USE OF GEOGRAPHIC INFORMATION SYSTEMS
FOR APPLICATIONS ON GAS PIPELINE RIGHTS-OF-WAY

APPLICATIONS DES SYSTEMES D'INFORMATIONS
GEOGRAPHIQUES AUX TRACES DES GAZODUCS

ANL/CP--74033

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DE93 004237

ABSTRACT

Geographic information system (GIS) applications for the siting
and monitoring of gas pipeline rights-of-way (ROWs) were
developed for areas near Rio Vista, California. The data
layers developed for this project represent geographic
features, such as landcover, elevation, aspect, slope, soils,
hydrography, transportation, endangered species, wetlands, and
public line surveys. A GIS was used to develop and store
spatial data from several sources; to manipulate spatial data
to evaluate environmental and engineering issues associated
with the siting, permitting, construction, maintenance, and
monitoring of gas pipeline ROWs; and to graphically display
analysis results. Examples of these applications include
(1) determination of environmentally sensitive areas, such as
endangered species habitat, wetlands, and areas of highly
erosive soils; (2) evaluation of engineering constraints,
including shallow depth to bedrock, major hydrographic
features, and shallow water table; (3) classification of
satellite imagery for landuse/landcover that will affect ROWs;
and (4) identification of alternative ROW corridors that avoid
environmentally sensitive areas or areas with severe
engineering constraints.

RESUME

Geographic information system (GIS) applications for the siting and
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INTRODUCTION

A geographic information system (GIS) is a set of tools for storing, retrieving, displaying, combining, and analyzing digital representations of geographic data. During the selection of new gas pipeline rights-of-way (ROWs), issues related to geographic data, such as environmental and social-political issues, are addressed. The gas pipeline industry also provides information to local, state, and federal regulatory agencies about potential pipeline construction impacts. Once constructed, these ROWs are regularly monitored to assess environmental and safety issues. Currently, information concerning these issues, both during the siting and after, is usually collated from several different map sources. However, these sources are often outdated and presented at different map scales, making accurate interpretation difficult. GIS makes it possible to store and update geographic data digitally and to display and overlay different data layers at the same scale. This overlaying capability makes GIS a powerful land management and decision support tool by allowing the user to visualize the relationships between different parameters on a spatial basis. A GIS can be used to assess environmental impacts, evaluate site suitability, detect change over time, manage resources, and model the effects of environmental phenomena across a landscape. These systems can also be interfaced with such tools as computer-aided design (CAD) and automated mapping/facilities management (AM/FM).

This study was designed to illustrate how a GIS can be used to site pipeline ROWs. A GIS was first used to develop a digital database with map layers containing information pertinent to environmental and engineering issues involved in pipeline ROW siting. A GIS analysis tool employing least-cost analysis was then used to route pipeline ROWs avoiding areas with environmental and/or engineering constraints.

METHODS

Study Area

The site selected for study is a 351.5-square-mile (9.1-hectare) area near Rio Vista, California , covering approximately half of Solano County and small portions of northwest Sacramento County and southwest Yolo County, California. The site lies 58 km (36 miles) southwest of Sacramento, California, and 74 km (46 miles) northeast of San Francisco, California. The study area is mapped on six 7.5-minute USGS quadrangle maps: Rio Vista, Birds Landing, Denverton, Elmira, Dover, and Liberty Island.

The Sacramento River runs through the eastern portion of the study area. This area is a nearly level floodplain and is under intensive irrigated farming. The central quarter is rolling to hilly and is used primarily for dryland, small grain, and pasture. The southwest corner, near Grizzly Bay is mostly marshland. An existing 20-year-old pipeline traverses the study area.

Geographic Information System

Geographic information systems are designed to store, manipulate, analyze, and display spatial data derived from a variety of cartographic and thematic sources. The GIS selected for this project was the Geographic Resources Analysis and Support System (GRASS) (Westervelt

1988) version 3.1, a public domain system developed by the U.S. Army's Corps of Engineers Construction Engineering Research Laboratory (USA-CERL) at Champaign, Illinois.

