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Network Structure and Economy: Modeling the Effect of Road Network Connectivity on Gross Domestic Products

Bishnu Prasad Devkota[1]*

[1] *Nepal Engineering College, Centre for Post Graduate Studies, Pokhara University, Nepal*
***Corresponding author**: enggbishnu@gmail.com

Abstract

The effect on Gross Domestic Product (GDP) due to road network development in the territory is evaluated and a model for the relationship between GDP and the road network development is being calibrated. Area of the land and the population plays an instrumental role for the development of road network. Two set of indicators, including link connectivity indices, road length, population, land coverage and physiographical regions as independent and GDP or economy as dependent are linked by statistical approach. The model thus formed is validated by using coefficient of determination or R^2 value and the result was again validated for two districts. The population of the districts was found multiplicative effect to the GDP while the road network connectivity has exponential effects. Thus the results of this study have important implications for future road project investments. The results of this research are also supported by the decision taken by Nepal government to develop ten new cities along the hilly regions of the country.

Keywords

Road Network – Planar Graph Theory – Economy – Regression Analysis – Policy Implications

1. Introduction

1.1 Background

The connectivity of the road network has different economic and societal consequences. For the development of economy, transportation system, especially the road system, plays an important role to the countries like Nepal. Road system undertakes the transport tasks of human beings and goods. The most of the social and economic activities including working, recreation, freight, should use road networks and the success of these activities highly depends on the performance of road systems. So the existence of a connected road network is essential for economic success of the country. However, rural road network in most of the developing countries like Nepal are still in poor condition and under developed. In rural area people spend much time and efforts on transport activities to fulfill their basic needs, for example, rural communities in Nigeria still do not have reliable access to main road networks and or easily connected to motorized routes within their locality [1]. The rural transport network system is, therefore, an essential requirement for rural economic development.

If are affordable and appropriated for accessibility and connectivity from farms-to-farms, farmstead-to-villages as well as farmstead-to-local markets, provisions of all weather motorized roads is the essential conditions for rural development [2]. Rural road accessibility and connectivity as a set of policies seeks to promote the well being of the rural and non-rural inhabitants by the means of supplying agricultural products both to the local markets as well as secondary industries in the sub-urban and in the urban centers [3]. It is also pointed out that, improved accessibility as well as highly connected road will create market for agricultural products, opens up new land for economic opportunities and at the same time encourages farmers to improved on their various farming in other to increase agricultural productivity and as well reduces spoilage and wastage of agricultural produce at various collection centers in Kolanut production in Nigeria [4]. It is obvious that the development of road infrastructure generate more income thereby enhancing the gross product of selected territory. However, the main concern of the researcher is to assess how these road networks and their connectivity affects the economy of the territory.

The most significant finding from [5] is that rural roads have benefit-cost ratios for national GDP that are about four times greater than benefit-cost ratios for high quality roads. Nepal's road network annually increased by 6.7% between fiscal year 1995/96 and fiscal year 2003/04, with the largest expansion occurring in roads classified as "district or rural roads", which grew annually by 11% during this period [6]. Road density expressed in length per unit area of land (km/km^2) or length in thousand of population (km/1,000 population) or length per unit economic activity (km/1 million of GDP) has been used commonly as a proxy for rural accessibility and the percentage of paved road as a measure of the quality of rural access. Bangladesh is well endowed with rural roads (a road density of $1.84 km/km^2$ compared to an average of $0.84 km/km^2$ for South Asia). In Sri Lanka, 81% of the road network is paved. It is also possible to have accessibility without "good" mobility (as characterized by motorable all-weather roads), as in Nepal's mountain districts where a system of engineered trails and suspension foot bridges, pioneered with Swiss assistance, has radically cut down on travel time and improved access to markets and services [7]. Accessibility is not dependent on mobility, and neither is good mobility a sufficient or necessary condition for good accessibility [6].

