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Development of Road Upgradation Plan to Support Agricultural Production in Dhanusha

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Abstract

There is widespread agreement in the literature that a region's transportation infrastructure and economic development are intertwined. This idea of economic growth with efficient transportation of people and products from one location to another can only be realized if there is a reliable transportation system. In this research, a methodology is proposed such that the place having high economic potentiality is linked with market centre's and existing link is already present then the network links are upgraded on the basis of production served by each link with budget constraint. Dhanusha district of Nepal is chosen for the application of this method. The main objective of this research is to develop an optimal road network maximize the production served considering agricultural development potential and Market centers of Dhanusha district with budget constraints. Agricultural potential of each local level units of Dhanusha in economic terms was used for finding production served by each link connecting to market centre based on which road upgradation plan of such transport linkages that can be done with budget constraint is obtained. This research was predominantly based on secondary data sources published by Government of Nepal (GoN) and other authentic and relevant publications related to Dhanusha. It is believed that the results of this research will be applicable in more inclusive transport planning of the district and the methodology shall be applicable in other districts of Nepal.

Keywords

Transport Linkage, Backbone Network, Production Maximization, Road Upgradation Model

1. Introduction

Nation's economy is directly impacted by and dependent upon transportation. It has resulted in the country's political, social, economic, and even cultural development. These investment decisions can strongly influence the use of the transportation system for decades to come.Planners can foresee upcoming transportation trends by using forecasting models. Nepal has a total population of 29.2 million with 83% living in rural areas. 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 rural areas refers to how quickly, cheaply, and easily inhabitants can obtain the facilities and services they require for daily living. The Majority of people reside in rural areas in underdeveloped nations like Nepal. One of the major lessons learnt from efforts in road development for years was that there is a large need for a rural road network in the country for overall economic development. The government of Nepal has realized this need and put its major emphasis on rural road network development as one of the important sectors within the framework of its Ninth Plan as well as its decentralization efforts. The goal of Nepal's fifteenth development plan is to lay the groundwork for the achievement of economic success and social harmony by preserving concord among the three tiers of government through the mobilization of internal and external resources as well as intergovernmental financing will be mobilized. In order to create productive employment, equitable distribution, and economic progress, including social protection and security, all of the nation's resources will be utilized throughout this planning era.

There is a high level of consensus among different literatures that the economic development of an area is linked with its transport infrastructures. One of the major constraints in the development of rural infrastructure in developing countries is a lack of sufficient funds. Aside from a lack of funds to build rural infrastructures (roads, water supply, electricity, and telecommunication network) and public facilities, a major issue is a lack of proper planning methodologies for the development, improvement, and management of rural infrastructures. As Agriculture is the major sector of Nepalese economy, it is believed that there must be transport linkages to the places where there is high agricultural development possibility which consequently increases the economic vitality of that area. A critical need for rural development is research on the comprehensive and integrated planning of rural infrastructures. The transport practitioners and planners are facing lots of difficulties in selection of proper methodology to prioritize the existing transport network of Nepal as well as in providing new transport linkages to places where necessary. To overcome this problem this study was conducted. Many areas have great possibility of development in industries like agriculture, tourism, trade etc. But these potentials are not uniformly distributed throughout the district and some are yet to be realized. Despite these huge potential, many regions of Nepal remain underdeveloped mainly due to lack of proper planning within limited available budget.

In this study, the topic of this work is envisaged and devoted to transport linkages and their planning within a limited budget from the perspective of agricultural development in this study. This concept of economic growth with smooth, safe, and cost-effective movement of people and goods from one location to another can only be realized if a proper and well-planned transportation network exists. The main objective of this research is to develop road upgradation plan to maximize the production served considering agricultural development potential and Market centre's of Dhanusha district with budget constraints.

2. Literature Review

A minimal spanning tree (MST) problem is the problem of finding the set of arcs that connect each node in a network while minimizing the total length of the selected arc [1]. Tillostson(1991) [2] used minimum spinning Tree (MST) for generating the road network for connecting the nodal points within the specified region using road links. Peters (1958) [3] formulated perhaps the first network generation problem attempting to incorporate the economic consequences of transportation investment. Prioritization ranking was prepared based on shortest path analysis of existing transport network such that Village Development Committees (VDCs) having high agricultural potential are linked to the district head-quarter first then also proposed new linkages by Bhattarai (2013) [4]. Shrestha et al.(2013) [5] formulated a solution for solving network problems in Gorkha and Lamjung Districts of Nepal by using the concept of backbone network and maximal covering problem to increase the accessibility to market centre's and health facilities.

