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Research Paper

Transportation Network Analysis, Connectivity and Accessibility Indices in North East, Nigeria.

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ABSTRACT: *Importance of transportation network for regional development cannot be overemphasized. This study assesses the level of development of road transport network in North-eastern Nigeria in order to compare the changes in connectivity and accessibility by roads over time (1961 and 2011) in the sub-region. In order to make the analysis successful, map analysis was done on road network using topological abstractions that actually represent series of vertices (nodes) and set of edges (links). To describe the degree of network accessibility of the north east sub-region, using topological maps, Nodes or Vertices and Edges or Links were counted. This was achieved through devising a matrix, from which the Shortest Path Matrix, the Associated Number Index and the Shimbel index were calculated for each of the periods under study. The results of the above computation of gamma, beta, and alpha indices indicated that there is a significant increase in road connectivity and accessibility in north-east Nigeria from 1961 to 2011. The beta index revealed that there is increase in the number of roads leading to each node from 1.13 in 1961 to 1.46 in 2011 respectively. Alpha was 3.7% in 1961 but increases to 23.4% in 2011. Gamma index also revealed an increase in road connectivity over the last five decades. The result further shows that road connectivity witnessed an increase from 42.9% in 1961 to 52.8% in 2011. The computation of road connectivity in north-eastern Nigeria was conducted using only Trunk **A** and **B** roads network in the area. The analysis also reveals that political processes coupled with government investment in road transportation were some of the key reasons behind the growth in road transportation in the region which consequently brought about improvement in both accessibility and connectivity.*

Keywords: *Accessibility, Connectivity, Network, Road and Transportation*

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I. INTRODUCTION

Transportation is a central dimension of the national and global production systems that are constantly reshaping the world, making it a topic of universal interest and importance. As societies and economic organizations become complex, the relevance of transport grows. The demand for transport is also a derived one, because it depends on the demand for the commodities carried or the benefit of personal travel, and each travel is unique in time and space.

The history of transportation in Nigeria dates back to the pre-colonial era. Within this period, transportation facilities such as roads, railways and air transport facilities were really non-existent with emphasis then on the bush paths. At present, the modes of transportation in Nigeria include roads, railways, airways, inland waterways, coastal waters, the deep sea, and the pipelines. However, Road Transportation has become the dominant land transport system today in the world and Nigeria in particular.

The economic development of Nigeria has reflected the development of her transport systems. This is particularly true of the road transport system, which is by far the most widely used mode of transport in the country. Of all commodity movements to and from the sea-ports, at least two-thirds are now handled by road transport while up to 90% of all other internal movements of goods and persons take place by roads (Onakomaiya, 2004).As such its role toward enhancing economic growth and diversification cannot be underestimated. Furthermore, Road networks are observed in terms of their components of accessibility, connectivity, traffic density, level of service, compactness and density of particular roads.

It is against this background that this paper assesses the level of development of road transport network in North-eastern Nigeria in order to compare the changes in connectivity and accessibility by roads over time (1961 and 2011) in the sub-region.

1. The Concept of Transport Network

Transportation systems are commonly represented using networks as an analogy for their structures and flows. The term **network** refers to the framework of routes within a system of locations, identified as nodes. A route is a single link between two nodes that are part of a larger network that can refer to tangible routes such as roads and rails, or less tangible routes such as air and sea corridors.

In other words, Network is defined as the interconnectivity or linkage of a set of components of a system in to a complete whole to produce a spatial and structured pattern. Network may be either static feature at a point in time or a dynamic phenomenon which is subjected to change through time (Chapman, 2008). This means that a road network grows with time. Smith (1977) identified three elements in a network called by various names. These are nodes, vertices or points, the edges, linkages or routes. These nodes, vertices or points refer to the settlements while the edge, linkages or routes refer to the roads. In the course of making the nodes and linkages easily identifiable, a network is transformed into a topological graph which is a representation of the geometry of a network showing the relationship between nodes and linkages without considering the scale of the map and morphology of the actual route.

The present analysis is concerned with the road. As such an analysis was carried out to determine its growth in North-East Nigeria and how such growth has led to an improvement in spatial integration over time by improving the level of connectivity and accessibility within the sub-region. In such an analysis, the settlements are regarded as nodes or vertices while the routes linking the settlements are regarded as edges or links.

II. MATERIALS AND METHODS

In order to make the analysis successful, map analysis was done on road network using topological abstractions that actually represent series of vertices (nodes) and set of edges (links). Furthermore, various indices have been developed describing the extent to which a network approaches maximum connectivity, which requires the existence of a direct link between each node (Kansky, 1963). These indices are all based upon the relationship between the number of edges and vertices in a network which is regarded as a topological graph. Thus, the Beta Index, the Gamma Index and Alpha Index were used to determine the change in road **connectivity** over time.