1.2 Objectives

objective of this study is to model the effect of the road network connectivity with the economy of the territory. The specific objectives are:

- To assess the indicators of road network connectivity in terms of measures and indices based on planner graph theory.
- To assess the effect of instrumental parameters: population and area of land and the factored variables on the economy
- To develop regression models between district economy and road network connectivity and finally recommend a best fit model

2. Literature Review

2.1 Road Network and Economy

As the road links districts, regions and people together, it shall be taken as a means of social and economic development [8]. The development of efficient road network is the way for enhancing mobility and accessibility which reduces the ravel time and cost. Thus transport network is important for social development [9] along with economic development [10]. The social and economic development associated with road network provides better access to education, health, delivery, employment opportunities and thus increasing the household income there by reducing poverty [5]. Moreover, road development shall also enhance an area's economic development by providing basic infrastructure for investment and harnessing of local and regional economic development potential [11] and also increases tourism flow [12]. The findings by [13] reveal that the total road network has significant growth spurring impact. When the network is disaggregated, asphalt road also has a positive sectoral impact, but gravel roads fail to significantly affect both overall and sectoral GDP growth, including agricultural GDP.

Despite of these in social and economic benefits, the road networks are also perceived as negative ecological effects on culture. Transportation infrastructure affects the structure of ecosystems, the dynamics of ecosystem function, and has direct effects on ecosystem components, including their species composition. Clearly, the construction of transport lines results in the direct destruction and removal of existing ecosystems, and the reconfiguration of local landforms. However, transportation systems, and more specifically, roads, have a wide variety of primary, or direct, ecological effects as well as secondary, or indirect, ecological effects on the landscapes that they penetrate. The effects of roads can be measured in both abiotic and biotic components of terrestrial and aquatic ecosystems [14].

Besides these threats, transportation network provides access to farmlands, school, work zone and settlement zones there by reducing travel time and cost. Thus, farmers tend to increase agricultural productivity by expanding crop production along developed roads which ultimately results in changed land use and thus growing the region's economy [11]. Alvarez and Blazquez, 2014 [15] were recommend that the both public and private sectors actively encourage investment in transport infrastructures in order to improve productivity growth and economic activity. The rapid development of road in Nepal is found growing since 1950. Tribhuwan Rajpath was opened to traffic since 1956 AD as a fist highway in Nepal. In 2014 cabinet has amended 12424 km as strategic road network [16]. However the history of rural roads is short and is started after 1993. Based on rural road statistics by DoLIDAR in 2013 AD, about 51,000 km of local roads is being constructed in Nepal [17]. However most of them are fair weather tracks, these roads plays important role for the development of the rural part of the country.

2.2 Network Robustness

Road network robustness is the insusceptibility of a road network to disturbing incidents, and could be understood as the opposite of network vulnerability. In other words, road network robustness is the ability of a road network to continue to operate correctly across a wide range of operational conditions [18] and [19].

2.3 Network Reliability

Several understandings about road network reliability exist from different interests in the research objectives. The most accepted definition of the network reliability is given by Billington and Allan 1992 as cited by li 2008 [20] as: *"Reliability is the probability of a road network performing its proposed service level adequately for the period of time intended under the operating conditions encountered."* The prioritization of investments in road networks based on vulnerability indicators is still a relatively underexplored approach [21].

3. Methodology

3.1 Study Area

The population for the study covers all 75 districts of Nepal. The the study rely on road network data presented on District Transport Master Plan (DTMP) as developed by Ministry of Local Development and Federal Affairs (MoLDFA). So the random systematic random sampling technique is applied to for the selection of districts, DTMP of which are available by May, 2015 including all physiographical and development regions of the country. The location of physiographical regions as given in [22] for total 25 districts that were considered for the development of the models are:

Mountainous Region: Sangkhuwasabha, Sindhupalchowk, Manang, Humla, Jumla
Hilly Region: Dadelkhura, Doti, Achham, Dailekh, Rukum Palpa, Parbat, Kaski, Bhaktapur, Ramechhhap, Kathmandu, Okhaldhunga, Khotang, Bhojpur, Panchthar
Terai Region: Sunsari, Saptari, Sindhuli, Chitwan, Makawanpur, Kapilvastu, Kailali

The validation of the model thus developed is done based on statistical approach. Again the results of the model is tested for Sindhuli and Bhojpur districts.

