

Implementing a GIS Methodology for Siting High Voltage Electric Transmission Lines

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Abstract

Standardization of high voltage electric transmission line siting methodologies, by using GIS spatial analysis tools, has great potential in helping predict and defend new optimal route corridors. A standard methodology that incorporates multiple weighted perspectives of influence can aid in the route approval by the governmental and regulating permitting entities and the support of the affected public. Users of transmission line siting methodologies must fully understand, implement, and remain unbiased in the tools used to ensure results remain consistent, reliable, and defensible. Great River Energy (GRE) had a need for a tool to help in the decision making process of siting their transmission lines. Too often in the past, a transmission line route was chosen using expert judgment, and then if needed, a case to defend it for the permitting process was built. By utilizing the Electric Power Research Institute-Georgia Transmission Corporation (EPRI-GTC) Overhead Electric Transmission Line Siting Methodology and applying needed changes based on corporate guidelines, regional factors, and work process, an adapted GRE transmission-siting model was developed by this study. GRE will have a valuable tool to utilize in new transmission line projects to help in the transmission line siting process for attaining regulatory and public approval. The steps, analysis, and results to build and run the methodology are included in this paper and utilized on a potential transmission project.

Introduction

The optimal goal in building new transmission lines is to effectively minimize the negative impacts on people and the environment while ensuring safety, reliability, and cost savings for the utility (Glasgow, 2008).

Transmission lines sited with professional experience using a classic approach of drawing eyeballed routes based on paper maps, aerial photography, and field visits lacked the detailed analytical and consistent

methodology needed to defend and document why the route chosen for the permitting process was selected. Consequently, by not having a standard comprehensive siting methodology defined, routes often had to be reworked multiple times resulting in schedule delays and cost overruns as additional routing problems were discovered.

The EPRI-GTC Overhead Electric Transmission Line Siting Methodology was used as a starting point in developing the analytical tools and process needed by Great River

Energy. The model was favored for use due to its structured processes and the use of GIS analysis concepts. A GIS system for analysis was favored because it can perform optimal route predictions based selection by incorporating multiple influence factors into its analysis. These influence factors are grouped into common viewpoints or perspectives addressing a common data theme or point of view. The critical factors to address are the perspectives of society, the environment, and engineering capabilities in determining the most suitable transmission routes. A GIS system can assemble large data quantities of the necessary factors into a meaningful analysis and output the results graphically. The results, both visually and statistically, help to convey the findings to the intended audience.

Finally, a consistent analytical model will become more acceptable as an industry standard by regulatory agencies as the methodology is used and adopted by other utility-based organizations. Of additional importance, the optimal route analysis can be reproduced, analyzed, and/or audited by an outside analyst to insure the findings are unbiased and defensible.

Methodology

Software Used

The GIS software used to perform the tasks in this transmission line siting methodology study was ESRI ArcGIS 9.2 (ArcView) and the ESRI Spatial Analyst extension. Tabular and statistical ranking analysis was performed utilizing Microsoft Excel software spreadsheets.

Analysis Steps Overview

The line siting methodology follows closely the EPRI-GTC (2006) methodology in developing the analysis

phases of a funneled approach to define suitable corridors for constructing high voltage transmission lines. The funneled approach (Figure 1) initially utilized a large geographic area of generalized data that through the analysis steps reduces into small detailed corridor areas of highly accurate data. Corridors were defined by GIS spatial and statistical analysis utilizing composite surface generation, least cost path analysis, and weighted results.

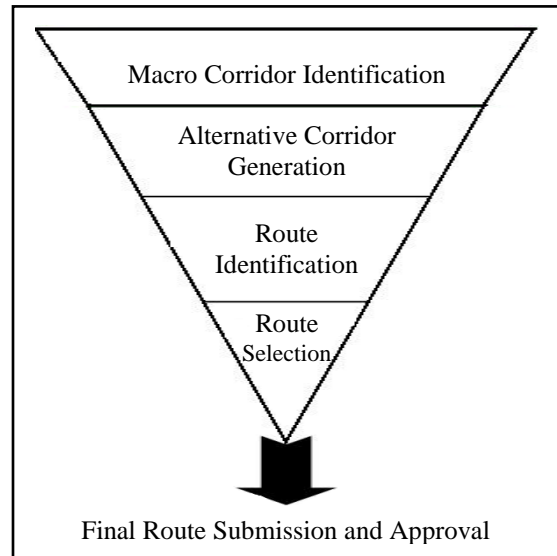


Figure 1. Analysis Phases.

Four analysis phases defined in the model include:

- 1) Macro corridor identification; large suitability corridors were developed which help to define the initial project boundary. For this, four suitability surfaces and optimal paths were created based on scenarios of locating with existing utility lines, locating with existing transportation corridors, crossing least developed lands and a composite average.
- 2) Alternative corridor generation; small corridors were created based on detailed data coming from three unique weighted perspectives of built environment, natural environment, engineering requirements, and a simple average composite.

- 3) Route identification; expert judgments of possible route segments by routing professionals, permitting agencies, and the affected public were made based on constructible line segments within the alternative project area that are analyzed for consideration by current engineering construction design criteria.
- 4) Preferred route selection; a statistical matrix weighting of all the proposed route segments by applying a weight value for delineated attribute values per segment of social perceptions, construction cost, and schedule then combining the scores for the complete route to determine the best optimal route.

Data Acquisition and Manipulation

GIS data were acquired or derived based on the funneled approach of the analysis phase (Figure 2). Prior to obtaining data, a preliminary generalized area of interest was created based on physical barriers and the known or assumed start and end location of the route.

