Road Network Planning for Sustainable Urban Development in Kirtipur Municipality, Nepal

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Abstract

Road network deals with the development of a comprehensive plan for construction and operation of transportation facilities. In order to develop efficient and better transport facility, it is necessary to have a proper road network. In sustainable road network planning, planners put into consideration factors like gradients or slope, land-use and geology with community and governmental interest. These different considerations make the planning process complex and generate confusion in the decision making process. The use of geographic information system (GIS) and multi-criteria analysis (MCA) has helped planners to reduce complexity and to achieve desired and more accurate results. MCA prevents the imposition of criteria limit and gives opportunity to decision makers to enter their own judgments. This provides a better communication among the decision makers and the entire community for creating a more open choice for analysis and possible changes if necessary. In this study, road network has been analyzed with optimal least cost path algorithm of spatial analysis in GIS using different ancillary data layers and each layer weight-scoring has been computed with MCA in spatial decision support system (SDSS). The optimal least cost path would provide the best option with certainty and considers a gradient, connected neighbors, thematic cost and surface distance in three dimensional spaces. The path gradient can be adjusted as per the requirements, depending upon the terrain conditions and possible to design a more realistic route automatically with appropriate parameters.

Keywords
Road planning, multi-criteria analysis, spatial decision support system, optimal least cost path.

1. Introduction

Road planning deals with definition of circulation infrastructure pavements, roads and terminals. It also covers the physical and operational characteristics of public transport (Vasconcellos, 2001). Effective road path is an essential interest of every developing country and acts as a means of interconnectivity between different parts and regions within and outside the country. Road network provides the country's economic and social well-being for the mobility of people and goods, but also over the long term it influences patterns of growth, land use and economic activities. But, road network development has damage and fragments the natural environment. Human- kind's quest for development has led to a point where any further development threatens the last remaining natural reserves. So, finding the optimal balance between infrastructure creation and nature conservation is achieving greater importance for sustainable development (World Bank, 2010).

Road network needs to the identifying and reserving of land for urban transport facilities that support connectivity between different location of urban place. Road network planning plays an undeniably key role in the economic growth of any region/ country. So, the planning can be done heedlessly and detrimental to the biophysical and social environment of the region. In road route planning generally one or a few alternative routes are proposed for environmental impact assessment (EIA) and strategic environmental assessment (SEA) using SDSS. An efficient road route planning system that directly takes into account the environmental, social and economical considerations in formulating, assessing and selecting alternative routes are proposed for sustainable infrastructure development (Keshkamat et al., 2009).

During the last decade, RS and GIS technology have been used for route-planning process. Costs are increased by long structures, by large volumes of cut and fill, and by unbalanced cut and fill. For designing the high quality road, needs suitable spatial data such as geology, land use, slope, soil and drainage. GIS coupled with MCA has helped to enhance multi-criteria decision making associated with planning process (Roy, 1996; Maha, 2012). The use of GIS with MCA has helped for decision makers towards actualizing the optimal route for desired choice and enhance in decision making process (Chakhar & Martel, 2003; Geneletti, 2004).

2. Study Area & Data used:

Study Area Kirtipur municipality has high rate of urban growth and urban sprawl has prevalent with the rapid development of urbanization and motorization. There is need of a comprehensive road network planning for the establishment systematic of dreamland city. The location of study area is shown in Figure1.