While considering agricultural development perspective, agricultural productivity can be used instead of population in maximum covering problem to increase the accessibility to market centres in the area using the concept of backbone network. Backbone network and branch network can be formed using the Concept of Minimum spanning tree and shortest path in Arc.GIS [6]. The matrix then obtained and transportation model formed can be solved using CPLEX optimizer[7].

3. Methodology

3.1 Research Design

Both single objective and multi-objective production-based planning have been carried out in literature. The current study purposes a bi-level methodology as shown in Figure 1 to develop the road upgradation plan. In first level, list of candidate links that can connect the market points within minimum distance from the backbone nodes that are the identified well known points from strategic road network are identified. In second step, a road upgradation model is solved that maximizes the total production served under the budget constraint.

3.2 Identification of Links important from Production Perspective

3.2.1 Backbone Network

Most agricultural communities in rural locations lack access to services and market centers within a reasonable distance. It is therefore vital to identify one or more nodes that can cover the majority of the facilities within the required ranges. Consequently, it is vital to organize places with potential for agriculture. Using the political boundaries to choose a suitable geographic location is one method of

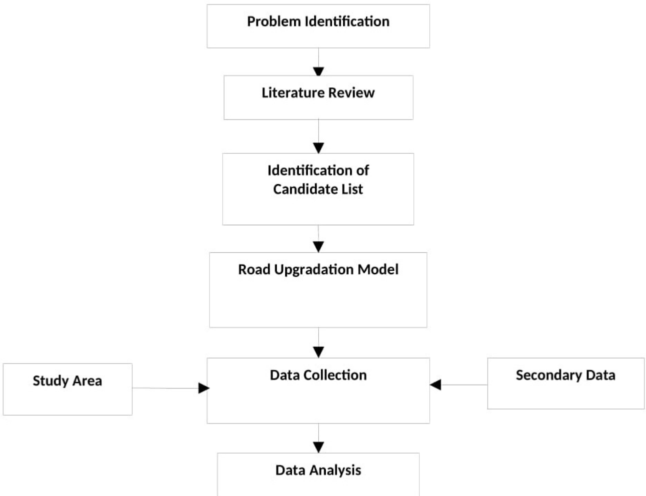

Figure 1: Framework of Research

organizing the agricultural areas. The position of such spots must therefore be determined using a suitable method. Hence, in order to cover all local level units, a network can be formed such that it acts as a backbone support to maximize the production served. The utilization of these distances can be impractical if we attempt to connect each analysis unit to the district headquarters. However, the journey distance will be significantly reduced if we connect market centre's to the national highway, and the national highway is well known. Since, model is formulated for district level upgradation, links that will fall in the teritorry of other districts are not considered. The lowest political tiers in Nepal are the local levels so, local level boundaries can be used to define political boundaries. These nodal points can be taken as the obligatory points in a rural road network.Therefore, these nodal points represent the areas of agricultural potential and can be taken as the obligatory points in a rural road network. After nodal points are identified, MST connecting the noted nodal locations serves as the region's fundamental rural road network, ensuring that each local level unit is connected just once. Within the networks in Nepal's Terai region, a typical rural road network structure was found. The branch and backbone networks define the pattern.

3.2.2 Branch Network

The market centers identified can then be located in map. The next phase is to determine the road linkages from market centre to backbone network. A transportation network backbone and branch network within a local level can be formed from which a distance matrix can be obtained as illustrated in Figure 2. Then, the shortest distance from each market centre to backbone network can be found using the Dijkstra's algorithm thus obtaining the shortest path matrix. For this purpose, we can use a facility allocation model. The location of nodal points can be considered as a location problem and distance matrix can obtained using the Dijkstra's algorithm to analyze the situation.

