Pipeline routing using GIS analysis

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A prototype least cost pipeline routing was performed using various data and GIS analysis. The Ahvaz-Marun oil pipeline in the south west of IRAN was chosen for the development of the prototype.

GIS is a science and technology which combines different data from various sources for route design processes through spatial analysis. Also, it is used to unify project processes including environmental characterisation and project team decision making [1].

Various research has already been performed in pipeline route design using GIS including optimal routing for pipelines [2,3], selection of best route for expansion line [4] and gas line route selection using high resolution remote sensing images [5].

This article describes one of the efforts toward investigating innovative approaches to pipeline routing. The present study was initiated to demonstrate the use of various data from different sources and GIS analysis for developing a least cost pathway for pipeline placement using the Ahvaz-Marun pipeline as an example. The study area selected is in Khuzestan Province in the south west of Iran. The site lies in the southern Zagros Mountains near the Persian Gulf and is an area of low relief along the proposed pipeline route. (Fig. 1).

Data acquisition
Maps and field work are required for pipeline routing, pipeline design and construction. For this route, topographic maps at scale of 1:25000 produced by the Iranian National Cartographic Centre (NCC) were used. The available largest scale geologic map of the area is at a scale of 1:250000. The area of interest for this analysis is shown in Fig. 2. The least cost pathway analysis, using various data and GIS analysis, was intended to confirm the best pipeline route within this site.

Input of topographic and geologic data
Topographic and geologic data of the Ahvaz-Marun pipeline area were prepared in a GIS ready format and used as input to the GIS database. The locations of roads, railways, wetland, forests and drainage features were derived from the topographic map layer. This layer that is produced by NCC is the base for the national topographic database (NTDB) and has a number of features for instance location of roads, railways, wetland, forests, drainage features and elevation points (Fig. 2).

In this project, a digital elevation model (DEM) was produced from the elevation data. The slope map, derived from the DEM, is shown in Fig. 3. It was used as input for the least cost pathway analysis. The lighter tones indicate greater slopes. Most of the steeper slopes were found near Marun while Ahvaz and other areas have low slopes between 0° and 5°.

Geological formations in the area under study are shown in Fig. 4. These boundaries between geologic units were extracted in digital form from the geological map and incorporated into the GIS database. These geologic units were divided into very hard rock, hard rock, soft rock and very soft rock based on the descriptions in the geological map legend.

Also, faults were considered in the analysis (least cost pathway) because crossing pipeline over them is dangerous and must be avoided. (Fig. 5).
Pipeline routing criteria

The factors influencing pipeline route selection are technical involving engineering requirements, environmental considerations and population density. However, these factors are chosen to balance engineering and construction costs against environmental costs and future liability [4].

The engineering and technical considerations used in this research include pipeline length, topography, surface geology, river and wetland crossings, road and railroad crossings and the proximity to large population centres. High relief terrain would result in higher construction costs and increase the need for pump stations [5].

Cost factors used in the least cost path analysis were calculated from the actual pipeline Iranian Petroleum Company project and the normalised baseline cost. Using cost of an existing pipeline project, percentages over the baseline costs were calculated for construction in rock, clearing of brush and tree, crossing of rivers, railroads, and passing through agricultural land and wetlands. Estimates were made of the slope ranges that are associated with four terrain categories including flat, rolling, sharp choppy and rough that are commonly used by pipeline estimators. The cost of a pump station, however, has not been considered in this analysis. As generally, it is not desirable to route pipelines through urban and industrial areas; these areas were assigned high costs above the baseline value.

Least cost pathway analysis

The pipeline project had no constrained point for passing except in Ahvaz (destination) and Marun (source). The objective of the cost pathway analysis was to compare the cost of an existing pipeline route to a least cost pathway between the two points. The analysis was performed using 30 m resolution cells (for raster layers). In other words, in each GIS layer a value was calculated and assigned for each 30 x 30 m cell in the study area.

The analysis was accomplished by entering map data into a GIS. GIS analysis is used for spatial modelling and data overlay. The GIS provided the framework for developing and overlaying all the input layers and carrying out spatial analysis. ArcView and ArcInfo software were used for the display and spatial analysis, respectively.

