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A REGRESSION BASED APPROACH FOR RAPID ESTIMATION OF EFFICIENCY OF ROAD NETWORKS USING CONNECTIVITY MEASURES: CASE STUDIES IN INDIAN SCENARIO

Gopal Chandra Banik*

Subrata Kr. Paul**

Abstract

An attempt has been made to estimate the efficiency of road networks using three well known connectivity measures, namely Alpha (α), Beta (β) and Gamma (γ) indices, taking case studies from Indian scenario. The outcome of the study suggests that efficiency of a given road network can be approximately estimated based on the values of the three indices with a statistically acceptable level of confidence, avoiding rigorous and resource-intensive computation-works. The proposed approach finds its application in planning of new road networks, particularly where, there would be necessity for selecting an optimum solution through rapid evaluation of the efficiency of a number networks representing alternatives.

Keywords:
Connectivity;
Efficiency of road network;
Graph theory;
Network topology;
Connectivity Efficienct Index.

***Research Fellow, School of Ecology, Infrastructure and Human Settlement Management (SEIHSM), Indian Institute of Engineering Science and Technology(IIEST), Shibpur, Howrah, India.**

****Assistant Professor, Department of Architecture, Town and Regional Planning Department, IIEST, Shibpur, Howrah.**

1. Introduction

Studies for planning and improvement of road networks have drawn significant attention in geographical-research since the last decade of the 20th Century, due to rapid urbanization and subsequent increased demand for mobility of people and linkage of goods and services (Morgado and Costa, 2011; Barabasi, 2003; Watts, 2003). Efficiency of road network is one of the major concerns in these studies.

Several factors affect efficiency of road networks. Rodrigue et al., 2014; Waugh 2000 identified the level of connectivity is an important measure to quantify efficiency of road network. Alpha (α), Beta (β) and Gamma (γ) Indices, put forward by Garrison (1960), are the most frequently referred amongst several graph-theory based network connectivity measures in existing literature of Sarkar et al., (2015); Morgado and Costa, (2011); Wang et al., (2009); Morlok, (1967); Kofi, (2010); Miller and Shaw, (2001). These indices provide tools for analysis of topological structures, in general (Wang et al., 2009; Kofi, 2010), and in particular, the degree of connectivity of networks (Taaffe and Gauthier, 1973; Haggett and Chorley, 1969, Derrible and Kennedy, 2010), represented by graphs, comprising of nodes or vertices and links or edges (Levinson, 2006; Borgatti and Halgin, 2011).

α, β and γ indices, can be expediently estimated for large and complex networks with simple inputs of the number of nodes and links. These have been successfully applied in various fields, such as, connectivity analyses of electronic and telecommunication networks (Wheeler and O'Kelly, 1999), airport networks (Ivy, 1995), where the major concern is to study the degree of connectivity amongst the various nodes. However, application of these indices are limited in case of road networks for two principal reasons: (a) First: the degree of connectivity estimated by the these indices takes into account only the number of nodes and links of networks without considering other important topological aspects, such as adjacency and incidence pattern between nodes and links (Deo, 2011) and the actual travel distances between the trip origins and destinations (i.e. nodes), which should be considered as an important determinant of road connectivity (Wang et al., 2009); (b) It is often a difficult task to interpret and relate the values of these indices with the corresponding efficiency of networks (hereinafter, referred as network-efficiency) in different geometry and scale, though in contemporary researches it has been recognized that the principal objective of road connectivity analyses is to measure network-efficiency (Waugh, 2000).

With the above background, this study aims to examine the following research questions with case studies from Indian scenario: (1) Whether statistically significant correlation exists between the network-efficiency and, the values of the α, β and γ indices in cases of road networks? (2) Whether the values of the indices are consistent with the corresponding network-efficiency across the major typology of road network-geometry? (3) Whether it is possible to established regression model with the indices for quick assessment of efficiency of road networks in real world scenario?

2. Literature Review

This section presents a literature review on road-networks with particular reference to elements, geometric typology, and modelling as graphs; concepts of network-connectivity and connectivity indices; road network efficiency; graph theory based connectivity indices that set the background for the adopted methodology presented in Section 3.

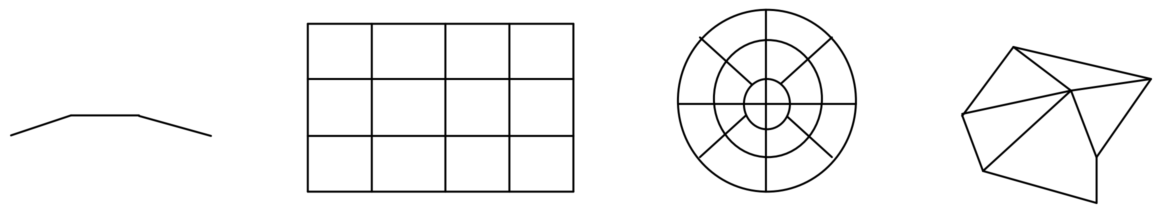
2.1 Road networks: elements, geometric typology and modelling as graph

Road networks belong to the ‘fixed-facility’ sub-system (Papacostas and Prevedousros, 2009) of transportation systems. Depending on the scale of study, it may comprises of road segments in different hierarchical importance[1], connecting the zones of trip origins and destinations.

