Optimum Route of Pipeline using ArcGIS

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Routing problems are those in which a location or route is chosen for its superiority to others as it may minimize a cost or maximize a benefit. Advancement in processing Digital Elevation Model (DEM) provides for new technological development and an increased capability to accomplish optimum route. Aerial photography and geospatial information systems represent opportunities for cost reduction. DEM when combined with Geospatial Information systems (GIS) bring new approaches to routing and would simulate the environment. The environmental simulation would help in determining the best possible route, depending on need-basis, as the shortest or least-cost path without going to the field. This simulation also provides a vertical profile for the route selected for analyzing. The optimum location and pipeline route generated is the best possible location, as efficient as possible, saving resources, time and cost. This paper would deal with one such problem of finding the least cost path using GIS, and DEM.

Introduction:

Planning a pipeline route for connecting between two nodes in the petroleum industry is complex, costly and time consuming based on distance and terrain. The distance between source and destination of pipelines ranges over many miles of varying terrain, and this terrain is mostly found in remote areas. Pipelines carrying petroleum products for distances are capital-intensive projects. With the fast development environment in the oil and gas industry, and with the increase in consumption of these products, the need for an optimum route becomes more important as this can reduce a huge operational cost.

Planning for the optimum route requires an extensive evaluation process to identify the best possible path. This path must comply with the requirements of the Company in terms of safety and cost.

The importance of decisions in pipeline construction is reflected by the Geographic Information System (GIS) technology, integrated into the decision support system.

The ArcGIS spatial analyst provides a broad range of powerful spatial modeling and analysis features, where users can create, query, map and analyze cell based raster data; perform integrated raster-vector analysis, derive new information from existing data; query information across multiple data layers; and fully integrate cell-based raster data with traditional vector data sources.

Using ArcGIS spatial analyst, GIS users can also derive information about geospatial data such as terrain analysis, spatial relationships, suitable locations, and the accumulative cost of routing from one point to another. ArcGIS spatial analyst integrates real-world variables such as elevation into the geospatial environment to help solve complex problems. ArcGIS spatial analyst provides new functionality for advanced customization and interoperability.

This paper tries to present some of these aspects by considering one of the toughest fields, Shaybah, situated in Saudi Arabia.

Study Area:

Shaybah is a remote area in Saudi Arabia, about 900 kilometers from Dhahran in the Rub'al-khali. Those who have been there agree that the location's topography and climate make the area both challenging and interesting. Salt flats, called Sabkhas, of about two square kilometers each, are interspersed among sand dunes up to 200 meters high. If we take an aerial view, the Sabkhas and dunes looks like craters of volcanoes. The stranded dunes sequence covering the whole Shaybah field makes linking the production oil pipelines throughout these dunes a new challenge for facilities engineers. They need a grading slope between these Sabkhas to reduce large slugging and avoiding back pressure.

The long pipeline surrounding Sabkhas will decrease the pressure and cost while at the same time it will require additional pumps, such as Electrical Submersible Pumps (ESPs), and using machines to penetrate the dunes (Horizontal Directional Drilling).

Fig 1: Shaybah Field

Least Cost Path Analysis:

The amount of terrain undulation along the pipeline is a measure of several costs throughout the pipeline lifecycle; costs that are evidenced in terms of “cut and fill,” operations, the type of equipment used, geotechnical issues and other things.

The short path route for the pipeline is a complex system. It relates closely to geographic location, terrain, elevation and other factors. There will be many different types of data involved. There is a need for more usage of raster data set to GIS. For the least cost path analysis, cells in rasters are evaluated and the path moves to the cell with smallest accumulated value. The process repeats itself until the source and destination are connected. The completed path represents the smallest sum of cell values between the two points.

Any combination of sources and destinations can be a part of a least-cost path analysis. For example, you can find the least-cost path from one source to many destinations or from many sources to a single destination.

If the shortest path between any two points is a straight line, then the least-cost path is the path of least resistance. Least-cost path analysis uses the cost weighted distance and direction surfaces for an area to determine a cost-effective route between a source and a destination.