Data Acquisition and Development

Thirteen GIS data layers were developed for this project. Some of the data used in this study were available in a digital format and could be used directly within the GIS. Some data were available digitally, but not in the correct format. In addition, data such as soils can require further development before they are ready to be manually digitized. Data costs for this study are representative of current data acquisition and development costs. These costs can range widely, however, depending on the availability, scale/resolution, areal coverage, format and age of the existing data. Over time, more data will become available as local, state and federal governments, as well as private interests, will have developed data for other GIS applications. Also, opportunities exist for cost-sharing activities between other parties interested in creating digital data in areas of mutual interest.

Elevation, Slope, and Aspect. The elevation data layer was obtained through SPOT (Systeme Pour l'Observation de la Terre) Image Corporation. The data file for elevation is referred to as a digital terrain model (DTM). A DTM is created from a pair of SPOT stereo panchromatic images. A panchromatic image is a black and white product with a spectral sensitivity that extends over the UV and visible portions (0.51 to 0.73 micrometers) of the spectrum.
A data layer with a slope in degrees of inclination was generated from the DTMs. An aspect data layer, a layer that indicates what direction slopes are facing, was also generated.

Panchromatic Image. During the process of creating DTMs, an "orthocorrected" panchromatic image is created. This product is created through a process of scanning stereo images, pixel by pixel, which results in the elimination of photographic scale variation and image displacement caused by relief and tilt. On an orthocorrected image true distances, angles, and areas can be measured directly from the image. Because features on an orthocorrected image are in their true, planimetric positions, orthocorrected panchromatic images are excellent black and white reference-base maps.

Landcover. A SPOT multispectral image was used to generate the landcover data layer. A SPOT multispectral image consists of reflectance data from three spectral bands: the green band (0.50 to 0.59 μm), the red band (0.61 to 0.68 μm), and the near infrared band (0.79 to 0.89 μm). Through a process called "unsupervised classification," the spectral data for each pixel are examined, and pixels are grouped into classes of similar spectral reflectance (spectral classes). These spectral classes may correspond to landcover classes, such as grassland, irrigated agriculture, or swamp/marsh. The landcover information contained in these spectral classes can be identified by "ground truthing" (an approach used to verify remote sensing information by field studies) or by comparing it to some reference data (such as larger-scale imagery or maps). The accuracy of the classified landcover layer is directly correlated to the amount of

field data used to verify the resulting categories. Because the nature
of this study was to demonstrate the usefulness of GIS for siting ROWs
and not to actually site one, no ground truthing was performed to
classify landcover. To identify landcover categories for this study,
Pacific Gas and Electric (PG&E) personnel who were familiar with the
area were consulted.

Soils. The soils data layer was digitized manually from the
U.S. Department of Agriculture's Soil Conservation Service (SCS) soil
survey maps for Solano County, California (Bates 1977). These survey
maps, which are part of the SCS soil survey reports written for each
soil survey area, were compiled onto aerial photographs at a scale of
1:24,000.
        The aerial photographs used for compiling the original soil survey
maps were not corrected for tilt, curvature, and ground relief.
Therefore, they could not be treated as maps, because distance
measurements on these photographs were not accurate. Because the soil
survey maps could not be used directly for digitizing, the soil polygons
from these maps were recompiled onto corrected aerial photographs
(orthophotographs). Orthophotographs can be treated as maps, because
distance measurements made between two features on an orthophotograph
are accurate. This recompilation process involved overlaying clear
acetate orthophotographs onto the original uncorrected aerial
photographs and aligning identifiable features on both photographs.
Soil polygons were redrawn onto the orthophotograph for a small area and
readjusted whenever features on both photographs no longer matched.
        The final recompiled soils map was then digitized, and each soil
polygon was labeled with its associated soil type. The resolution of
the final digitized soils data layer was 20 m. Because the soil survey
contains information pertaining to the physical and chemical
characteristics of each soil type, as well its suitability for various
land uses, the digitized soils map was reassigned attributes related to
soil properties, such as depth to bedrock, depth to watertable, and
erodibility. This process of reassigning attributes to spatial data is
termed "reclassing." The resulting reclassed maps were used in the
siting analysis.

