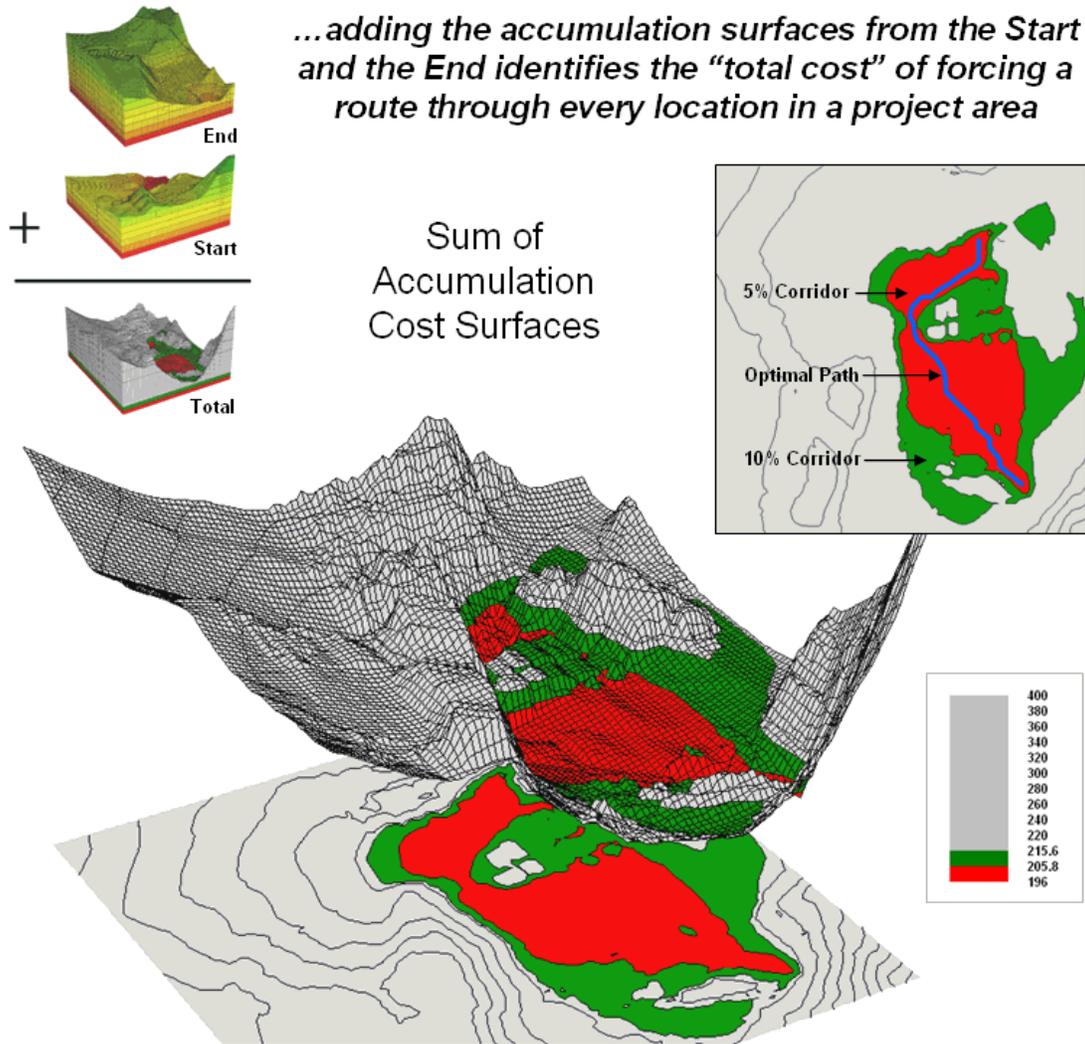


Figure 2. The sum of accumulated surfaces is used to identify siting corridors as low points on the total accumulated surface.

The technique generates accumulation surfaces from both the Start and End locations of the proposed power line. For any given location in the project area one surface identifies the best

route to the start and the other surface identifies the best route to the end. Adding the two surfaces together identifies the total cost of forcing a route through every location in the project area.

The series of lowest values on the total accumulation surface (valley bottom) identifies the best route. The valley walls depict increasingly less optimal routes. The red areas in figure 2 identify all of locations that within five percent of the optimal path. The green areas indicate ten percent sub-optimality.