3.2 Research Design

The Flow Chart of Modeling Road Network and Economy has shown in Figure 1.

3.3 Graph theory-based measures and indices

The connection and arrangement of a road network is usually abstracted in network analysis as a directed planar graph G=(v,e), where 'v' is a collection of nodes or vertices that are connected by directional links 'e' (edges) [23]. The study by Patarasuk 2013 [11] uses graph theory-based concepts in Lop Buri province, Thailand by employing alpha (a), beta (b), and gamma (c) indices to determine road connectivity. These indices are commonly used as measures of the levels of circuitry, complexity, or connectivity, respectively, in a network. In general, the higher the values of these indices, the higher degree of circuitry, complexity, and connectivity. Connectivity index algorithms used in the study are based on planar graphs, or graphs that can be made to lie in a plane such that no edges intersect at a point other than a node or vertex [24]. Network indices: a, b, and c have the following equations:

$$alphaindex, a = \frac{C}{C_{max}} = \frac{e-v+1}{2v-5} \tag{1}$$

$$betaindex, b = \frac{e}{v} \tag{2}$$

$$gammaindex, c = \frac{e}{e_{max}} = \frac{e}{3v-6} \tag{3}$$

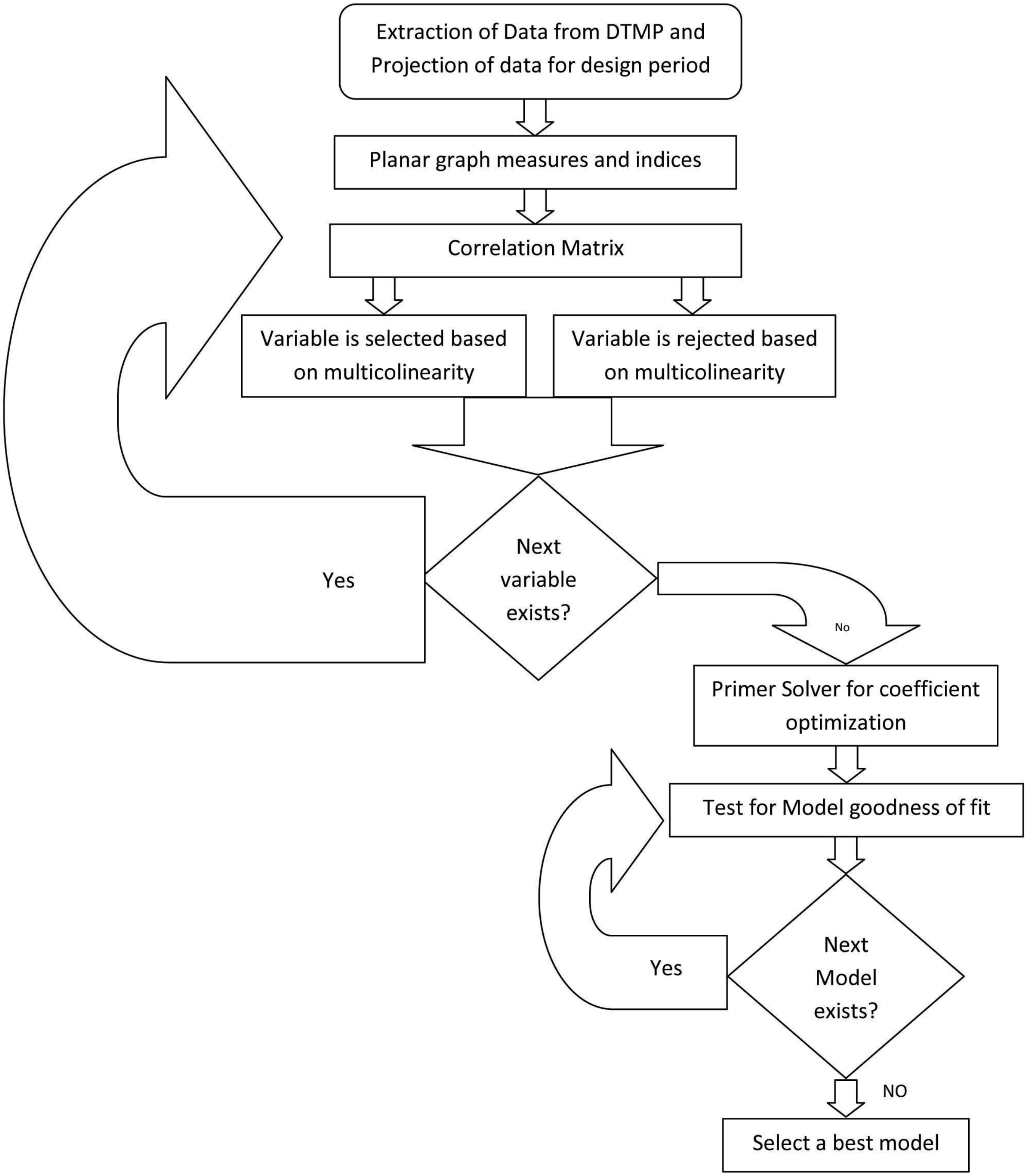

Figure 1: Flowchart of Modeling Road Network and Economy

Where e is the number of links and v is the number of nodes of the road network system.

In this study, an edge or link refers to a road segment and a node or vertex refers a point of an intersection where at least two road segments meet. Each of these indices was calculated for each district to measure the dynamics of road connectivity in districts.

Minimum Spanning Tree

In the graph theory, the minimum spanning tree is the network or connectivity in which there is one and only one, sequence of edges between any two pairs of nodes. In MST network removal of any edge from the graph will divide the network into two disconnected parts and the number of edges will always be one less than number of vertices/nodes. If number of nodes are 'v' then corresponding edges in MST network would be

$$e_{min} = (v–1) \tag{4}$$

