Prioritization of Road Network Sections to Upgrade Dry Weathered Condition: An Accessibility Approach in Rural Areas of Nepal.

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Abstract: Selecting the upgrading road project in rural areas of Nepal is most challenging task. This paper suggests a methodology to prioritize the rural road network sections to upgrade the “Dry- Weathered Road” in rural areas of Nepal. The methodology evaluates the socioeconomic impact of network upgrading as an accessibility index of a village. A two stage process was carried out where; first stage selects the sections which can provide higher accessibility to the isolated villages during rainy season. Second stage gives the ranking of road network sections to improve overall network performance. A method of sensitivity analysis was employed to identify the threshold value of critical population and distance. Redundancy evaluation of the alternative link was performed whether a detour route was in acceptable range. Finally priority list of dry weathered links of a district level road network was prepared for the selection of upgrading projects.

Keywords: Accessibility; Reliability; Redundancy; Road Network Planning; Vulnerability

1. INTRODUCTION

In rainy season, most of rural roads of Nepal are not functional due to flooding in river, soil erosion in mountainous area, earthen condition of pavement and unavailability of bridge termed as “Dry Weathered Road”. Due to failure on connection; many villages, cities or towns become isolated; rural life becomes hard; people have to walk more than a day to reach the service center; raises the transportation cost and loss on economy. Disconnection is the most severe problem after natural disaster and road closure due to bad weather. The severity and weakness in the network differs from location to location.
Practitioners are facing the problem on selection of upgrading project to make a reliable network. Identification of weakest location and critical links in a network and prioritizing them for the improvement projects is the crucial task for the planners. One popular methodology is evaluating the project based on cost benefit analysis (CBA). But, CBA method always gives economic evaluation of project and could not address the connectivity problem of rural areas. With this backdrop, this paper suggests a network evaluation methodology based on the accessibility of the villages. The methodology prepares the priority list of the road network section for upgrading project from “Dry weathered road” to “All weathered road”.
In the following section, a brief review is carried out on the existing practices for the selection of road network projects and reliability research. Next section proposes a network evaluation

methodology based on the accessibility importance of villages. This will followed by an application result of the new methodology in district road network. Finally conclusion is drawn.

2. LITERATURE REVIEW

Out of 28000 km of road 17,000 km i.e. 60% of the road network is not functional in rainy season in Nepal (Upadhyaya 2009). A district transport master plan (DTMP) guideline (DoLIDAR 2010) proposed a scoring system for the prioritization of the road network mainly based on cost efficiency. The DTMP guideline suggests 50% score for the population per unit cost for the new linkage. Similarly for the upgrading projects traffic volume is the main decision factor (Shrestha and Shrestha 2011). However, cost efficiency could not address the accessibility problem and traffic volume in rainy season (i.e. in closed road) is meaningless.

A large volume of research has been carried out under the subject of transport network reliability. (Pokharel and Ieda 2012) classified the reliability research into six groups including conceptual studies, mathematical theory, evaluation methodologies, descriptive studies, application or case studies, and the ways to improve reliability. Several evaluation methodologies have been proposed for the identification of critical link in the network(Taylor, Sekhar et al. 2006) suggest the condition of node vulnerability and link criticality by calculating the accessibility index of the link at the emergency situation. The accessibility index gives a socioeconomic impact of network disruption and finds out the link which has highest change in the accessibility index after disaster compared to normal condition. Accessibility index of a node is calculated at normal condition and after assumption of failure of each link one at a time which does not addressed multiple link failure case. (Sohn 2006) also suggests accessibility index in a flood plain, the considered link is taken only from the 100 year floodplain. (Jenelius, Petersen et al. 2006) suggest link importance and municipality exposure, each and every link is evaluated through the change in generalized travel cost. (Scott, Novak et al. 2006) suggest a network robustness index (NRI) of a link. The NRI calculates the change in total travel cost in a network due to failure of particular link. (MLIT 2011b) evaluates the degree of weakness of the specific link in a network which lies under vulnerable scenario and calculates the ratio of total travel time in a network before and after disaster. (MLIT 2011a) analyzes the degree of isolation by calculating the detour ratio and disaster tolerance function. Existing evaluation methodologies consider various dimensions such as socioeconomic impact of network disruption, connectivity, consist of simple data and computation process, important theoretical and practical concepts. The main weaknesses of existing evaluation methodologies are lacks of 1) consideration of multiple link failure condition. 2) Criteria for the selection of links to be evaluated and 3) consideration of redundancy (Pokharel and Ieda 2012).