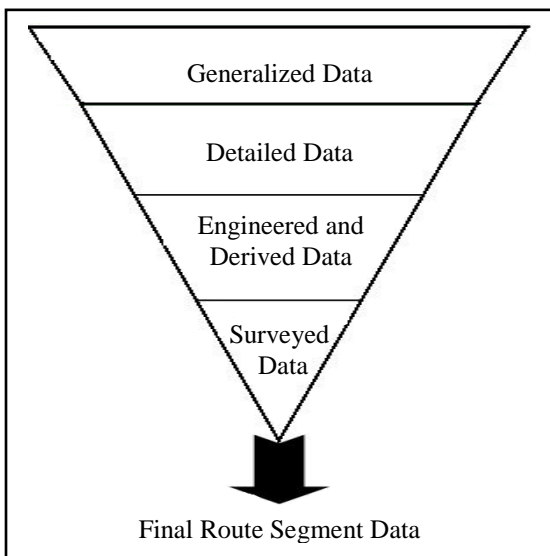


Figure 2. GIS Data Needed.

Generalized GIS data, obtained primarily from Federal and State governmental entities, were compiled for

the area of interest, and used in the macro corridor identification. The generalized data helped to define the project area and establish initial avoidance areas. GIS layer attribute values were created based on key attribute column types the model requires. Table 1 defines specific data layers and common data source required for use in the macro corridor generation phase.

Table 1. Macro GIS Data and Common Sources.

GIS Data	
Classification Type	Source
Open Water	GAP Layer
Urban	GAP Layer
Open land	GAP Layer
Surface Mining / Rock Outcrop	GAP Layer
Forest	GAP Layer
Agriculture	GAP Layer
Wetland	GAP Layer
Transmission Corridors	GRE
Distribution Corridors	GRE/Industry Sources
Other Utility Corridors	GRE/Industry Sources
Secondary Roads	GAP Layer
Primary Roads	DOT
Interstate Roads	DOT
Rail	DOT
Slopes >30	DEM
Avoidance Areas	
Airports	DOT
Historic Areas	LMIC
Parks	DNR
Non-Spannable Waters	DNR
Wildlife Refugees	DNR
Protected Areas	DNR
Culturally Significant Areas	LMIC

Data that were more detailed were required within the defined project boundary area for the alternative corridor selection phase. Detailed GIS data and high-resolution aerial photography obtained needed to be the most accurate and current data available to provide the most accurate results. This imagery can usually be obtained from local county and municipal entities or a photogrammetry vendor. From these data, additional data were derived using queried analysis, GIS spatial analysis, and air photography interpretation.

Additionally GPS field data collections were performed to gain additional specific data needed for the analysis. Data were subdivided into three perspectives, within each perspective was a common layer tier, and within each common layer was a suitability tier attribute for the alternative corridor generation phase.

In tier one, GIS layer attribute values were given a suitability value between one, as most suitable, to nine, the least suitable. The values were aggregated together by a distinct category or data range of common feature types. Data values were calibrated to the suitability scale using a Delphi Process of transmission sitting experts performed during EPRI-GTC (2006) electric utility stakeholder's workshops. Minor changes were made to the suitability values based on the changes in agriculture types and natural environment features that aligned most closely with the upper Midwest landscape.

In tier two, each layer that represents similar features were grouped together and weighted based on its relative importance within the perspective. The weighting was used was based on the EPRI-GTC (2006) model which used an Analytical Hierarchy Process (AHP) to set the percent influence weighting for each layer group.

The third tier represented the combination of all the common data values of the suitability and weights of each perspective of built, engineering, and natural environment into a single surface. Table 2 illustrates the breakdown of perspectives, tiers, and suitability values.

All avoidance areas were combined together in a raster feature class. These were classified with a cell value of zero if it was an avoidance area and removed from the raster surface for further consideration.

GIS layers of avoidance include:

- Avoidance Areas
- Airports
- Building and Buffers
- Cemetery Parcels
- Church Parcels
- County and City Parks
- Day Care Parcels
- Eligible NRHP Districts
- EPA Superfund Sites
- Military Facilities
- Mines and Quarries
- National and State Parks
- Non-Spannable Water Bodies
- NRHP Archaeology Districts
- NRHP Archaeology Sites
- NRHP Historic Districts
- NRHP Structures
- School Parcels
- Sites of Ritual Importance
- USFS Wilderness Areas
- Wild and Scenic Rivers
- Wildlife Refuges

Specific detailed and highly accurate data were collected for the final two phases of route identification and preferred route selection. The collection methods varied and included field visits, engineered survey, public meetings, property ownership information procurement, and consultant data services like soil boring and archeological reviews. In addition, unique project perception values such as schedule timeframes, visual impacts, and cost considerations hypothetically could be included in the analysis. The data were linked to specific line segments that were analyzed in the preferred route statistical matrix. Criteria values were populated using GIS overlay and a proximity query that updated the attributes of the vector GIS line route segment features. The criteria values included items like corridor length in wetlands, length along road right-of-way, and/or count of physical structures within a distance.

Table 2. GIS Siting Tiers for Alternative Corridor Generation.

Built Environment		Engineering Requirements		Natural Environment	
Building Density	37.40%	Linear Infrastructure	48.30%	Wildlife Habitat	36.00%
0-0.5 Buildings/Acre	1	Rebuild Existing Transmission line	1	Background	1
0.5 - 0.2 Buildings/Acre	3	Parallel Existing Transmission line	1.4	Concerned Species of Habitat	3
0.2-1 Buildings/Acre	5	Parallel Road ROW	3.6	Natural Areas	9
1-4 Buildings/Acre	7	Parallel Gas Pipelines	4.5	Streams/Wetlands	20.90%
4-25 Buildings/Acre	9	Parallel Railroad ROW	5	Background	1
Land Use	19.10%	Background	5.5	Streams <5cfs+ Regulatory buffer	5.1
Undeveloped	1	Future DOT Plans	7.5	Non-forested wetlands	6.1
Nonresidential	3	Parallel Interstate/expressways	8.1	Rivers/Streams >5cfs+ Regulatory buffer	7.4
Residential	9	Road/Rail ROW	8.4	Riparian Areas	8.4
Eligible NRHP Historic Structures	13.90%	Scenic Highway ROW	9	Trout Streams buffer	8.5
Background	1	Intensive Agriculture	42.60%	Buffered Forested Wetlands	9
900-1200	2.8	Background	1	Land Cover	20.90%
600-1200	3.6	Nursery Farms	5	Open Land, Pasture, Scrub/Shrub, etc.	1
300-600	5.2	Fruit Orchards/Vineyards	5	Managed Forested Areas	2.2
0-300	9	Center Pivot Agriculture	9	Row Crops	3
Proximity to Buildings	11.50%	Slope	9.10%	Developed Land	6.5
Background	1	Slope 0-15%	1	Hardwood/Natural Forest	9
900-1200	1.8	Slope 15-30%	5.5	Public Lands	16.00%
600-900	2.6	Slope >30%	9	Background	1
300-600	4.2			WMA Non-State-Owned	4.8
0-300	9			Other Conservation Land	8.3
Proposed Development	6.30%			USFS	8
Background	1			WMA State-Owned	9
Proposed Development	9			Floodplain	6.20%
Spannable Lakes and Ponds	3.80%			Background	1
Background	1			100-Year Floodplain	9
Spannable Lakes and Ponds	9				
Land Divisions	8.00%				
Edge of Field	1				
Land Lots	7.9				
Background	9				