Hydrography. The U.S. Geological Survey (USGS) maps hydrography
on the 7.5-minute quadrangle maps. These maps also have additional
information, such as transportation corridors, political boundaries, and
topographic contours. Digitizing off of these paper 7.5-minute
quadrangle maps is difficult, because all the other extraneous
information can confuse the digitizer. Paper maps are also an unstable
source for digitizing, because they can easily shrink or stretch. An
alternative is to order color separations from USGS. These separations
come on a stable mylar base and contain information on only one theme,
such as hydrography. The hydrography separations for the six
quadrangles covering the project study area were digitized to produce
the hydrography map layer.

Transportation. As with the hydrography layer, 7.5-minute
quadrangle color separations for transportation features were used to
digitize the transportation map layer.

Wetland Inventory. Wetland inventory data can be obtained from
the U.S. Fish and Wildlife Service. These data are available either

digitally (already digitized and in a GIS format) in files representing a 7.5-minute quadrangle or on 1:24,000-scale paper maps. For this study, digital files were available and were downloaded directly into GRASS.

Endangered Species. The California Fish and Game Department is in the process of converting all the threatened and endangered species data for the state into a digital format. Unfortunately, the system used to digitize the data allows for overlapping polygons, and GRASS cannot import data containing overlapping polygons. Therefore, this type of data format could not be used. Paper maps were available, however, and were used to digitize point and polygon data for threatened and endangered species.

Geology. Geology map coverage for the study area was limited. The geology map digitized for this study was a 1:62,500 scale map that did not cover the northeast corner of the study area. This scale is smaller than the other layers used in this study (1:24,000). The acceptable resolution to represent data from a 1:24,000 scale map is 20 m; however, the geology map cannot be used at a resolution less than 50 m. For this reason, the geology map was not used in the analysis but was used to provide further information for the engineering siting process.

LEAST-COST ANALYSIS

Assigning Costs

A GIS least-cost method, based upon environmental and engineering parameters, was used to locate alternative pipeline ROWs through the study area. This least-cost analysis was a three-step process. The first step was to assign cost values to the different categories of a GIS data layer. These values can be monetary if the cost of traversing specific areas is known, or subjective if relative or weighted costs are used. For instance, using a subjective method, areas with more severe limitations due to environmental sensitivity or engineering constraints may be given higher costs than areas without these limitations. The costs in this study were assigned subjectively to illustrate the least-cost method of siting pipeline ROWs. In addition, costs were not assigned cumulatively. For instance, when a grid cell contained more than one cost category, it was assigned the cost for the category with the highest cost instead of adding the costs together.

Environmental Costs. To assess the environmental impacts on siting a new pipeline ROW, two environmental cost data layers were created. The categories of these layers represent environmentally sensitive features, such as endangered species habitat, wetlands, erosive soils, and high intensity agriculture. Existing transportation ROWs were also included in one cost layer because in many cases they are considered good corridors for pipeline ROW routing by the gas industry. Unitless cost values for these features were assigned subjectively. Areas thought to be of higher environmental concern during permitting were assigned higher relative costs.

For this study, threatened and endangered species habitats were considered to be the most environmentally sensitive areas in the study area. Habitats with species listed as threatened or endangered on the

federal list and in the state of California were given the highest cost
(80) in the cost data layers.   Locations with threatened or endangered
species listed only on the federal list but not on the state list were
given a lower cost (67).   All wetlands, as designated by the U.S. Fish
and Wildlife Service, were given a slightly lower value (65).   Soils
classified by the U.S.D.A. Soil Conservation Service as highly erodible
were assigned a cost value of 50.   The landcover map categories -
irrigated cropland, cropland, improved grasslands, and rangeland - were
given cost values of 45, 40, 35, and 32, respectively.   In the cost
layer for case 1, the transportation ROWs were given an incrementally
lower cost value than the surrounding areas (Table 1).   The cost layer
for case 2 did not contain cost categories for transportation (Table 1).
The lowest cost for these maps started at 31 because a base cost of 30
was built into each grid cell.   This cost was used to address the issue
of distance in the model, because if a base cost of 30 were accrued
whenever a grid cell was crossed, the shortest least-cost route would be
selected.