The Beta Index; $\beta = \frac{e}{v}$ ..... (1)

The Gamma Index; $\gamma = \frac{e}{3(v-2)} \times \frac{100}{1}$ ..... (2)

The Alpha Index; $\alpha = \frac{e-v+1}{2v-5} \times \frac{100}{1}$..... (3)

- ✓ The Beta Index expresses the number of edges present in relation to the number of vertices to be connected and therefore, may be viewed as indicating the average number of links leading into or out of each node. When the average of each is considered the period with the highest value indicates the one with maximum connectivity while the one with least indicate least connected.
- ✓ Gamma Index is the ratio of the number of edges in a network to the maximum which may exist between specific numbers of vertices. The denominator in the expression reflects the fact that the addition of a single vertex necessarily increases the number of possible edges by 3. In an event of comparing the various periods, the network with the highest percentage indicates the period with the highest connectivity while the one with the least percentage is least connected.
- ✓ Alpha Index is a ratio based on the number of circuits in a network rather than the number of edges. Alpha index is closely related to gamma index. A circuit is defined as a path through a network which begins and ends at the same node without passing over any edge more than once. This implies that when a traveler is faced with a network with $\alpha=0$ it means he can only proceed along a single path while several options exist in the case of a network with $\alpha=1$. This therefore means that the period with the highest connectivity is the one with the highest ratio.

To describe the degree of network **accessibility** of the north east sub-region, using topological maps. Nodes or vertices and edges or links were counted; this was achieved through devising a matrix, from which the Shortest Path Matrix, the Associated Number Index and the Shimbel index were calculated for each of the periods under study.

The Shortest Path Matrix; refers to the number of arcs used in the shortest path between all possible pairs of nodes. Using topological map, the lowest possible numbers of arcs that can be used from one node to

the other are counted. The value obtained is written in the matrix box of the row against column. The totals of each row were added up and the lowest total indicates the town which is most accessible while the highest number or total connotes the least accessible.

The Associated Number is the number of arcs needed to connect a node to the most distant node from it. It is the highest number in each row. The highest number among all the numbers of the row for each town under consideration is the associate number. The row with the least associated number value indicates the most accessible while the row with the highest value indicates the least accessible.

The Shimbel Index highlights the total value for each row in the matrix table. It indicates the number of arcs needed to connect any node with all other nodes in the network by the shortest path matrix. The numbers of each row is added for each town. The town that has least total among all the rows is the most accessible while the highest total among the entire rows is the least accessible.

Table 1.0 Town as Node on the Topological Map

Settlements	Identification Code	Settlement	Identification Code
Maiduguri	**A**	**Wukari**	**N**
Biu	**B**	**Gamboru-Ngala**	**O**
Gombe	**C**	**Bama**	**P**
Bauchi	**D**	**Misau**	**Q**
Damaturu	**E**	**Azare**	**R**
Potiskum	**F**	**Gashua**	**S**
Kari	**G**	**Mayo Belwa**	**T**
Toro	**H**	**Nguru**	**U**
Numan	**I**	**Bali**	**V**
Yola	**J**	**Babaldu**	**W**
Gombi	**K**	**Damasak**	**X**
Mubi	**L**	**Darazo**	**Y**
Jalingo	**M**	**Dikwa**	**Z**

Source: Author's Work, 2018.

III. ROAD NETWORK CONNECTIVITY INDEX IN NORTH-EAST NIGERIA

Road connectivity is defined as the relative degree of connectedness within a transportation network. Therefore, in order to determine the change in connectivity over time in north-east Nigeria, three graphic theoretic measures were used in analyzing the network connectivity, which are all based upon the relationship between the number of edges and vertices in a network. They include: **Beta, Gamma and Alpha** indexes.

Table 1: Number of Road Edges and Vertices in North-East Nigeria (1961-2011)

Periods	No. of Links (Edges)	No. of Nodes (vertices)
1961	18	16
2011	38	26

Source: Author's Work, 2018.

It is however interested to note that the number of both edges and vertices continuous to increase from 1961 to 2011. And that can best be seen from the topological graphs above. The alpha, beta and gamma indices were calculated from the topological maps to show the degree of connectivity in the sub-region.