The corridors are useful in delineating boundaries for detailed data collection, such as high resolution aerial photography and ownership records. The detailed data within the macro-corridor is helpful in making slight adjustments in centerline design, or as we will see next month in generating and assessing alternative routes.

Author's Notes:

[<click here>](#) to download a PowerPoint slide set summarizing the Routing and Optimal Path process.

[<click here>](#) to download a PowerPoint slide set describing calibration and weighting.

[<click here>](#) to download an animated PowerPoint slide set demonstrating Accumulation Surface construction.

[<click here>](#) to download an animated PowerPoint slide set demonstrating Optimal Corridor analysis.

[<click here>](#) to download a short video (.avi) describing Optimal Path analysis.

A Recipe for Calibrating and Weighting GIS Model Criteria

(GeoWorld, September 2003)

[\(return to top of Topic\)](#)

The past two sections have described procedures for constructing a simple GIS model that determines a preferred route for a proposed electric transmission line. The discussion focused on the spatial logic inherent in the solution and its expression as a flowchart and processing code. The model's structure is representative of most suitability models and is composed of a series of processing steps that are analogous to a cooking recipe—do this, and this, then that, and that, etc.—except the result is a prescriptive map instead of a chocolate cake.

As in cooking, the implementation of a spatial recipe provides ample room for interpretation and varying tastes. For example, one of the criteria in the routing model seeks to avoid locations having high visual exposure to houses. But what constitutes “high” ...5 or 50 houses visually impacted? Are there various levels of increasing “high” that correspond to decreasing preference? Is “avoiding high visual exposure” more or less important than “avoiding locations near sensitive areas.” How much more (or less) important?

Calibrating Map Layers (Most Preferred) 1 3 6 9 (Least)

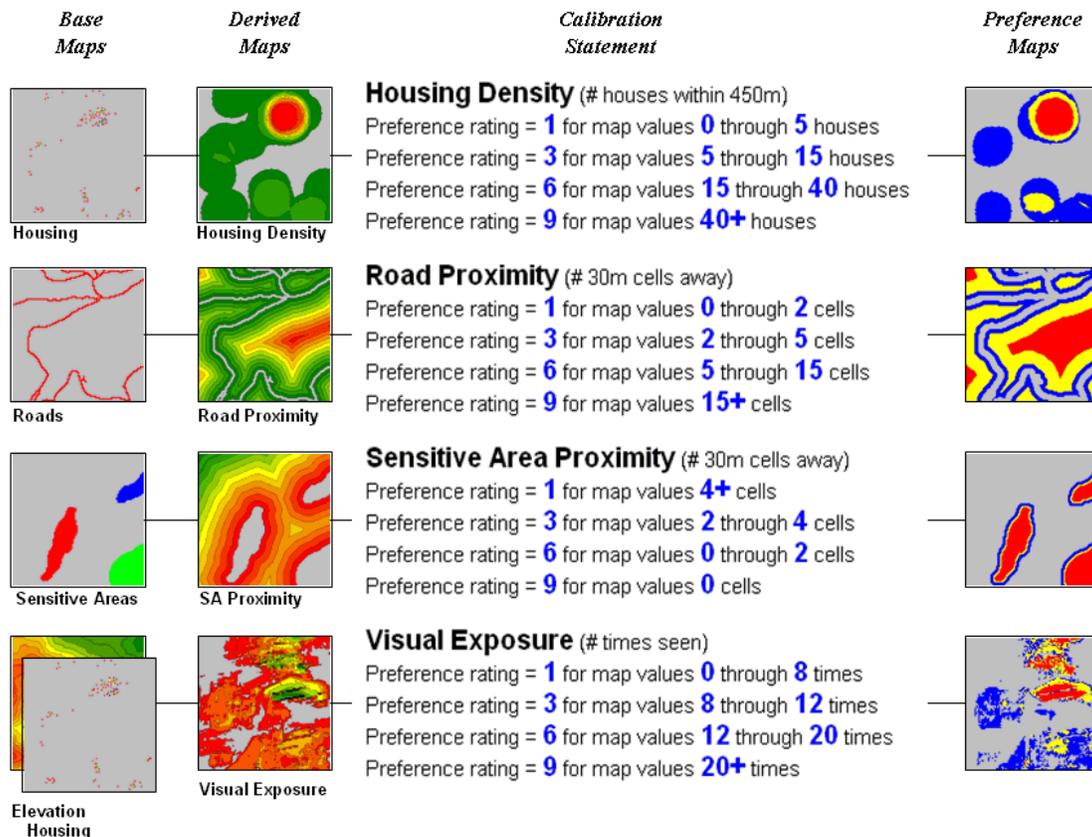


Figure 1. The Delphi Process uses structured group interaction to establish a consistent rating for each map layer.

