Optimizing Road Alignment Via Corridor: A Least Relative Cost Raster Grid Analysis

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Abstract — **Utilizing raster layers for route alignment based on multiple criteria proves advantageous in developing a comprehensive grid cost layer, applicable at various stages of multiple parameter decision evaluation (MPDE). Integrating a lowest cost alignment algorithm into a prospective ground view, or employing false color synthesized remote sensing data, enhances planning and aids in formulating execution strategies. Optimal route alignment design hinges on multiple factors considered within the corridor analysis model, identifying the most effective road path from a source to a destination. To achieve this, a grid data layer depicting landscape types can be prepared using per-pixel classification of images to generate a relative cost layer. Additionally, a slope grid layer can be derived from a digital surface model. The optimal path is determined by minimizing costs while considering environmental, socioeconomic, and technological factors. This grid-based corridor evaluation was implemented in the Hesarghatta region to assess its applicability for road construction.**

Keywords— Grid cost layer, Alignment planning, Geographic information discussion support, weighted overlay, multiple parameters evaluation, Grid slope.

I. INTRODUCTION

The region surrounding Hesarghatta near Bangalore, India, features moderate variations in slope and soil strength. With both urban and rural land cover and land use, the area exhibits the diverse characteristics of a suburban landscape, posing challenges for appropriate road alignment and construction. To minimize construction costs influenced by topographic factors, road alignment should avoid steep slopes. Utilizing grid alignment analysis with the D-8 algorithm, a relative grid cost layer is generated, indicating the expenses of traversing each grid cell within the raster layer. This approach has proven effective in determining new road alignments that minimize both execution and environmental costs.

The lowest cost path, implemented within a Geographic Information System (GIS), is a valuable tool for road alignment. Highway design involves developing the most economically viable road between two chosen endpoints, considering topography, soil strength, land cover, and both design and operational issues. The lowest grid cost alignment can generate the most suitable route through the landscape. Parameters influencing road construction expenses include the alignment length from source to destination, proximity to built-up areas, total stream crossings along the alignment, and slope variations.

During the planning phase of road development, making informed decisions in choosing and screening appropriate road alignment alternatives is crucial, as it can save both time and money. A relative virtual raster cost layer assigns a subjective ranking from 1 to 5 to indicate the expenses of moving across cells, with 5 representing the highest cost.

Integrating the cost parameters associated with the chosen factors results in the overall expenditure. This involves creating an expense layer for each parameter and combining them to generate an overall expense layer. Cost distance measurement is performed cardinally in eight directions, comprising four diagonal and four lateral links. Each cell in the overall expense layer represents the cost of movement between cells, calculated by obtaining the mean cell values of the two concerned cells and considering link lengths of 1.414 for diagonal links and 1.0 for lateral links.

The expenses are accumulated by determining the cumulative costs for every grid from the starting point to the designated location using an identification algorithm. Dijkstra's algorithm is applied to derive a raster-based least-cost alignment between the starting and ending points. By selecting criteria for road planning in a multi-criteria approach, the accumulation of costs in the grid layer is established. This method proves advantageous in heterogeneous terrain, streamlining the identification of suitable sites for culvert construction, facilitating straightforward adjustments, and reducing time expenditure.

II. MATERIALS AND METHODOLOGY

The GIS terrain corridor evaluation module was utilized to perform a least-cost corridor raster analysis in the Hesarghatta project region. Raster layers representing land use and land cover were created using the maximum likelihood image classification technique. Each cell in the image classification layers was assigned relative costs based on the ease of movement. The underlying logic considered lower road construction costs for barren land compared to built-up areas and water features, where construction costs were expected to be higher. Similarly, the slope variation layer, derived from the fill depression Digital Elevation Model (DEM), was assigned relative costs. Areas with lower slopes were assigned reduced costs for road construction. Soil areas characterized by higher compressive strength were given lower relative construction values. The overall cost layer was obtained by integrating the three levels of relative cost using an additive operator. The range of relative costing values was from 1 to 5, representing varying degrees of cost. The slope cost layer was given a weight of 2 in the construction of the total cost layer, acknowledging the crucial role of slope as a parameter influencing road construction costs, especially concerning the prevailing gradient. The methodology used in this process is depicted in detail in Figure 1.