The Beta Index (1961) **Beta index:** $\beta = \frac{e}{v}$ ……(1)

Where; β = Beta
e = No. of Edges
v = No. of Vertices

$\beta = \frac{18}{16}$
= **1.13**

The Gamma Index (1961) **Gamma index;** $\gamma = \frac{e}{3(v-2)} \times \frac{100}{1}$ …… (2)

$= \frac{18}{3(16-2)} \times 100$

$= \frac{18}{42} \times 100$

= **42.9%**

The Alpha Index (1961) **Alpha index;** $\alpha = \frac{e-v+1}{2v-5} \times \frac{100}{1}$ ..... (3)

$= \frac{18-16+1}{2 \times 16-5} \times 100$

$$= \frac{18-17}{32-5} \times 100$$
$$= \frac{1}{27} \times 100$$
$$= \mathbf{3.7\%}$$

Note; that the above calculation of beta, gamma and alpha indices in (1961) shows that there were about 1.13 roads leading to each node according to Beta Index. While the Gamma and Alpha indices both indicated a connectivity ratio of 42.9% and 3.7% respectively.

The Beta Index (2011) **Beta index** $\beta = \frac{e}{v}$ …… (1)

$$\beta = \frac{38}{26}$$
$$= \mathbf{1.46}$$

The Gamma Index (2011) **Gamma index;** $\gamma = \frac{e}{3(v-2)} \times \frac{100}{1}$ …… (2)

$$= \frac{38}{3(26-2)} \times \frac{100}{1}$$
$$= \frac{38}{72} \times 100$$
$$= \mathbf{52.8\%}$$

The Alpha Index (2011) **Alpha index;** $\alpha = \frac{e-v+1}{2v-5} \times \frac{100}{1}$.....(3)

$$\alpha = \frac{38-26+1}{2\times26-5} \times \frac{100}{1}$$
$$= \frac{38-27}{52-5} \times 100$$
$$= \frac{11}{47} \times 100$$
$$= \mathbf{23.4\%}$$

The above measure of connectivity has so far attempted to establish the degree of changes in connectivity of road network in north-east Nigeria. The result of the above computation of gamma, beta, and alpha indices indicated that there is a significant increase in road connectivity and accessibility in north-east Nigeria from 1961 to 2011. The beta index revealed that there is increase in the number of roads leading to each node from 1.13 in 1961 to 1.46 in 2011 respectively. Alpha was 3.7% in 1961 but increases to 23.4% in 2011. Gamma index also revealed an increase in road connectivity over the last five decades. The result shows that road connectivity witness an increased from 42.9% in 1961 to 52.8% in 2011.

However, the above computation of road connectivity in north-east Nigeria was conducted using only Trunk **A** and **B** roads network in the area.

IV. ROAD NETWORK ACCESSIBILITY INDEX IN NORTH-EAST NIGERIA

Accessibility is defined as the measure of the capacity of a location to be reached by, or to reach different locations. Therefore, the capacity and the arrangement of transport infrastructure are key elements in the determination of accessibility (Rodrigue 2005).All locations are not equal because some are more accessible than others, which implies inequalities. The notion of accessibility consequently relies on two core concepts:

- The first is **location** where the relativity of space is estimated in relation to transport infrastructures, since they offer the mean to support movements.
- The second is **distance**, which is derived from the connectivity between locations.

Connectivity can only exist when there is a possibility to link two locations through transportation. It expresses the friction of distance and the location which has the least friction relatively to others is likely to be the most accessible.

In order to compare the degree of accessibility in north-east Nigeria, shortest path matrix was constructed to determine both the associate number and the shimbel index which are all measures of accessibility.

Table 2: Shortest Path Matrix of North-East Nigeria (1961)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Total	AN	SH
A	**0**	1	2	3	1	2	3	4	2	3	2	3	3	4	1	1	35	4	35
B	1	**0**	1	2	2	3	3	3	1	2	3	4	2	3	2	2	34	4	34
C	2	1	**0**	1	3	3	2	2	1	2	3	4	2	3	3	3	35	4	35
D	3	2	1	**0**	3	2	1	1	2	3	4	5	3	4	4	4	42	5	42
E	1	2	3	3	**0**	1	2	4	3	4	3	4	4	5	2	2	43	5	43
F	2	3	3	2	1	**0**	1	3	4	5	4	5	5	6	3	3	50	6	50
G	3	3	2	1	2	1	**0**	2	3	4	5	6	4	5	4	4	49	6	49
H	4	3	2	1	4	3	2	**0**	3	4	5	6	4	5	5	5	56	6	56
I	2	1	1	2	3	4	3	3	**0**	1	2	3	1	2	3	3	34	4	34
J	3	2	2	3	4	5	4	4	1	**0**	1	2	2	3	4	2	42	5	42
K	2	3	3	4	3	4	5	5	2	1	**0**	1	3	4	3	1	44	5	44
L	3	4	4	5	4	5	6	6	3	2	1	**0**	4	5	4	2	58	6	58
M	3	2	2	3	4	5	4	4	1	2	3	4	**0**	1	4	4	46	5	46
N	4	3	3	4	5	6	5	5	2	3	4	5	1	**0**	5	5	60	6	60
O	1	2	3	4	2	3	4	5	3	4	3	4	4	5	**0**	2	48	5	48
P	1	2	3	4	2	3	4	5	3	2	1	2	4	5	2	**0**	43	5	43

Source: Author's Work, 2018.