3. METHODOLOGY

During emergency situation, or when extreme disaster happens three types of problems are observed. The first one is connectivity failure between two locations; there is no other option/route/link to connect between the two locations, hence, some areas become isolated. Second, travel time is increased due to detour route. Third, traffic flow increases in the other survived route immediately after disaster and causes the problem of capacity/congestion. A severe impact on the community can arise such as problem on rescue and evacuation, problem on post disaster logistic supply and negative impact on economy(Pokharel and IEDA 2012).

To overcome the problem of isolation, suggested methodology evaluates the performance of each links and compare between them.

3.1 The Model

3.1.1 Accessibility Index of an Area

Hansen accessibility index(Hansen 1959) gives a model for the accessibility index of an area with respect to the service center. And (Taylor, Sekhar et al. 2006) used this index(eq:1) to evaluate the road network links.

$$A_i = \sum_{j=1} P_j / L_{ij} \qquad (1)$$

Where,

- A_i: Accessibility index of an origin node
- P_j: attraction of the service center, used as population
- L_{ij}: shortest path between origin node i to service center j. The shortest path is computed by using Dijkstra algorithm.

3.1.2 Accessibility Index of an Area with Population

Though (Hansen 1959) accessibility index gives the index of an area it does not consider population in a village particular area. Therefore, we simply improved the Hansen accessibility index here by considering the population of the village (origin node) P_i. The final model will be:

$$A_i = P_i * \sum_{j=1} P_j / L_{ij} \qquad (2)$$

Normalized model of accessibility index of the population:

$$A_i = \frac{P_i * \sum_{j=1} P_j / L_{ij}}{P} \qquad (3)$$

Where, P is the total population in the analysis area.

$$P = \sum P_i + \sum P_j \qquad (4)$$

3.2 Evaluation of Redundancy

A recently published manual of Ministry of Land, Infrastructure, Transport and Tourism Japan (MLIT 2011a) gives a simple and practical measure for the evaluation of redundancy as a detour ratio. Detour ratio calculates the lengthiness of the alternative shortest path when one or more links closed in a regular shortest path.

$$DR_{ij} = \frac{L_{ija}}{L_{ij}} \qquad (5)$$

Where,

- L_{ij}: shortest path between i and j

L_{ija}: alternative shortest path when one or more links fail in the shortest path (In every step shortest path is computed by Dijkstra's algorithm).

The acceptable limit of a detour ratio for the rural areas of Nepal is assumed as 2, i.e. people will use the alternative path 2 times longer than dry weathered shortest path in rainy season.

3.3 Critical Population and Distance

The main variables of proposed model are population of origin and distance between the origin node and service center (Eq: 3). With the general uses of this model, less populated areas can be neglected and the areas which are very near from the service center will be overvalued. A method of sensitivity analysis is proposed to identify the critical population and distance. Critical population (CRP) is a bench mark population which treated all origin nodes equally if the population is less than critical population. Similarly, within some mobility range distance from service center to all origin nodes are treated equally if the distance is lower than the critical distance (CRD).

3.4 Network Performance Index (NPI)

With the application of redundancy evaluation and sensitivity analysis the final model for the calculation of accessibility index of a village (origin node) will be:

$$A_i = \frac{P_i * \sum_{j=1} P_j / (L_{ija} * \delta)}{P} \qquad (7)$$

$$\delta_{ij} \quad =1, \text{ if } DR_{ij} <= 2 \qquad (8)$$
$$=\infty, \text{ if } DR_{ij} > 2$$

$$L_{ija} \quad = CRD, \text{ if } L_{ija} <= CRD \qquad (9)$$
$$= L_{ija}, \text{ if } L_{ija} > CRD$$

$$Pi \quad = CPR, \text{ if } Pi <= CRP \qquad (10)$$
$$= Pi, \text{ if } Pi > CRP$$

A network performance Index (NPI) is calculated based on accessibility index of all village presents in an analysis area. In our definition, a total accessibility index of all villages (origin node) is termed as a network performance index of that network (Eq: 11).

$$NPI = \sum A_i \qquad (11)$$

3.5 Upgrading the Dry Weathered links

Two steps process is proposed for the upgrading the dry weathered links. First step prioritized the links which are important to recover the isolation state of villages and second step identifies the links which are important to improve the overall performance of a road network.