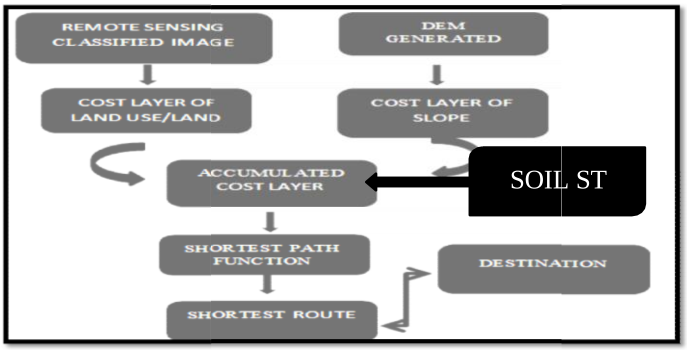
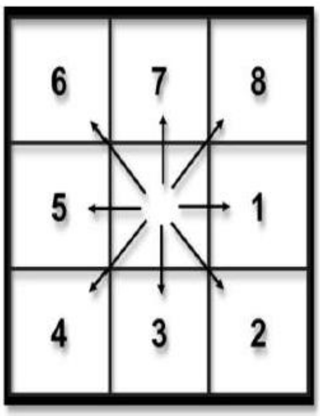


Figure 1: Flowchart depicting the Methodology for Automated Routing Process

The process of acquiring the measure of cost distance is designed to determine the total expense from every cell to the closest source, identifying the cell with the most cost-effective construction path based on the algorithm used. This algorithm is aimed at finding the quickest path from the starting point to the selected destination. The resulting cost distance raster shows the total cost for each cell to return to the nearest location. However, it does not specify which source cell to return to.

To address this, the cost backlink tool produces a direction raster, essentially a roadmap that determines the route to be taken from any cell along the least-cost path back to the nearest source. The algorithm assigns a series of integers between 0 and 8, where '0' indicates the source location, and values 1 through 8 encode the directions, starting from the right and going clockwise. This configuration is depicted in detail in Figure 2.



0	Source
1	Right
2	Lower-Right
3	Down
4	Lower-Left
5	Left
6	Upper-Left
7	Up
8	Upper-Right

Figure.2: The Algorithm's Eight Movement Directions

Slope is calculated using a Digital Elevation Model (DEM), in which each pixel corresponds to an elevation value. Within the cost path model, a slope raster is generated in eight directions using the steepest slope layer. This is illustrated in Figure-3.

As shown in Fig. 4, maximum likelihood supervised image classification is used to create the land use/land cover raster layer. The land use/land cover cost layer was subsequently generated using this layer. By giving barren land, a lower cost value and agricultural land, populated areas, and water bodies in the area a higher cost value, this layer was used to derive the relative cost layer for land use/land cover.