Criteria for Analysis:

A cost path consists of sequentially connected links that provide the route for each cell location to reach a source cell. A cost path distance (or cost distance) from any cell to a source cell is the accumulative cost of all links along the path for the cell to reach the source cells. There are many possible paths to reach each source cell, and there are many paths to reach the many source cells. There is one least-cost path, depending upon the model criteria.

To find the least cost path for a proposed route pipeline between two Sabkhas in Shaybah field (Sabkha A & Sabkha B). To do that we will have to keep the construction cost down, minimizing slugging and back pressure of oil and also avoid surface facilities.

The following objectives are to be considered;

- The least-cost path should be primarily composed of land with a shallow slope because steep terrain will increase the operating cost.
- The longer the path, the higher the construction costs; therefore, the distance between the two sites needs to be considered.

The first step towards least cost path analysis is the conversion of contour data to Digital Elevation Model (DEM) usually done through ArcGIS Spatial Analyst Extension. The DEM (digital elevation model) is a raster version of the contour data. The source of contour data is Surveying Services Division (SSD) of Saudi Aramco.

Deriving Slope Map:
The Slope helps to identify the maximum rate of change in surface value over a specific distance, and it is expressed in degrees or percentage. Calculating the slope is one of many functions of the spatial analyst tool and this function was used to derive a slope map from DEM.


Fig 2: Slope Map

Reclass Slope Map:
The Slope map was reclassified on a scale of 1 to 10. The darker shades represent areas of shallow slope, areas where construction costs will be less expensive. The result helps to differentiate the slope classes and hence provide an opportunity when choosing location.


Fig 3: Reclass Map

Creating Total Cost Layer:

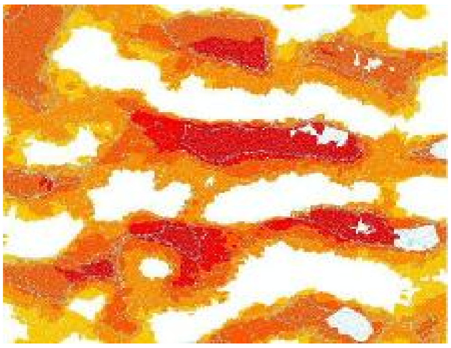
Fig 4: Total Cost Surface

The darker shades indicate areas through which it will be less costly to construct. This is an example of a version of total cost. We can consider various combinations of contributing factors, thereby creating several total cost surface alternatives.

Cost Distance and Cost Direction Analysis:


Fig 5: Cost Distance

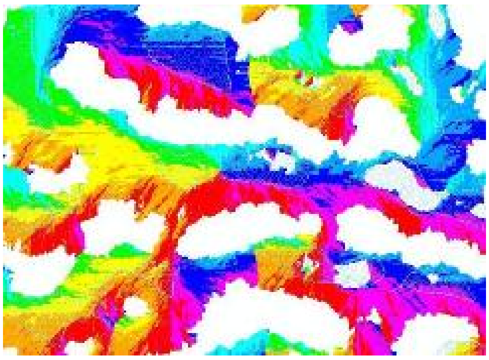
Fig 6: Cost Direction

Once total cost layer is created, we need to derive cost distance and cost direction surface. One surface is increasing costs as we travel farther away from the source. The other surface model is increasing costs depending on the direction we are traveling. Both of these surfaces act as inputs to calculate the least-cost path. The Cost Distance layer represents how costs accumulate as we move further away from the one of the Sabkhas. The cost distance layer takes into account distance measurements from the source and the values of the total cost layer for each location on the map. The cost direction layer takes into account the total cost layer and determines the bearing to the easiest (least costly) path back to the source.

When combined, these layers are like an obstacle course. The farther away you are, the more it costs you in time, money, or effort to reach the goal.

Least-Cost Path:

The least-cost path distance from a cell to a source cell is the smallest (or least) cost distance among all cost path distances from the cell to the source cells.