3.5.1 Prioritization of Dry Weathered Links for the Recovery of Isolation State

1. Accessibility indices (Ai) of all villages are calculated at dry weathered condition and the villages which have zero value are termed as isolated villages.
2. Calculate the Network Performance Index (NPI^k) by adding the accessibility index of isolated villages only with the assumption of dry weathered link (k) recovered one at a time.

$$NPI^k = \sum A^k_{i(isolated)} \qquad (12)$$

Where,

k: 1, 2, 3, 4…………..n (closed links in rainy season).

3. Calculate the NPI for all dry weathered links and select a link in a top priority which has maximum NPI.
4. Repeat the step 2 and 3 with the consideration of connected village and recovered link in previous step until all villages get connected.

3.5.2 Prioritization of Dry Weathered Links to Improve Overall Network Performance

After recovery of isolation state of villages, there may be more links remains still in closed condition during rainy season, which we need to prioritize for the upgrading.

1. Network Performance Index is calculated with the assumption of recovery of each remaining dry weathered link (k) one at a time by calculating the percentage improvement on overall network performance from the worst condition.

$$NPI^k = \frac{\sum A^k_i - NPI^{Rainy}}{NPI^{Dry} - NPI^{Rainy}} x100\% \qquad (13)$$

Where,

NPI^{Rainy} : Network Performance Index (NPI) in rainy season.

NPI^{Dry} : Network Performance Index (NPI) in dry season.

k :1,2,3………..n; remaining closed links in rainy season after recovery of isolation

2. Calculate the NPI for all remaining dry weathered links and select a link in a top priority which has maximum NPI.
3. Repeat the step 1 and 2 with the consideration recovered link in previous step until all dry weathered links prioritized.

4. APPLICATION OF EVALUATION METHODOLOGY IN RURAL ROAD NETWORK OF NEPAL

The accessibility approach with the consideration of population has been applied to evaluate the rural road network in Nepal. Other factors such as economic benefit, cost benefit could attract the attention for the evaluation, however, population can be considered reasonably as all inclusive variables because rural people of Nepal are struggling to get the minimum access to the basic services.

The study place has been selected in Syangja district among 75 districts of Nepal, lies on 230 km west of Kathmandu and 30 K.M west of Pokhara (A famous tourism center in Nepal). Total area of the district is 1164 sq. km. Figure 1 shows the location of study place.