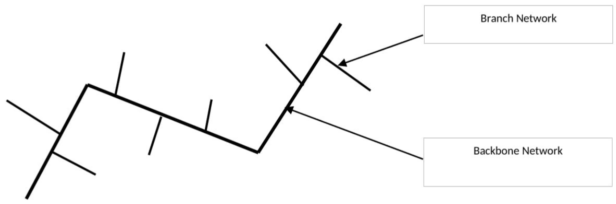

Figure 2: Backbone And Branch Network

3.3 Development of Road Upgradation Model

3.3.1 Calculation of Economic Worth of Each Analysis Unit

District agricultural production will be proportionally divided based on cultivable land and households for horticulture and livestock of each rural municipality respectively.

$$A_k = \frac{c_k}{\sum c_k} * TotalProduction (3.1)$$

Where, A_k is the production of A product in analysis unit k. Total Production denotes total production of A in whole district. C_k is the cultivable area of local level unit k for major crops, cash crops and horticulture; households for livestock. $\sum C_k$is the sum of cultivable Area of local level units where A is available for major crops, cash crops and horticulture; households for livestock Production. P_k is the sum total of production of all types of crops in local level unit k and $\sum A_k$ is the total agricultural production in local level unit k. After the calculation of agricultural products in each local level unit, production is multiplied by the average annual market price and productivity in terms of economic units can be obtained. The economic worth of each analysis unit can be achieved by adding economic productivity of each product of the same analysis unit. Prioritization of links is usually based on economic returns.

3.3.2 Road Upgradation Model

Road upgradation model can be formulated for improving links already identified from candidate list to higher surface levels so, upgrading candidate links among those identified Several market nodes of a road network are considered to contain the people and amenities, and these nodes are connected by road links to form an undirected graph. The mathematical formulation takes into account a single surface for new constructions and many possibilities for road surfaces, including asphalt, gravel, and earthen for link upgrades. The model enables examination of the distribution of public resources in an effort to best utilize the available budget. The model maximizes the production served subjected to budget constraint for road improvement. In this study, taking production instead of population Model can be formulated which seeks to maximize the production served by links subject to budget and spatial constraints.The objective of the model as given in equation (3.2) is to maximize the economic benefit road upgradation in terms of production served in the region due to the surface improvement subjected to the budget constraint as given in equation (3.3). The possible road improvement types are earthen to gravel (s1), gravel to bituminous (s2) and earthen to bituminous (s3). Equations (3.4) and (3.5) determine the production served by each link. Equation (3.6) determines the improvement cost of each link. Equation (3.7) ensures that each link will have only one type of improvement. $x_i j^S$ in the equation is the binary decision variable of the model which equals1 if a link (i,j) is to be upgraded with surface improvement type s and is 0 as given in equation (3.8).

Maximize: $Z = \sum_{S=1}^{3} \sum_{(i,j)\varepsilon L, i<j} W_{\text{ij}} * X_{\text{ij}}^{S}$ (3.2)

Subject to: $\sum_{S=1}^{3} \sum_{(i,j)\varepsilon L, i<j} I_{\text{ij}}^{S} * X_{\text{ij}}^{S} \leq B$ (3.3)

Weightage (W_{ij})=$P_{\text{ij}} * d_{\text{ij}}$ (3.4)

$$W_{\text{ij}} = \frac{\text{Total Production in } the \text{ area (Economic units)}}{\text{Total } r\text{oad link lengt}h \text{ in same area}} \quad (3.5)$$

$$I_{\text{ij}}^{S} = I^{S} * d_{\text{ij}} \quad (3.6)$$

$$\sum_{s=1}^{3} x_{\text{ij}}^{s} \leq 1 \forall (i,j) \in L,\ i<j\ \forall s \in S \quad (3.7)$$

$$x_{\text{ij}}^{s} \in (0,1) \forall (i,j) \in L,\ i<j \quad (3.8)$$

When seen as an undirected graph, the network G = (N, L). Where, N and L, respectively, are the sets of branch nodes and road linkages. The following symbols are employed. W_{ij} is weight of link (i, j), d_{ij} is the distance from node i to node j. B is the available investment budget. I_{ij}^{S} is the cost of improving link (i,j) with surface type S. Budget constraints in this study are used to investigate decision scenario.

3.4 Study Area

For the purpose of Dhanusha District was chosen. Dhanusha District is one of the 8 districts of Madhesh Pradesh situated in the Outer Terai. The district covers an area of 1206.55 km^2 and has a population (2021) of 8, 72, 713 [8]. The district consists of one sub-metropolitan city, 11 urban municipalities and 6 rural municipalities.

