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GIS – OR Based Optimum Route Selection

Application of Advanced Optimization Models with GIS for Terrain Problems#

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1. INTRODUCTION

Routing for road development, electric power-line development, subway rail-link development and fiber-optic information highway development are all spatially distributed optimization problems that belong to similar class.

Water front development by land reclamation from sea, has become an important way to cope with increasing demand for land in urban areas. Many infrastructures have been built on reclaimed land. Japan has been a forerunner in reclaiming land from sea because of its limited plains. Through excavation of huge volumes of elevated terrain and transporting them to the site of reclamation, Japan has successfully developed many types of infrastructures ranging from simple coastal extensions for urban development to complex artificial island developments. Special transportation infrastructures are normally built for such mud transportation. The problem of routing this infrastructure belongs to the same class. Identification of excavation sites is also an interesting optimization problem

A GIS based Optimization approach was developed to solve such problems and was successfully applied to many routing problems. This approach is presented here by means of a case study. A GIS based fuzzy approach for site selection is presented in another paper titled "Live stock evacuation center selection using GIS based Fuzzy method"[1].

2. PREFERENCES AND CONSTRAINTS IN ROUTE MODELLING

Many well-developed mathematical models exist for spatially distributed routing problem. However, solutions had always been difficult because of the immense volume of data that need to be manipulated. Advent of GIS database has really provided a convenient way to model and solve such problem at practical levels and this approach was applied for our problem.

A schematic development of a generalized routing problem is as explained in figure-1. The objective of the routing is to find the shortest path, within the limits of the preferences and constraints. Land preferences and constraints can be effectively expressed as relative cost of routing, and hence calculation of cost-effective path is more appropriate for terrain problems[2),3),4)]. A good model must take into account preferences/constraints at appropriately fine resolution for practically meaningful solution. While modeling a routing problem the following preferences/constraints are often faced:

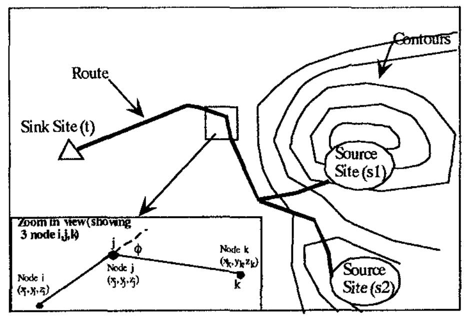

Fig-1: Schematic diagram of routing problem

Minimize

$$\sum_{\forall j:(i,j)\,\xi\,A}\sum C_j{*}d_{ij}{*}X_{ij} + \sum_{\forall j:(j,i)\,\xi\,A}\sum C_j{*}d_{jk}{*}X_{jk} + f(\phi) + g(\theta)$$

Subject to

$$\sum_{\forall j:(i,j)\,\xi\,A} X_{ij} - \sum_{\forall j:(j,i)\,\xi\,A} X_{ji} \quad \begin{cases} = 1 & \text{if } i=s \\ = 0 & \text{if } i \neq s,t \text{ for all } i\ \varepsilon\ N \\ = -1 & \text{if } i=t \end{cases}$$

$$|z_j - z_i|{*}X_{ij} \le k_1(\phi_{max}) \quad \text{for all } (i,j)\ \varepsilon\ A$$

$$|x_j - x_i|{*}X_{ij} - |y_j - y_i|{*}X_{ij} \le k_2(\theta_p, \delta) \quad \text{for all } (i,j)\ \varepsilon$$

Fig-2: Generalized Mathematical model for GIS based routing. k_1 and k_2 are constants

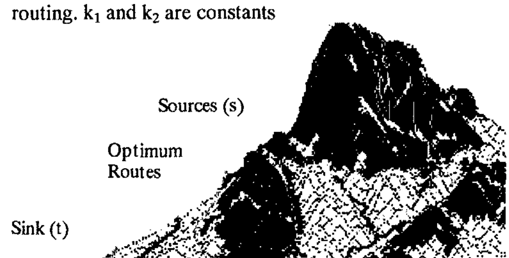

Fig-3: 3 dimensional image of section of the case study area, showing the case-2 routes, source sites with rail, road river networks. There are many source sites and one sink site. Each source site was independently routed using the above model.

(i) *Land Preference:* It is often preferred to construct route along certain land types. For example, riverbeds are preferred while constructing long belt-conveyors in developed areas.