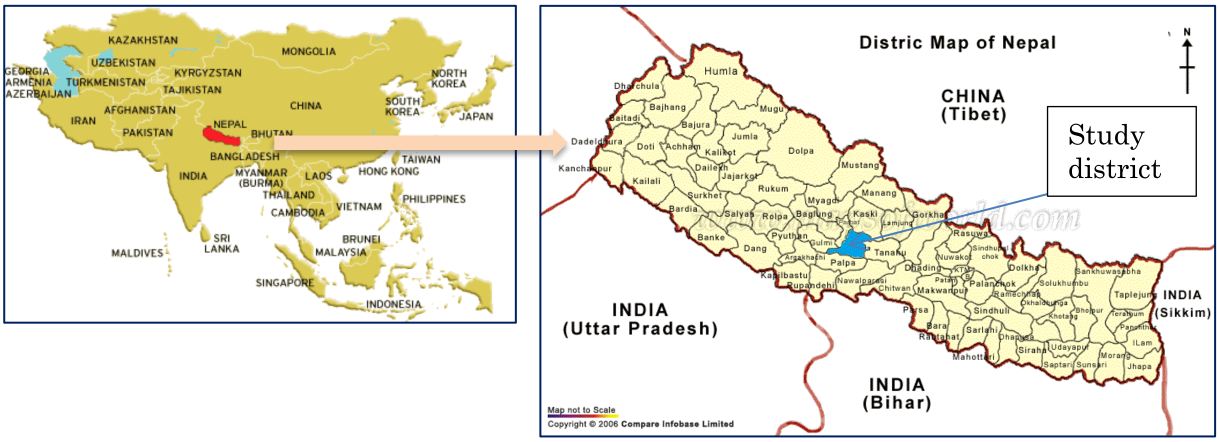

Figure 1: District map of Nepal with study district

Figure 2 shows the government published accessibility map of the Syangja District. In this map the yellow part represents the road available within two hour of walking distance .Which means most part of the district road is accessible within 2 hour walking distance. But these roads are only available on dry season and most of the road network sections are closed during rainy season. Out of 757 km, 627 km i.e 82% of road network are dry weathered and finally the road with yellow hatching on the map has meaningless in rainy season.

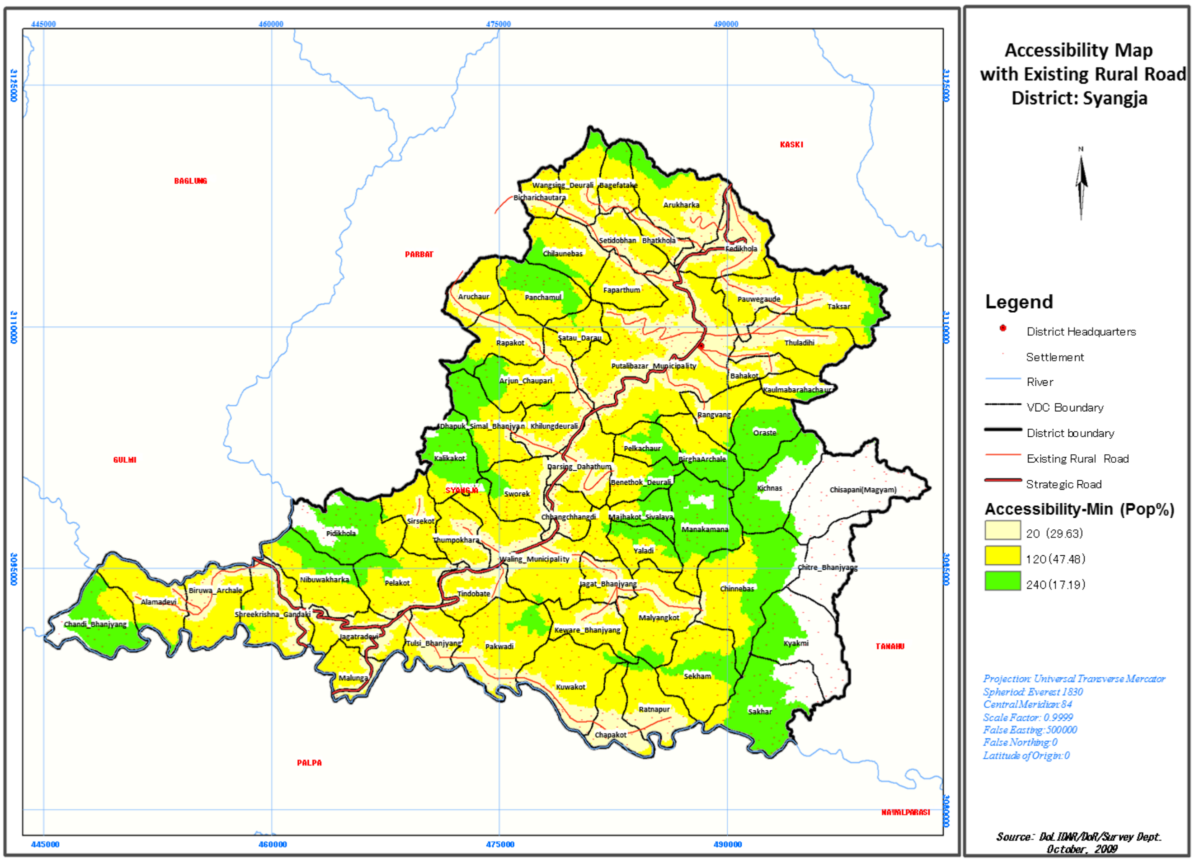

Figure 2: Government defined accessibility map, Syangja, Nepal
Source: DoLIDAR 2009

4.1 Identification of Critical Population and Distance

A method of sensitivity analysis is employed to identification of critical distance and population. Figure 3 shows the sensitivity analysis for the distance. The tendency of network performance index vs. critical distance curve without considering critical population (i.e. CRP=0) is dramatically changes from 10 km so we decide the critical distance is 10 km. As in the Figure 4 the network performance index vs. critical distance curves in various critical populations verifies the chosen value of critical distance.