Key
Tier 3 Perspective
Tier 2 Data Layers
Tier 1 Features

Specific detailed and highly accurate data were collected for the final two phases of route identification and preferred route selection. The collection methods varied and included field visits, engineered survey, public meetings, property ownership information procurement, and consultant data services like soil boring and archeological reviews. In addition, unique project perception values such as schedule timeframes, visual impacts, engineering design and cost considerations hypothetically could be

included in the analysis. The data were linked to specific line centerline segments that were analyzed in the preferred route statistical matrix. Criteria values were populated using GIS overlay tools and proximity queries that updated the attributes of the vector GIS centerline route segment features. The criteria values included items like corridor length in wetlands, length along road right-of-way, line angles, and/or count of physical structures and features within a specified distance of the route centerline.

Least Cost Path and Surface Analysis

The transmission siting methodology depends significantly on two common GIS analysis functions. The first is the “Least Cost Path” algorithm which creates a line connecting a start and end point by taking into consideration the minimum cumulative path (addition of adjacent raster cells) to traverse the surface (ESRI, 2006). The raster values are based on the suitability values and distance away from the source. The least cumulative raster addition between the start and end while avoiding areas of avoidance (nodata cells) is selected for the least cost path optimal route (Figure 3).

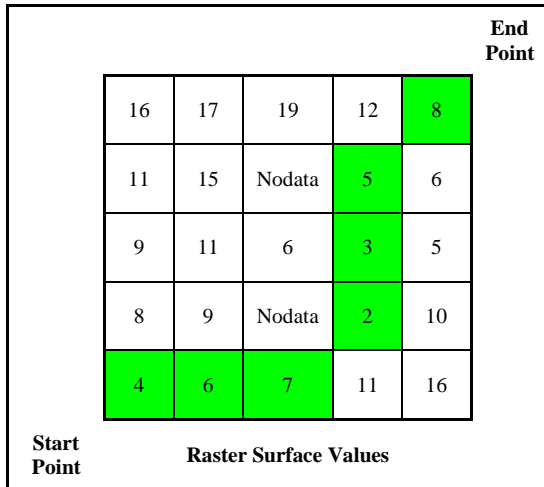


Figure 3. Least Cost Path Calculation Diagram.

Surface analysis was used to determine optimal corridor suitability areas. Cost distance surfaces were created for both the starting and ending locations. They are combined to create the composite cost distance surface. This surface if viewed three dimensionally would show a valley between the start and end locations. The floor of the valley represents the optimal path and further up the walls represents less optimal areas (Berry, 2008).

Histograms were used to classify the surface to highlight values that fell within the first statistical break. In the histogram (Figure 4), the x-value cells

represent the grid suitability values and the y-values represent the count of cells per value. This statistical break was found by utilizing a histogram and accepting all grid cell values that were less than the first statistical break. This statistical break is defined within the EPRI-GTC Electric Transmission Line Siting Methodology as where the values abruptly stop decreasing on the x-axis of the histogram (EPRI-GTC, 2006).

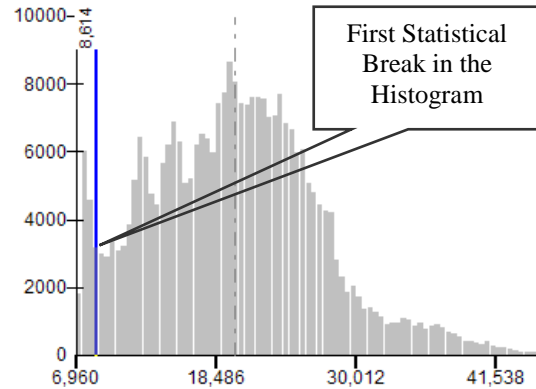


Figure 4. Representative Histogram and First Statistical Break.

Model Creation

Utilizing the ESRI ArcToolbox and Model Builder, two toolboxes were created; one toolbox for macro corridor identification that performed the analysis for phase one and the other for alternative corridor generation which performed the analysis for phase two (Figure 5). The models were created to be used over in future projects with no modifications to the tasks performed.

The macro tool set was divided into three models for the identification of three unique suitability surfaces per scenario in the macro corridor road, macro corridor utility, and macro corridor cross-country models (1.1.1-1.1.3). Macro corridor create composite model (1.2.1) created a composite surface used to define the project area. The models were designed to create the surfaces from the GIS data that was within the area of interest on a consistent basis.

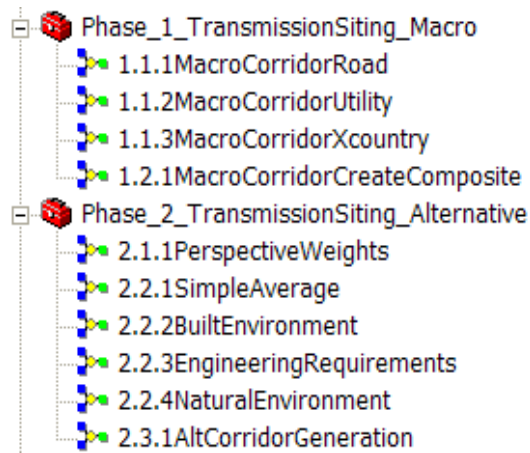


Figure 5. Models Created in ArcToolbox.