The answers to these questions are what tailor a model to the specific circumstances of its application and the understanding and values of the decision participants. The tailoring involves two related categories of parameterization—calibration and weighting. **Calibration** refers to establishing a consistent scale from 1 (most preferred) to 9 (least preferred) for rating each map layer used in the solution. Figure 1 shows the result for the four decision criteria used in the routing example.

The *Delphi Process*, developed in the 1950s by the Rand Corporation, is designed to achieve consensus among a group of experts. It involves directed group interaction consisting of at least three rounds. The first round is completely unstructured, asking participants to express any opinions they have on calibrating the map layers in question. In the next round the participants complete a questionnaire designed to rank the criteria from 1 to 9. In the third round participants re-rank the criteria based on a statistical summary of the questionnaires. “Outlier” opinions are

discussed and consensus sought.

The development and summary of the questionnaire is critical to Delphi. In the case of continuous maps, participants are asked to indicate cut-off values for the nine rating steps. For example, a cutoff of 4 (implying 0-4 houses) might be recorded by a respondent for Housing Density preference level 1 (most preferred); a cut-off of 12 (implying 4-12) for preference level 2; and so forth. For discrete maps, responses from 1 to 9 are assigned to each category value. The same preference value can be assigned to more than one category, however there has to be at least one condition rated 1 and another rated 9. In both continuous and discrete map calibration, the median, mean, standard deviation and coefficient of variation for group responses are computed for each question and used to assess group consensus and guide follow-up discussion.

Weighting of the map layers is achieved using a portion of the *Analytical Hierarchy Process* developed in the early 1980s as a systematic method for comparing decision criteria. The procedure involves mathematically summarizing paired comparisons of the relative importance of the map layers. The result is a set map layer weights that serves as input to a GIS model.

Weighting Map Layers



Step 1 Answer pairwise comparison questions:

- (VE vs. SA)— avoiding locations of high *Visual exposure* is **extremely** more important (rating= 9) than avoiding locations close to *Sensitive Areas*.
- (VE vs. R)— avoiding locations of high *Visual exposure* is **strongly** more important (rating= 5) than avoiding locations far from to *Roads*.
- (VE vs. HD)— avoiding locations of high *Visual exposure* is **equally** important (rating= 1) than avoiding locations of high *Housing Density*.
- (SA vs. R)— avoiding locations far from *Roads* is **strongly to very strongly** more important (rating= 6) than avoiding locations close to *Sensitive Areas*.
- (SA vs. HD)— avoiding locations of high *Housing Density* is **very strongly to extremely** more important (rating= 8) than avoiding locations close to *Sensitive Areas*.
- (R vs. HD)— avoiding locations of high *Housing Density* is **strongly** more important (rating= 5) than avoiding locations close to *Sensitive Areas*.

Step 2 Complete importance table:

	VE	SA	R	HD
VE	1	9	5	1
SA	"1/9"	1	"1/6"	"1/8"
R	"1/5"	6	1	"1/5"
HD	"1/1"	8	5	1

Step 3 Calculate weights:

	Weights
VE	10.64
SA	1.00
R	3.23
HD	10.38

Figure 2. The Analytical Hierarchy Process uses pairwise comparison of map layers to derive their relative importance.

In the routing example, there are four map layers that define the six direct comparison statements identified in figure 2 (#pairs= $(N * (N - 1) / 2) = 4 * 3 / 2 = 6$ statements). The members of the group independently order the statements so they are true, then record the relative level of importance implied in each statement. The importance scale is from 1 (equally important) to 9 (extremely more important).

