INVESTIGATION OF AN AHP BASED MULTI CRITERIA WEIGHTING SCHEME FOR GIS ROUTING OF CROSS COUNTRY PIPELINE PROJECTS

Colin Nithin Nonis
Senior Engineer,
Water & Utilities BU,
L&T- ECC Division, P.B. No 979,
Chennai – 600 036, INDIA
colin@lntecc.com

Koshy Varghese
Professor
Dept. Of Civil Engg, IIT MADRAS,
Chennai – 600 036, INDIA
koshy@iitm.ac.in

K S Suresh
Manager
Water & Utilities BU,
L&T- ECC Division, P.B. No 979,
Chennai – 600 036, INDIA
kssuresh@lntecc.com

ABSTRACT

Pipelines are the most efficient, cost effective and environmentally friendly means of fluid transport [1]. When selecting the route of a cross country pipeline, the goal is to route it so that it has the greatest utility to the public while minimizing negative impacts to people and the natural environment. In order to accomplish this goal of addressing several factors, a large amount of location based information needs to be analyzed. Hence the manual routing processes are very tedious in nature. The advent of new techniques like that of Geographic Information System (GIS) has made the routing process of pipelines more systematic and effective.

This work identifies the various factors which need to be considered while routing a pipeline in the Indian scenario. A GIS to represent the various factors and automatically route the pipeline has been developed. A main drawback in the system is the lack of a structured methodology to derive the relative preferences of the different factors affecting the route. To address this issue, an AHP based methodology was developed. The GIS and the AHP methodology have been tested on case studies in the Indian scenario.

KEYWORDS

Analytical Hierarchy Process, Geographic Information Systems, Least Cost Path, Pipeline Routing, Weighting systems.

1. INTRODUCTION

Throughout the world, a large network of pipelines transports oil, gas, water and other products. Transmission or trunk pipelines are examples of engineering marvel requiring large investments, long gestation periods and operating life. This inexpensive, reliable and high capacity transport is critical to national economy and security [1].

Pipeline alignment is an optimization between several factors such as social issues, environmental issues, cost of the project and so on. Manual pipeline routing uses available maps, surveys and experience and is seriously constrained due to lack data handling capabilities. GIS techniques have an edge over the conventional methods in terms of speed of processing and analytical capability.

Further more, there is a distinct lack of a structured methodology to arrive at weightages for the factors affecting the pipeline route. In previous works, the weighting of factors has been done based on experience of the design team. It was found that there was a lack of a formalized decision making methodology that enabled analytical tradeoffs to be made.

The objectives of this work were:

- To identify the different factors affecting the routing process in the Indian scenario and to develop a GIS to route a cross country pipeline.
- To investigate an AHP based approach to elicit expert opinion to derive weightages for the factors affecting the route.
- To utilize these weightages in the GIS solution and to implement this system in case studies in the Indian scenario.

2. LITERATURE REVIEW

Luettinger et al. (2005) brings out the importance of the stakeholders perspective in the routing process [2]. They mention that the construction of a large-diameter transmission pipeline through heavily developed cities will create many challenges. There will be many engineering obstacles, environmental issues, construction issues, and general public concerns related to the construction of a pipeline of this size and length. Feldman et al. (1995) point out that the factors influencing pipeline route selection are technical and engineering requirements, environmental considerations, and population density [3]. Delavar et al. (2000) applied the least cost pathway analysis for the route selection process [4].

The critical issue in the GIS methodology is assigning the weights to the factors affecting the pipeline route. Edlin (2004) points out that, Geographic information systems (GIS), Multi-criteria decision making (MCDM), and Expert Systems (ES) techniques have been used in resolving the problems of lack of transparency in the weighting process [5]. Huang (2004) has demonstrated that AHP can be used Hazardous material routing [6].

3. SOLUTION METHODOLOGY

The GIS based approaches for pipeline routing process utilize relative rankings and weights on considering factors affecting the potential routes. Prior to the actual route design, corridor selection needs to be done [7]. The area to which the proposed pipeline should limit is first identified for collecting and assembling data like aerial photography, building/house location, existing utilities etc.