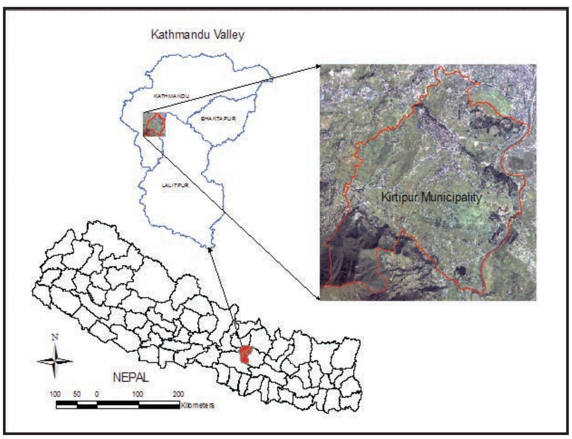

Figure1: Study Area

Its location is 27º 38’ 37" to 27º41’ 36" N and 85º 14’ 64" to 85º 18’ 00" E with it extent and at present has 19 wards and covers 17.87 sq. km. It is bordered by the Bagmati River with Lalitpur Submetropolitian City to the east, Machhengaun Village Development Committee (VDC) to the west, Kathmandu metropolitan city (KMC) to the north, and Chalnakhel VDC to the south. The town was built initially within a wall surrounded strategically by dense vegetation and opens ground as outer rings. Data used The following datasets were used in the study; these are listed below in Table 1.

Table1:

Description of Data used

Data Type	Year	Scale / Resolution	Source
Remotely Sensed Data:			
GeoEye -1	2012	2m	UBMP
Base Map:			
Topo map	1996	1:25000	DOS
Urban map	1998	1:2000	DOHUD
Ancillary Vector Layers/Data:			
Geology	2007	1:30000	NLUP
Field Data:			
Ground Control Point (GCP)	2012		Field Works
Ground Truth	2012		Field Works

3. Road Alignment

Road alignment is the location of the centre line of the road in the ground. It has included two components; one is the horizontal alignment which is the straight connected path with its horizontal deviation and horizontal curves and other is the vertical alignment which is the change in gradient defined by ruling gradient and the vertical curves of the road. It is chosen carefully based on the consideration of the road construction cost with its maintenance and road improvement, operation of vehicle cost and accident rate with its requirement and different factors (Khanna & Justo, 1971).

Road Alignment Requirements: The basic requirements of ideal alignment between two terminal stations are short, easy, safe and economical.

Road Alignment Factors: The various factors are considered while selecting the road alignment. In general, obligatory points, traffic flow, geometric design, slope stability, drainage, resisting length, economic condition are considered as factors in road network planning (Khanna & Justo, 1971).

4. Methodology

The procedure helps to select a least cost route that is supposed to be the best and reducing overall road development and maintenance costs. The proposed route planning procedure can be divided into the following four basic steps:

4.1 Thematic Cost Raster: A scoring system in the range of 0 to 9 is used, with zero signifying the minimum cost and 9 implying the highest cost. Similarly, the influence factor of each layer is weighting with between 0 to 1 values so that the whole influence of the thematic cost raster is 1 or 100%. The weighting-scoring (rating) values are based on a comparative study of various thematic data layers and discussions with experts working in the area of transportation engineering. Multi Criteria Evaluation is used for the thematic cost raster generation and is computed as (Saha et al., 2005):

$$\text{Thematic Cost Value} = \Sigma \text{ Weight} * \text{Score} \qquad 1$$

4.2 Selection of Connected Neighbors: Neighbourhood is the location within proximity of some starting-point or grid cell. In a 3x3 pixel window, there are eight direct neighbors (two horizontal, two vertical and four diagonal). The turn angle interval (angle between an incoming and outgoing path at a pixel) for the route is restricted to a minimum 450 angle. In GIS, a raster based model based on the neighborhood relationship concept are used to each pixel can be represented as a network node. This step involves finding various possibilities of the connected nodes in terms of horizontal and vertical factor respectively in terms of moving direction with the horizontal relative moving angle (HRMA) and the moving from one cell to another cell in vertical direction with the vertical relative moving angle (VRMA) to slope or gradient.

4.3 Calculation of Neighborhood Movement Cost (NM-cost): Once connected neighbors are found, the cost of moving to the connected neighbor from a source is called as neighborhood movement cost (NM-cost and calculated as (Saha et al., 2005) :

$$\text{NM Cost} = \text{Surface Distance} * \text{Thematic Cost Raster} \qquad 2$$

However, if the topography is uneven, the slope of the terrain varies in different ranges with different directions. Therefore, the NM-cost must consider this direction dependency (anisotropy), for which, the NM-cost may be given as:

$$\text{NM Cost} = \text{Surface Distance} * \text{Thematic Cost Raster} * \text{Slope Cost} \qquad 3$$

