Raster-based GIS data guide economic pipeline construction

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Pipelines

Raster-based GIS routing models prevent pipelines from becoming an economic burden on the companies and countries involved in their construction and operation by minimizing not just the economic costs, but also the environmental and social costs of any new project.

Reducing pipeline construction costs, potential environmental damage, and construction time requires appropriate route planning. Planning should analyze all factors that will affect the route. Frequent changes of surface (land use, topography, streams, etc.) and underground (soil, geology, etc.) characteristics result in a dense data set. Geographical information systems based on raster data models can efficiently manage and analyze this data.

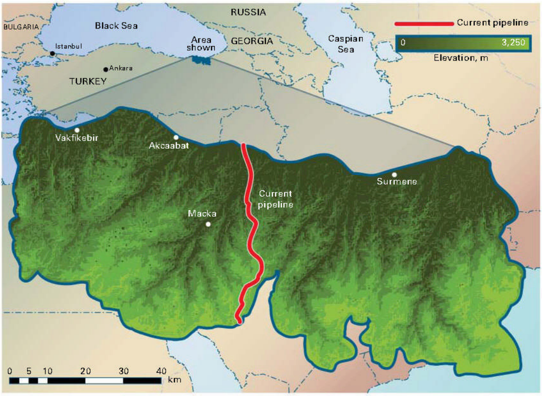
This article presents the raster-based GIS model developed for pipeline routing and lists the model's advantages in pipeline implementation. Routes defined with network analysis techniques over raster-based GIS models minimize economic, environmental, and time costs, depending on the quality of data used.

Background

Route selection is the most important step in the pipeline planning process; affecting technical, economic, sociological, and time components of the project as a whole.[1] This primacy requires defining the factors affecting route selection and weighing these factors, organizing the resulting data into a usable database. GIS technologies allow these steps to be taken in the integral manner required to make accurate routing decisions (OGJ, June 22, 1998, p. 63).

EASTERN BLACK SEA REGION NATURAL GAS TRANSMISSION LINE

Fig. 1



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Studies using GIS technologies to examine the physical, environmental, political, social, economic, and legal factors affecting the planning and operation of pipelines have used the factor and weight principle.[2,3]

Some studies compare the cost of routes selected using conventional methods (economic, social, and time costs) with the costs of routes selected using GIS based models.[2] Other studies have selected the most appropriate route among several alternatives by using GIS techniques. Studies have also used only one or a few of the important factors affecting pipeline route selection, ranging from fault lines[4] to landslide areas (OGJ, Jan. 1, 2007, p. 58).

Turkey offers important pipeline passage opportunities in terms of both operational guarantees and geographical location. The acceleration of natural gas pipeline construction activities in recent years has also expanded the use of natural gas in Turkey. Despite the high level of activity, however, pipeline routing has remained largely nonautomated.

Turkish pipelines have so far used conventional methods and standard topographic maps. Manual routing defines the straight line between the reserve and the target destination. Topographic maps guide when the line is allowed to depart from the straight line within limits of a corridor. Such processes can slow or even stop pipeline projects, particularly if an unexpected sharp turn, excavation, or other labor intensive maneuver is required (OGJ, Aug. 21, 2006, p. 57).

Unnecessary stream, highway, or railway crossings increase the construction costs, duration, and operational costs of the project. Safety costs, including those brought about by unexpected landslide zones, are foremost among those associated with the last. Undetected environmental factors (underground waters, soil type, geological structures, etc.) may also require maintenance and repair earlier than had been anticipated in design (OGJ, May 29, 2000, p. 68).

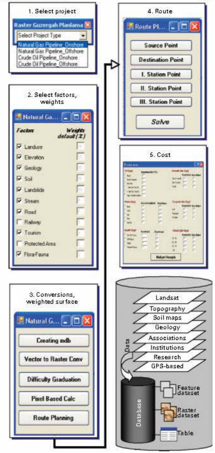
Failure to account for factors affecting routing can negatively affect construction activities, operation, and life cycles of the pipelines. Avoiding these negative outcomes required that Turkey develop an efficient GIS supported routing method for pipelines.

Two different processes—using vector or raster data models—guide GIS routing. Thematic cost calculation, design and modeling simplicity, and ease of incorporating remote sensing data make raster based routing the preferred process.[3,5,6] Raster based network analyses can also guide routing on surfaces where no defined routes exist, in networks composed of layers lacking attributes of the concerned features, and in artificial directional limitations. Scientific research demonstrates that raster based methods more effectively address surface routing problems when compared to vector based networks because surface routing is performed as a cell to cell connection, not as a straight line.[7,10]

This article first examines the applicability of current raster based analysis models to routing pipelines in Turkey, exploring the models' simplicity and flexibility before turning to an example of its use in pipeline routing. Research determined subjects of study area and their weight before transferring the required data for processing and analysis.

A case study shows advantages of the model when compared with classical routing methods, comparing the route

Model workflow Fig. 2



of a current natural gas pipeline with the optimal route defined by the model in terms of cost and environmental exposure.