Road networks can be represented in the forms of weighted graphs (G), as ordered quadruples, denoted by G = {V, E, f, g}(Raza and Aggarwal, 1986; Xie and Levinson, 2007; Miller and Shaw, 2001; Rodrigue et al., 2014), where V is the set of vertices, E is the set of edges, f is an assignment of weights to the vertices and g is an assignment of weights to the edges. The vertices denote nodes of trip origins and destinations and the edges represent road-links connecting the nodes. Trip productions-attractions at the nodes, are the weights for the vertices and the impedances of the road links are the weights for the edges.

[1]Indian System of Road Classification (IRC : 73-1980)
At the regional level roads are classified in five hierarchies as follow: National Highway(NH), State Highway(SH), Major District Roads(MDR), Other District Roads and Village roads
Urban roads are classified as follow: Arterial roads, sub-arterial roads, feeder roads, collector/local street

The topology, i.e. the relationship between nodes and links characterizes the network geometry and the level of connectivity (Rodrigue et al., 2014). In Indian context, four categories of road network geometry are observed: Linear, Gridiron, Radial and Irregular (Figure 1 (A-D) (Sarkar, et al., 2015).



[A] [B] [C] [D]

Figure 1. *Geometric Category of Road Network in India*

2.2 Concept of connectivity and connectivity-efficiency in road networks

Connectivity refers to the quality or condition of being connected or the ability to make and maintain a connection between two or more nodes (Goutam, 1992). Taaffe and Gauthier (1973), defined 'connectivity' as the degree of connection between all vertices. According to David Waugh (2000), "Connectivity is a means of measuring the efficiency of a network (the more vertices that are connected to each other, the more efficient the network) and comparing, quantitatively, different networks." Rodrigue et al., (2014) opined that the layout of nodes and links is often a major determinant for connectivity-efficiency of a road network.

2.3 Graph Theory based Connectivity Indices

Graph Theory is the most frequently applied technique for evaluating the connectivity of transportation networks (Derrible and Kennedy, 2010). The application of graph theory in the field of transportation geography for analyzing connectivity of road networks emerged in the late 1950's and early 60's through the pioneering works of Garrison (1960); Garrison and Marble (1961; 1964; 1965) and Kansky (1963).The works focused on topologic measures of networks through quantitative analyses with the applications integrated with studies related to transportation-economics (Morgado and Costa, 2011; Derrible and Kennedy, 2010). Before Garrison and Kansky, in the early 60's AvondoBodino (1962) formulated an application of graph theory to transportation system, but he did not consider network design. Garrison and Marble

(1961; 1964; 1965) introduced three graph theory measures, namely α, β and γ indices, which are directly linked to network design. Similarly, Kansky (1963) also introduced new indicators related to complexity and network specificities, namely Eta (η), Pi (π), Theta (θ) and Iota (i) indices. Morlok (1970) critically reviewed the indices and the network structures. However, applications of these connectivity indices were limited in real world scenario due to constraints of limited computing technology and data inadequacy during the subsequent two decades (Morgado and Costa, 2011). In the last decade of the 20th Century, due to rapid urbanization and increasing demand of road network facility as well as fantastic development in computing technology made again possible to critically revisit the graph based connectivity indices in recent past (Derrible and Kennedy, 2010; Raza and Aggarwal, 1986; Black, 2003; Taaffe and Gauthier, 2009; Wang et al., 2009; Patarasuk, 2013; Rodrigue et al., 2014).

The graph-theory based measures of network structure (i.e. connectivity) is broadly classified into two groups (Raza and Aggarwal, 1986): First, 'non-ratio measures' i.e. Cyclometric Number and Graph-Diameter and, second 'ratio measures' which includes α, β, γ, η, π, θ and i indices. Amongst these, α, β and γ indices (as detailed in Table 1), which are commonly used as measures of the levels of circuitry, complexity, or connectivity for a network respectively, have been taken up for the present study.

Table 1:α, β and γ indices for Network Connectivity

Indices	**Description**	**Definition**		**Ranges of Theoretical Values and Interpretation**
		Planner Graph	**Non Planner Graph**	
α Index (Kansky, 1963; Wang et al., 2009; Kofi, 2010; Patarasuk, 2013)	It measures the circuitry of a network, or the degree to which a network provides alternative links between origin and destination nodes.It is defined as the ratio of the observed number of fundamental circuits to the maximum number of circuits which may exist in the system.	$\propto = \frac{e - v + p}{2v - 5p}$	$\propto = \frac{e - v + p}{\frac{v^2 - 3.v + 2}{2}}$	$0 \leq \alpha \leq 1$ Zero (0) indicates a minimallyconnected network, 1 represents maximally connected network.

Indices	Description	Definition		Ranges of Theoretical Values and Interpretation
		Planner Graph	Non Planner Graph	
β Index (Kansky, 1963; Morlok, 1967; Wang et al., 2009, Patarasuk, 2013)	It is described as the ratio of links to nodes and it reflects the complexity and completeness of a network.	$\beta = \frac{e}{v}$	$\beta = \frac{e}{v}$	0 ≤β≤ 3 Zero(0) indicates a network having only nodes, but no link. 3 indicates existence of all possible links between the nodes.
γ Index (Kansky, 1963; Taaffe and Gauthier, 1973; Morlok, 1967; Patarasuk, 2013)	It is a measure of connectivity that describes the ratio between numbers of observed links and the number of possible links.	$\gamma = \frac{e}{3[v-2]}$	$\gamma = \frac{2e}{[v^2 - v]}$	0 ≤γ≤ 1 Zero (0) indicates a network having only nodes, but no link. 1 indicates a completely connected network.
Where, e = number of edges, v = number of vertices, p = number ofsub-graphs.				