The four models for macro analysis included:

- 1.1.1 Macro Corridor Road; model created an optimal route near existing road and transportation corridors.
- 1.1.2 Macro Corridor Utility; model created an optimal route co-locating with existing utility corridors.
- 1.1.3 Macro Corridor Cross Country; model created an optimal route crossing least populated and undeveloped areas.
- 1.2.1 Macro Corridor Create Composite; model created a composite average of all the scenarios and computed the project study area vector boundary.

The alternative tool set was subset into six models. The first of the perspective weights model (2.1.1) was for the generation of the perspective weights. The simple average model (2.2.1) created the simple composite perspective, while three models of built environment, engineering requirements, and natural environment (2.2.2-2.2.4) created the weighted alternative route perspectives. Finally, the alternative corridor generation model (2.3.1) created the alternative corridors area and optimal routes. The models were designed to

create the surfaces from the data that was within the project area consistently.

The models for alternative corridor generation included:

- 2.1.1 Perspective Weights; model created suitability scores of raster features and combined them into their perspective type.
- 2.2.1 Simple Average; model combined the perspectives types with equal weighting between and created the composite cost distance suitability surface and optimal route for this perspective.
- 2.2.2 Built Environment; model combined the perspective types with five times weighting influence on the built environment perspective and created the composite cost distance suitability surface and optimal route for the perspective.
- 2.2.3 Engineering Requirements; model combined the perspectives types with five times weighting influence on the engineering requirement's perspective and created the composite cost distance suitability surface and optimal route for the perspective. Additionally it performed a route straightening calculation to minimize optimal path turns and length.
- 2.2.4 Natural Environment; model combined perspectives types with five times weighting influence on the natural environment perspective and created the composite cost distance suitability surface and optimal route for the perspective.
- 2.3.1 Alternative Corridor Creation; model created the alternative corridors, computed the project area, and converted the optimal paths to vector routes.

Analysis

A transmission-siting project is either a load serving (bringing power to a distribution substation) or reliability project (ensuring power quality and failover). Prior to using this siting model, the start and an end location are identified, usually by a project scope document. Additionally the area of interest is defined as a broad encompassing area and the necessary GIS data collected for the phase one macro corridor identification.

Phase 1- Macro Corridor Identification

GIS data necessary for phase one analysis is assembled and macro models of road, utility, and cross-country scenario (1.1.1 - 1.1.3) within the phase one toolbox is run to create scenario surfaces and optimal routes. The models take the required vector GIS features and convert them to raster features with a grid cell size of 100 square feet. Each raster data layer is then reclassified on key attribute values and given its suitability numeric value of one to nine per scenario (Table 3). All raster layers are combined to create a new raster using the mosaic method of “mean” to create the cost surface. Avoidance areas are removed from the cost surface using a mosaic method of “first” and reclassified to change the zero values to “nodata”. Then a cost distance analysis is run from both the start and end to determine the least accumulative cost distance for each cell. These two accumulative cost distance surfaces are combined to form a composite cost distance suitability surface for each scenario. Finally, the least cost path algorithmic tool is run to create the optimal route for each macro corridor scenario.

All scenarios are combined in the model, macro corridor create composite (1.2.1). The model creates a new raster

using the mosaic method of “mean” to create the average cost surface. From the surface, a cost distance analysis is run from both the start and the end to determine the least accumulative cost distance for each cell. These two accumulative cost distance surfaces are combined to form a composite cost distance suitability surface. The least cost path algorithmic tool is run to create the combined optimal route.

Additionally within the model, each scenario composite cost distance suitability surface is reclassified to accept only values that fall within the first statistical break. The resulting corridor areas are converted to a vector format, combined, and dissolved to create the project area.

Table 3. Macro Analysis Layer Suitability Surface Values Per Scenario.

GIS Data Classification Type	Suitability Surface Values		
	Roads	Cross-Country	Utility
Open Water	7	7	7
Urban	9	9	9
Open land	2	1	2
Surface Mining / Rock Outcrop	9	9	9
Forest	2	1	2
Agriculture	2	1	2
Wetland	9	9	9
Transmission Corridors	5	5	1
Distribution Corridors	5	5	2
Other Utility Corridors	5	5	3
Secondary Roads	1	5	5
Primary Roads	1	5	5
Interstate Roads	9	9	9
Rail	2	5	5
Slopes >30	9	9	9
Avoidance Areas	NoData	NoData	NoData

Phase 2- Alternative Corridor Selection

Utilizing the phase two toolbox and the perspective weights model (2.1.1), GIS data layers that are within the defined project area, are converted to raster layers with fifteen-foot grid cells. Data values for the necessary attributes are

preserved for the tier one data and utilized to set the suitability score for the required GIS layers.

Tier two value cells must be present for each cell within the project area for the raster calculation to weight the perspective surface for the entire project area. Therefore, a layer that is not continuous, a background layer is added to set a value to a non-influential suitability for the no data areas within the project area. The tier two data layers are multiplied by its tier influence and combined together to form the perspective.

Each perspective is equally significant and combined using a raster calculation of perspective addition in the simple average model (2.2.1). The simple average perspective model keeps the influence of each perspective the same. For perspective models of built environment, engineering requirements, and natural environment (2.2.2 - 2.2.4) a perspective is emphasized to the specific perspective of the named model. Emphasis of a perspective is achieved by weighting the perspective five times as great as the remaining two perspectives and combining them together with a raster calculation. This significantly alters the values to the perspective of influence but retains some of the influence of the other perspective (EPRI-GTC, 2006).

Avoidance areas are removed by using a conditional statement and raster calculation to remove the values from analysis for each perspective in creating the cost surface. A cost distance analysis is run from the start to the end to determine the least accumulative cost distance for each cell. Then the least cost path algorithmic tool is run to create the optimal route.

Additionally within the engineering requirements model (2.2.3), a straightening calculation is used for the influence of straightening to remove angles and reduce overall route length.