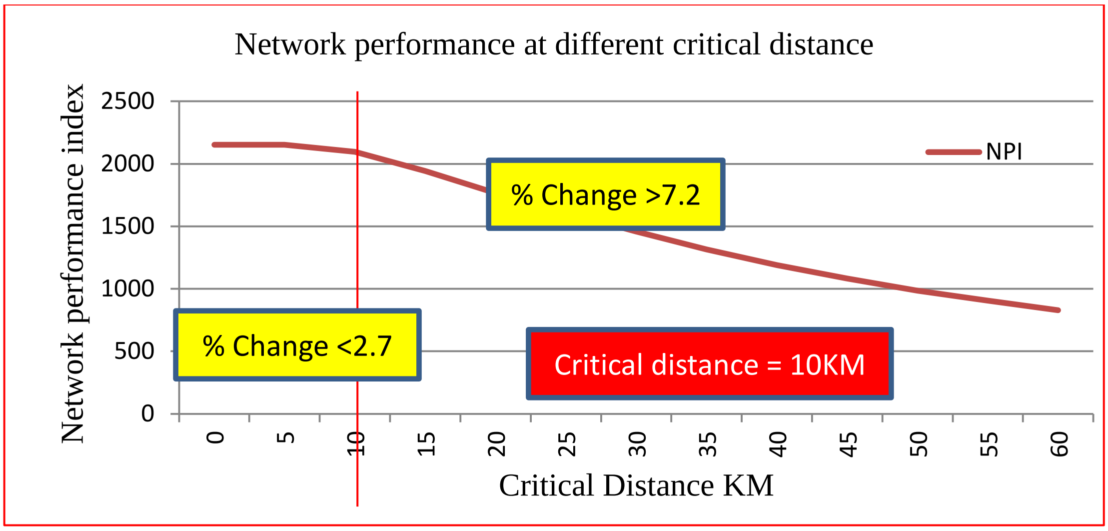

Figure 3: Critical distance vs. Network performance index without considering critical population, Syangja, Nepal

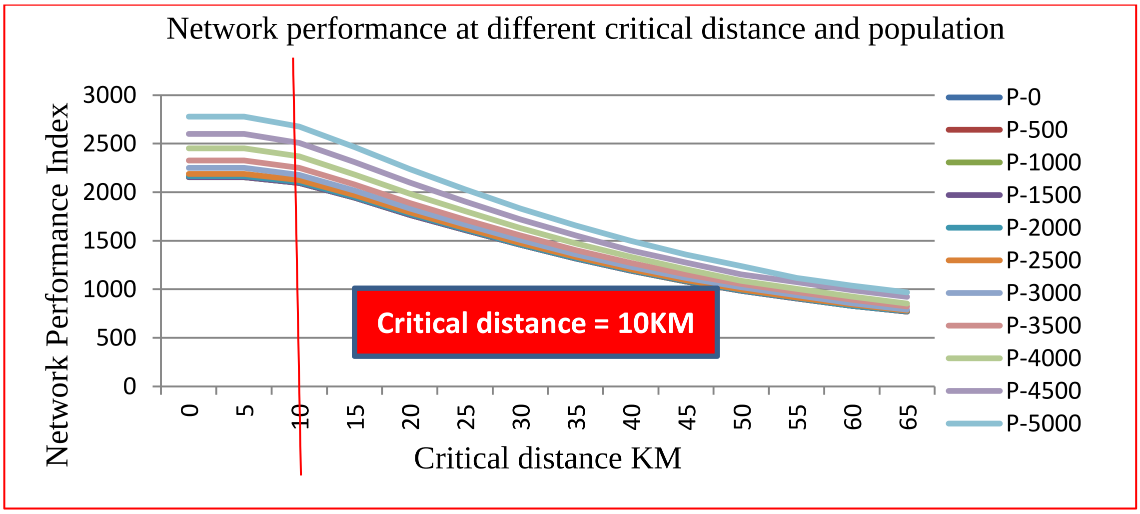

Figure 4: Critical distance and Network performance index at various critical populations, Syangja Nepal