3.5 Data Collection

Research was predominantly based on secondary data. For the purpose of analysis data related to agriculture were looked. The agricultural availability of different agricultural products in different Municipalities/rural municipalities (local level units) was obtained from the "District Transport Master Plan (DTMP) 2014: Dhanusha"[9] and annual agricultural reports. The actual production of each product was obtained from "Statistical Information of Nepalese Agriculture 2020/21 (2077/078)" [10]. Agricultural products were categorized into 4 different categories they were major crops of the district, cash crops, horticulture and live stocks. The major crops were categorized into 5 categories, pulses into 5, cash crops into 8, horticulture into 7 and livestock products into 4 respectively. Households and other demographic data were obtained from "Preliminary Report of Population Census report 2021" [8]. Cultivable areas for each local level unit were obtained from the topographic map of Dhanusha. For the economic value of each product national annual average price of agricultural commodities were taken from "Economic Survey Report 2020/21" [11]. Data related to existing transport networks and Market centres were also obtained from "District Transport Master Plan (DTMP) 2014: Dhanusha" [9]. Additional road linkages were added from Google Earth Pro.

4. Results and Discussion

4.1 Identification of Backbone and Branch Network

Total population in the local levels is 8, 72, 713 inhabitants. The 18 local levels cover an area of 1206.55 square kilometer in most agricultural communities in rural locations lack access to services and market centers within a reasonable distance. It is therefore vital to identify one or more nodes that can cover the majority of the facilities within the required ranges. Consequently, it is vital to organize places with potential for agriculture. However, the journey distance will be significantly reduced if we connect market centres to the national highway, and the national highway is well known. In the case of Nepal, local level boundaries may be used to define political boundaries. The lowest political tiers in Nepal are the local levels. One point on national highway in each district if connected by national highway is then taken as main node. In this way 15 were points selected as main nodes as shown in Figure 2. The market centers identified from DTMP as shown in Figure 3 can then be located and after eliminating points that fall on back bone network as it is assumed to be already served, 26 branch nodal points were selected as shown in Figure 5. Most of the nodal points in the area have been discovered to be connected via local road links.