Calculation to perform the straightening:

Adjusted Cost Surface =
 $i + ((9 - i) / 9) * \text{Cost Surface}$
Where i = influence of straightening between zero for no straightening and nine for total straightening.

The approach modifies the discrete cost surface by making disproportional increases between the higher and lower cost surface values. This has the effect of reducing the length and minor angles of the optimal route in the favorable areas while continuing to avoid unsuitable areas (Berry, 2008). Lower values between one and three have slight straightening influence whereas higher values, up to nine have more extreme influence in straightening. An influence value of nine will produce a totally straight line whereas a value of zero will have no straightening effect on the line. This straightening and shortening of the route is important because the dollar cost to construct a straighter shorter route is taken into account and an improved optimal route is defined for the engineering requirements perspective (Figure 6).

Finally, the cost distance analysis is run from the end to the start point and is averaged with the cost distance surface from start to end to form a composite alternative cost distance suitability surface. Raster layers are created and added to the map display for each of the four perspectives include the optimal path and composite alternative corridor cost distance suitability surface.

Alternative corridor generation model (2.3.1) takes each perspective composite cost distance suitability surface and performs a re-class to accept only values that fall within the first statistical break. These accepted values make up the alternative corridors boundaries that are used for determining the possible route segments that could be constructed within these areas. These corridors are next converted to a polygon

vector format and combined together to create the alternative project area. Additionally the optimal routes are converted from raster to vector as guidelines for route identification segments.

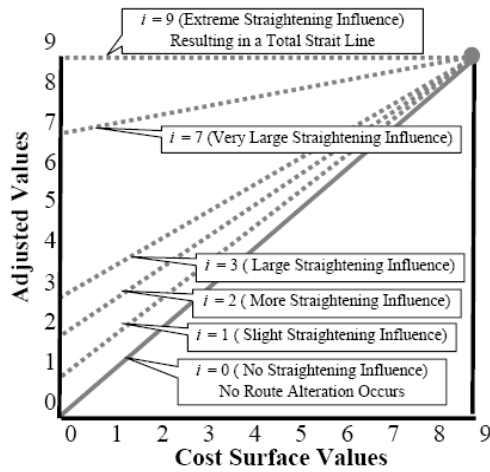


Figure 6. Straightening Calculation Results.

Phase 3- Route Identification

The optimal routes and corridors determined by the alternative model are used to define constructible line segments. Optimal routes are calculated based on fifteen-foot grid cells, where in reality for the line being proposed, a seventy-foot corridor is required. The routes are precisely drawn and segmented in ArcGIS as a vector line feature. A proximity analysis on the route segments is performed to ensure the necessary corridor width is available. Additionally, other factors of constructability are factored in to ensure there is enough corridor clearance from structures, water and transportation crossings are possible, and soil is suitable for construction. Reliance on expert judgment internally from land rights, engineering, surveying, and environmental staff along with outside input of consultants, governmental entities and the affected public, is considered to help define the route segment possibilities.

Each constructible segment is given a unique segment identification

number for route analysis. The unique segment identification numbers are sequentially numbered for clarification as closest to the starting point and from north to south for clarity. Within each segment are measurable values of social, environmental, and engineering considerations. These attribute values are populated in the attribute tables for each segment using GIS overlay and proximity analysis, engineering considerations, survey drawings, and social factor inputs.

Phase 4- Preferred Route Selection

Route segment data from GIS is imported into a Microsoft's Excel spreadsheet for analysis in the segment data worksheet. Attribute value types that have zeros for all line segments are removed from further consideration analysis.

A matrix of unique complete routes possibilities is defined and given a route identification number within the route worksheet. These route combination values, defined in the spreadsheet, are imported into a UI combo box control in ArcMap for graphical representation of the complete chosen route (Figure 7). This control sets a definition query to display only the route segments that make up the selected route from the chosen item in the combo box and graphically .

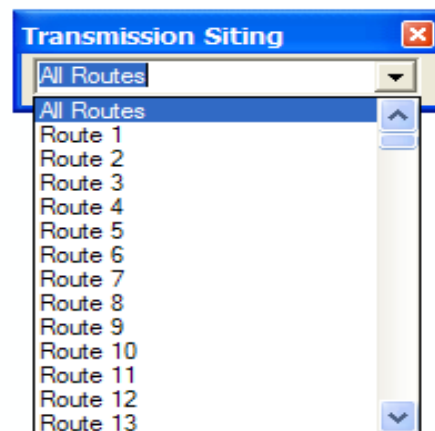


Figure 7. ArcMap UI Combo Box Control of Possible Routes.

Next, a route data worksheet summarizes each of the possible unique segment factors together for each of the possible routes. Additionally, the average of any attribute that measures length or area is calculated and used to normalize the weighted results.

Factors are determined to be part of social, environmental, or engineering consideration and are given a weighted factor between one and nine. The criteria factors are ranked within each consideration from a top rank of one to the count of all the factors within the consideration. Rankings are based on typical factors from past and current project. A criteria weight is then established as three for the top rank and each subsequent ranking as three divided by the total count of criteria less than the previous criteria. The category weight factor is established as the highest value of three for the social factors. This is because they most closely relate to the acceptability of a route being approved by the permitting agencies. The engineering factors are ranked as the lowest value of one due to permitting agencies not factoring cost increases or schedule delays as important route siting considerations. Finally, the category weight is multiplied by the criteria weight to create the route-weighted factor. A top criteria and category weight value of three is used because the resulting highest multiplied weight factor equals nine.

For each route possibility, each consideration factor is multiplied by its weighted factor in the route analysis worksheet. For considerations of counted factors, a linear conversion takes place by multiplying its weight by the counted value. For considerations of length or area, normalization is achieved by dividing its measured value by the average of all measured values within the consideration factor then multiplying by its weight value. This helps to prevent the factor from skewing the results based

on the potentially larger measured value. Next, all the weighted consideration values are summarized and the lowest calculated route is determined to be the preferred route for permitting and construction. Additionally other top segment alternatives are retained in case of unforeseen permitting problems or easement acquisition of the preferred route is not attained.