4.4 Selection of least-cost route: For direct horizontal/ vertical connection involves finding least cost shortest path using path distance and is calculated as (Saha et al., 2005):

$$\text{Path distance} = \text{Surface Distance} * \text{Thematic Cost Raster} * \frac{\Sigma \beta_i \times p}{n} * q; i=1,\ldots,4 \qquad 4$$

where p & q are the horizontal and vertical factor for each cell respectively and n is the total number of cell. Similarly, for the diagonal direct connection, i.e. the Bishop's pattern, the neighbour-distance is calculated as:

$$\text{Path distance} = \text{Surface Distance} * \text{Thematic Cost Raster} * \sqrt{2} * \frac{\Sigma \beta_i \times p}{n} * q; i=5,\ldots,8 \qquad 5$$

where p & q are the horizontal and vertical factor for each cell respectively and n is the total number of cell. Accumulation path distance is the accumulation cost to from cell to the end cell and given by

$$\text{Accumulation Cost} = \Sigma a_i \qquad 6$$

where is the path distance of the link from one cell to the adjacent another cell.

5. Result & Analysis

Triangulated irregular network (TIN) surface was generated using contour data in 2m contour interval from urban base map TIN surface was smoothed for the purpose of engineering quality contours using linear interpolation and converted into DEM with TIN to Raster tool in ArcGIS 10 (in Figure 2).

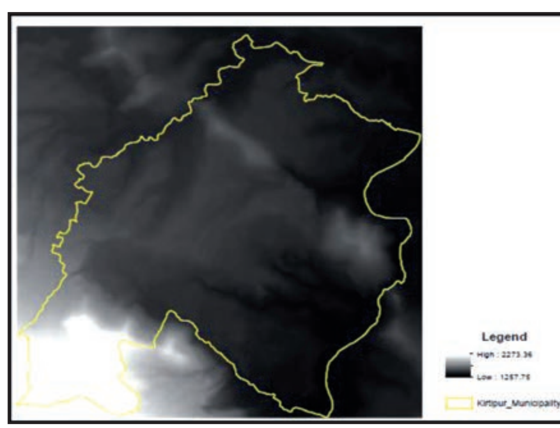

Figure 2: DEM of the Study Area

Land use land cover (LULC) map for the year 2012 were prepared by maximum likelihood classifier (MLC) technique of multi-spectral Geoeye-1 images.

LULC map was categorized into five classes such as built-up, agriculture, forest, water body and open space. The validation of classification results were done for the quantification and evaluation of error using confusion matrix which compares the class-by-class based on the training samples and classification result classes. These error matrices were evaluated and the overall accuracy has found 87.67% with KIA 0.8337. The LULC map is shown in Figure 3.

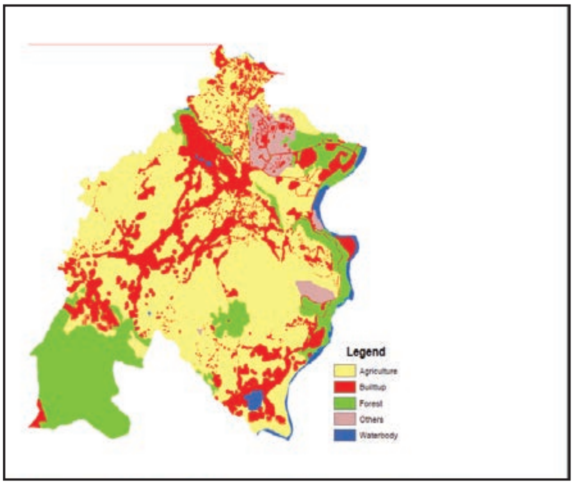

Figure 3: Land use land cover

The thematic road network was generated from ortho-rectified Geoeye-1 image. The road network was categorized into four classes as highway, feeder road, major road and minor road. In road raster; some pixels have the raster value of highway, feeder road, major road and minor road but not cover all pixels by these road types having discrete type of geographic phenomenon. So, this discrete geographic phenomenon was converted into continuous phenomenon by reclassification of No data of road raster into one category as No Road. The continuous raster of road network map is shown in Figure 4.