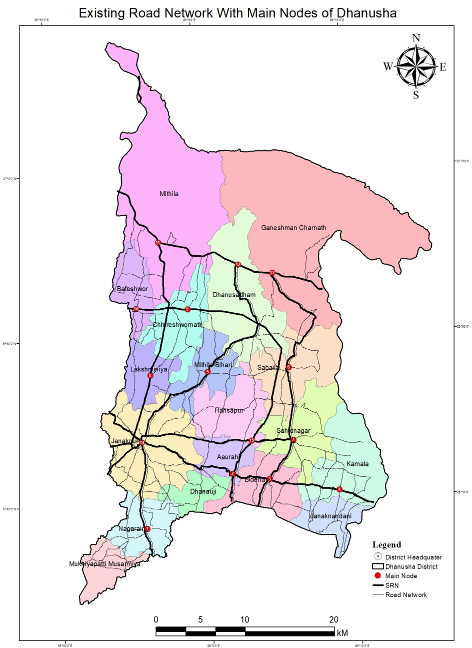

Figure 3: Map showing Main nodes

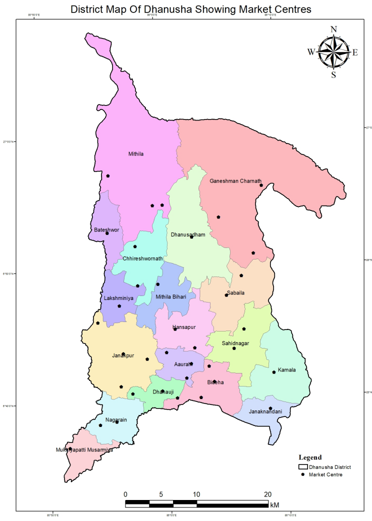

Figure 4: Map showing Market Centres

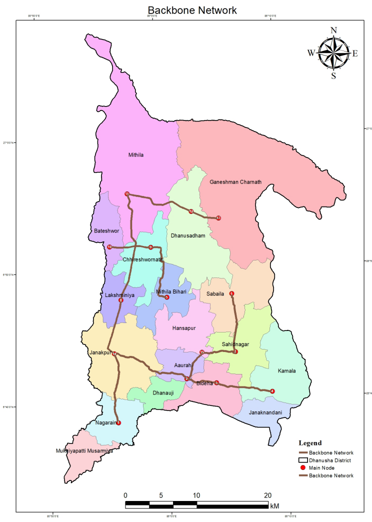

Figure 5: Map showing Backbone Network

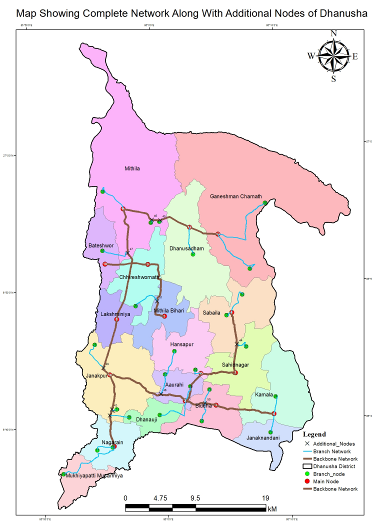

Figure 6: Map showing Backbone and Branch Network

4.2 Road Upgradation Plan for Dhanusha

A branch node and a main node represent a centre and a point on highway of analysis unit. Main variable is agriculture which was categorized into different categories and sub-categories as stated in data collection. Firstly, availability of different agricultural products in different local levels was identified. Cultivable area of each local level unit was extracted from topographical map of Dhanusha using Arc. GIS 10.8[6]. The total production of those agricultural products of the district was then proportionally divided based on cultivable land and Household of each analysis unit. After the calculation of agricultural products in each analysis units (P_k), production was multiplied by the average annual market price and productivity in terms of economic units was obtained as shown in Table 1. The economic productivity of each product was summed to get the productivity of each analysis unit. Local Level units were ranked based on the total economic worth obtained from agriculture. Prioritization ranking was prepared based on shortest path analysis of existing transport network such that links to market centres of each local level unit to the backbone network first which carries maximum production is upgraded first.

Then road upgradation model formulated in previous section was solved in CPLEX Optimizer V22.1 [7] to maximize the production served by overall geographical network.Cost of Improvement of Surface from Earthen to Gravel, Gravel to Bituminous and Earthen to Bituminous is taken as 5M/Km, 10M/Km and 15M/Km. Annual Budget for road improvement varies from 500 million to 700 million. As all the links in backbone network must be Blacktop, Cost of improving all backbone links to blacktop is calculated as shown in Table 2. Then, Budget (B) is obtained by subtracting cost of improving all backbone links to blacktop.

Table 1: Per Km Agricultural Production Served by Local Levels in Millions(Nrs.)

SN	Local Level Units	Production in Millions (P_k)	Road Length (Km)	Production Served per km Road Length
1	Kamala Urban Municipality	1288.79	68.16	18.91
2	Lakshminiya Rural Municipality	720.38	40.42	17.82
3	Mukhiyapatti Musarmiya Rural Municipality	568.47	35.80	15.88
4	Nagarain Urban Municipality	2771.43	77.42	35.8
5	Sabaila Urban Municipality	4982.12	93.35	53.37
6	Sahidnagar Urban Municipality	1301.63	72.71	17.9
7	Aaurahi Rural Municipality	575.6	47.72	12.06
8	Bateshwar Rural Municipality	16717.57	47.71	350.4
9	Bideha Urban Municipality	1193.38	46.80	25.5
10	Chhireshwarnath Urban Municipality	4867.73	86.10	56.54
11	Mithila Bihari Urban Municipality	1425.38	64.36	22.15
12	Dhanusadham Urban Municipality	6787.45	65.22	104.07
13	Ganeshman Charnath Urban Municipality	3839.38	38.56	99.57
14	Hansapur Rural Municipality	1041.29	64.89	16.05
15	Janaknandani Urban Municipality	534.12	45.05	11.86
16	Janakpur Sub-Metropolitan City	1456.21	119.66	12.17
17	Mithila Urban Municipality	2402.57	69.94	34.35
18	Dhanauji Rural Municipality	453.06	32.51	13.94

Table 2: Road Upgradation List in Backbone Network

SN	Link	Upgradation	Weightage (Nrs.) in Millions	Icost (Nrs.) in Millions
1	15-7	G-BT	90.72	52.5
2	44-7	G-BT	104.06	40.1
3	44-6	G-BT	213.48	40
	Total		408.26	132.6