Results

The analysis techniques were applied to a potential future transmission line project. The project was a reliability-based project with the start and the end locations defined as two existing substations. The project area was well developed containing many routing challenges and avoidance areas.

These challenges (Figure 8) included:

1. Mostly Urban Area Developed
2. River Crossing
3. Schools and Churches
4. Treatment Center
5. Cemeteries
6. Parks and Golf Course
7. Commuter Rail Station
8. Highway Expansion
9. Historic Areas
10. Industrial Areas



Figure 8. Project Area of Interest and Routing Challenges.

Phase I- Macro Analysis Results

Macro corridor models of road, utility, and cross-country scenarios (1.1.1-1.1.3) created the three analysis scenarios of locating near transportation corridors of existing road and rail rights of way, crossing least developed areas, and locating the line with existing utility corridors of electrical lines and gas pipelines.

The results of the macro corridor road model (1.1.1) show results as expected along primary road corridors and rail lines (Figure 9). Due to there being only two continuous road routes from east to west, two defined alternative corridors resulted from the analysis.

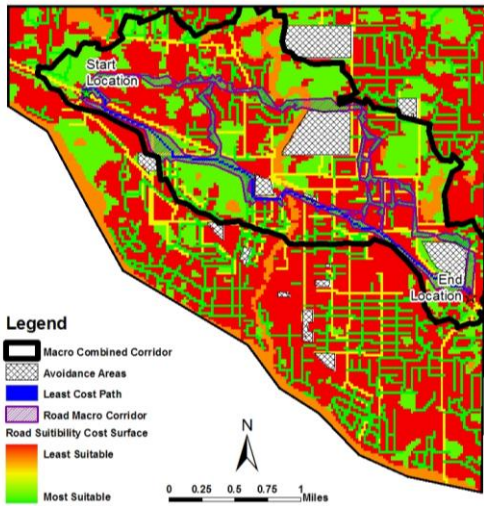


Figure 9. Road Corridor Scenario Results.

The results of the macro corridor utility model (1.1.2) brought the route corridors south following overhead electrical distribution line and cutting through a municipal golf course. This golf course area was designated as an open area in the GAP dataset and not initially excluded from the macro analysis. The route corridors were mainly comprised either of distribution overhead lines that followed the road and railroad right-of-way or through lot divisions, which caused the surface results to be similar to the road corridors scenario (Figure 10).

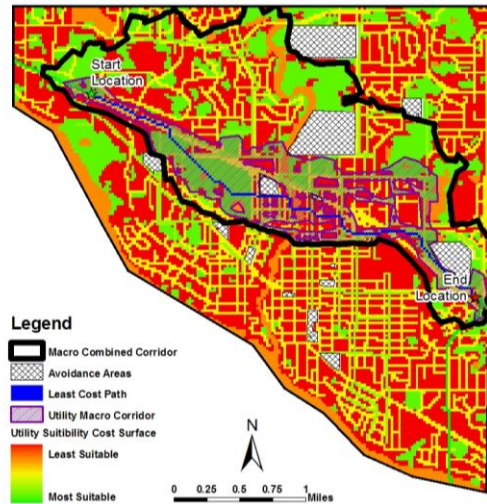


Figure 10. Utility Scenario Results.

The results of the macro corridor cross-country model (1.1.3) create a route through undeveloped areas, parklands, and wetland areas. Due to the GAP dataset not being current, some of the areas defined as undeveloped have had recent residential and commercial developments or have been set aside for future scenic and recreation areas. There was a high level of developed areas that existed within the project area as seen in the low suitability scores displayed in red (Figure 11).

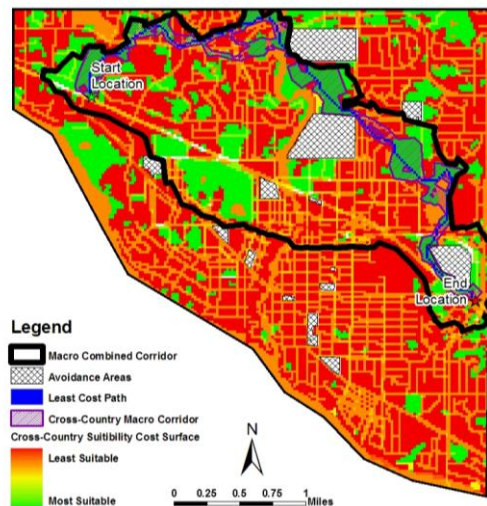


Figure 11. Cross Country Scenario Results.

The macro corridor create composite model (1.2.1) was run and a larger resulting corridor was defined called the project area. The corridor was defined to include the results of all the

scenarios by the merging of all the corridor scenario results and including the areas within. A final combined optimal route was established from the model utilizing the least cost path tool (Figure 12).

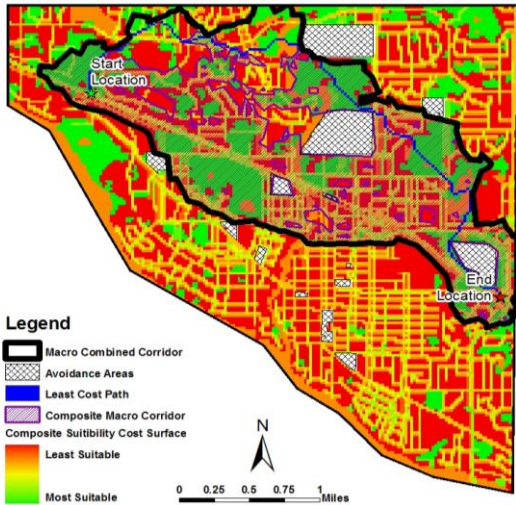


Figure 12. Resulting Combined Optimal Route and Project Area.

The resulting combined optimal macro route was similar to the cross-country scenario, due to the low suitability values of the open areas. The results were favorable for optimal construction because open areas were the most favorable within all the scenarios. Most importantly, the resulting project area was developed as a starting point for phase two data collection and analysis (Figure 13).