This information is entered into the importance table a row at a time. For example, the first statement views avoiding locations of high Visual Exposure (VE) as extremely more important

(importance level= 9) than avoiding locations close to Sensitive Areas (SA). The response is entered into table position row 2, column 3 as shown. The reciprocal of the statement is entered into its mirrored position at row 3, column 2. Note that the last weighting statement is reversed so its importance value is recorded at row 5, column 4 and its reciprocal recorded at row 4, column 5.

Once the importance table is completed, the map layer weights are calculated. The procedure first calculates the sum of the columns in the matrix, and then divides each entry by its column sum to normalize the responses. The row sum of the normalized responses derives the relative weights that, in turn, are divided by minimum weight to express them as a multiplicative scale (see author’s note for an online example of the calculations). The relative weights for a group of participants are translated to a common scale then averaged before expressing them as a multiplicative scale.

Generating Alternative Routes

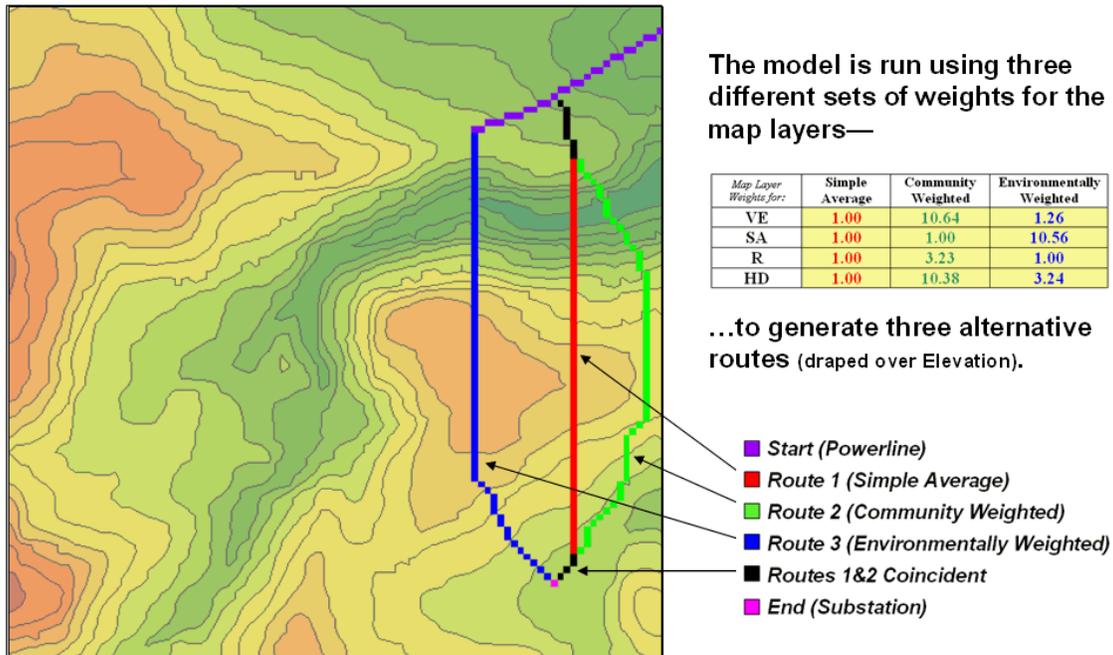


Figure 3. Alternate routes are generated by evaluating the model using weights derived from different group perspectives.

Figure 3 identifies alternative routes generated by evaluating different sets of map layer weights. The center route (red) was derived by equally weighting all four criteria. The route on the right (green) was generated using a weight set that is extremely sensitive to “Community” interests of avoiding areas of high Visual Exposure (VE) and high Housing Density (HD). The route on the

left (blue) reflects an “Environmental” perspective to primarily avoid areas close to Sensitive Areas (SA) yet having only minimal regard for VE and HD. Next month’s column will investigate qualitative procedures for comparing alternative routes.

Author's Note: Supplemental discussion and an Excel worksheet demonstrating the calculations are posted at www.innovativegis.com/basis/, select “Column Supplements” for *Beyond Mapping*, September, 2003.