Materials, methods

Trabzon province, in Turkey's Black Sea region, served as the study area (Fig. 1). The province measures 4,660 sq km and has a population of 975,137. It has a rough topographic structure, with areas other than agricultural lands either covered with forest or barren.

Botas built the Eastern Black Sea region natural gas transmission line, using conventional routing. The studied length of pipeline measures 46 km. Routing the pipeline through landslide areas, as well as unnecessary streams and road crossings, caused a budget overrun and failure to complete the project according to the schedule.

A Landsat ETM+ satellite image dated Sept. 19, 2000, defined land cover[11] with a controlled classification method that used a maximum likelihood algorithm, producing 10 land cover classification maps. These maps include areas with pasture, water, deciduous and coniferous trees, mixed wood trees, green tea fields, hazelnut orchards, rocky areas, settlements, and agricultural areas. Standard topographical maps of 1/25,000 scale produced by the General Command of Mapping provided digital height data for the region. Table 1 shows other data used, with scales, data sources, and weighting.

RASTER-BASED ROUTE SELECTION LAYERS, WEIGHTS

Table 1

Layers	Scale	Data source	Weight, %
Land use	1/25,000	Landsat ETM Topographic maps	20
Elevation	1/25,000	General Command of Mapping	15
Geology	1/25,000	General Directorate of Mineral Research & Exploration	15
Soil	1/50,000	General Directorate of Rural Services	10
Stream	1/50,000	Landsat ETM, GDMR	10
Road	1/25,000	Landsat ETM, Topographic maps (GCM)	10
Landslide	1/25,000	GDMR, Landsat ETM	10
Tourism	1/50,000	Topographic maps (GCM), Ministry of Culture and Tourism	
Protected area	1/50,000	Topographic maps (GCM), Ministry of Culture and Tourism	3
Flora, fauna	1/25,000	General Directorate of Forestry	3
Administrative unit	1/25,000	General Directorate of Cadastre	—

High elevations and uneven topography created problems during pipeline construction. Only 16% of the studied area sloped less than 10°, 43% of the area sloped 10-50°, and 40% sloped more than 50°. Divided more broadly, a quarter of the study area sloped less than 30°, and the remaining three quarters sloped more than 30°.

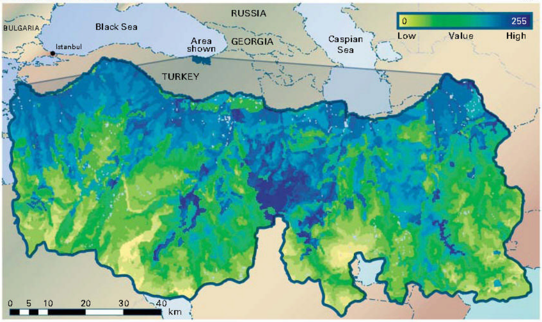
Considering land use, agricultural activities, and other factors, a pipeline route should meet the following criteria:

- Due to diversity of flora and fauna, a pipeline should not pass through any area that is the habitat or breeding place of a threatened species.
- To ensure optimal use of resources, the number of passages over highways, streams, lakes, and rocky places should be minimized.
- To minimize sociological problems, pipelines should be kept away from highly-populated areas and recreational areas.
- To extend operational life and decrease maintenance and repair costs, pipelines should not pass through geologically unfavorable areas or landslide areas.
- To optimize construction and operation, the pipeline should be close to main roads and easily meet its own energy needs.

Table 1 lists data layers created in raster format and their weights; the material necessary to perform an

RASTER-WEIGHTED SURFACE

Fig. 3



integrated route analysis.

Raster-based routing

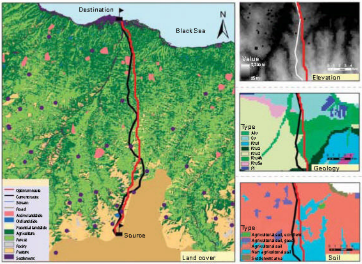
Optimal pipeline routing rests on an integrated examination and analysis of all data. A raster based GIS model depends on collecting all factors that would affect routing on a single raster based surface. Each pixel on this surface has a digital value representing cost of pipeline works. These digital values and direction distance data determine optimal pipeline routing.

An interface based on the proposed model examined its applicability. Development of the interface used the C# software language and ArcGIS 9.2 software, allowing the user to choose which factors determined route selection. Users can increase or decrease the weight of any factor on the basis of cost criteria. The user can enter areas that will definitely act as barriers (flora and fauna areas to be preserved, active erosion areas, fault lines, etc.) in advance, effectively defining the route. The user can also define stops between the start and end of the route.

The interface then allows calculating the cost of alternative routes. Finished pipeline projects and their cost reports provide unit costs. Fig. 2 shows the work flow of the model and the process steps of the database.

OPTIMAL ROUTING

Fig. 4



Case study

Basic steps for finding a minimum cost path over a surface partitioned into regions of different resistances include:[12,13]

• Creating a friction surface for each evaluation criterion, where each cell in the grid is assigned a value based on the relative cost of traversing that cell.

• Weighing and combining multiple friction surfaces to create a cost of passage surface, representing the total cost associated with traversing each cell.