From the distance sheet extracted from the network diagram, minimum spanning tree is obtained. Prim's algorithm is a greedy algorithm that finds a minimum spanning tree for a weighted undirected graph. This means it finds a subset of the edges that forms a tree that includes every vertex, where the total weight of all the edges in the tree is minimized. The algorithm operates by building this tree one vertex at a time, from an arbitrary starting vertex, at each step adding the cheapest possible connection from the tree to another vertex. The connectivity coefficients for MST would were determined using the equation 1, 2, 3 and 4.

3.4 Gross Domestic Products

Gross domestic product (GDP) at market prices is the expenditure on final goods and services minus imports: final consumption expenditures, gross capital formation, and exports less imports. GDP is one of the primary indicators used to gauge the health of a country's economy. It represents the total monetary value of all goods and services produced over a specific time period - as the size of the economy. This indicator is measured in currency amount (Local Currency or USD) per capita (GDP per capita) [25]. Gross domestic product can be calculated using the following formula [26]

$$GDP = C + G + I + NX \tag{5}$$

Where, "C" is equal to all private consumption, or consumer spending, in a nation's economy, "G" is the sum of government spending, "I" is the sum of all the country's businesses spending on capital and "NX" is the nation's total net exports, calculated as total exports minus total imports (NX = Exports - Imports).

3.5 Statistical Analysis

Regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on the relationship between a dependent variable and one or more independent variables (or 'predictors'). Simple regression, Multiple regression, Factorial regression, Polynomial regression, Response surface regression, Mixture surface regression, One-way ANOVA, Main effect ANOVA, Factorial ANOVA, Analysis of covariance (ANCOVA), Homogeneity of slopes are the frequently used tools of regression analysis. The concept of these analysis shall be formulated as:

$$Y = f(X_1, X_2, X_3, X_4, \ldots\ldots X_n) \tag{6}$$

Where, Y=Dependent Variable, based on economy and X_1, X_2, X_3........... are independent variables based on network connectivity and salient features of the district or region The analysis shall be performed by using SPSS version 16 and Microsoft Office Excel-2007.