The base maps for the corridor selected are collected and the derived maps are generated. Once the derived maps are ready, the suitability analysis is done and a route is found abiding by the governing criteria.

Fig 1 shows the schematic representation of the methodology. Each of the components has been discussed in detail.

3.1 Selection of Factors Affecting the Route

The first step in a routing process is the selection of the factors affecting the pipeline route. Several spatial and non spatial factors affect the pipeline route.
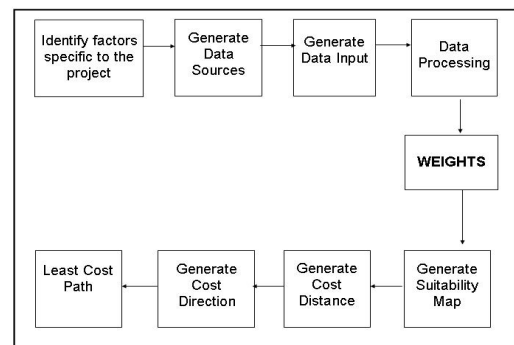

Figure 1 Schematic Representation of the Methodology

When a new routing process is initiated, the list of multiple criteria variables has to be decided first and then the criteria by which these variable constraint the routing process. The criteria refer to the rules which the route should abide to. In general the following factors were found to be more important and are addressed in greater detail in this work.

- Avoid areas with steep slopes
- Avoid road crossings, but proximity to the roads should be high
- Avoid railway crossings
- Avoid river crossings
- Avoid prohibited areas (Cities, Towns, Reservoirs and so on)
- Avoid reserved forest areas
- Avoid areas with high land cost
- Avoid unfavourable soil type

3.2 Data Sources

Maps, satellite imagery and aerial photography are required to make decisions for the route alignment. In the event of maps not being available, field surveys have to be employed and data about the target area should be collected. In this work, the topographic sheet numbers were first identified using the meta server of Survey of India and the required toposheets were procured from them. By visual examination of the target area, the corridor that was most suitable for pipeline routing was identified.

3.3 Data Input

The topographic maps of the area have to be scanned, geo referenced and prepared for further analysis. All spatial features such as roads, rivers, railway lines, town limits and so on have to be digitized for further processing.

3.4 Data Processing

The digitized layers are to be processed so that the route abides the criteria mentioned above. Data processing is done based on the type of spatial attribute. Therefore, we can have

- Processing line features
- Processing polygon features

Figure 2 shows the overview of processing of some features. The first step in data processing is converting the vector data to raster. This is followed by calculating the feature distance cost. (Feature distance cost refers to the weighted cost as one moves away from the feature) This is very important is the processing of features such as roads, land cost polygons and so on. The final step is reclassification.
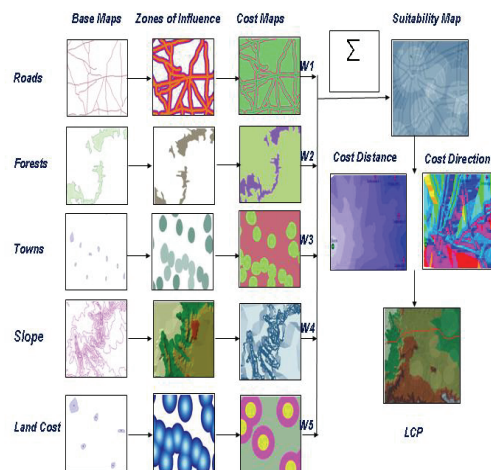

Figure 2 Overview of the Solution Methodology

3.5 Assigning Weights to the Variables

A weighting system has to be devised for weighing each of the map layers. The weighting system forms the backbone of the methodology. The weighted layers are all summed up to form the suitability layer. This layer forms the basis of the GIS analysis. The Analytical Hierarchy Process has been used to derive weightages for the thematic layers. The suitability layer is analyzed for the optimal route. The AHP has been discussed in detail in the next section.

