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A Methodology for Definition of Road Networks in Rural Areas of Nepal

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***Abstract*—**This work provides a practical method for the development of rural road networks in rural areas of developing countries. The proposed methodology enables to determine obligatory points in the rural road network maximizing the number of settlements that have access to basic services within a given maximum distance. The proposed methodology is simple and practical, hence, highly applicable to real-world scenarios, as demonstrated in the definition of the road network for the rural areas of Nepal.

***Keywords*—**Minimum spanning tree, nodal points, rural road network.

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I. Introduction

NEPAL has a total population of 26.5 million with 83% living in rural areas [1]. 87% of the total area of Nepal lies in hills (52%) and mountains (25%). Construction of rural roads is one of the major infrastructure development projects in Nepal in order to improve accessibility in rural areas. Accessibility in the rural areas is the easiness of getting facilities and services that the rural residents need for everyday life at minimum time, effort and cost [2]. Planning the road network in rural areas is therefore crucial, not only in terms of network efficiency (concerning accessibility), but also regarding construction and operation costs, as limited funding is available.

There are different planning methodologies for the definition of rural road networks. The most relevant methodologies are United Nations Centre for Human Settlements [3], International Labor Organization (ILO) [4], Department of Local Infrastructure and Agricultural Roads (DoLIDAR) [5], and Computer aided method [6] in the rural context of Nepal. Also, it can be found different rural road planning methods proposed by different authors. The relevant models in the context or rural areas are GIS based model [7], facility based model [8], settlement based interaction model [9], and road planning in rural areas [10], [11]. However, most of these methods are associated with prioritization procedures requiring huge volume of data collection from rural areas which is time consuming and costly. This has made the planning of a road network in rural areas a complex job hampering the design of an effective network in the planning phase paying more attention to the prioritization indicators and process.

In many models, the prioritization process is very complex taking too many indicators for ranking road links, some of them possibly irrelevant. Many indicators consider social and economic aspects, from which only few of them may be significant in the context of rural areas. Typically, rural roads are constructed in order to connect the rural settlements, thus improving accessibility. Therefore, road access to the settlements may be the most significant indicator.

In case of Nepal, most of the rural road projects are being implemented at a district level (Nepal has 75 districts), based on the District Transport Master Plan (DTMP). DoLIDAR has published a manual providing a set of guidelines for the preparation of the DTMP [5]. Mainly, four major steps are proposed: inventory of rural road networks; collection of demands from the lowest level of political units (Village Development Committee – VDC); preparation of perspective plan (long list of road links); and preparation of 5 year rural road master plan (after prioritization of rural road links). The 5 year rural road master plan is referred as the DTMP. The DTMP preparation process focuses on discussions, debates and approval by local stakeholders, being the most important basis for development of the district level road network. Usually, various implementing partners are involved in road construction in the district as the rural development program. The DoLIDAR manual constitutes the guiding document for the planning of rural roads in Nepal.

The most recent version of the DTMP manual [5] incorporates the Centrality Index concept as used by [6] to define a hierarchy for market centers (the manual focuses mostly in connecting market centers). However, the analysis for rural road network considering accessibility to the settlements is still lacking. It is not clear that the developed networks are effective concerning the connection/covering of settlements in the rural areas. Also, all the settlements in rural areas cannot be connected by roads due to technical and financial constraints. However, the settlements can be covered within a reasonable distance introducing nodal points in the planning regions. If the nodal points are established properly, all the settlements can be covered and access to roads may be better. Otherwise, the settlements may be beyond the coverage, which is not desirable. Hence, the main problem in the planning process is identification of nodal (obligatory) points to connect/cover the rural settlements. If the nodal points can be determined properly the network can be

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Open Science Index, Civil and Environmental Engineering Vol:7, No:6, 2013 publications.waset.org/13942.pdf

developed connecting the nodal points that may connect/cover the rural settlements effectively.