Building the Whole Model: Partitioning Sums of Squares

A fundamental principle of least squares methods is that the variation on a dependent variable can be partitioned, or divided into parts, according to the sources of the variation. Suppose that a dependent variable is regressed on one or more predictor variables, and that for convenience the dependent variable is scaled so that its mean is 'zero'. Then a basic least squares identity is that the total sum of squared values on the dependent variable equals the sum of squared predicted values plus the sum of squared residual values. Stated more generally,

$$\sum(y-\bar{y})^2 = \sum(\hat{y}-\bar{y})^2 + \sum(y-\hat{y})^2 \tag{7}$$

where the term on the left is the total sum of squared deviations of the observed values on the dependent variable from the dependent variable mean, and the respective terms on the right are (1) the sum of squared deviations of the predicted values for the dependent variable from the dependent variable mean and (2) the sum of the squared deviations of the observed values on the dependent variable from the predicted values, that is, the sum of the squared residuals. Stated yet another way,

$$TotalSS = ModelSS + ErrorSS \tag{8}$$

Note that the Total SS is always the same for any particular data set, but that the Model SS and the Error SS depend on the regression equation. Again the coefficient of determination value shall be computed as:

$$R^2 = \frac{ModelSS}{ErrorSS} \tag{9}$$

Building the Whole Model: Testing the Whole Model

Given the Model SS and the Error SS, one can perform a test that all the regression coefficients for the X variables are zero. This test is equivalent to a comparison of the fit of the regression surface defined by the predicted values (computed from the whole model regression equation) to the fit of the regression surface defined solely by the dependent variable mean (computed from the reduced regression equation containing only the intercept). The whole model hypothesis mean square

$$MSH = (ModelSS)/k \tag{10}$$

where k is the number of columns of X (excluding the intercept column), is an estimate of the variance of the predicted values. The error mean square

$$s^2 = MSE = (ErrorSS)/(n-k-1) \tag{11}$$

where n is the number of observations, is an unbiased estimate of the residual or error variance. The test statistic is

$$F = MSH/MSE \tag{12}$$

where F has (k, n - k - 1) degrees of freedom. The stepwise regression is used by [27] to calibrate the regression model. The basic procedures of stepwise regression involve

1 Identifying an initial model,

2 Iteratively ”stepping,” that is, repeatedly altering the model at the previous step by adding or removing a predictor variable in accordance with the ”stepping criteria,” and

3 Terminating the search when stepping is no longer possible given the stepping criteria, or when a specified maximum number of steps has been reached.

Building Models via Best-Subset Regression All-possible-subset regression can be used as an alternative to or in conjunction with stepwise methods for finding the ”best” possible submodel. Neter, Wasserman, and Kutner (1985) [28] discuss the use of all-possible-subset regression in conjunction with stepwise regression ”A limitation of the stepwise regression search approach is that it presumes there is a single ”best” subset of X variables and seeks to identify it. As noted earlier, there is often no unique ”best” subset. Hence, some statisticians suggest that all possible regression models with a similar number of X variables as in the stepwise regression solution be fitted subsequently to study whether some other subsets of X variables might be better.” This reasoning suggests that after finding a stepwise solution, the ”best” of all the possible subsets of the same number of effects should be examined to determine if the stepwise solution is among the ”best.” If not, the stepwise solution is suspect.

All-possible-subset regression can also be used as an alternative to stepwise regression. Using this approach, one first decides on the range of subset sizes that could be considered to be useful. Several different criteria can be used for ordering subsets in terms of ”goodness.” The most often used criteria are the subset multiple R-square, adjusted R-square, and Mallow’s Cp statistics. When all-possible-subset regression is used in conjunction with stepwise methods, the subset multiple R-square statistics allows direct comparisons of the ”best” subsets identified using each approach[28].