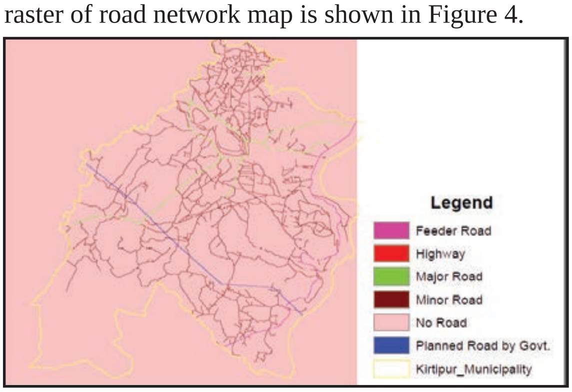

Figure 4: Reclassified Road Network

The thematic drainage network was also generated from ortho-rectified Geoeye-1 image. The drainage network was categorized into four classes as river/ lake, khola, major stream and stream. In raster drainage; some pixels has the raster value of river/ lake, khola, major stream and stream but not cover all pixel by these drainage type having discrete type of geographic phenomenon. So, this discrete geographic phenomenon was converted into continuous phenomenon by reclassification of No data of drainage system raster into one category as No Stream. The continuous drainage system map is presented in Figure 5.

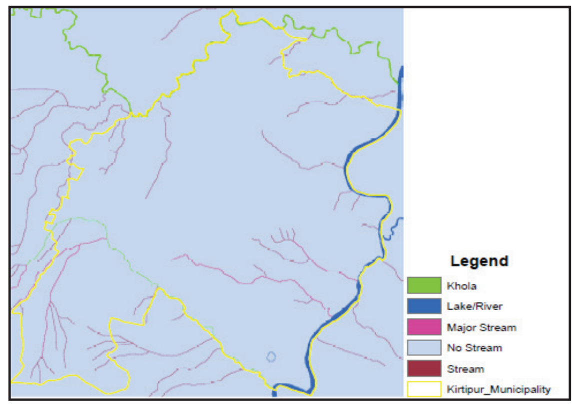

Figure 5: Reclassified Drainage Network

The thematic distance to settlement layer was generated from the existing settlement from the LULC map and verified from Geoeye-1 image using Euclidian distance in spatial analysis tool and found distance ranges from 0m to 1732m. These ranges of distance to settlement was categorized into six categories from 0m to 100m, 100m to 300m, 300m to 500m, 500m to 1km, 1km to 1.5 km and 1.5 km to above. The result of reclassification of distance to settlement map is shown in Figure 6.

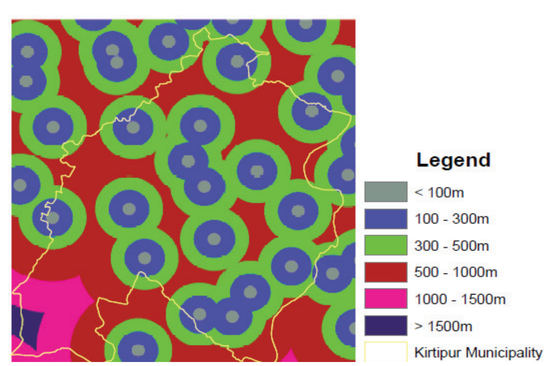

Figure 6: Reclassified Distance to Settlement

The slope was derived from the DEM and its ranges from 00 to 720. This range of slope was categorized into five categories such as from 0% to 5%, 5% to 10%, 10% to 15%, 15% to 20% and 20% to above. The result of reclassification of slope map is presented in Figure 7.