3. Methodology

The technique of Regression Analysis has been adopted to examine the relation between connectivity-efficiency Index (formulazted) of road networks and, the corresponding values of the α, β and γ indices, taking the former as the dependent variable and the latter as the independent variables.

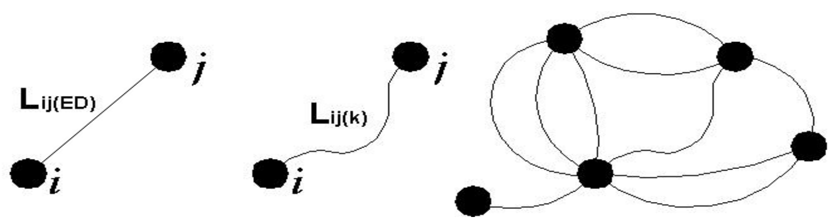
Eleven case study areas have been taken covering major three typologies of road networks in three scales of regional planning hierarchy, such as State level (Macro scale), Metropolitan level (Meso scale) and Town level (Micro scale), prevalent in India.

The statistical significance of the derived relations between the connectivity-efficiency and the α, β and γ indices was checked using 'Students t-test' (Mahmood and Raza, 1977).

3.1 Estimating Efficiency of Road Networks:

For the purpose of present study an index for estimating the efficiency of road networks, hereinafter referred as Connectivity-Efficiency Index (CEI), has been formulated. The theoretical underpinning of the CEI is founded on the theory of consumer behavior in microeconomics related to transportation, which indicates that for a trip of given origin and destination and a given set of alternative paths, a traveler, in most of the instances, prefers to choose the one that has least impedance[2] and thus, minimizes 'disutility', i.e. travel time and /or cost (Meyer and Miller, 2001).

With the aforesaid background, the theoretical construct of CEI, is introduced with a simplest possible hypothetical network, represented by a weighted graphs (denoted by G1) indicated in Figure 2.



[G1] [G2] [G]

Figure 2.*Weighted Graphs Representing Transportation Networks*

Let us consider that the network (denoted by graph G1) is consisting of two given nodes (say i and j) and one link and, the volume of trip interchanges is also given. Now, if the link (connecting the nodes i and j) is so constructed that its impedance (physical distance for this time) is equal to its Euclidian Distance (ED)[3] and the capacity is adequate for maintaining a desired Level of Service (LoS) for the given volume of trips, the network becomes most favorable for the network-users (travelers). Under the given conditions (origins-destinations, trip interchanges and LoS), since the impedance between the two nodes cannot be further reduced, the efficiency (from the traveler's point of view) of this network cannot be enhanced any more by improving the alignment of the link. Thus the efficiency of this network can be deemed as a

[2]The impedance (time and cost) of a land based link (functioning with a desired LoS) bears a direct and linear relation with its physical distance.

[3] Euclidian Distance (ED) refers to the direct (minimum) distance between two points.

maximum. Let us call this network as 'Users' Optimal Network' (UON)[4] and deploy it as a standard for assessing the efficiency of a given network.

Now, if the link, in the above network, is replaced by another link with the capacity and the LoS remaining the same as before, a new network is formed (Figure 2., denoted by graph G2). The G2 has a similar degree of connectivity as G1, but as the impedance between the nodes, increases, the efficiency of connectivity deteriorates. From the criterion of impedance, the relative connectivity-efficiency of G2 can be expressed, with respect to G1 (i.e. the UON of G2), by an index, defined as the ratio of impedance between the nodes in the given network to that of its corresponding UON (3.1). This index, hereinafter, is referred to as Connectivity-Efficiency Index (CEI).

$$CEI_{[G2]} = I_{i\text{-}j[UON,\ G2]} \,/\, I_{i\text{-}j[G2]} \qquad (3.1)$$

Where,

$I_{i\text{-}j[UON,\ G2]}$: Impedance between the nodes in the UON *G2*

$I_{i\text{-}j[G2]}$: Impedance between the nodes in the given network denoted by graph *G2*.

The above definition of CEI may be extended as indicated in (3.2) for a network, represented by a multi-nodal multi-graph *G* (Figure 2.), which is common in real-world situation.

$$CEI_{[G]} = \sum_{i}\sum_{j} I_{i\text{-}j[UON,\ G]} \;/\; \sum_{i}\sum_{j} Min\ I_{i\text{-}j[G]} \qquad (3.2)$$

Where,

$CEI_{[G]}$: Connectivity-efficiency Index of the network denoted by graph *G*

$I_{i\text{-}j[UON,\ G]}$: Impedance between origin *i* to destination *j* in the UON, corresponding to the network denoted by graph *G*

$Min\ I_{i\text{-}j[G]}$: Minimum impedance between origin *i* to destination *j* in the network

[4] A UON optimizes (maximizes) the network users' benefit. For a multi-nodal UON, the distances, between the nodes, are equal to their corresponding ED. A UON, corresponding to a network denoted by graph G, is an imaginary network having number of nodes and trips-interchanges same as the graph G, but all the nodes are directly connected with each other.

denoted by graph *G*

It is to be noted that the value of CEI has no dimension and it lies between 0(zero) to 1, where, value 1 denotes the most efficient network (for travelers point of view) and it is only possible in case of Users' Optimal Networks), whereas zero indicates a situation where the nodes are disconnected and / or link-impedances tend to infinity.