- [Delphi and AHP Worksheet](#) an Excel worksheet templates for applying the Delphi Process for calibrating and the Analytical Hierarchy Process (AHP) for weighting as discussed in this sub-topic (*GeoWorld*, September 2003)
- [Delphi Supplemental Discussion](#) describing the application of the Delphi Process for calibrating map layers in GIS suitability modeling
- [AHP Supplemental Discussion](#) describing the application of AHP for weighting map layers in GIS suitability modeling

Think with Maps to Evaluate Alternative Routes

(*GeoWorld*, October 2003)

[\(return to top of Topic\)](#)

The past three sections have focused on the considerations involved in siting an electric transmission line as representative of most routing models. The initial discussion described a basic three step process (*step 1* Discrete Cost → *step 2* Accumulated Cost → *step 3* Steepest Path) used to delineate the optimal path.

The next sub-topic focused on using multiple criteria and the delineation of an optimal path corridor. The most recent discussion shifted to methodology for calibrating and weighting GIS model criteria used for determining preferred areas for siting.

The top portion of Figure 1 identifies the calibration ratings assigned to the four siting criteria that avoid locations of high housing density (HD), far from roads (R), near sensitive areas (SA) and high visual exposure (VE).

The bottom portion of the figure identifies weighted preference surfaces reflecting Community and Environmental concerns for siting the power line. The community perspective strongly avoids locations with high housing density (weight= 10.23) and high visual exposure to houses (10.64). The environmental perspective strongly avoids locations near sensitive areas (10.56) but has minimal concern for high housing density and visual exposure (3.24 and 1.26, respectively).

The routing solution based on the different perspectives delineates two alternative routes. Note that the routes bend around areas that are less-preferred (higher map values; warmer tones) as

identified on their respective preference surfaces. The optimal path considering one perspective, however, is likely far from optimal considering the other.