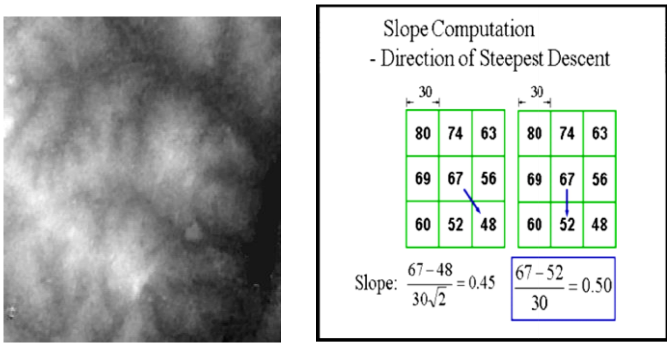


Figure 3: Slope computation-based digital elevation model (DEM) of the area

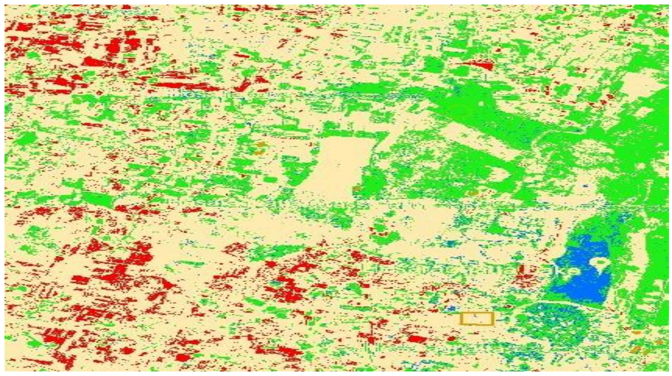


Figure 4: Supervised Classified Image Input for Land Use/Land Cover Cost Layer Calculation

III. RESULT AND DISCUSSION

A cost raster layer uses a node-link cell representation to illustrate the expense or difficulty of traversing each cell. Additional factors such as water gaps, traffic density, and environmental concerns can be included with appropriate weights to optimize the least-cost path's efficiency. It is important to note that the starting point and final destination can be adjusted as needed. The multi-criteria approach aims to identify a least-cost corridor, evaluated in terms of topography, land use, slope variation, soil strength variation, and additional elements it passes through.

Figure 5 illustrates the least-cost corridor connecting the two endpoints. This corridor represents a new road alignment that navigates through less rugged terrain while adhering to the minimum gradient requirement. The resulting alignments display an irregular polyline pattern, originating from the initial point and traversing various features, considering the cost associated with the fastest available path. Along the least-cost path, two stream crossings are identified. These crossings mark locations where culvert constructions are recommended, contingent upon acquiring the requisite hydrological parameters at each site.

The resulting alignments showcase an irregular polyline pattern, originating from the starting point and traversing various features while prioritizing the cost of taking the shortest possible route. These alignments are visually depicted as irregular polylines overlaid onto a 3D representation of the terrain's elevation, as shown in Figure 6. This visualization aids in simulating the road route in the region and offers a clear depiction of areas requiring cut and fill operations.

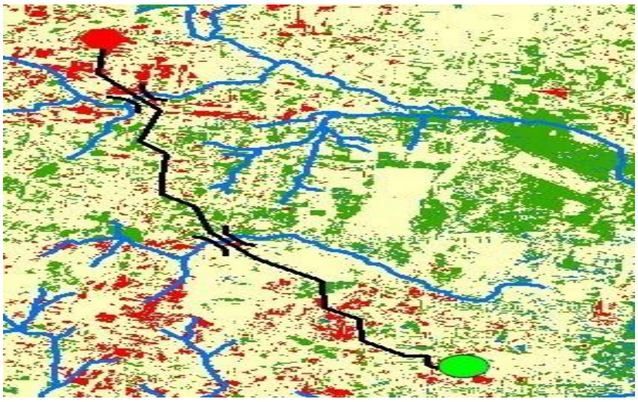


Figure 5: Least Cost Alignment

Utilizing the GIS corridor raster model, which relies on the total cost raster layer to determine the cost path, has proven effective in avoiding settlements, valuable agricultural land, lakes, and steep slopes. The success of this approach can be attributed to the careful assignment of relative cost values to specific regions. However, it's important to note that the alignment crosses culvert sites without considering the factors that govern site selection. This limitation stems from the exclusion of these factors from the algorithm. Despite this, it can be concluded that the study has successfully achieved its objective within the chosen criteria.