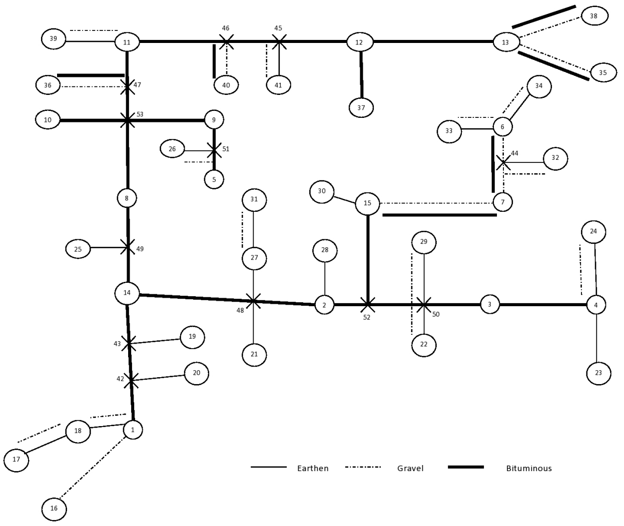

Figure 7: Road Upgradation Plan with Annual Budget of 500 Million

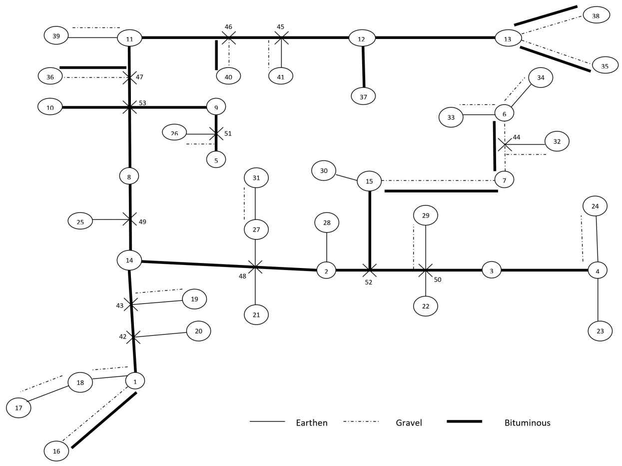

Figure 8: Road Upgradation Plan with Annual Budget of 600 Million

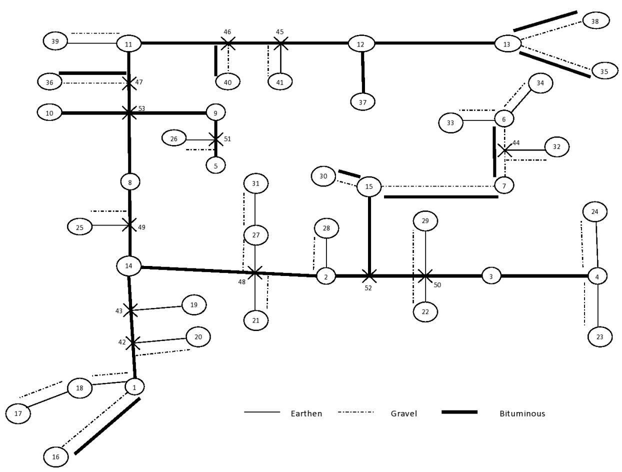

Figure 9: Road Upgradation Plan with Annual Budget of 700 Million

5. Conclusion

A model is proposed for general rural road networks. Adding some constraints, the model can also be used for backbone and branch rural networks in different regions of Nepal. The proposed model maximizes production served covered by overall geographical network formed. The numerical results shows: A total of 19 links that can connect to the major market centers to the existing strategic road network. The road upgradation plan upgradation of 7 links from gravel to bituminous, 12 links from earthen to gravel can maximize the production served in the district within the budget limit of 500 Million. A total of 21 links that can connect to the major market centers to the existing strategic road network. The road upgradation plan upgradation of 8 links from gravel to bituminous, 13 links from earthen to gravel can maximize the production served in the district within the budget limit of 600 million. A total of 27 links that can connect to the major market centers to the existing strategic road network. The road upgradation plan upgradation of 9 links from gravel to bituminous, 18 links from earthen to gravel can maximize the production served in the district within the budget limit of 700 million. The methodology developed was tested in real road networks of Dhanusha district of Nepal considering production area and market centres. The model found is simple, practical, and realistic in the context of rural areas of developing countries like Nepal.

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