4. Data and Study area

4.1 Case Study Areas

The case study areas are introduced in Table 2 and delineated in Figure 3.

Table 2: Case Study Areas

Sl. No.	**Name of Study Area**	**Administrative Identity and Spatial Coverage (Area in Km^2)**	**Geometric Typology of Road Network**	**Planning Hierarchy**
1.	Assam	State; Area :78,438km^2	Irregular	State level (Macro scale)
2.	Arunachal Pradesh	State; Area: 83,743km^2	Linear	
3.	Middle Ganga basin (from Kanpur to Ghazipur)	State of Uttar Pradesh (part); Area: 61.05km^2	Linear	
4.	Kolkata Metropolitan Area (KMA)	Metropolitan Area comprising of 3 Municipal Corporations; 38 Municipalities and 24 Panchayatsamitis (rural administrative units); Area 1,851 km^2	Irregular	Metropolitan level (Meso scale)
5.	National Capital Region (NCR)	Union territory consisting of 20 districts from three neighborhood States Haryana, Rajasthan, and Utter Pradesh along with the National	Irregular	

		Capital Territory; Area: 46,204km^2		
6.	Chennai Metropolitan Area (CMA)	Metropolitan area comprising of Chennai City Corporation, 16 Municipalities, 20 Town Panchayats and 10 Panchayat Unions; Area: 1,283km^2	Irregular	
7.	Bally	Municipal town; Area:11.00 km^2	Irregular	Town level (micro scale)
8.	Bidhannagar	Sector I,II and III of the Municipal town; Area: 14. 00 km^2	Irregular	
9.	North Dum Dum	Municipal town; Area:19.72 km^2	Irregular	
10.	Chandigarh	Capital town of the Punjab state Area:114 km^2	Gridiron	
11.	Connaught place, New Delhi	Part of Delhi, National Capital of India Area: 0.40 Km^2	Radial	

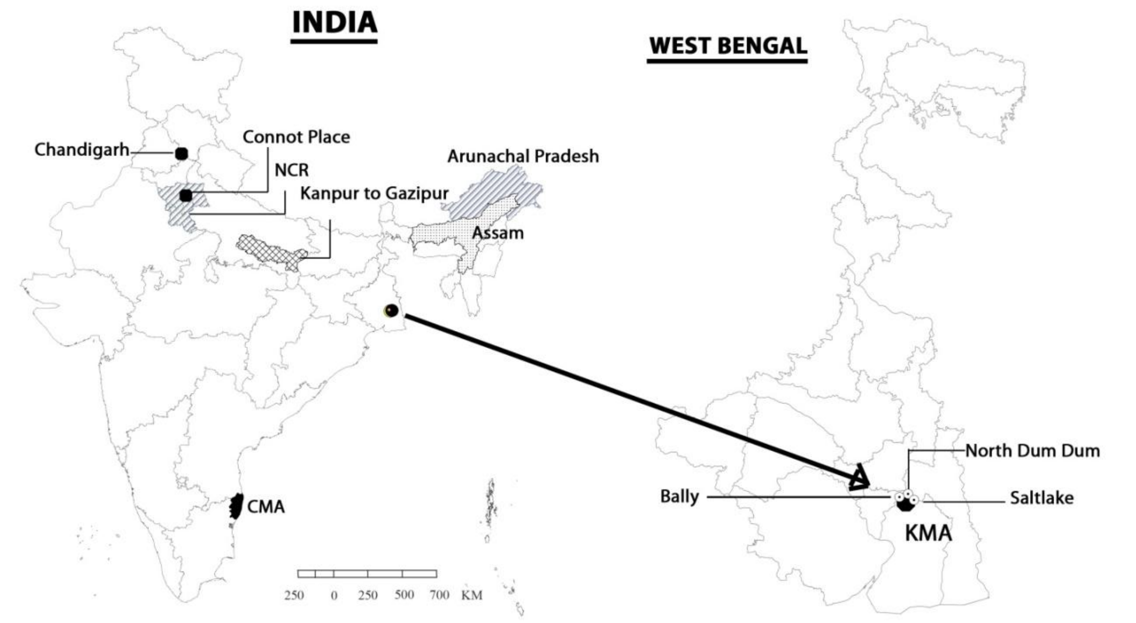


Figure 3. *Location of the study areas*

4.2 Weighted graphs representing road networks of the study areas

Representing the road networks of the study areas as weighted graphs was a pre-requisite for estimating the corresponding values of α, β and γ indices as well as the CEIs. Table 3 indicates the particulars for the constructed weighted graphs (for sample Figure A.1 – A.3 in Appendices:1), which represent the road networks of the study areas (herein after referred as study networks)