4. Data collection

Following continues and categorical data were collected

- Road Network data
  - Road length (SRN, DCRN, VCRN)
  - Number of Nodes and Linkages
- Demographic Data
  - Population

- Geographic data
  - Terrain Type
  - Area of Land
- Economic data
  - GDP

Total 30 DTMPs are collected from DoLIDAR [29] in 2015. All the existing road network data were extracted including number of linkages and road classification (SRN, DCRN, VR, UR). Demographic and physiographic data were taken from Central Bureau of Statistics (CBS) reports-2011. The population data thus collected was made projection to the period at which the existing DTMP report was prepared. Again the GDP data were collected from United Nation Development Program (UNDP) [30] and was projected to the year just next of the year mentioned on DTMP reports using national growth rate. Thus the aggregate of the variable on which the research is based on shall be presented as:

- Dependent Variable
  - GDP of the districts
- Independent Variables
  - Alpha, beta and gamma indices of existing, delta and MST network including 9-variables
  - Population
  - Land area
  - Road Length (SRN, DCRN, VR, UR)
  - Total road length
  - Total road length
  - Physiographical region: mountainous, hills and terai
- Factored Variables
  - Alpha, beta and gamma
  - indices for (delta-existing), (existing- MST), (delta-existing-MST) network including 9-variables
  - Product of Alpha*beta*gamma indices
  - Road density per square kilometer area
  - Road density per 1000 population

5. Results and Discussions

5.1 Variable Selection Process

Based on correlation matrix, it has observed that most of the network indicators are correlated: links, nodes, alpha, beta, gamma indices for delta, existing and MST network and their factored variables. So, it is good decision to consider only one network indicator in order to prevent multicolinearity effect. The variable selected for this study is the 'beta' index, which has found with higher relation to GDP of the district and also used by [31] in his model. Road density per square kilometer area was found highly related with GDP than per 1000 population. However, the population itself is found strongly related with the economy of the district, so it is considered for model calibration. Among different classified roads, SRN was found high relation with GDP whether the VR and UR are strongly related with the local people benefits. This is also supported by the findings of [5] in china that the high priority roads are important for overall economic development and local roads are for poverty reduction. Thus the selected variables considering higher effect with economy and preventing multicolinearity based on correlation matrix tables presented in Table 1 and Table 2, are:

- Population (pop)
- Existing Beta index (Eb)
- Road density per square kilometer area (PerA)
- Length of SRN (SRN)

5.2 Model Calibration

The regression analysis is performed for various form of the model and the goodness of fit is tested in order to determine the best fit model. The result statistics of the various models are presented in Table 3, where

- X_1=Population (Pop)
- X_2= Length of SRN (SRN)
- X_3= Road density per square kilometer area (Per A)