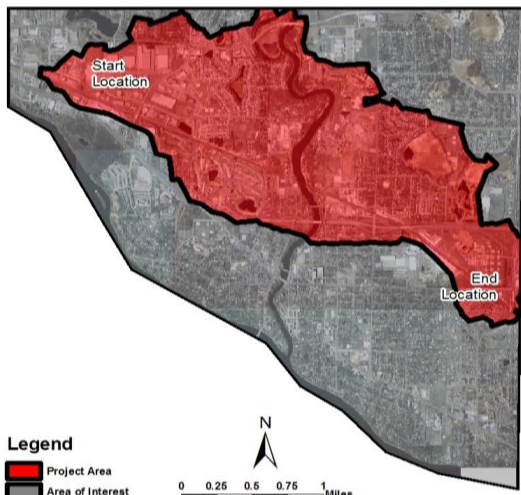


Figure 13. Resulting Project Area Boundary from Phase 1 Macro Analysis.

Phase 2- Alternative Corridor Results

The perspective weights model (2.1.1) created the avoidance areas and the three weighted perspective surfaces of built environment, engineering requirements, and the natural environment. These three surfaces were used in the creation of the four alternative corridors of simple-average, built environment, engineering requirements, and the natural environment.

The simple average model (2.2.1) created the simple average optimal route and alternative corridors. The optimal route begins by following the railroad right-of-way on the north side, crosses to the south side near the golf course to avoid residential homes. It crossed back on the north side of the railroad to follow the electric distribution corridor crossing the river. The route continued on a northeasterly path to avoid future development areas and the commuter rail station. Next, it routed back towards the railroad and the expressway overpass. The route followed the expressway to avoid industrial areas near the railroad and eventually returned to the railroad corridor to the route end (Figure 14).

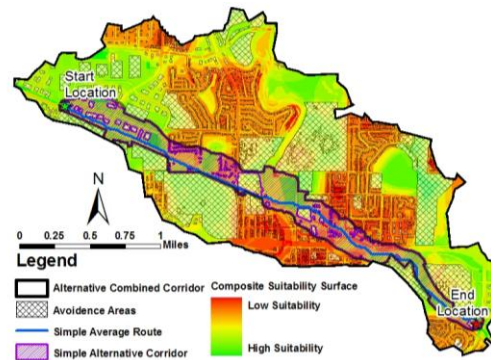


Figure 14. Simple Average Route Corridors.

The built environment model (2.2.2) created the built environment optimal route and alternative corridors. This model minimized routing through highly developed residential areas. From the composite cost distance suitability surface, low suitability scores of the high

residential areas are shown in red and are toward the route center of the study area. The high suitability areas of the industrial areas and open spaces are shown in green and were at the areas near the start and end locations. The route in comparison to the simple-average route initially followed the railroad on the opposite south side. This reduced the number of affected business properties it traversed. Additionally it routed to the north side of a scrap metal recycler to follow lot lines and increase the amount of open areas crossed. The route across the river created a new crossing through undeveloped areas and past the river maximizing open areas and distances away from structures (Figure 15).

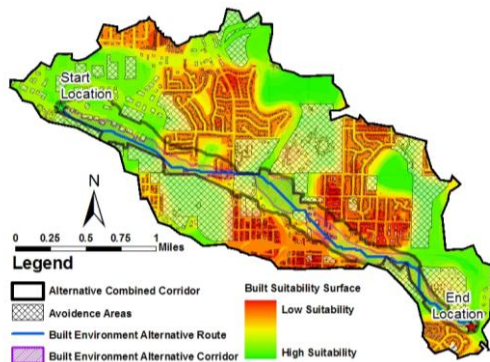


Figure 15. Built Environment Route Corridors.

The engineering requirements model (2.2.3) created the engineering requirements optimal route and alternative corridors. Influences of collocation with existing road right-of-ways and distribution lines were evident as it followed more closely with both. Deviations occurred from the simple average route in areas where road or distribution lines were present and did not deviate far away from the most direct route between the two points. The smoothing calculation of $i =$ one to three reduced the amount of turns and overall length of the route without removing the influence from lower suitability values within the perspective surface (Figure 16).

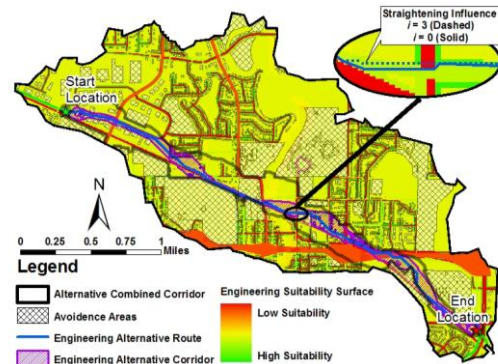


Figure 16. Engineering Requirements Route Corridors.

Model 2.2.4 created the natural environment optimal route and alternative corridors. The route followed very closely the simple average route except near the river crossing. Like the built environment, the route favored undeveloped areas but strictly avoided any naturally significant areas. It followed a northerly route through undeveloped areas and minimized wetland impacts and sensitive habitat (Figure 17).

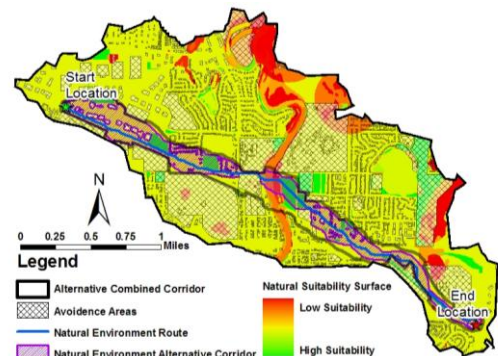


Figure 17. Natural Environment Route Corridors.

At the conclusion of phase two, the resulting alternative corridor project area was developed as a starting point for phase three route identification and data collection. This area defines and sets the focus for the expert judgment by the siting professionals, design engineers, permitting agencies, and the affected public to define the possible routes that the transmission line could be constructed within (Figure 18).