Table 3: Details for Graph Construction of Transportation Networks of the Study Areas

Study Area		**Node**		**Link**		
Sl. No.	**Name**	**Definition**	**Number**	**Definition**	**Number**	**Link weightage (Impedances)**
1.	Assam	CBD of the Major towns in the state.	99	NH, SH, and MDR connecting the towns	157	Distance between two nodes (in Km) as calculated from the respective District Maps (NATMO)
2.	Arunachal Pradesh		15		13	
3.	Middle Ganga Basin	CBD of the towns within the study area	58		133	

						using a GIS platform
4.	KMA	Activity Centroid of the Travel Analysis Zones (TAZs) delineated for the study on the basis of the boundaries of the municipal corporation / municipality/ other (rural / notified areas) administrative units	30	Major, arterial and / or sub-arterial roads connecting the nodes	56	Distance between two nodes (in Km) as calculated from the respective town maps using a GIS platform
5.	NCR		20		53	
6.	CMA		29		68	
7.	Bally	Activity centroids of the Municipal wards, which have been taken as TAZs.	18		32	
8.	Bidhan Nagar		19		39	
9.	North Dum Dum		10		19	
10.	Chandigarh		18		28	
11.	Connaught place, New Delhi	Activity centroids of the TAZs delineated on the basis of the existing road layout.	21		34	

5. Analysis

5.1 Estimation of the Indices

α, β and γ indicesof the study networks were estimated based on the equations applicable for planer graphs as indicated in Table 1 and the data inputs as indicated in Table 3. CEI were computed as indicated in Section 3.1using computer codes. Euclidian distances were computed from the co-ordinates of the nodes and the minimum paths were computed using the Floyds' Algorithm (for sample Table B.1 – B.3 in Appendices:1). The estimated values of the indices are indicated in Table 4.

Table 4: Indices Values for Study Networks

Sl. No.	**Study Area**	**α-Index**	**β-Index**	**γ-Index**	**CEI**
1.	Assam	0.306	1.586	0.54	0.591

Sl. No.	Study Area	α- Index	β- Index	γ- Index	CEI
2.	Arunachal Pradesh	0.067	0.867	0.333	0.397
3.	Middle Ganga Basin	0.685	2.293	0.792	0.868
4.	KMA	0.491	1.867	0.667	0.710
5.	NCR	0.971	2.650	0.981	0.837
6.	CMA	0.755	2.345	0.840	0.703
7.	Bally	0.484	1.778	0.667	0.627
8.	Bidhan Nagar	0.636	2.053	0.765	0.808
9.	North Dum Dum	0.667	1.900	0.792	0.665
10.	Chandigarh	0.355	1.556	0.583	0.788
11.	Connaught place, New Delhi	0.378	1.619	0.596	0.838

5.2 Examining the relation between the CEI and α, β and γ Indices

The study of the correlations (r) among the CEI (dependent variable), α, β and γ indices (independent variables) was a prerequisite for postulation of regression models. The correlations among the variables have been measured using Pearson's Product Moment Method. Table:5 shows the computation of correlation co-efficient among the variables.

Table 5: Correlation Coefficient (r) among the variables

	CEI (Y)	α- Index (X1)	β- Index (X2)	γ- Index (X3)
CEI	1.00	0.650	0.715	0.683
α- Index		1.00	.974	0.997
β- Index			1.00	0.976
γ- Index				1.00

5.3 Calibration of Regression Models:

The correlation coefficients (Table 5) confirm that since α, β and γ indices are highly correlated among them. Therefore, three simple linear regression models, as indicated in (i)-(iii), may be postulated (Papacostas and Prevedousros, 2009).

*CEI = a1 + b1 * α ……………………………………………………………….(i)*

*CEI = a2 + b2 * β ……………………………………………………………….(ii)*

*CEI = a3 + b3 * γ ……………………………………………………………….(iii)*

where, a1, 2, a3, b1, b2, b3 are calibration constants.

The estimation of the postulated models was done in two stages:

Initially, all of the eleven study networks we considered that resulted in the models as indicated in (iv)-(vi) and in Figure 4.a- c. The test of significance (t-test at n-2 degree of freedom) between the variables indicated that according to the Fisher's table, the calibrated models are significant at 95% confidence limit, but insignificant at 99% confidence limit (Table 6).

*CEI = 0.521 + 0.363 * α ……………………………………………………… (iv)*

*CEI = 0.325 + 0.208 * β ……………………………………………………….(v)*

*CEI= 0.338 + 0.545 * γ……………………………………………………….…(vi)*

The above observations prompted for the second stage of regression analysis, in which only the 7 irregular and 2 linear networks were considered. The rationale for excluding the gridiron and the radial networks lies in the fact that unlike the former 9 networks, there exist apparent disparities in the relation between the independent and dependent variables (Table 4). The second step of regression analysis led to the models, as indicated in (vii)-(ix) and in Figure 4.d-f, significant at 99% confidence limit (Table 6).