Table 1: Correlation Matrix-I for All Variables

	Links	Nodes	Da	D b	D c	E a	E b	E c	M b	M c	D-E a	D-E b	D-E c	E-M a	E-M b	E-M c	D-E-M a	D-E-M b	D-E-M c	A*B*G	GDP
Links	1																				
Nodes	1	1																			
Da	-0	-1	1																		
D b	0.6	0.6	-1	1																	
D c	-1	-1	1	-1	1																
E a	0.8	0.7	-0	0.5	-0	1															
E b	0.8	0.7	-1	0.6	-1	1	1														
E c	0.7	0.6	-0	0.2	-0	1	0.9	1													
M b	0.6	0.6	-1	1	-1	0.5	0.6	0.2	1												
M c	-1	-1	1	-1	1	-0	-1	-0	-1	1											
D-E a	-1	-1	0.6	-1	0.6	-1	-1	-1	-1	0.6	1										
D-E	-1	-1	0	-0	0.1	-1	-1	-1	-0	0.1	0.8	1									
D-E c	-1	-1	0.5	-1	0.5	-1	-1	-1	-1	0.5	1	0.9	1								
E-M a	0.8	0.7	-0	0.5	-0	1	1	1	0.5	-0	-1	-1	-1	1							
E-M b	0.8	0.7	-0	0.5	-0	1	1	1	0.5	-0	-1	-1	-1	1	1						
E-M c	0.8	0.7	-0	0.5	-0	1	1	1	0.5	-0	-1	-1	-1	1	1	1					
D-E-M a	-1	-1	0.6	-1	0.6	-1	-1	-1	-1	0.6	1	0.8	1	-1	-1	-1	1				
D-E-M b	-1	-1	0.3	-0	0.3	-1	-1	-1	-0	0.3	0.9	1	1	-1	-1	-1	0.9	1			
D-E-M c	-1	-1	0.2	-0	0.2	-1	-1	-1	-0	0.2	0.9	1	1	-1	-1	-1	0.9	1	1		
A*B*G	0.7	0.7	-0	0.4	-0	1	1	1	0.4	-0	-1	-1	-1	1	1	1	-1	-1	-1	1	
GDP	0.4	0.4	-0	0.2	-0	0.4	0.4	0.4	0.2	-0	-0	-0	-0	0.4	0.4	0.4	-0	-0	-0	0.4	1

Table 2: Correlation Matrix-II for All Variables

	GDP	Trans	Pop	Area	SRN	DCRN	VR+UR	Total	per A	per P	Links	Nodes	E a	E b	E c
GDP	1.00														
Trans	0.99	1.00													
Pop	0.94	0.89	1.00												
Area	-0.30	-0.27	-0.30	1.00											
SRN	0.44	0.43	0.51	0.09	1.00										
DCRN	0.00	-0.03	0.09	-0.03	0.13	1.00									
VR+UR	0.24	0.22	0.39	0.07	0.31	0.43	1.00								
Total	0.22	0.19	0.37	0.05	0.37	0.71	0.94	1.00							
per A	0.65	0.63	0.63	-0.57	0.25	0.17	0.37	0.36	1.00						
per P	-0.27	-0.23	-0.35	0.14	-0.17	0.51	0.26	0.37	-0.06	1.00					
Links	0.44	0.41	0.54	-0.44	0.27	0.35	0.29	0.37	0.48	-0.09	1.00				
Nodes	0.41	0.38	0.51	-0.44	0.26	0.44	0.30	0.41	0.46	-0.06	0.99	1.00			
E a	0.40	0.35	0.50	-0.49	0.37	0.17	0.19	0.24	0.49	-0.14	0.77	0.69	1.00		
E b	0.40	0.35	0.51	-0.57	0.38	0.23	0.22	0.28	0.51	-0.16	0.80	0.74	0.99	1.00	
E c	0.38	0.33	0.45	-0.31	0.33	0.06	0.12	0.14	0.42	-0.12	0.69	0.59	0.96	0.90	1.00

- X_4= Beta Index of existing network (Eb)
  A, B, C, D, E = are regression coefficients or constants

Based on analysis, it is found that the population is the major parameter for the contribution of economy of the district. So in order to increase GDP throughout the country, the uniform distribution of the population shall be the important constraint. However due to varying geographical conditions in Nepal, population density varies