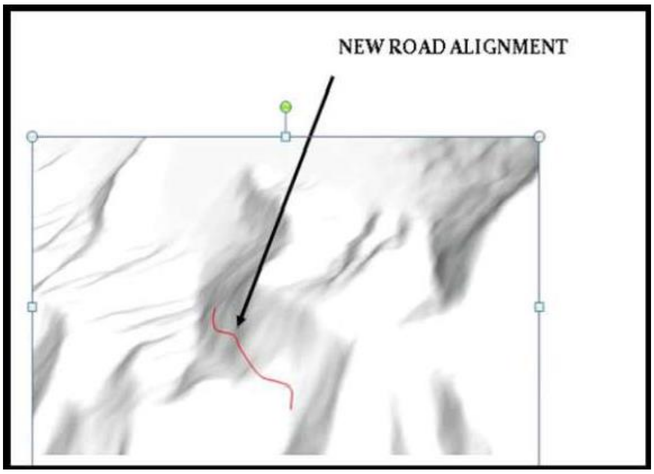


Figure 6: 3D Simulated View of the Corridor Illustrating Earthwork Considerations

IV. CONCLUSION

The raster-based analysis employed to determine the least-cost path leverages multi-criteria evaluation, offering an efficient alternative to the labor-intensive and time-consuming traditional ground-based methods. This approach allows for the easy incorporation of modifications, additions, or deletions of raster data layers, thereby enhancing the efficiency of route planning compared to conventional methods. Additionally, this technique can be applied to the re-alignment of existing routes within the complex planning process.

To further enhance this methodology's capabilities, exploring the integration of its output with roadway design software is worthwhile. Such integration could facilitate the preliminary design of alternative routes and enable the recalculation of construction costs based on the roadway design software's outputs. Developing a GIS model with automatic analysis and calculation capabilities for earthwork volumes would serve as a valuable decision-making tool. Moreover, studying the impact of different factors on various areas would contribute to a more comprehensive understanding of the system.

V. REFERENCES

[1]. Alexandre B Gonc, Alves, “An extension of GIS based least-cost path modelling to the location of wide paths” International Journal of Geographical Information Science 24, 7, July, 983–996,2010

[2]. AASHTO, 2003., “User Benefit Analysis for Highways”. American Association of State Highway Administration and Transportation Officials, Washington, D.C.

[3]. Cruz-Chávez MA, Moreno-Bernal P, Rivera-López R, Ávila-Melgar EY, Martínez-Bahena B, Cruz-Rosales MH. GIS Spatial Optimization for Corridor Alignment Using Simulated Annealing. Applied Sciences. 2020; 10(18):6190. https://doi.org/10.3390/app10186190

[4]. Effat, H. A., Hassan, O.A., 2013. “Designing and evaluation of three alternatives highway routes using the Analytical Hierarchy Process and the least-cost path analysis, application in Sinai Peninsula, Egypt. The Egyptian. J. Remote Sensing. Space Sciences (2013) 16, 141–151.

[5]. Khalil, N, et al., 2020. “Horizontal Corridor Optimization of Highway Using GIS Considering Retaining Wall Costs in Mountainous Areas”. Jordan Journal of Civil Engineering, Volume 14, No. 4.

[6]. Murekatete, R. M., and T. Shirabe. 2018. “A Spatial and Statistical Analysis of the Impact of Transformation of Raster Cost Surfaces on the Variation of Least-Cost Paths.” International Journal of Geographical Information Science 32 (11):2169–2188. doi:10.1080/13658816.2018.1498504.

[7]. Stephan Tischler, “Finding the right way-a new approach for route selection procedures?” World Conference on Transport Research – (WCTR) Shanghai 10-15 July,2016.

[8]. Vaishali Mahavar, Jayesh Juremalani, Indra Prakash, Khalid Mehmood, “Optimum Route Planning of a City Using GIS Technology” Journal of Emerging Technologies and Innovative Research (JETIR) 402- 412,2019.

[9]. Yashas, S. R., Harish, S. N., Muralidhara, H. R., 2016. “Effect of California Bearing Ratio on the Properties of Soil”, American Journal of Engineering Research (AJER), 5(4), pp-28-37.

[10]. Sani Suleiman, V C Agarwal, Deepak Lal, Aminuddeen Sunusi, “Optimal Route Location by Least Cost Path (LCP)Analysis using (GIS)-A Case Study”, International Journal of Scientific Engineering and Technology Research, 04, 44, 9621-9626,2015.