A lacking part in the DoLIDAR manual is the development of networks. There are no specific analytical methods for networks taking all the connecting points together. Including in this document, most of the methods and models focus on linking with road links between the defined points. The prioritization process is always highlighted giving possibly too much attention on the priority setting side, which could be done at a second planning phase (after fixing the network). Without fixing the network properly, prioritization may also not give the real scenario. If the method for defining the road network is not appropriate and practical, the impact of this will be huge in national context.

The planning of rural road networks can be done in two stages. In the first stage, the planning exercise needs to be focused in defining the road network that most effectively connects all the identified nodal points. The aim of rural road network planning should be to connect the most number of settlements possible. However, all the settlements cannot be connected by rural roads, particularly in hilly regions, due to topographic constraints and scarcity of funds. Therefore, a minimum connection level where nodal points cover most of the settlements may be a better approach. Even considering a minimum connection level, often, all the road links cannot be constructed at the same time due to funding constraints. Hence, the links are to be prioritized for construction/upgrading. This can be dealt in the second stage of planning. The network links can be prioritized considering financial constraints, social indicators and economic indicators.

This paper primarily focuses on the definition of the road network, which is to be done in the first stage of planning. For this, a two phase methodology is proposed in Section II. Section III presents the application of methodology in the Lamjung district of Nepal (a hilly region). Finally, in Section IV, conclusions are drawn and future work proposed.

II. Proposed Method

The proposed methodology can be divided into two main phases. The first phase is focuses on identifying the nodal points in the rural areas, while the second phase focuses on generating the rural road network connecting the nodal points previously identified.

Fixing the location of the nodal points (first phase), can be determined using a facility location model [12]. In this context, the most suitable facility location model seems to be the maximum covering location model (MCLP) [13]. The model tries to cover the maximum number of settlements within a specified covering distance. The number and location of the nodal points should be defined in such a way that they cover almost all the settlements. When a significant number of settlements are not covered, an extra point can be added. The definition of the maximum covering distance is typically a political issue, and may vary from case to case.

For generating the road network (second phase), the nodal points within the specified region need to be connected using road links. For this, a minimum spamming tree (MST) can be used [3], [11], [14]. The MST will allow obtaining the minimum level of connection of the road network in rural areas. All the existing road links in the planning region (and possibly even new ones) can be considered to find the MST network. The MST can be solved using distance, cost or time (typically distance is used).

The process of defining the rural road network can be seen in the flowchart of Fig. 1 and will be described below.