3.6 Raster Data Analysis

The final step is to apply the least cost path procedure and find out the optimal route.

According to Berry J. K. [7], the steps in implementing the LCP are as follows:

- To develop a discrete cost surface that indicates the relative preference for routing at every location in a project area,
- To generate an accumulated cost surface characterizing the optimal connectivity from a starting location (point, line or area) to all other locations based on the intervening relative preferences,
- To identify the path of least resistance (steepest downhill path) from a desired end location along the accumulated surface.

4.   THE ANALYTICAL HIERARCHY PROCESS

Analytical Hierarchy Process (AHP) is a quantitative method for ranking decision making alternatives by developing a numerical score to rank each decision alternative based on how well each alternative meets the decision maker's criteria [8].

The AHP is a decision-making approach developed by Saaty in 1980. The process aids in the solution of complex multiple criteria problems in a number of application domains. In AHP, one constructs hierarchies, then makes judgments or performs measurements on pairs of elements with respect to a control element to obtain ratio scales which are then incorporated into the whole structure to select the best alternative.

The three basic steps for considering decision problems by AHP are:

- Construction of a structural hierarchy
- Establishment of comparative judgments
- Synthesis of priorities

4.1   Establishment of Comparative Judgments

A decision maker or an expert needs to be provided with pair wise assessments of all the variables affecting the routing process to establish a preference matrix, the synthesis of which will result in weightages for the multi criteria variables.

A questionnaire (Fig 3) with all the pair wise comparisons can be presented to an expert. The expert responds to a pair wise comparison, by returning the relative importance of the two criteria on a scale that has been proposed by Thomas L Saaty.

AVOID	RHS* criteria more important than LHS* criteria									LHS* criteria more important than RHS* criteria									AVOID
Steep Slopes	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Road Crossings
Steep Slopes	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Railway Crossings

Figure. 3 An extract of the Primary Questionnaire to Gather Expert Opinion

The responses are consolidated in a preference matrix and synthesized to obtain the weightages.

4.2 Drawbacks in the Application of AHP

Previous works on this topic have failed to incorporate the sub classes of a particular criterion in the routing process. Example: Roads are considered as one criterion and the subclasses of roads such as metalled roads, unmetalled roads and so on have not been considered. This is evidently not a correct practice as the influence exerted by each sub class will be different from another.

The difference in the influence exerted by each sub class can be explained with the aid of the following example. Consider the case of Railway lines in which the expert cannot definitely say that all the sub classes of the road layer i.e. Avoiding National Highway, Metalled, Unmetalled and Cart tracks are more important than avoiding railway lines. There will be a transition point where in the constituents of one criteria will start becoming less important when compared to the other criteria or vice versa Ex: Avoiding a National Highway is more important than avoiding a Railway crossing, but avoiding a railway line is more important when compared to a cart track. Hence there is a transition.

It was found that that the conventional way of gathering pair wise comparison for AHP model cannot be implemented as the result of the pair comparisons being very large in number. This in turn will make the expert's job of answering the questionnaire very cumbersome. Inconsistency in judgments might creep in as a result. Therefore the need to modify the methodology of gathering expert opinion arises.

4.3   Modified   Approach   to   Establish Comparative Judgments

To resolve the problem highlighted in the previous section, it was necessary to modify the existing procedure to collect pair wise judgments from the expert. Hence a second questionnaire (Fig 4) was designed to supplement the information obtained from the main questionnaire.

Criteria	Importance w.r.t National Highway	Is Criteria more important than Railway Crossings (based on Traffic conditions/train freq) (Yes or No)	AHP Scale
National Highway	1		
Metalled Roads			
Unmetalled Roads			
Cart Tracks			

Figure 4 Secondary Questionnaire

In the modified procedure, the expert, first needs to quantify the importance of the sub classes w.r.t the parent criterion as a fraction of 1. Example: The importance of Metalled roads w.r.t National Highways is 0.6.