Table 3: Formulation , Calibration and Comparisiton of Regression Models

Model Description	Model Form	(A)	(B)	(C)	(D)	(E)	Adjusted R-square Value	Remarks
Linear Model	$Y=A+BX_1$	-15643.111	0.100				0.8820	Model-1
Multiple Regression Model	$Y=A+BX_1+CX_2$	-12146.073	0.1035	-32.132			0.8789	Model-2
	$Y=A+BX_1+CX_2+DX_3$	-14086	0.0969	-26.737	5290.222		0.8786	Model-3
	$Y=A+BX_1+CX_2+DX_3+EX_4$	16782.266	0.09999	-10.485	7942.181	30646.14	0.8876	Model-4
Exponential or Power Model	$Y=A+B^{CX}{}_4$	-7460.216	14681.428	1.000			0.1428	Model-5
	$Y=A+B*C^{(X_2*X_3)}$	13855.616	0.92896	21.850			0.9128	Model-6
	$Y=A+BX_1+C*D^{(X_2*X_3)}$	-1827.6404	0.506865	0.548	21.850		0.9860	Model-7
	$Y=A+BX_1+CX_2+DE^{(X_2*)X_3)}$	-903.48623	0.051701	-9.026	0.546	21.85063	0.9856	Model-8
Polynomial Model	**Pop**: $Y=A+BX+CX^2+DX^3$	-4167.9665	0.08002	-7.00E-08	4.47E-14		0.9865	Model-9
	SRN: $Y=A+BX+CX^2+DX^3$	31280.072	-571.531	4.121	0.005796		0.1090	Model-10
	PerA: $Y=A+BX+CX^2+DX^3$	-12675.204	158767.76	-181450.2	52593.86		0.5432	Model-11
	Eb: $Y=A+BX+CX^2+DX^3$	-70333.695	187944.72	-14924.42	34967.60		0.0622	Model-12
Composite	$Y=A+BX_1+CX_1{}^2+D*E^{(X_2*X_3)}$	-3516.646	0.067253	-2.156E-8	3.668E-5	21.85063	0.9881	Model-13

from least 3.75 (Dolpa) to 2738.85 (Kathmandu) persons per square kilometer based on CPS-2011 [32]. So development of new settlement at mountainous region will be helpful to increase GDP. This result is supported by the concept of 10 new town development along the Mid-hill highway in hilly regions by Nepal Government. Again, road density per square kilometer area is found as another important parameter, so it is crucial to consider in order to enhance the GDP of the region. According to Fan and Chan-Kang 2005 [5], road investments yield highest economic returns in eastern and central region of China and the contribution to poverty reduction are greatest in western and southern China. This implies that there is need to formulate different regional priorities depending on whether economic growth or poverty reduction is the most important goal for the region or country. High quality fast tracks are important for economic growth of the country and rural roads are important for poverty reduction. The next indicator 'beta index' implies the circuitry of the network. Which is important for road network robustness and to enhance mobility and thus to enhance the road network reliability.

The combination of above four indicators will be high populated region with sufficient road density and network connectivity. This is the recommendation of this research in order to enhance GDP of the region.

5.3 Selection of Model

The process is repeated and finally following model is found best fit.

$$
\begin{aligned}
GDP = & -3516.644 + 0.0672 * (Population) \\
& - 2.15x10^{-8} * (Population)^2 + 3x10^{-5} \\
& * 21.8506^{(betaIndex)*(RoadDensityperkm)}
\end{aligned} \quad (13)
$$

5.3.1 Field Validation of Model

Table 4: Evaluation of Model on two districts

District Name	Actual GDP	Predicted GDP	% Error
Bhojpur	8084	8026.8408	-1
Sindhuli	10822	14496.006	34

6. Conclusions and Recommendations

This study has examined the relationships between road network development and economic products through network connectivity and GDP. Objective graph theory based indices are employed to describe the level of connectivity which was extracted from DTMPs as prepared by MoLDFA and statistical tests were performed to examine the relationship. The correlation matrix was used to screen the indicators as well as to prevent the effect of multicolinearity between independent variables. The results show that even though the total length of roads in the study area increases, the economy not always so. Which shall be due to the fact that the connectivity shall not increases as length increases as the network indices are related with circuitry and complexity of the road network structures rather than the length and type of road. The most evident relationships are found between populations with GDP and finally the study has shown that the road network indices in combination with the road density per unit area of land greatly affect the economy of the districts. The population of the districts was found multiplicative effect to the GDP while the road network indices have exponential effects. Thus the study have important implications for future road project investments and the results are also supported by the decision taken by Nepal government to develop ten new cities along the hilly regions of the country.

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