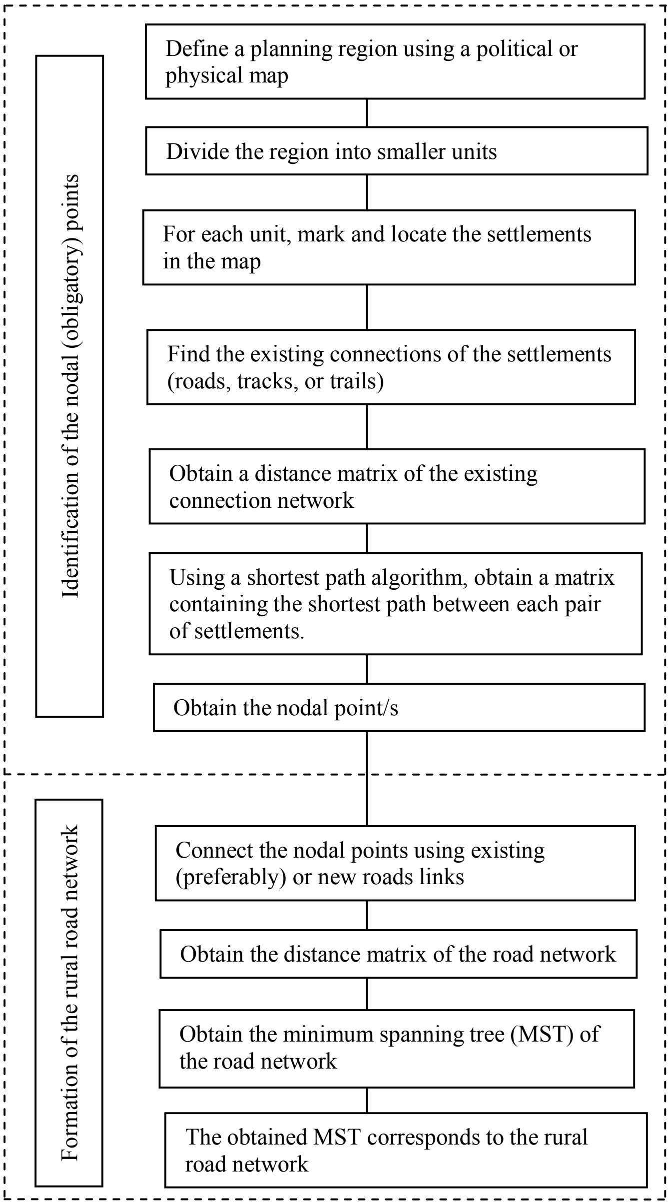

Fig. 1 Process for rural road network definition

The planning process is proposed to start out by defining the region to be studied, using either a physical or a political map. Afterwards, the region can be subdivided into smaller units (such as VDC in the case of Nepal), and likewise, marked in the map. Then, the existing settlement connectivity within each unit needs to be identified. For this connectivity,

Open Science Index, Civil and Environmental Engineering Vol:7, No:6, 2013 publications.waset.org/13942.pdf

existing roads, tracks and trails can be considered in the case of rural areas. The resulting network can also be marked in the map, from which the distances can be estimated. The estimated distance should be based on the existing linkage length (not the Euclidian distance) since it can be much higher than the Euclidian distance, particularly in hilly terrains. Using this information a distance matrix can be obtained for each unit of the region under study.

From the distance matrix, a short distance matrix can be obtained using an appropriate algorithm (e.g. Floyd-Warshall algorithm [15]). The main objective of the above process is to identify a point (among the settlements) from where the remaining settlements can be reached through the shortest distance (i.e. nodal point). From this matrix, the nodal point can be identified even by eye judgments (identifying the point from where the sums of the distances to other points are minimum). However, it would be difficult when two or more points are in competitive situation and more nodal points are needed within the unit. Hence, Mixed Integer Programming (MIP) software (e.g. CPLEX) can be used. The problem can be formulated as a MCLP [13] problem and can be solved using MIP based on the short distance matrix. Within a unit, at least one nodal (obligatory) point is required to cover the settlements inside the unit boundary.

The same process can be repeated to identify the nodal points for each of the units. The obtained set of nodal points in the region is to be connected by a road network.

Once the nodal points are identified, the method proceeds to the second planning phase. Here, the main goal is to obtain a rural road network connecting all the nodal points. All the possible alternative links between the nodal points can be considered, namely, existing roads, tracks, trails and possibly even new links. The network obtained at this stage can be taken as a perspective network from which a matrix with the distances between the nodal points can be obtained. Using the distance matrix, a MST of the network can be obtained using Prim's algorithm [16]. This will provide a minimum connection level of the rural road network of the region under study.

The obtained MST connects all the nodes in the network, which can be categorized as nodal or intermediate (connection) points. The first categories of points (the nodal points) are important nodes which cover the settlements and the (most important) public facilities in specified areas. The second categories of points (the intermediate points) are road connecting nodes which are introduced in order to connect the links to the road network. In terms of connectivity and accessibility to settlements, the nodes in the second category are typically not as important as the ones in the first category. Hence, the intermediate points can be removed from the MST network to make the required rural road network as small as possible (and likewise more economical). In this way, after obtaining a MST of the complete road network, the above situation should be carefully judged. Furthermore, some links can be required to be inserted in the MST network due to its strategic or political importance.

Finally, the modified MST can be considered as the rural road network to be implemented/upgraded in the region under study.

III. Test Case: A Hilly Region of Lamjung District

The applicability of the methodology is tested and explained for the definition of the rural road network in a region which consists of 11 VDCs of the Lamjung district (Nepal) as shown in Fig. 2.

The region is surrounded by rivers in the east, south, and west and connected by a rural road to higher standard road (feeder road). The district headquarter is linked by the feeder road to the national highway network. The district headquarter is the main service center in the district and acts as a supply centre of goods and services to the VDCs of the district.