For shortest or least-cost path analysis, we identify at least two points or locations: the source and the destination. Using ArcGIS spatial analyst we can generate least cost path as shown above and also the shortest path from the source to the destinations. The results indicate the optimum route between two points. These routes are further utilized in the petroleum industry for running simulation models in terms of well optimization.

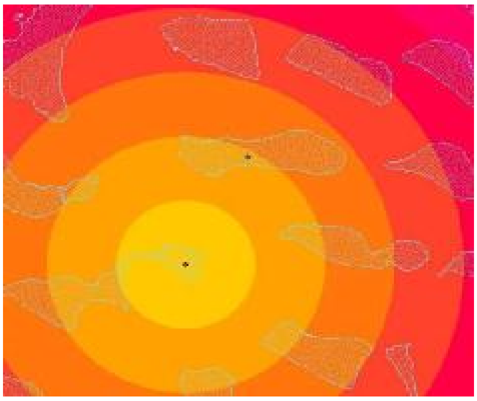

Fig 7: Source & Destination Points

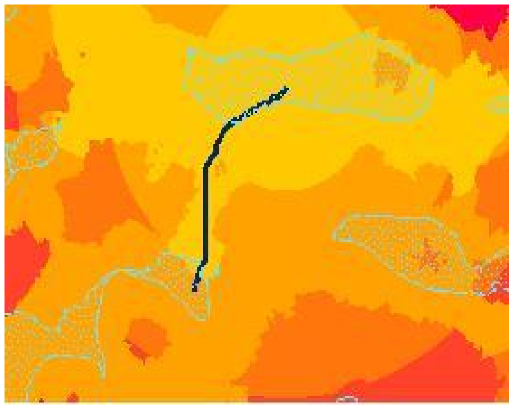

Fig 8: Least Cost-Path

The vertical profile for the least cost path used for simulations.

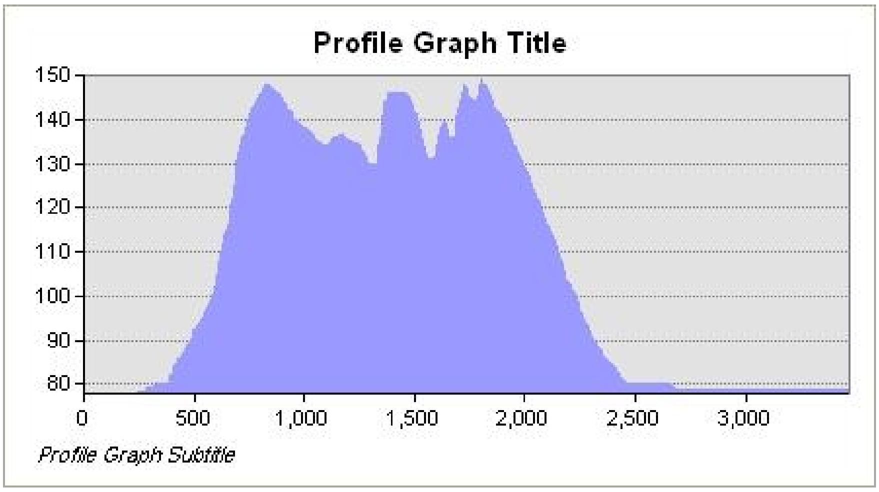

Fig 9: Profile for the Route

Cost Savings

Using an enhanced route selection process eliminates multiple site visits and drastically minimizes field operation costs. The least-cost-path analysis can effectively establish an optimal data collection corridor.

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Conclusions:

Saudi Aramco's increasing oil production has contributed to increasing construction of pipelines. The Company also has the goals of generating the optimum route to assure safety in design, construction, operation, maintenance and emergency response.

With complexity in well planning, pipeline routing needs to be more sophisticated in terms of raster analysis.

As demonstrated in this paper, the ArcGIS spatial analyst module can be used in the optimum route selection of the pipeline process to minimize impacts on back pressure and costly aspects during construction.

People and software are the key elements to any geographic information system and are just as important to a successful and enhanced routing process.

References:

ArcGIS 9.2 Desktop Help-‘Spatial Analyst’