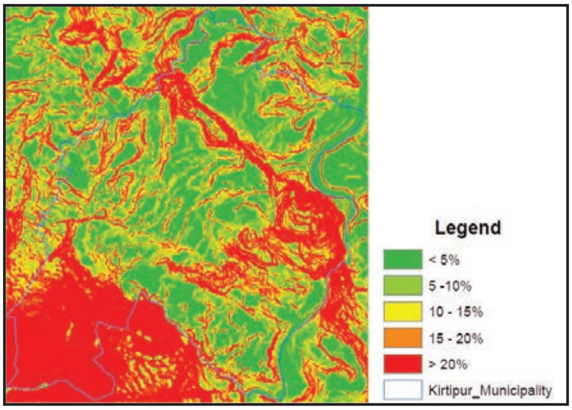

Figure 7: Classified Slope Map

The thematic cost raster surface was generated with the weighted overlay of different raster having different score (attribute rating) and weight (factor/criteria rating) consultation with expert using MCE technique in customize tool with model builder and python. Slope is the most important parameter in road planning in a mountainous terrain for maintaining the ruling gradient of road alignment. Slope is categorized into five sub-categories and individual sub-categories have rating with its score value in the ordinal number from 0 to 9. Road construction and maintenance in the steep slope is high cost comparative to the flat terrain. The score of different slope categories are shown in Table 2.

Table 2: Score of Slope Category

Slope	Score
< 5 %	2
5-10%	5
10-15%	7
15-20%	8
> 20%	9

LULC data has required for estimating the cost of land acquisition during road route planning. The areas covered with river sediments are also not suitable for road construction, as these are susceptible to flood inundation. The score of different LULC categories are shown in Table 3.

Table 3: Score of LULC Category

LULC	Score
Agriculture	6
Built-up	8
Forest	4
Open Space	2
Waterbody	9

Lithology mainly concerned with structure of rock type which has been considered mainly for the costs of blasting, excavation, cut-and-fill works, etc. The score of different lithology categories are shown in Table 4.

Table 4: Score of Lithology Category

Lithology Category	Score
Quartizite	9
Slate	7
Limestone	5
Lacustine	3
Alluvial Fan	1

The road network is mainly defines its order by the road type. The road type map has been used here to consider the reduction in the cost of construction so that planned route followed the existing route of road. Generally, where the existing metallic road such as highway and feeder road exist, there is no need for more excavation work for base and sub-base only upgrading is required. The score of different road categories are shown in Table 5.

Table 5: Score of Road Class

Road Class	Score
Highway	1
Feeder Road	3
Major Road	5
Minor Road	7
No Road	9

The drainage system is categorized by the order of the stream. The drainage-order map has been used to consider the cost of a possible bridge construction. Generally, the width of the river channel increases with increasing order of drainage, which results in a corresponding increase in the cost of bridge construction. The first- and second-order drainages (streams) have been assigned very low ratings where as higher-order drainages (river/khola) has assigned the high value. The pixels without any channel have been assigned a low cost. The score of different drainage type are shown in Table 6.

Table 6: Score of Drainage Type

Drainage Type	Score
River	9
Khola	7
Major Stream	5
Minor Stream	3
No Stream	1

For the accessibility to people, distance to settlement is an important factor in the road planning. Main road inside the settlement is not good for the vision of safety to avoid accident. The score of distance from settlement are shown in Table 7.

Table 7: Score of Distance to Settlement

Distance to Settlement	Score
< 100m	9
100- 300m	2
300-500m	5
500-1000m	7
1000-1500m	8
>1500m	9

The proposed road alignment alternatives were generated based on slope, LULC, lithology, road network, stream system and distance settlement. The first alternative weight was assigned from expert knowledge and validated from Analytic hierarchy process (AHP) pair wise comparison. In all pair wise comparison test we get overall consistency having limit less than 0.1. The weight obtained from the AHP pair wise comparison for the alternative 1, alternative 2 and alternative 3 are shown in Table 8.

Table 8: Weight of different Alternatives

Factors	Weight		
	Alter-1	Alter-2	Alter-3
Slope	0.25	0.22	0.23
LULC	0.20	0.19	0.19
Lithology	0.15	0.15	0.15
Road Network	0.15	0.17	0.19
Drainage Network	0.15	0.14	0.11
Distance to Settlement	0.15	0.12	0.13

Path distance and path direction i.e. back link of the surface cost path computes the total cost surface from the source location to each and every pixel. The result of path distance and path direction were computed from source (Kirtipur Centre Nayabazar) using path distance spatial analysis tool (in Figure 8).