Similarly for the critical population, Figure 5 shows the tendency curve of critical population vs. network performance index without considering critical distance (i.e. CRD=0). The population 3500 where curve changes dramatically is decided as a critical population. Figure 6 shows the tendency of curves of critical population vs. network performance index in different critical distance. The curve shows similar pattern on different critical distance hence decided value is OK.

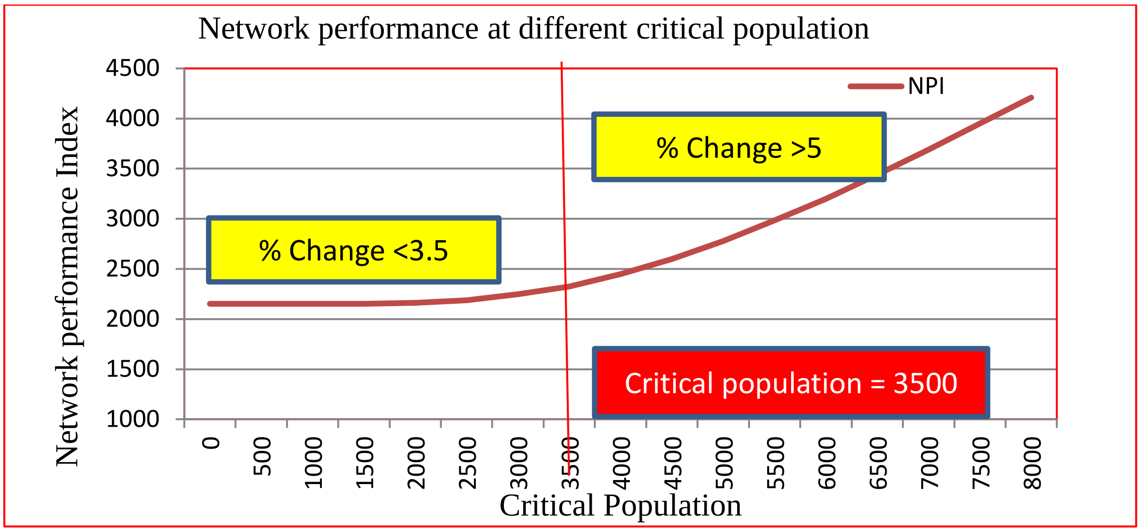

Figure 5: Critical population vs. network performance index without considering critical distance, Syangja Nepal