TABLE I
VDCs with Coverage by Nodal Points

VDCs	Total settlements	Covered settlements	Covered (%)	Nodal point
Dhamilikuwa	22	17	77.27	Dhamilikuwa
Chakratirtha	18	18	100.00	Satdobato
Bhalayakharka	14	10	71.43	Dharamdhunga
Kolki	18	17	94.44	Bakot
Pyarjung	11	11	100.00	Lamagaun
Turture	16	16	100.00	Bhaisikholagau
Raginas	16	12	75.00	Bhaiswara
Bharate	20	20	100.00	Bharate
Archalbot	12	12	100.00	Upalloalainche
Srimanjyang	14	14	100.00	Newargau
Gauda	24	19	79.17	Parjedanda
Total	185	166	89.73	

Fig. 2 Identified nodal points and settlements in the region

In this case, each VDC is treated as the subdivision of the region (unit). For each of the VDCs the settlements were identified and marked on the map, as shown in Fig. 2. The number of settlements in each VDC can be seen in Table I. The region has a total of 185 settlements. The connectivity of

Open Science Index, Civil and Environmental Engineering Vol:7, No:6, 2013 publications.waset.org/13942.pdf

the settlements (by roads/tracks/trails) in each VDC has been explored in the available maps. The distance between the connected settlements are estimated and allow obtaining a distance matrix.

Using the distance matrix, the shortest distance between any two pairs of VDCs can be obtained using the Floyd-Warshal algorithm [15], thus forming the shortest path matrix. The nodal point in each VDC has been identified using the MCLP model [13]. The mathematical models were solved using MPL for Windows 4.2 as the modeling language with CPLEX 10.0’s Mixed Integer Programming solver. The maximum service distance has been set as 4km (approximately, 1 hour walking distance).

The identified nodal point in each VDC is shown in Fig. 2 and identified in the fifth column of Table I. The first column of the Table is the VDC name; the second column shows the number of settlements in each VDC. The third column shows the number of settlements covered by the nodal point and the fourth column shows the percentage of covered settlements out of the total settlements in the VDCs. Within the maximum service (covering) distance of 4km to the nodal point, the coverage by the nodal point varies from 71% to 100%. In average, around 90% settlements are covered by the nodal points within the proposed service distance. After identification of nodal points for 11 VDCs in the region, the first phase of proposed methodology is complete (see flow chart in Fig. 1).

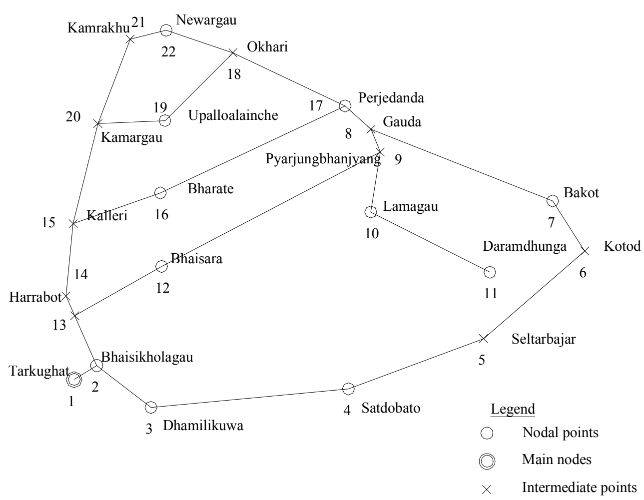

Fig. 3 Rural road network in the region

In the second phase, the nodal points identified in the first phase are treated as obligatory points for the rural road network. The next step is to identify the road linkages to the nodal points of the 11 VDCs. The nodal points are proposed to be connected by rural road links, as shown in Fig. 3 considering spatial and technical constraints. The length of the links in kilometer (km) is shown in Table II. Each nodal point is to be connected by at least one road link in the network. Then, the complete road network is obtained (Fig. 3).