The topographic, geologic and land use data were used to develop a least cost pathway for pipeline placement. The least cost analysis was performed by assigning cost factors associated with the crossing of slopes, streams, wetlands, roads, railroads, rock, agricultural land, and urban and industrial areas; developing a cumulative cost surface; and then calculating a path of least resistance across that surface. The location of stream, road, and railroad crossings were digitised from the topographic map.

Least cost pathway analysis is a modification of algorithms that traditionally are used in GIS for drainage basin analysis, with the path constrained to flow through specific nodes to specified endpoints. The first step in least cost pathway analysis is
the generation of a single weighted surface layer, based on input layers generated from a table of weights that contribute to the cost of traversing between two points (cells) [6, 7, 8, 9].

The combined weighted surface is analogous to a topographic surface, in that it has peaks (areas of relatively high cost) and valleys (areas of relatively low cost). The cost surface is shown in Fig. 6.

The darkest tones show the areas with highest costs and the lightest tones indicate areas with lowest costs. The highest costs are in urban areas and in large bodies of water and roads. Moderate costs are in forest and wetland with high slope. The lowest costs were in areas with bare ground, dry grass, less dense native vegetation and agriculture. From the weighted surface a cumulative cost surface was generated. Least cost pathways could follow the resulting surface. Cumulative cost surface utilises a single point of origin and accumulates the sum of cells as one moves from the origin.

The accumulative cost surface consists of the sum of cells between any location on the surface and the point of origin. Sums accumulate as they radiate out from the point of origin. The cumulative cost surface does not show which cell to return to or how to get there. A separate surface has to be generated to return a surface with a value range from 0 to 8 that can be used to reconstruct the route to the origin. Each value (0 to 8) identifies which neighbouring cell to move into to get back to the origin. Once the accumulative cost and direction surfaces are created, the least-cost path route can be derived from any designated destination cell or the end point [6, 7, 8, 9].

There are a total of 1084 cells along the existing pipeline route and 1034 cells along the least cost pathway (Fig. 7). Table 1 shows that the existing pipeline route traversed a larger number of urban, roads and wetlands cells than the least cost pathway.

For each 30 x 30 m in resolution element, there exist as many cells as there are data layers. In each data layer, specific costs above the baseline cost are associated with each feature listed in Table 1.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Existing Route</th>
<th>Least Cost Pathway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban and industrial</td>
<td>8</td>
<td>5</td>
</tr>
<tr>
<td>Crossing of roads</td>
<td>23</td>
<td>9</td>
</tr>
<tr>
<td>Crossing of rivers</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Wetlands</td>
<td>46</td>
<td>12</td>
</tr>
<tr>
<td>Forest</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Very hard rock and hard rock</td>
<td>203</td>
<td>175</td>
</tr>
<tr>
<td>Slope &lt; 20°</td>
<td>823</td>
<td>952</td>
</tr>
</tbody>
</table>

Table 1: Number of cells where existing and least cost pathway cross various features.

Conclusions

The results of the least cost analysis are shown in Fig. 7 and Table 1. Incremental costs resulting from terrain, geology, and land use were accumulated for these routes (existing and proposed pipelines) along the cost surface. The existing pipeline path was 34 km long and the least cost pathway...
was 32 km long. The least cost pathway was shorter and the analysis indicated that it would be 29% cheaper to construct than the existing pipeline path. These results indicate that the proposed pipeline route is the most cost-effective.

Most of the cost difference between the existing pipeline route and the least cost analysis can be attributed to the greater cost associated with the larger number of urban, road and river crossing cells.

Methods also need to be developed to eliminate sharp angles from the least cost pathway. Actual costs should include costs incurred by construction and environmental considerations. However, having built a database that includes topography, geology and land use from satellite imagery and available maps for an area of interest, additional data can be incorporated to refine the model. However, these techniques must be used in conjunction with the many years of field experience of pipeline industry personnel and refined on a case by case basis to obtain the maximum benefits.

References


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