TABLE 1.   Environmental Cost Categories

Category	Case 1 With Transportation	Case 2 Without Transportation
Base Cost	30	30
Transportation through		
Landcover Classes	31	N/A
Rangeland	32	32
Improved Grasslands	35	35
Cropland	40	40
Irrigated Cropland	45	45
Transportation through		
Erodible Soils	49	N/A
Erodible Soils	50	50
Transportation through Wetlands	64	N/A
Wetlands	65	65
Transportation through		
Endangered Species	66	N/A
Endangered Species	67	67
Transportation through California		
Endangered Species	79	N/A
California Endangered Species	80	80

Engineering Costs.   Two engineering cost layers were created by
combining information from data layers representing geographic features
considered to be engineering limitations for pipeline installation and
management.   The first of these cost maps included the categories of
depth to bedrock, hydrography, depth to watertable, soil erodibility,
plastic/organic soils, and irrigation ditches (Table 2).   Although
irrigation ditches can represent an inconvenience during pipeline
construction, they do not represent a severe limitation.   In the second
least-cost analysis, irrigation ditches were not included in the cost

layer. In addition, because plastic/organic soils do not represent as much of a problem during pipeline construction as they do for pipeline maintenance after construction, they were also excluded (Table 2).

A shallow depth to bedrock was considered to be the most limiting engineering factor for pipeline installation. This category was assigned a cost value of 85. A cost value of 65 was assigned to major hydrographic features (i.e., permanent streams, lakes, and rivers) representing an impediment to pipeline construction. Areas with shallow water tables were assigned a cost value of 50. Erodible soils represent an unstable environment for pipeline installation and were assigned a cost of 45. For one of the cost layers, plastic/organic soils and irrigation ditches were assigned values of 42 and 37, respectively. A base cost of 30 was assigned to all other grid cells.

TABLE 2. Engineering Cost Categories

Category	Case 1 Construction and Maintenance	Case 2 Construction Only
Base Cost	30	30
Irrigation Network	37	N/A
Plastic/Organic Soils	42	N/A
Erodible Soils	45	45
Shallow Water Table	50	50
Major Hydrography	65	65
Shallow Bedrock Depth	85	85

Combined Costs: Because both environmental and engineering constraints are considered when siting a new pipeline ROW, cost layers were created that combined both environmental and engineering factors. In the first layer, engineering factors were given the highest values: shallow to bedrock (100) and hydrography pertinent to engineering (90). The California threatened and endangered species habitat and the U.S. Fish and Wildlife wetlands were assigned costs of 80 and 70, respectively (Table 3). In the second layer, the order was inverted to assign the environmental factors the higher costs (Table 3).

TABLE 3. Combined Engineering and Environmental Cost Categories

Case 1 Engineering Dominant	Case 2 Environmental Dominant
Base Cost -- 30	Base Cost -- 30
Shallow Bedrock Depth -- 100	Major Hydrography -- 70
Major Hydrography -- 90	Shallow Bedrock Depth -- 80
California Endangered Species -- 80	Wetlands -- 90
Wetlands -- 70	California Endangered Species -- 100

Cumulative Cost Layer

During the second step of this least-cost analysis, the total cost of traversing the space between a starting point and each grid cell in the cost map layer was determined. This determination is made by assigning adjacent grid cells a cost value equal to the sum of the cost of the original grid cell and the adjacent grid cell. This is done iteratively throughout the data layer until the furthest grid cell from the original grid is reached and assigned the highest cumulative cost value. This resulted in a new map resembling an elevation data layer, where high elevations were areas with higher cumulative costs, and the lowest point in the model was the original input point. This step was performed on all six of the cost layers.