A MST of the network (Fig. 3) is obtained using the Prim’s algorithm. The obtained MST of the network for the region is shown in Fig. 4. However, the MST can be modified as discussed in the following paragraph.

TABLE II
LINKAGES TO NODAL POINTS

Links	Length (km)
1-2	1.10
2-3	2.92
2-13	2.35
3-4	6.39
4-5	4.23
5-6	4.50
6-7	13.00
7-8	7.00
8-9	2.38
8-17	1.56
9-10	1.45
9-12	11.30
10-11	13.50
12-13	4.98
13-14	2.18
14-15	4.55
15-16	12.50
15-20	3.49
16-17	10.50
17-18	3.45
18-19	8.60
18-22	6.70
19-20	8.50
20-21	2.72
21-22	11.00

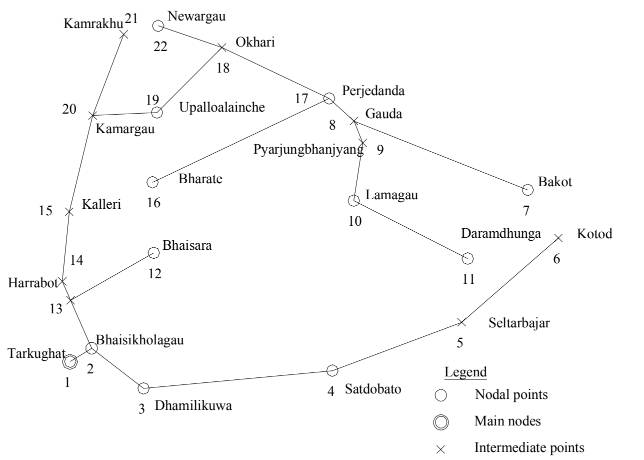

Fig. 4 MST of the rural road network using Prim’s algorithm

In the network (Fig. 3), six nodal points (nodes 2, 3, 4, 12, 16, and 17) are connected by existing links and the remaining five nodal points are not connected yet. The link 17-18 is in developing stage. Links 18-19 and 18-22 can be developed only after developing link 17-18. But, the MST (Fig. 4) network shows that it is better to include links 9-10, 10-11, 8-7, 18-19, and 18-22 in the network. These are new linkages in the network. However, the MST did not included link 12-9 which is already developed.

The network (Fig. 4) contains some intermediate points (nodes 5, 6, and 21) that can be removed. If link 12-9 (11.30km) can be included in the network, we can also remove

Open Science Index, Civil and Environmental Engineering Vol:7, No:6, 2013 publications.waset.org/13942.pdf

intermediate nodes 14, 15, and 20 from the network. Then, we can remove links 13-14, 14-15, 15-20, and 20-19 (total 18.72km) in the network. Though links 4-5 and 5-6 have been already developed, they are not effective in the network as it couldn't connect the nodal points. Hence, links 4-5 and 5-6 can also be removed from the MST network. The later MST network is recommended rather than the previous one as it is short. Hence, the MST can be modified including the link 12-9. The final MST is presented in Fig. 5. This can be considered as the minimum level of rural road connectivity necessary to cover the region within a 4 km service distance.

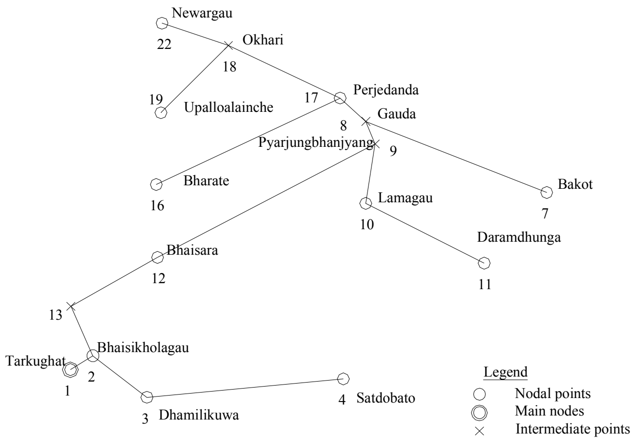

Fig. 5 Modified MST of the rural road network

Looking at the implementation of the methodology in the 11 VDCs of Lamjung district, it can be concluded that the proposed methodology is simple and practical for identifying the appropriate obligatory points and for helping to define the rural road network development in rural areas such as in Nepal. However, from an engineering perspective, the selection of the appropriate road alignment is important in case of the hilly areas.