The subclasses are now compared against other criteria and the expert will judge the comparisons in the form of a Yes or a No. If the expert response is Yes, then the AHP scale value for that criterion can be calculated by multiplying the AHP scale value of the parent criterion with the relative importance value. If the user response is a NO, then the expert is asked to provide the AHP scale value for that particular comparison. When the expert response changes from a YES to a NO, the transition point can be observed.

The AHP scale values are consolidated in the preference matrix and the basic AHP routine is performed to obtain the weightages. The preference matrix will also contain pair wise comparison between the sub classes. Hence the pair wise assessments for those comparisons also have to be obtained from the expert.

5. IMPLEMENTATION OF THE METHODOLOGY

The methodology implemented in the following sequence:

- Data Input
  - Acquiring topographic maps of the target area
  - Acquiring satellite imagery of the area
  - Identification of factors affecting the route.
  - Creating new layers for the analysis
- Data Analysis

- Vector Data Analysis: Processing the data, weighting and Overlay
- Raster Data Analysis: Suitability layer, Cost distancing and Cost direction

The methodology was implemented on a practical problem in the Indian scenario. This problem was a live project of Larson & Toubro (ECC). Arc GIS 8.1 was used for the processing geo spatial information.

Criteria	Importance w.r.t National Highway	Is Criteria more important than Railway Crossings (based on Traffic conditions/train freq) (Yes or No)	AHP Scale
National Highway	1	Y	9
Metalled Roads	0.6	Y	9* 0.6 = 5
Unmetalled Roads	0.4	N	8
Cart Tracks	0.2	N	9

Figure 5 Secondary Questionnaire with Sample Expert Opinion

5.1 The Weighting System

A weighing system was developed using the Analytical Hierarchy Process for the case study. A questionnaire was designed to present all the pair wise comparisons of the criteria to the expert and a numerical scale has been provided, so that expert and quantitatively could rank one criteria over another and establish the comparative judgments. A sub questionnaire was also designed to counter the effect of variation in the different classes of the criteria. The questionnaire developed was developed was presented to 3 experts from Larson & Toubro (ECC), India. The AHP process was automated using VBA in MS EXCEL environment for synthesis of the comparative judgments. The pair wise comparisons of the criteria serve as input to the VBA module. The VBA module was programmed to display the weightages in graphical format.

6. RESULTS AND DISCUSSION

6.1 Results Obtained from the AHP Module

The weightages derived for the input datasets by collecting expert opinions from experts at Larson

& Toubro (ECC) are presented in the following table. Inconsistency ratio was 0.363. Hence the judgments can be considered fairly consistent

Table 1 Weightages for the Input Datasets

	Expert 1	Expert 2	Expert 3	AVERAGE
Slopes	0.0420	0.0640	0.0306	0.0455
NH	0.0463	0.0679	0.0991	0.0711
Metalled	0.0232	0.0246	0.0414	0.0297
Unmetalled	0.0143	0.0095	0.0117	0.0118
Cart Roads	0.0101	0.0095	0.0090	0.0095
Railways	0.0842	0.0933	0.1352	0.1042
Rivers	0.1335	0.1584	0.1072	0.1330
Prohibited	0.2368	0.2437	0.1539	0.2115
Forest	0.2368	0.2097	0.2005	0.2156
LandCost	0.0688	0.0775	0.1614	0.1026
Soil	0.1042	0.0419	0.0500	0.0654

6.2 Results and Analysis of Least Cost Pathway Analysis

The suitability map, cost distance and direction rasters were obtained. The routes obtained by are displayed over the DEM of the area.

The methodology was first implemented without using any weightages to make a comparison between a non AHP aided approach and an AHP aided approach. The results (Fig 6) clearly bring out the difference in the two routes, thus highlighting the importance of the weightages. The non AHP aided route was found to have cut across a prohibited area which is unacceptable. When weightages are implemented, the methodology is able to correct to route as per the defined criteria.