The above matrix (Table 1.2) revealed that the shortest path matrix shows that Biu and Numan were the most accessible towns in north-east Nigeria with a value of 34 each. Followed by Gombe and Maiduguri in terms of accessibility whereby both have a value of 35 each on the shortest path matrix table, while Wukari with identification code **N** has the highest value of 60 on the matrix table making it the least accessible town in the sub-region. Followed by Mubi and Toro with a value of 58 and 56 respectively.

The Associated Number (AN) also indicated that Biu, Gombe, Maiduguri and Numa were most accessible towns with a value of 4 each. While Kari, Mubi, Potiskum, Toro, and Wukari were the least accessible towns in north-east Nigeria in 1961 with a value of 6 each. Likewise, the value of the shimbel (SH) on the matrix table revealed that Biu and Numan were the most accessible with a value of 34 each while Wukari was the least accessible with a value of 60.

Table 3: Shortest Path Matrix of North-East Nigeria (2011)

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	Total	AN	SH
A	0	1	2	3	1	2	3	4	2	3	2	3	3	4	2	1	4	3	2	4	3	4	4	1	3	1	65	4	65
B	1	0	1	2	1	2	3	3	1	2	1	2	2	3	3	2	4	3	2	3	3	3	3	2	2	2	56	4	56
C	2	1	0	1	2	1	2	2	1	2	2	3	2	3	4	3	3	4	2	3	3	3	2	3	1	3	58	4	58
D	3	2	1	0	4	3	2	1	2	3	3	4	3	4	5	4	3	4	3	4	5	4	1	4	1	4	77	5	77
E	1	1	2	3	0	1	2	4	2	3	2	3	3	4	3	2	3	2	1	4	2	4	4	2	3	2	63	4	63
F	2	2	1	3	1	0	1	4	2	3	3	4	3	4	4	3	2	1	1	4	2	4	4	2	2	3	65	4	65
G	3	3	2	2	2	1	0	3	3	4	4	5	4	5	5	4	1	2	2	5	3	5	3	3	1	4	79	5	79
H	4	3	2	1	5	4	3	0	3	4	4	5	4	5	6	5	4	5	5	5	6	5	2	5	2	5	102	6	102
I	2	1	1	2	2	2	3	3	0	1	2	3	1	2	4	3	4	5	3	2	4	2	3	3	2	3	63	5	63
J	3	2	2	3	3	3	4	4	1	0	1	2	2	3	5	2	5	6	4	1	5	3	4	4	3	4	79	6	79
K	2	1	2	3	2	3	4	4	2	1	0	1	3	4	4	1	5	6	3	2	4	4	4	3	3	3	74	6	74
L	3	2	3	4	3	4	5	5	3	2	1	0	4	5	5	2	6	7	4	3	5	5	5	4	4	4	98	7	98
M	3	2	2	3	3	3	4	4	1	2	3	4	0	1	5	4	5	6	4	1	5	1	4	4	3	4	81	6	81
N	4	3	3	4	4	4	5	5	2	3	4	5	1	0	6	5	6	7	5	2	6	1	5	5	4	5	104	7	104
O	2	3	4	5	3	4	5	6	4	5	4	5	5	6	0	3	6	7	3	6	4	6	6	2	5	1	110	7	110
P	1	2	3	4	2	3	4	5	3	2	1	2	4	5	3	0	5	6	3	3	4	5	5	2	4	2	83	6	83
Q	4	4	3	3	3	2	1	4	4	5	5	6	5	6	6	5	0	1	3	6	4	6	4	4	2	5	101	6	101
R	3	3	2	4	2	1	2	5	3	4	5	6	4	5	5	4	1	0	2	5	3	5	5	3	3	4	89	6	89
S	2	2	2	3	1	1	2	4	3	4	3	4	4	5	3	3	3	2	0	5	1	5	4	1	3	2	72	5	72
T	4	3	3	4	4	5	5	5	2	1	2	3	1	2	6	3	6	5	5	0	6	2	5	5	4	5	96	6	96