*CEI = 0.423 + 0.474 * α ……………………………………………………… (vii)*

*CEI = 0.193 + 0.258 * β ………………………………………………….……(viii)*

*CEI = 0.212 + 0.674 * γ ……………………………………………………… (ix)*

Table 6: Test of significant (t-test) of the regression analysis

	for 9 study areas excluding gridiron (Chandigarh) and radial (Connaught place) networks				**for all study areas**			
Regression analyses	**r**	**p value of t-test at (n-2) degree of freedom**	**Theoretical value of 't' at level of significant**		**r**	**p value of t-test at (n-2) degree of freedom**	**Theoretical value of 't' at level of significant**	
			0.05	**0.01**			**0.05**	**0.01**

CEI and Alpha index	0.864	4.514			0.650	2.566		
CEI and Beta index	0.914	5.975	2.36	3.50	0.715	3.068	2.26	3.25
CEI and Gamma index	0.872	4.713			0.683	2.805		

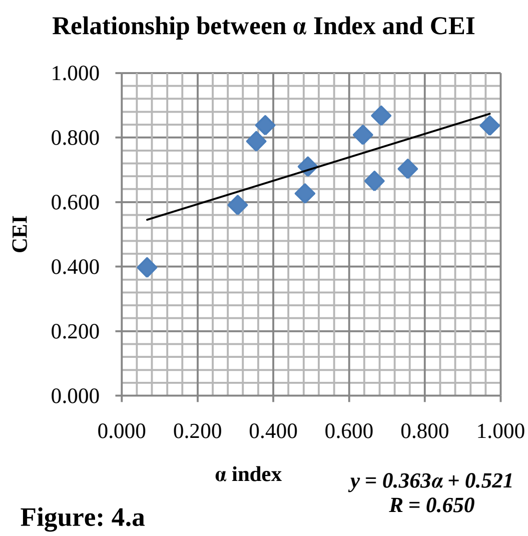


Figure: 4.a

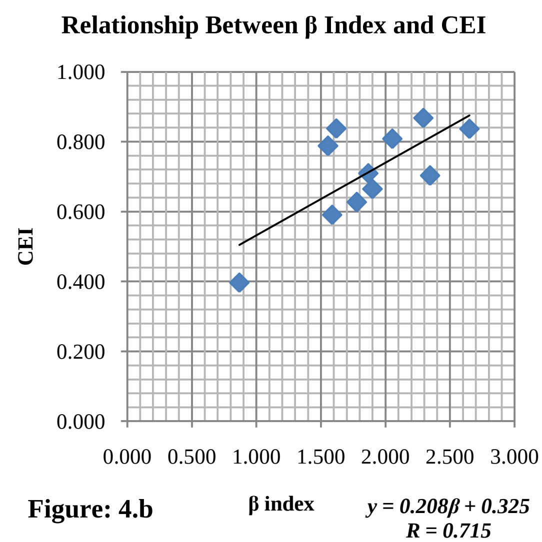


Figure: 4.b

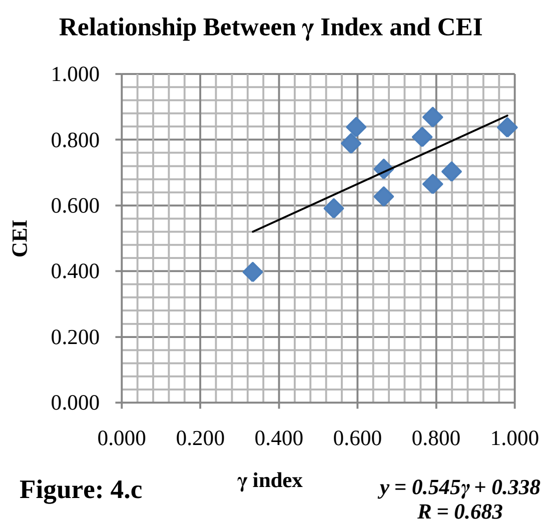


Figure: 4.c

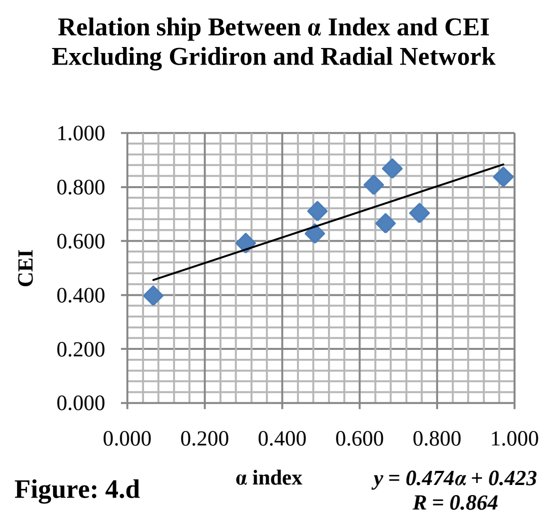
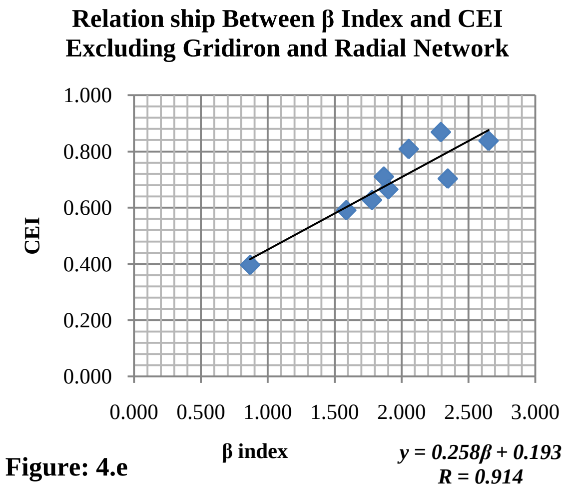