7. CONCLUSIONS

From this study conclusions can be made in the following areas:

7.1 Multi Criteria Weighting for Pipeline Routing

- The Analytical Hierarchy Process to derive weightages and the GIS methodology to route the pipeline have been successfully integrated.

- It was also noticed that the mode of gathering expert opinion for the AHP model could not be implemented in its conventional form, because it could not incorporate the sub classes of particular criteria. An attempt to do so would have resulted in the making the expert's job of

assessing the pair wise comparison too tedious.

- Therefore an AHP model with a modified procedure to collect expert opinion has been successfully implemented in the case study and its results show that it clearly scores over the conventional method of gathering pair wise comparisons.

- The results of the case studies also support the fact that this study has been able to emulate the expert decision making capability.
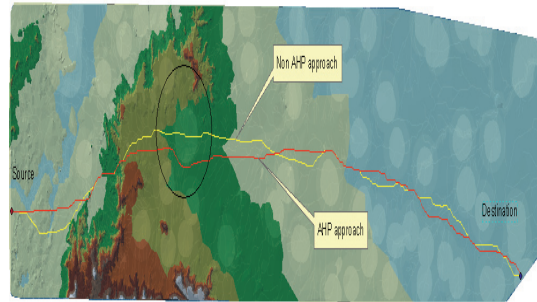

Figure 6 Comparison between Routes Obtained - AHP approach and Non AHP Approach

7.2 Conclusions from the Case Study in the Indian Scenario

- The route suggested by this methodology cannot be considered as the optimal route. This is because of the fact that there are several other ground realities that affect the route. These ground realities can be ascertained only after a detailed ground survey is made.

- The route suggested by this study serves as an excellent aid for the execution team to make the preliminary changes and report the ground realities affecting the proposed route. The design team can then incorporate changes and arrive at a route which can then be considered optimal. Thus the results of this study help immensely in reducing the numerous options for the design and the execution team.

- The results of this study clearly demonstrate the benefits of integrating GIS and AHP, the combination of which,

served as a decision support system for the pipeline routing process.

8. REFERENCES

[1] Dubey, R. P., (2000) A Remote Sensing and GIS based least cost routing of pipelines, <http://www.gisdevelopment.net/>, Visited on August 8th, 2005.

[2] Luettinger, J.,and Thayne Clarke (2005) Geographic Information System-based Pipeline Route Selection Process, Journal of Water Resources Planning and Management, P 193-200

[3] Feldman, S., Ramona E. Pelletier, Ed Walser, James C. Smoot and Doughlas Ahl, (1995) A Prototype for Pipeline Routing Using Remotely Sensed Data and Geographic Information System Analysis, REMOTE SENS ENVIRON, P 123-131

[4] Delavar, M. R. and Fereydoon Naghibi., (2003) Pipeline Routing Using Geospatial Information System Analysis, <www.scangis.org/scangis2003/papers/12.pdf>, Visited on August 18, 2005

[5] Eldin, N., and K. A. Eldarandy (2004) A computer aided system for site selection of major capital investments, Conference Proceedings, 1st ASCAAD International Conference, Saudi Arabia, 3-12

[6] Huang, B., (2004) A GIS-AHP Method for HAZMAT Route Planning with consideration of Security, Environmental Informatics Archive, Volume 2, 814-830

[7] Berry, J. K., (2004) Optimal Path Analysis and Corridor Routing: Infusing Stakeholder Perspective in Calibration and Weighting of Model Criteria, <http://www.innovativegis.com/basis/present/GeoTec04/GIS04_Routing.htm>, Visited on August 18, 2005

[8] Berry, J.K. (2004), "Map Analysis: Routing and Optimal Paths", <www.innovativegis.com/basis/>, Visited on August 20, 2005

[9] Saaty, T.L, (2003). Decision-making with the AHP: Why is the principal eigenvector necessary. European Journal of Operational Research, 145, 85–91.