U	3	3	3	4	2	2	3	5	4	5	4	5	5	6	4	4	4	3	1	6	**0**	6	5	2	4	3	96	6	96
V	4	3	3	4	4	4	5	5	2	3	4	5	1	1	6	5	6	5	5	2	6	**0**	5	5	4	5	100	6	100
W	4	3	2	1	4	3	3	2	3	4	4	5	4	5	6	5	4	5	4	5	5	5	**0**	5	2	5	98	6	98
X	1	2	3	4	2	2	3	5	3	4	3	4	4	5	2	2	4	3	1	5	2	5	5	**0**	4	1	79	5	79
Y	3	2	1	1	3	2	1	3	2	3	3	4	3	4	5	4	2	3	3	4	4	4	3	4	**0**	4	75	5	75
Z	1	2	3	4	2	3	4	5	3	4	3	4	4	5	1	2	5	4	2	5	3	5	5	1	4	**0**	84	5	84

Source: Author's Work, 2018.

The above shortest path matrix revealed that Gamboru - Ngala with a value of 110 was the least accessible town in north-east Nigeria in 2011, while, Biu on the other hand is the most accessible town with a value of 56 on the matrix table. Furthermore, an evaluation of the shortest path matrix above revealed shows that an Associated Number (AN) indicated that Biu, Damaturu, Gombe, Maiduguri and Potiskum were the most accessible towns with a value of 4 each. Likewise, Gamboru - Ngala, Mubi and Wukari were the least accessible towns with a value of 7 each in 2011 in the sub-region.

The value of Shimbel (SH) on the same matrix table above also identified Biu as the most accessible town with a value of 56, followed by Gombe with a value of 58. Gamboru - Ngala, Wukari and Toro towns were the least accessible tows with a value of 110, 104 and 102 respectively.

Table 4: Summary of the Comparison in Connectivity Indices in North-East Nigeria

Connectivity Variables	1961	2011
Beta Index (β)	1.13	1.46
Gamma Index (γ)	42.9%	52.8%
Alpha Index (α)	3.7%	23.4%

Source: Author's Work, 2018.

Table 5:Summary of the Accessibility indices of North-East Nigeria

Accessibility Indices	**Most Accessible (1961)**	**Least accessible (1961)**	**Most Accessible (2011)**	**Least accessible (2011)**
Shortest Path	34	60	56	110
Associated Number	4	6	4	7
Shimbel index	34	60	56	110

Source: Author's Work, 2018.

2. Road Transport Improvement in North-East Nigeria

The provision of transport facility is described to be an important factor in political interaction, co-operative and social interaction both at the micro and macro level of the regional economies (Ogundana, 1974). In North-east Nigeria, road transportation is the most popular and developed. In consequence both the Federal and the State governments have made enormous capital investment in the development of road transportation in the region and the country at large. Another key area that led to the rapid development of road transport system in north-east Nigeria was the creation of new states governments. In 1967 the whole sub region was North-Eastern State, a former administrative division of Nigeria with the capital situated in Maiduguri. The state was eventually divided in to Bauchi, Borno and Gongola states. Gombe state was later split out of Bauchi, Yobe out of Borno and Gongola was split into Taraba and Adamawa states. All these political processes brought about massive improvement in road transportation both in terms of connectivity and accessibility in the sub region in which new nodes and links came up as a result of that.

In 1961 the topological graph of the road network indicated that was 18 links or edges and 16 nodes or vertices while in 2011 the number of both vertices and edges increases to 38 and 26 respectively. This is a clear indication of road transport development over the period of time.

V. CONCLUSION

The study has so far attempted to analyze the level and nature of connectivity and accessibility of roads network in North-East Nigeria over the period of time. 1961 and 2011 were used in the course of this analysis in order to compare both connectivity and accessibility over time. As such Beta, Gamma and Alpha indices were used to measure connectivity over the two periods of time (1961 to 2011). While the Shortest Path Matrix, Associated Number and the Shimbel index were used to consider the nature of accessibility over the time under study. As such,all of these indices mention above revealed that there was a substantial improvement in connectivity and accessibility in the region over time.

The analysis also revealed that political processes coupled with government investment in road transportation were some of the key reasons behind the growth in road transportation in the region which consequently brought about improvement in both accessibility and connectivity. This in turn led to increase in interaction, economic integration, promote the improvement and modernization of agricultural activities, make exchange of agricultural products easier, facilitate the dispersal of economic activities, promote the social and political cohesion among the states as well as facilitate the execution of various beneficial political and administrative programmes and projects.

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