Route Determination

In the final step, a least-cost path was traced between a new point and the lowest point in the cost model (the original input point). This process finds the lowest grid cell that can be reached through directly adjacent cells that are less than or equal in value to the grid cell reached immediately prior to it. This step created a map layer representing the path of least resistance through each of the six cost maps. For this pipeline siting analysis, the input points were located where an existing 20-year-old pipeline enters and exits the study area .

RESULTS

Environmental Results

Least-cost analyses were performed using cost layers that represented various environmental constraints to siting a new gas pipeline ROW. Areas with environmental sensitivity for ROW construction were given weighted cost values based on their degree of sensitivity. These values were subjectively selected for this study; other values could be easily substituted and the analysis rerun using different cost values. The cost analyses may also be performed repetitively by varying the cost values for the input layers in order to determine the sensitivity of the routing to the inputs and their associated cost values. If the monetary value for constructing a new pipeline through various environmentally sensitive areas were known, then monetary cost could be used as a basis for assigning costs.

The gas industry prefers to route new pipeline ROWs along existing transportation ROWs when feasible. Having roads parallel to a ROW provides for easier access to the pipeline for maintenance after construction. When transportation ROWs were given the lowest cost on the cost layer, the resulting route followed transportation corridors, even where this meant going through a high-cost, environmentally sensitive area. This type of analysis was not used because the desired result was to route the pipeline along transportation corridors when reasonable but not to force the route into environmentally sensitive areas just because transportation corridors exist.

To correct for this undesirable routing, transportation ROWs were assigned different costs depending on where the transportation corridors were located (Table 1). A cost of 79 was assigned to transportation ROWs in the habitat for California-listed threatened and endangered species. In areas designated as habitat for federally listed threatened

and endangered species, transportation ROWs were given a cost of 66.
When transportation ROWs coincided with wetlands, a cost of 64 was
assigned. A cost of 49 was assigned to transportation ROWs through
areas with erodible soils. Transportation ROWs running through the
landcover classes were given the lowest value in the cost layer, 31.
The least-cost analysis for this map resulted in a route that was
influenced by transportation ROWs but was not totally controlled by
them. The total route length was 31.0 m.

A least-cost analysis was also performed without considering
transportation ROWs in the model. The total length for this pipeline
route was 30.5 m. Both alternatives had a total length greater than
that of the original 20-yr-old pipeline (29.7 m).

Engineering Results

Least-cost analyses were performed on cost maps where engineering
constraints to pipeline construction and maintenance were assigned
relative values. In the first analysis, six engineering characteristics
were assigned values in the cost layer (Table 2). The second analysis
did not consider irrigation ditches or plastic/organic soils. In the
first analysis, the route was influenced by areas of plastic/organic
soils and irrigation networks in the northern half of the study area.
For both alternatives, the route was strongly influenced by the areas of
shallow depth to bedrock. When only the top six cost categories were
considered, the path was much more direct in the northern portion of the
study area, closely following the path of the original 20-yr-old
pipeline. Although the total length traversed by both alternative
routes was substantially the same (six categories, 31.7 m; four
categories, 31.4 m), the total weighted costs may be quite different,
based on the unit costs of the cells the route traverses.

Combined Environmental and Engineering Results

Some of the environmental and engineering constraints were
combined in a single cost layer and used for least-cost analysis. In
the first analysis, the features with the two highest engineering cost
values in the engineering cost layer (shallow depth to bedrock and major
hydrographic features) were given the two highest costs in the combined
cost layer. This resulted in a ROW 32.9 m in total length. In the
second analysis, endangered species habitat and wetlands from the
environmental cost layer were assigned the highest costs in the combined
cost layer. The ROW sited in the second analysis was a total of 32.2 m
in length. Results from both of these analyses show there are subtle
differences between the cases where engineering or environmental
constraints are dominant. The subtle differences in these routes can
cause increases in permitting and construction costs associated with
wetlands, endangered species, and hydrography. These differences in
routing allow decision decision makers to focus attention on specific
areas that control the location of the ROW and evaluate those areas in
detail.