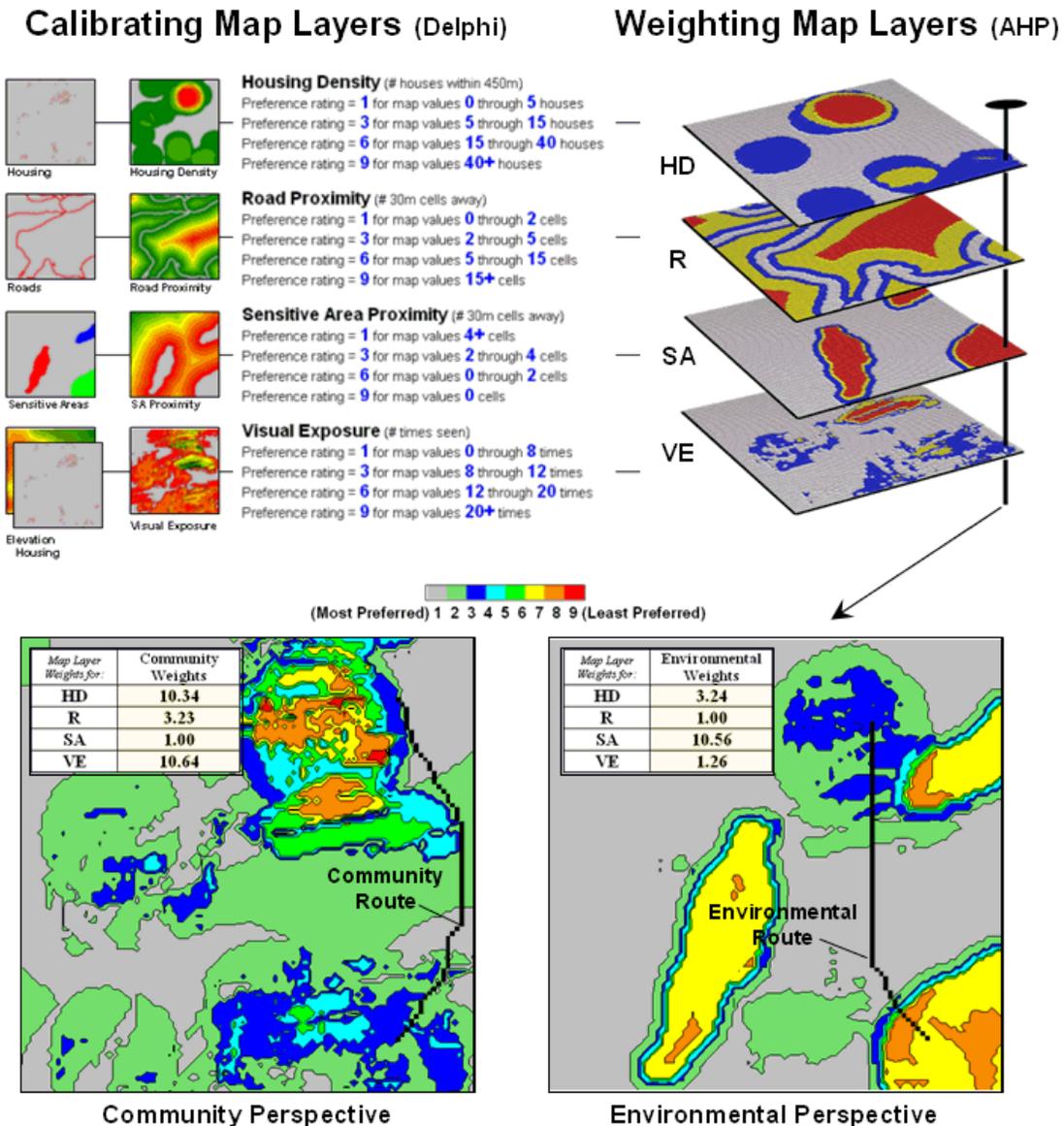


Figure 1. Incorporating different perspectives (model weights) generate alternative preference surfaces for transmission line routing.

One way to compare the two routes is through differences in their preference surfaces. Simple subtraction of the Environmental perspective from the Community perspective results in a difference map (figure 2). For example, if a map location has a 3.50 on the community surface

and a 5.17 rating on the environmental surface, the difference is -1.67 indicating a location that is less preferred from an environmental perspective.

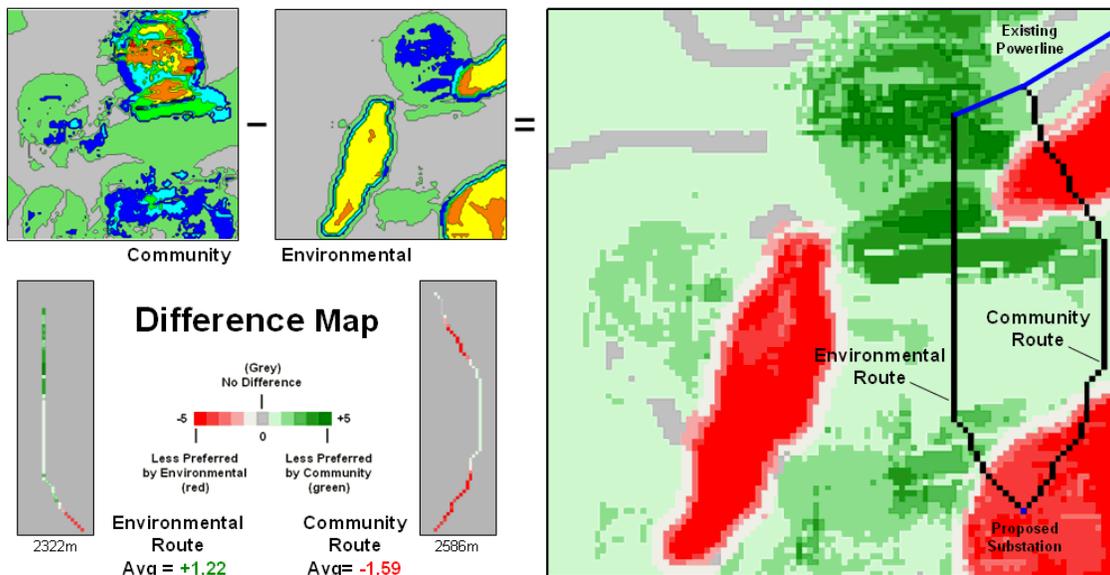


Figure 2. Alternative routes can be compared by their incremental and overall differences in routing preferences.

The values on the difference map on the right side of the figure identify the relative preference at each map location. The sign of the value tells you which perspective dominates—negative means less preferred by environmental (red tones); positive means less preferred by community (green tones). The magnitude of the value tells you the strength of the difference in perspective—zero indicates no difference (grey); -1.67 indicates a fairly strong difference in opinion.