(ii) *Land Constraints:* It is often required that a route must

Keywords: Spatial Optimization Problem, GIS, Routing

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avoid certain land types like built land, protected natural parks, historical sites or dangerous terrain.

(iii) *Route Gradient(ϕ):* There is often restriction on how steep a route can be (ϕmax). For example it is preferred to restrict the power-line's gradient to within 30~40% and Roads to within 15%. Cost of construction can be expressed as function of route gradient, f(ϕ). It must be noted that the route gradient is different from the surface gradient.

(iv) *Route Curvature* (θ): Often the construction costs increase with the number of turns in the route from the preferred direction (θp) as additional construction effects are required. Curvature cost can also be expressed as a function, g(θ).

(v) *Crossings:* The route must cross the minimum number of roads, rivers, railway lines, high-voltage power lines and other utility lines. Modeling of crossings may require huge volumes of data depending on the domain of routing and the level of study. At a detailed scale, one may need to take into account the bridges, culverts and tunnels to exploit the existing infrastructure to maximum advantage. Crossing can be considered as a special type of land constraint and can be expressed as cost.

By considering entire domain as a 2 dimensional mesh and by considering each cell as a node, it is possible to develop a generalized mathematical model. The cost per unit length of routing (C_i) at any cell i on the domain of routing is

$$C_i = c * p_k + f(\phi) + g(\theta);$$

c = reference cost
k = land-use type at cell i
ϕ = Gradient of the route at i
θ = Deviation from preferred direction (θ_p) at i

$c * p_k$ can be directly calculated from land-use map, natural habitat protections, road, rail maps by evaluating the land preferences, constraints and crossings using a GIS system. Preferences can be graded and arranged in the descending order of preference. Those areas that are most preferred was attributed a cost of 1 per unit length of route. By expressing all land information as aligned meshes, overlaid calculation is possible using GIS. Relative costs can determine relative to the most preferred land. If the route demands transportation across the sea, suitable cost that, represent the cost for shipping can be included for the Land-type 'Sea'. Thus a generalized cost matrix can be developed.

The formulation of the overall model is as shown in figure-2. The evaluated cost and the elevation digital map can be used in the mathematical model as data within a GIS friendly programming environment to select the best route between any town points

3. CASE STUDY

The above method was applied to routing in one of our consulting problem with considerable success. The study required construction of routes at master plan level (1:20,000 resolution) to evaluate the excavation sites, from the transportation perspective, for a water front development project. The domain of the routing study was an area of 10kmx10km that included mountainous terrain as well as township.

Various types of topographic information were collected including digital elevation map (50m resolution), flora and fauna habitats, protected forests, forest reserves, national parks, historical sites, river network, road network, power-line network, land-use information and land development information. All information were converted to 50m resolution and aligned with the digital elevation map.

Two cases were studied and the constraints and preferences considered in each case are detailed in table-1

Table-1: Preferences and constraints of case study

Case – 1:	
Land Preference:	No Special preference
Land Constraint:	Must avoid protect/restricted lands
Route gradient:	Must be within 20%
Route Curvature:	No special limitation
Case-2:	
Land Preference:	River-beds preferred with preference ratio of 1:10
Land Constraint:	Must avoid protect/restricted lands
Route gradient:	Must be within 20%
Route Curvature:	No special limitation

For the case-1, all land types was attributed a unit cost. All areas with land constraints were attributed 9999, representing a huge cost value. For the case-2, riverbeds were attributed an unit cost since preference was for routing along river, All other regions were attributed a unit cost of 10. Constrained areas was attributed a cost of 9999.

Since roads/ railway lines could not be adequately represented on a 50m-mesh resolution, they were not included in the construction of cost matrix. However finally upon selection of route, the crossing were counted GIS and displayed.

Optimum routes generated by solving the model for case-2 is as shown in the figures 3, displaced over a 3-dimensional view of the terrain surface. Using GIS, the following information were easily tabulated

- 3 dimensional routes lengths
- Statistical tabulation of land types cells in the route
- Tabulation of road, river, power-lines and road crossings

4. CONCLSION

GIS based OR approach is effective for solving many terrain related optimization problems. A detailed data consideration including the road barriers can provide a comprehensive solution suitable for practical implementation.

5. REFERENCES

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