Comparison of GIS and Conventional Siting Methods

Using GIS, the spatial relationships between important parameters
such as wetlands, hydrology, and endangered species can be readily seen
on a common database, at common scales. This allows the decision makers

to focus the routing studies on particular areas critical to successful permitting and cost minimization. Evaluating these relationships by conventional means is often complex , requiring multiple maps and interations of field data collection.

Currently, gas industries approach the issue of siting by selecting a route and then collecting the required data from map sources and field surveys to evaluate their selection based on environmental and engineering criteria. If problems are encountered with the selected route, an alternative route is chosen and the process begins again. This type of procedure can be time consuming and costly. GIS allows for the collection and development of data pertinent to the routing of ROWs prior to route selection. GIS analyses are then used to determine the placement of multiple routes prior to field checking. Field checking can then be narrowed down to a few alternative routes, to select the best among them.

CONCLUSIONS

This study illustrates how GIS can be used to assess alternative routes for new gas pipeline ROWs. Routes were selected by assigning costs to geographic areas on the basis of environmental and engineering characteristics that could affect pipeline construction and maintenance. Least-cost analyses were then used to select possible pipeline routes that avoided areas of high environmental or engineering cost. Resulting routes can be changed by varying the inputs into the cost layer, either by including or excluding cost categories or by changing the actual costs assigned to each category.

When transportation ROWs were included in the environmental least-cost analysis, the resulting route was different than that obtained when transportation was not included. Furthermore, altering the value assigned to transportation ROWs influenced the degree to which the route followed a transportation ROW, regardless of other environmental constraints.

When engineering criteria were used as the cost layer values, routes were generated that avoided areas with engineering constraints to pipeline construction or maintenance. Including or excluding minor constraints, such as irrigation ditches and plastic/organic soils, changed the results of the least-cost analysis.

In the final analyses, environmental and engineering costs were combined for two cost layers, one that assigned higher costs to engineering criteria and one that assigned higher costs to environmental criteria. Least-cost analyses were performed using these two cost layers. The outcomes from these analyses differed only slightly.

The results show that GIS is a good method of siting new pipeline ROWs on the basis of environmental and engineering constraints to pipeline construction and maintenance. The cost and time needed to use this GIS approach compare favorably with those needed for the current methods used by gas pipeline company land planners and engineers. The types of criteria used, as well as the costs or weights given to these criteria, can be changed easily. This provides the flexibility to assess several alternatives quickly and easily.

To use this approach for an actual siting, using real costs, the GIS must be coupled with a costing model which incorporates historical cost data for engineering and environmental permitting. To do this adequately, cost databases need to be developed and verified that describe the cost to obtain a permit for installing a gas pipeline ROW

through environmentally sensitive areas. Furthermore, these databases need to be developed regionally or within service areas.

Further research may be needed to determine how sensitive the model is to various input categories and their assigned costs. For instance, one might wish to investigate the magnitude of cost change for shallow bedrock depth that will cause a change in the resulting route. In addition, if monetary costs for the construction and maintenance of pipelines through areas with engineering constraints or environmental sensitivity were known, they could be used in the least-cost analysis. In some regions of the country, proximity to population centers, federal land ownership, coastal erosion characteristics, or the existence of archaeological sites may be important issues. These types of costs could also be included in the analysis.

Coupling of GIS with other methods, including statistical and physical analyses, needs to be investigated. In addition to the statistical interface cited above, GIS may be coupled to physical models in the areas of hydrology, geology, transportation, storage, and production. In some instances, the coupling may extend to incorporating the models into the GIS. Available models need to be investigated for their compatibility with GIS and with the interfaces defined and established in this study.

ACKNOWLEDGEMENTS

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