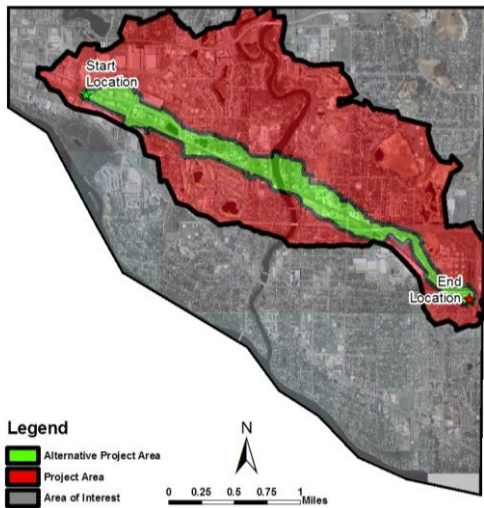


Figure 18. Resulting Alternative Project Area Boundary from Phase 2 Analysis.

Phase 3- Route Identification

Possible routes were defined, drawn, and scrutinized by expert judgment into possible constructible segments that fall within the alternative project area. The optimal routes generated from the phase two alternative corridor selection acted as a starting guide for where the transmission line could possibly be constructed. Transmission line siting staff collected additional data utilizing aerial photography, field visits, surveys, and public meetings to aid in the segment generation. Some segments were added that fell outside the alternative corridor boundary due to potential issues with locating along the railroad corridor and through some industrial areas as discovered through public meetings and preliminary discussions with the affected property owners. Once all the constructible route segments were created, they were sequentially numbered and attributed with the collected and derived data values. Most of the derived data was created utilizing GIS spatial analysis tools of proximity or overlay analysis. The resulting defined route possibilities were 37 unique route segments that are next analyzed and weighted in the preferred route selection phase. (Figure 19).

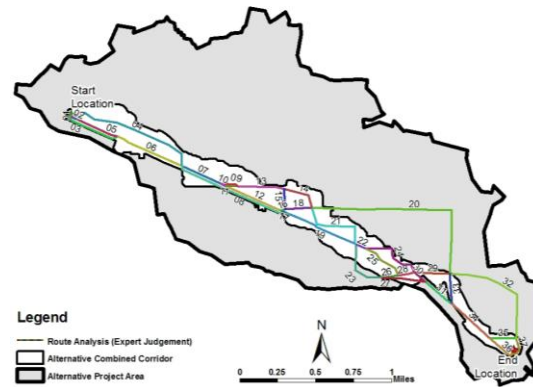


Figure 19. Numbered Route Segments.

Phase 4 - Preferred Route Selection

The statistical matrix used for route selection created a ranking of the possible 37 route segments and 318 unique route combinations. From the analysis, the top route was compared to the next top nine routes to determine what characteristics made the route more favorable. The average and median routes along with the bottom five routes were included in examining and concluding the results (Figure 20).

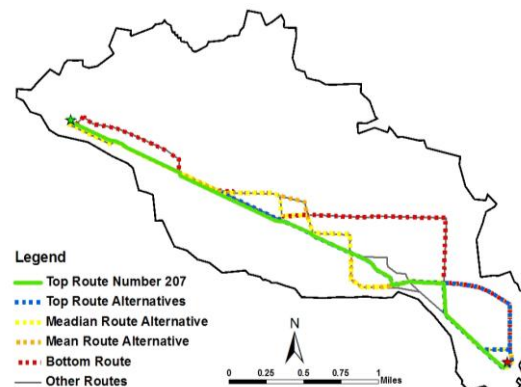


Figure 20. Top, Alternative Top, Median, Mean, and Bottom Route Selection.

The most favorable route followed closely to the simple average optimal route from phase two, only deviating near a commuter rail station and following a more direct route through an industrial area (Figure 21). Key weighted values of the social considerations of residential proximity and structure encroachments had the highest influence on selecting the route.

Schools and churches although weighted the highest had only marginal influence based on the low number of these in the project proximity.

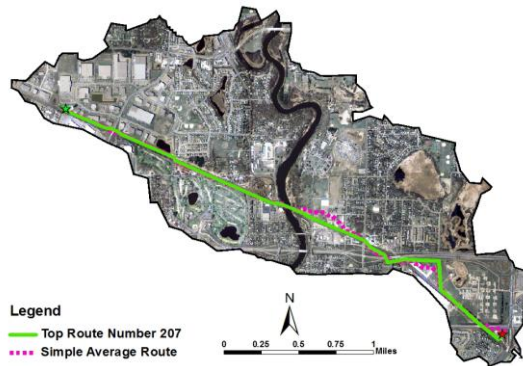


Figure 21. Phase 2 Simple Corridor Route and Preferred Statistical Route Map.

Discussion/Conclusions

During the lifespan of this transmission project, review of the results and route changes will be scrutinized against the model to try to uncover weaknesses in the methodology and/or potential flaws. Potential changes to the methodology will be tested against the current project to strengthen the methodology. Next, it is desired to utilize the model and compare results of this project along with past and upcoming projects. Further refinements may be needed to benchmark and assess accuracy between the model results and the final constructed project. Additionally, budgeted resources for the acquisition and creation of needed GIS data sets along with the possibility of contracting a fly-over to acquire high-resolution air photography for the project area are being considered.

Possible problems using the methodology primarily include that the models results are only as good as the data used. Important data types used in the analysis may not exist or be incomplete. If errors are introduced into the analysis, outputs will be erroneous. Careful and consistent use of the tool and documentation of known limitations in data is required to help reduce

potential errors, project biases, and tool misuse.

The model produces a consistent, defensible, and transparent siting process for transmission line route decision-making. It improves the productivity of staff in determining optimal corridors and reduces the risks of public, regulatory, and legal scrutiny. It is the intent of the methodology to effectively aid in the decision making of a transmission siting team to present the optimal routes based on sound analysis methodology, scientific backing, and expert judgment for permitting with potential cost, public relations, and time saving benefits.

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Project Resource Products Procurement

All project specific documents including highly detailed model diagrams, statistical analysis spreadsheets, and data sources can be acquired by sending a letter of request to the following email address: AJSCHM05@smumn.edu

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