Figure 8: Path Distance and Direction from Source

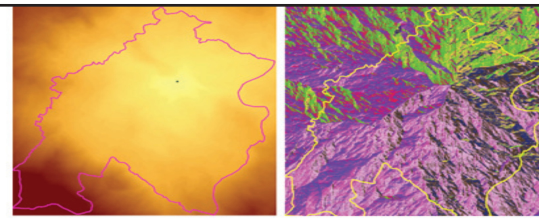

Figure 9: Path Distance and Direction from Source

Least cost path route was computed from the optimized path distance and its back link raster (path direction) to the different destination location using least cost path algorithm (cost path) in spatial analysis tool in ArcGIS 10. The proposed road network in 2030 obtained using least cost path for major road from Nayabazar Kirtipur as source (existing urban centre) to different destination location which will be future urbanized. The proposed three alternative road networks from different weight for thematic cost surface and then least cost path were determined (in Figure 9).

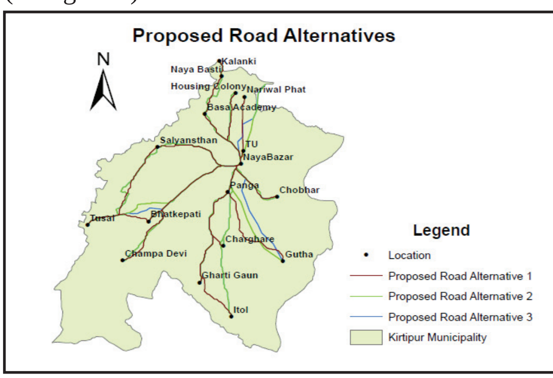

Figure 9: Road Network Alternatives

The multi-criteria analysis was carried out using weighted summation method and interval standardization for ranking of alternatives in Definite Software. Sensitivity analysis was also conducted to analyze the sensitivity of ranking through assessment of the score and the weight uncertainty in defining the priority of alternatives. Relative importance for each effect showed that the road length is most important compared to others effects. The result of multi-criteria is shown in Figure 10. The uncertainty in length and gradient used are 0.10% and 0.15%

respectively. Road network alternative 1, 2 and 3 have total accumulation value 0.75, 0.50 and 0.67 respectively. The results indicate that proposed road network alternative 1 is better compared to proposed road network alternatives 2 and 3.

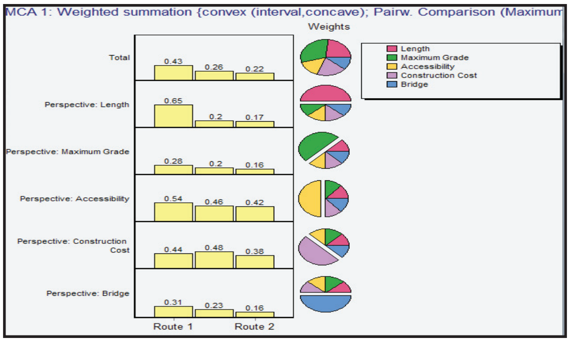

Figure 10: Multi-criteria Analysis

From multi-criteria analysis and sensitivity analysis the proposed road network alternative 1 is the best for construction having less length and suitable maximum gradient. The road length and suitable gradient of proposed road network alternative 1 is minimum ranking level, so this alternative is selected for purposed road network in future 2030.

6. Conclusion

The planning of road has become a complex task with the consideration of different criteria's/factors associated with its weight-scoring. The analysis for sustainable road network planning has achieved with the ground parameters, expert knowledge and model in ArcGIS or customized with python. In spatial analysis assessment, the intermediate and final results from the model has based on its pre-assumption of criteria consideration and related with its weight-score. MCE within SDSS has analyzed based on the raster based spatial analysis; which provides a wealth of capability for incorporating terrain information surrounding the location of infrastructure development. Road network planned using least cost path algorithm gives good result considering the engineering parameters. It is fast and efficient technique considering with gradient, friction surface, connected neighbors in 3D.The road route gradient can be adjusted as per the requirements, depending upon the terrain conditions. Hence, it is possible to design a more realistic route in an automated way by changing some of the parameters as needed.

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