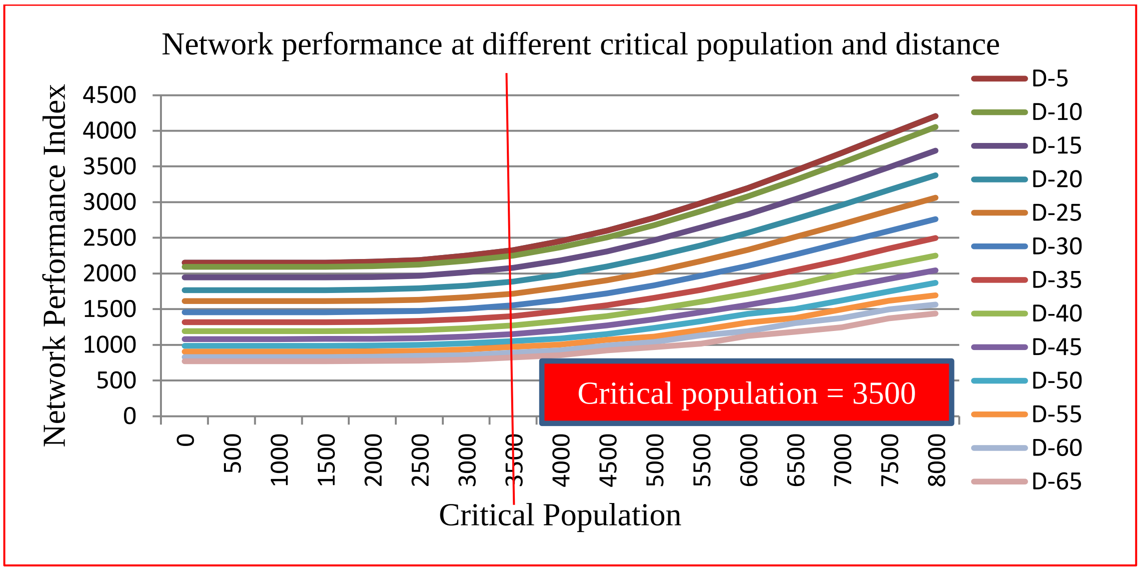

Figure 6: Critical population vs. network performance index at various critical distances, Syangja Nepal

4.2 **Prioritization of Dry Weathered links for the upgrading projects**

With the decision of the critical distance and population, the priority list of the dry weathered road section has been identified by following the step by step calculation processes proposed in section 3.5. We adopted the detour ratio as 2 for this, because the case we choose is for the analysis in rural area of developing country, where all weathered road length is very low.
There are 55 villages isolated out of 75 village and town during rainy season in Syangja district.
Figure 7 shows the comparative chart of Network Performance Index (NPI) of each link with

the assumption of first recovery. The link which has highest NPI selected as a top priority and will assume as an "all weathered link" for the next iteration.

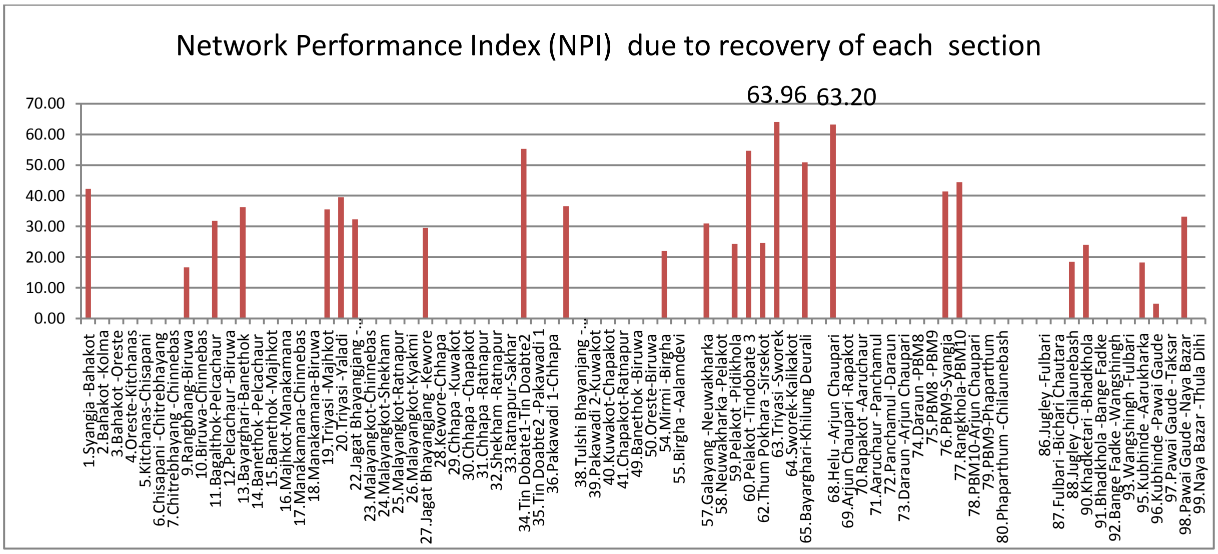

Figure 7: Comparative chart of Network Performance Index (NPI) of each link with the assumption of first recovery.

Figure 8 shows the links with priority list to be upgraded for the recovery of isolation state of village and to be improved for the achievement of overall network performance.