Figure: 4.d



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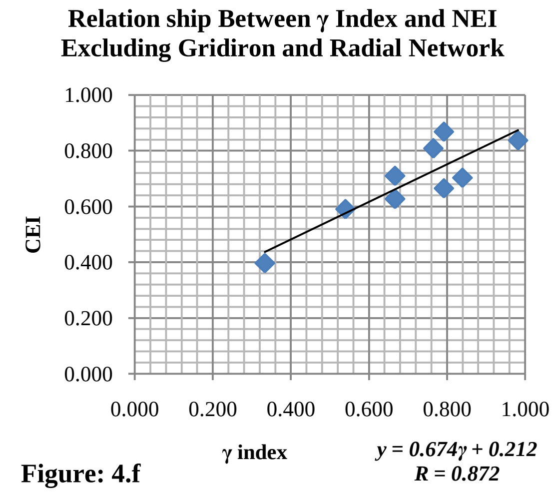

Figure: 4.f

Figure 3.5 *Trend Lines showing the relationship between the CEI and the α, β, γ indices at different situations*

4. Discussion on Results:

The results of the regression analyses indicated that the connectivity-efficiency of a given road network (CEI for this time) bears statistically significant positive correlations with α, β, γ indices within the value-ranges of (0.067-0.971), (0.867-2.65), and (0.333-0.981) respectively. Among the three connectivity indices under reference, the β index is the best correlated.

The t-test indicated variation in the statistical degree of confidence in the two stages of analyses. It revealed that the relations between the CEI and the α, β, γ indices are stronger in cases of irregular and linear networks at any Regional Scale than gridiron and radial networks and thus, it is not strictly consistent across all the geometric typology of road networks observed in India. In this context it is noteworthy that gridiron and radial road networks seldom exist in Indian scenario and are absent in state or metropolitan level. The lower level of statistical confidence in the t-test in cases of gridiron and radial networks may be explained from the fact that for the two types networks, the regular geometric patterns leads to high values of CEI, conversely, at the same the pattern allows limited number of links for a given set of nodes and, thus it results the lower values of α, β, γ indices.

From the above discussions, it directly follows that the, β, γ indices can be used for quick assessment the connectivity-efficiency of road networks. Benchmarking, specific to different typology of road network geometry is necessary for better consistency and accuracy.

5. Concluding Remarks

In the attempt of estimating connectivity-efficiency of road networks using the α, β, γ indices of connectivity, the study provides a tool that may approximate the connectivity efficiency of a given network with simple inputs of its number of nodes and links at a statistically acceptable level of confidence, yet avoiding the rigorous and resource-intensive computation-work that is imperative for computing CEI. It may find its application in planning of new road networks, particularly where, there would be necessity for selecting an optimum solution through rapid evaluation the connectivity-efficiency of a number networks representing alternatives.

However, further investigations with more case studies in different road network situations (mainly road geometry) are imperative prior to adopting any specific result from the current investigation that is limited with the obvious shortcomings of small sample size.