Alignment of the alternative routes on the difference map provides a visual evaluation. Where a route traverses grey or light tones there isn't much difference in the siting preferences. However, where dark tones are crossed significant differences exist. The two small insets in the lower left portion mask the differences along the two routes. Note the relative amounts of dark red and green in the two graphics. Nearly half of the Community route is red meaning there is considerable conflict with the environmental perspective. Similarly, the Environmental route contains a lot of green indicating locations in conflict with the community perspective.

The average difference is calculated by region-wide (zonal) summary of values along the entire length of the routes. The +1.22 average for the Environmental route says it is a fairly unfriendly community alternative. Likewise, the -1.59 average for the Community route means it is

environmentally unfriendly.

The schematic in figure 3 depicts a “map stack” of the routing data. Mouse-clicking anywhere along a route pops-up a listing of the values for all of map layers (drill-down). In the example, the difference at location column 77, row 18 is -1.67 that means the location is environmentally unfriendly although it is part of the Environmental route. This is caused by the 1.00 *SA_proximity* map value indicating that the location is just 30 meters from a sensitive area.

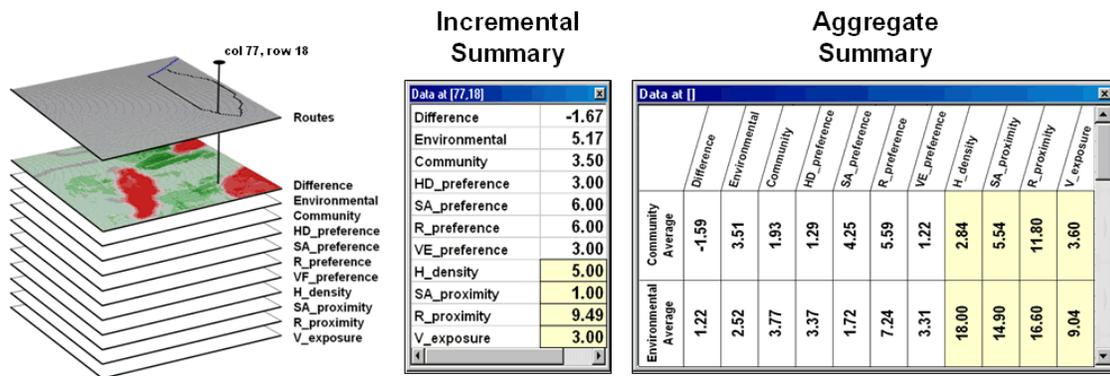


Figure 3. Tabular statistics are used to assess differences in siting preferences along a route (incremental) or an overall average for a route (aggregate).

In addition to the direct query at a location (incremental summary), a table of the average values for the map layers along the route can be generated (aggregate summary). Note the large difference in average housing density (only 2.84 houses within 450m for the Community route but 18.0 for the Environmental route) and visual exposure (3.60 houses visually connected vs. 9.04).

In practice, several alternative perspectives are modeled and their routes compared. The evaluation phase isn't so much intended to choose one route over another, but to identify the best set of common segments or slight adjustments in routing that delineate a compromise. Rarely is GIS analysis used as a decision *making* system that dictates a solution. Most effective applications utilize the analysis as a decision *support* system that encourages “thinking with maps.”

Further Online Reading: (*Chronological listing posted at www.innovativegis.com/basis/BeyondMappingSeries/*)

[‘Straightening’ Conversions Improve Optimal Paths](#) — discusses a procedure for spatially responsive straightening of optimal paths (November 2004)

[Use LCP Procedures to Center Optimal Paths](#) — discusses a procedure for eliminating “zig-zags” in areas of minimal siting preference (March 2006)

[Connect All the Dots to Find Optimal Paths](#) — describes a procedure for determining an optimal path network from a dispersed set of end points (September 2005)

[Building Accumulation Surfaces](#) — reviews how proximity analysis and effective distance is used to construct accumulation surfaces (October 1997)

[Analyzing Accumulation Surfaces](#) — describes how two surfaces can be analyzed to determine the relative travel-time advantages (November 1997)

[Determining Optimal Path Corridors](#) — describes a technique for determining the set of n^{th} best paths between two points (December 1997)

[Analyzing Stepped Accumulation Surfaces](#) — describes a technique for forcing an optimal path through a series of points (January 1998)

[\(return to top of Topic\)](#)

[\(Back to the Table of Contents\)](#)