• Using a spreading function to combine separate grids representing source points and destination points with the cost of passage grid to calculate an accumulated cost surface.

• Tracing the lowest cost line down the accumulated cost surface from a departure point to a destination.[14]

Testing the model required attempting to optimize the route of current gas pipeline with it. Process steps for the optimum route defined over the model include:

• *Type of project, factor selection.* The first process step is defining the type of pipeline planned. According to the type of project selected, the user receives factors that affect the route and factor weights as defaults. The user can select any of the factors over this interface on the basis of the existing data and can change factor weights according to the details of the project. Classifying data into a geo database organizes them for use in this step.

• *Raster conversions, classification.* The model then makes projection conversions for the vector based positional data organized in a database and converts data into raster format. The data scale (pixels of the pipeline used equalled 50 × 50 m) allows adjustment of the required pixel dimension identification. Sub factor classifications (complexity grading) required for the data converted into raster format occur automatically in line with data obtained from current engineering activities and operations (Table 2).

• *Pixel based calculation, weighted surface.* Factor weights and classified raster data layers enable pixel based mathematical calculations, obtaining the weighted surface showing pipeline construction costs (Fig. 3).

- *Absolute-relative barriers.* Obtaining the weighted surface allows the areas absolutely impossible to be passed and the areas with high passage costs to be modeled as barriers on the surface. This step used ∞ value in subunit classification for absolute barriers (earthquake areas, flora and fauna areas, etc.). An algorithm prevents the route from passing over pixels to which this value is assigned. A value of 9, assigned to places with high passage cost (roads, streams, and erosion areas), means passage is quite difficult.
- *Source, destination, stops.* A user can model the route's source, destination, and stops on a weighted surface. The model marks related points for this procedure and records them in the database as a separate file. This process step allows the route points over the interface to be shown (Fig. 2).
- *Optimal routing.* After these interim procedures, a cost distance algorithm using ArcGIS 9.2 software generates the final route. Fig. 4 shows the optimum route defined by these steps.

SUBFACTOR WEIGHTS Table 2

Land use		Soil	
Agriculture	6	Agriculture, excellent	9
Forest	7	Agriculture, good	8
Rocky	8	Agriculture	7
Pasture	3	Nonagriculture	3
Settlement	9	**Stream**	
Elevation, %		River	9
<20	1	Stream	7
20-30	2	Wide-Brook	5
30-40	3	Brook	3
40-50	4	Branch	1
50-60	5	**Road**	
60-70	7	Level I, highway	9
>70	9	Level II, express way	8
Geology		Level III, district road	7
Alv, v,pl	3	Level IV, asphalt county road	6
Kru5a, kru5b	5	Level V, dirt county road	3
Ev, jkr, jlh	6	Level VI, seasonal road	1
Kru1, kru3	7	**Protected area**	
Kru2, kru4	8	Level I	∞
Gama2, gama3	9	Level II	7
Landslide		Level III	5
Active	9	Flora, fauna	
Old	8	Flora	∞
Potential	7	Fauna	∞

Route examination

Model development first subjected the current route to evaluation of economic, sociologic, and environmental factors affecting route selection. Route data guided passage characteristics increasing cost (Table 2). Distance and population data provided the basis for examining environmental damage caused by the route and social problems resulting from proximity to settlement areas.

Calculations on the 10 m either side of the pipeline route determined 22 hectares of forest and 15 hectares of agricultural field (hazel nut and green tea) were damaged and detected three passages over landslide areas, 13 passages over highways, and 9 passages over streams. The average distance from the pipeline of 18 settlements measured 470 m. The optimal route would damage 20 hectares of forest and 15 hectares of agricultural fields, crossing 11 highways and 6 streams. It lies 870 m from settlement areas (Table 3).

ROUTE EVALUATION Table 3

Cost type	Examination criteria	Current route	Optimal route
Economic	Pipeline length	46,121 m	44,735 m
	Study area (10 m either side of line)	92.24 hectares	89.11 hectares
	Road passages	13	11
	Stream passages	9	6
	Active landslide passages	2	0
	Inactive landslide passages	1	0
	Protected fauna passages	3	1
	Rocky area passages	9,812 m	2,620 m
Environment	Pasture, grassland, brush passages	12,300 m	19,420 m
	Agricultural field passages (hazel nut, green tea, etc.)	7,700 m	7,900 m
	Forest passages	11,210 m	10,090 m
	Other	5,099 m	4,705 m
Sociologic	Average distance to settlement	470 m	870 m
	Archaeological site passages	0	0
	Average distance to tourism center	640 m	1,430 m
	Cost, US $	4.52 million	3.48 million

Results

Construction costs of the optimal route run nearly 23% lower than construction costs of the constructed route. The lower number of streams, highway passages, and passages over landslide areas in OR than in CR drives the cost difference. Other factors affecting cost include elevation differences, geological elements, and soil structure. OR passes through fewer forests and biologically important fauna areas than CR. The shorter route length also causes less damage to the environment. OR also maintains a 1,430-m distance from tourist areas. ✦

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