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Appendices: 1

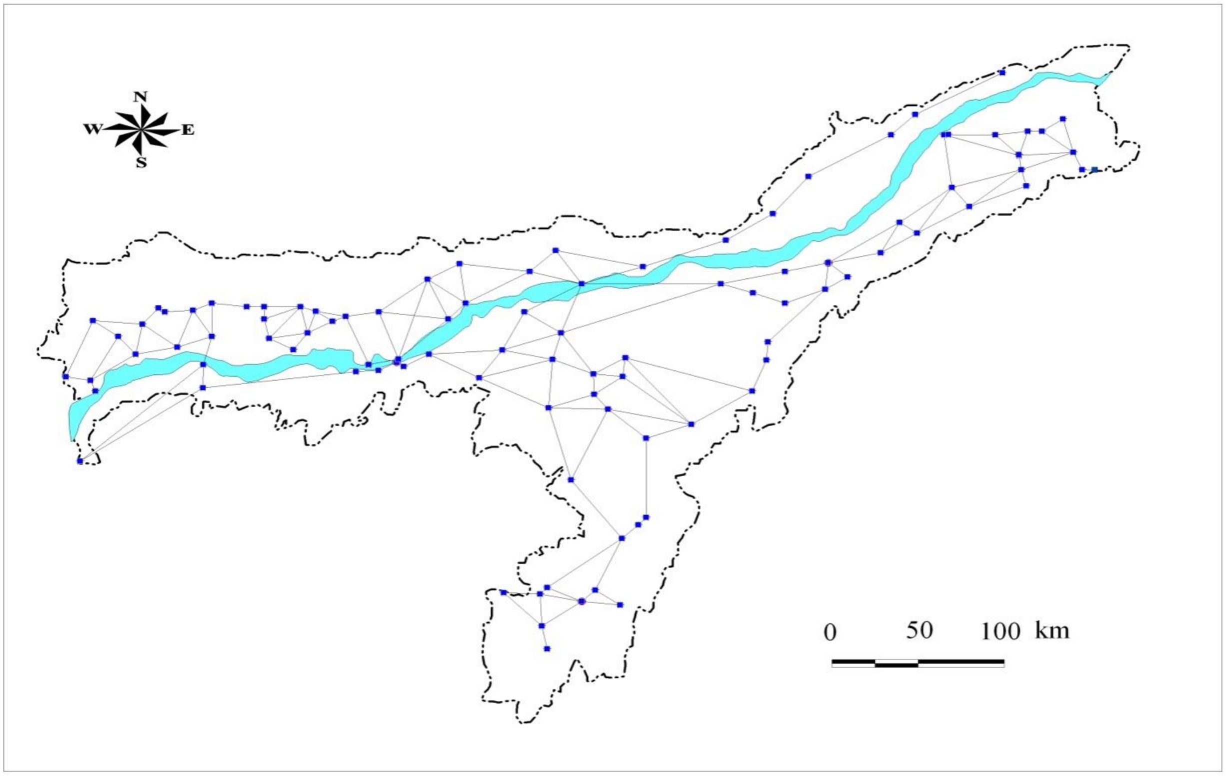

Figure A.1 Weighted Graph Representing Transportation Network of Assam

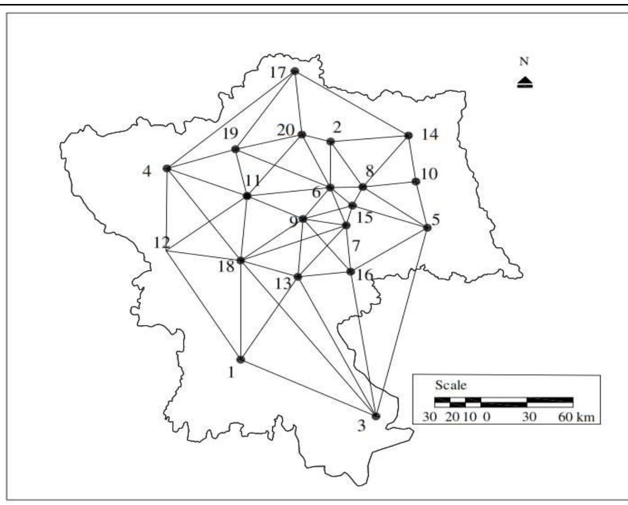

Figure A.2 Weighted Graph Representing Transportation Network of NCR.

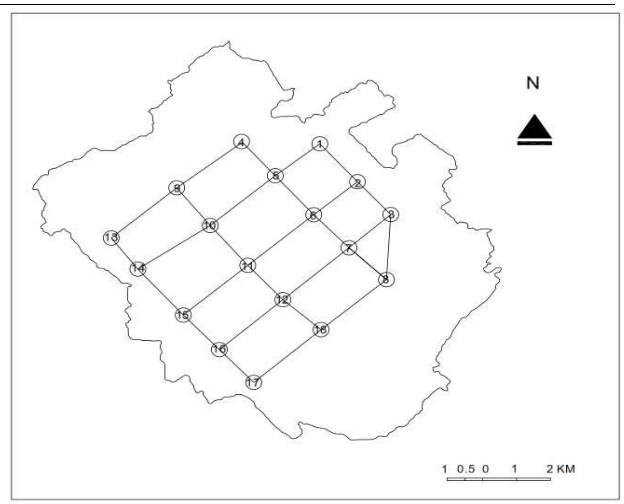

Figure A.3 Weighted Graph Representing Transportation Network of Chandigarh

Table B.1: Calculation for $CEI_{[G]}$ for Assam

Sl no.	Origin node (i)	Destination node (j)	$I_{i-j[UON, G2]}$	$I_{i-j[G2]}$
1	1	1	0	0
2	1	2	391.96	525.50
3	1	3	112.76	188.10
4	1	4	252.13	647.60
5	1	5	322.53	519.50
….	….	….	….	….
….	….	….	….	….
n	99	98	152.68	280.50
n	99	99	***0***	0
∑			2175920.46	3682813.22
$CEI_{[G]}$			**0.591**	

Table B.2: Calculation for $CEI_{[G]}$ for NCR

Sl no.	Origin node (i)	Destination node (j)	$I_{i-j[UON, G2]}$	$I_{i-j[G2]}$
1	1	1	0	0
2	1	2	167.42	204.00
3	1	3	97.07	104.00
4	1	4	145.68	180.50
5	1	5	154.18	187.40
….	….	….	….	….
….	….	….	….	….
n	20	19	44.75	62.50
n	20	20	0	0
∑			36315.90	43399.20
$CEI_{[G]}$			**0.837**	

Table B.3: Calculation for $CEI_{[G]}$ for Chandigarh

Sl no.	Origin node (i)	Destination node (j)	$I_{i-j[UON, G2]}$	$I_{i-j[G2]}$
1	1	1	0	0
2	1	2	1.63	1.63

3	1	3	3.06	3.06
4	1	4	2.27	3.12
5	1	5	1.65	1.65
….	**….**	**….**	….	**….**
….	**….**	**….**	….	**….**
n	18	17	***2.58***	2.58
n	18	18	***0***	0
∑			1283.37	1629.43
$CEI_{[G]}$			**0.788**	