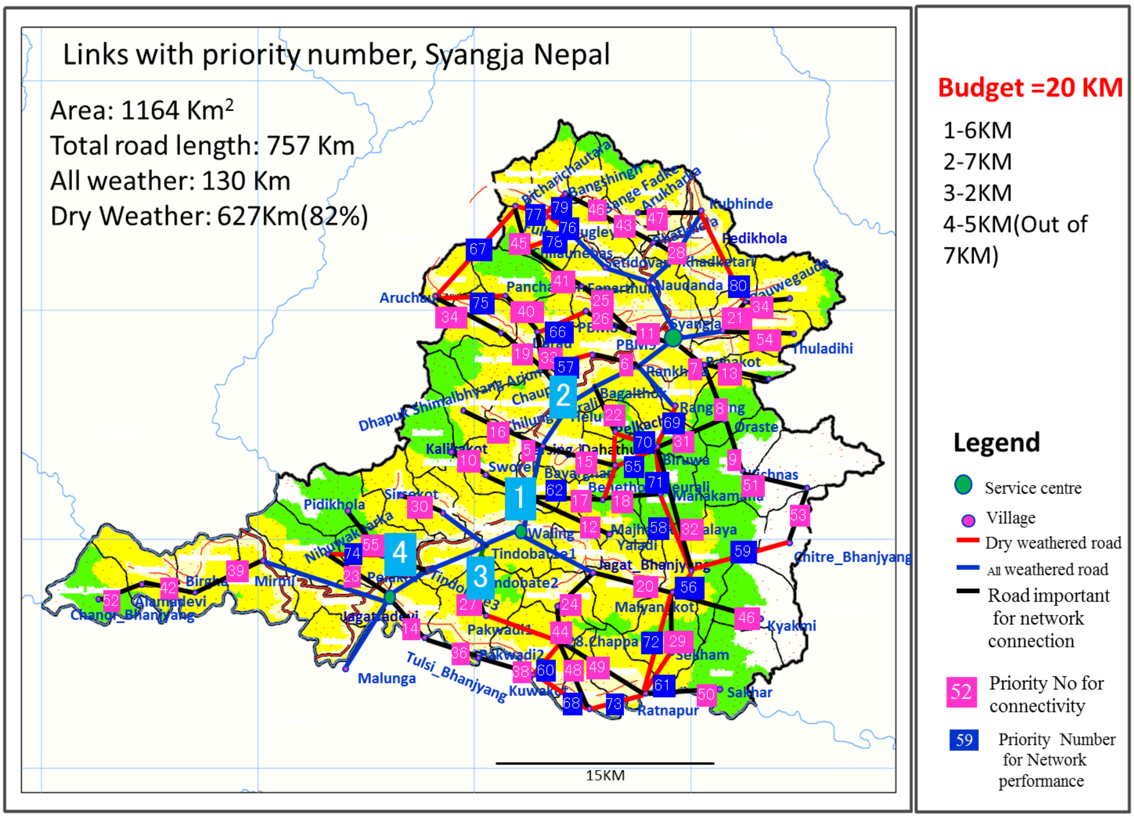

Figure 8: Links with priority number

For example, if government has budget only for 20km road construction in particular year than upgrading project consists the section which cover the length from priority no 1 to 4. Remaining links can be upgraded by the next year.

5. CONCLUSION

More than 60% of rural road network sections of Nepal are not functional in rainy season. To upgrade those road network from “dry weathered” to “all weathered” practitioners needs a priority list of the dry weathered links. Existing prioritization processes are mostly based on the cost benefit approach, however severity due to isolation cannot address by the existing comparison criteria.

In this paper, a network evaluation methodology was employed to prioritize “dry weathered road” network links for the selection of upgrading project. A Network Performance Index (NPI) was derived in order to quantify the impact of upgrading of particular link in a network considering accessibility of a village. Index was obtained after assumption of improving the dry weathered links based on accessibility and network closure vulnerability approach. Cumulative effects of link improvement were observed by comparing the links. Proposed methodology prioritized the dry weathered road network links in two stages. First stage prioritized links for the network connection. Second stage ranked links to increase the overall network performance. The method of sensitivity analysis was also employed to identify the critical population and critical distance. Critical population and critical distance were taken as a threshold value which treated the less populated area and area within the some mobility range equally. Redundancy evaluation of the alternative link was employed whether detour route was in acceptable range or not. Finally priority list of the dry weathered links of one district among 75 districts was prepared for the selection of upgrading projects.

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