IV. Conclusion

In order to define a rural road network, a methodology composed of two phases is proposed in this paper. The covering approach was found to be useful to identify the nodal points which cover the settlements within the VDCs. The nodal points can be taken as the obligatory points in a rural road network. Hence, this method provides a way of establishing the obligatory points in rural road alignment taking care of rural settlements in the first phase.

The definition of linkages to the nodal points in the second phase can form a basic rural road network. The MST obtained through this process can be considered as the minimum level of road connectivity in rural areas (such as in Nepal).

The proposed methodology can be a practical and realistic approach for identifying obligatory points and forming rural road networks in rural areas. The implementation of the methodology in the Lamjung district of Nepal leads to believe that it is suitable for the rural road network definition. Future work includes prioritization of links considering financial constraints, social and economic indicators.

References

[1] Central Bureau of Statistics (CBS), *Nepal in Figures*. National Planning Commission secretariat, Government of Nepal, 2011.
[2] R. Dennis, *Rural transport and accessibility: A synthesis paper,* International Labor Organization, Geneva, 1998.
[3] UNCHS (United Nations Centre for Human Settlements), *Guidelines for the Planning of Rural Settlements and Infrastructure: Road Networks*. Nairobi, Kenya, 1985.
[4] K. Dixon-Fyle, *Accessibility Planning and Local Development: The application possibilities of the IRAP methodology*. Development Policy Department, International Labor Organization, Geneva, 1998.
[5] DOLIDAR (Department of Local Infrastructure Development and Agricultural Roads), *Approach for the Development of Agricultural and Rural Roads*. Lalitpur, Nepal, 2012.
[6] C. B. Shrestha, "Developing a computer-aided methodology for district road network planning and prioritization in Nepal," *Transportation Research Board,* vol. 3, pp. 157-174, 2003.
[7] A. K. Singh, "GIS Based Rural Road Network Planning for Developing Countries," *Journal of Transportation Engineering* doi:http://dx.doi.org/10.1061/(ASCE)TE.1943-5436.0000212, 2010.
[8] A. Kumar, and P. Kumar, "User friendly model for planning rural road," *Transportation research record*, vol. 1652, pp. 31-39, 1999.
[9] C. B. Shrestha and J.K. Routray, "Application of settlement interaction based rural road network model in Nawalparasi district of Nepal," in *Proc. Conf. Technology transfer in road transportation in Africa,* Tanzania, 2001, pp. 268-287.
[10] A. Kumar and H. T. Tilloston, "A planning model for rural roads in India," in *Proc., Seminar on roads and road transport in rural areas*, Central Road Research Institute, New Delhi, 1985.
[11] A. K. Makarachi and H. T. Tillotson, "Road planning in rural areas of developing countries," *European Journal of Operational Research*, vol. 53, pp. 279-287, 1991.
[12] J.K. Shrestha, A. Benta, R.B. Lopes, N. Lopes, and C. Ferreira, "A numerical model for rural road network optimization in hilly terrains," in *Proc. First ECCOMAS Young Investigators Conference (YIC2012)*, University of Aveiro, Portugal, 2012.
[13] R. L. Church, and C. ReVelle, "The maximal covering location problem," *Regional Science Association,* vol. 32, pp. 101-118, 1974.
[14] D. L. Oudheusden and L. R. Khan, "Planning and development of rural road networks in developing countries," *European Journal of Operational Research*, vol. 32-3, pp. 353–362, 1987.
[15] R. W. Floyd, "Algorithm 97: Shortest Path," *Communications of the ACM,* doi:10.1145/367766.368168 vol. 5(6), pp. 345, 1962.
[16] R. C. Prim, "Shortest connection networks and some generalizations," *Bell System Technical Journal*, vol. 36, pp. 1389–1401, 1957.