This paper examines the relevance of network analysis in transportation planning, the concept of transportation network, models of network structure, the network efficiency assessed by various stakeholders using indices such as cost, input, output. The paper took a closer look at network connectivity using beta, alpha and gamma indexes. Network accessibility in Iyoba ward in Orhionmwon local government area was used as a case study were it was found that Evbodobian has a ‘Konig number’ of 7 and ‘Shimbel Index’ of 2 is the most accessible town which on a normal ground would be a place where facilities that is meant for the generality in the ward is to be located. Finally the relevance of network analysis was critically examined citing various examples as it relates to the country.

Introduction

Network analysis is a branch of graph theory which aims at describing quantitative properties of networks of interconnected entities by means of mathematical tools. Any domain which can be described as a set of interconnected objects is a domain application for network analysis (Bellomi and Bonato, 2009). Network analysis is of paramount interest to the transportation planner because transport flows take place on transport networks. Transport flows can be defined as the movement of goods and services between places (Okoko, 2006).

Models of Network Structure
As Whynne (1979) put it, transport structures, or networks, are integrated patterns in which groups of centres (nodes) are linked by set of routes. A network is a combination of several routes into a more or less integrated structure, permitting movements between many nodes. So, a network can therefore be defined succinctly as a set of routes that connects junctions and terminal.

A node may be a settlement or junction, and a link is defined as a line of contact e.g. road, rail, waterway etc. Nodes are also referred to as vertices, and links are also known as arcs. When a node occurs at the end of an arc i.e. at a terminus, it is known as an end node. One arc only may link two nodes and an arc leading to an end node is termed a branch (Fig.1).

![Fig. 1 Nodes and Links](image_url)

There are infinite numbers of types of network but six principal ones have been identified and characterized. They were first recognized by Bunge (1966) and are based on a hypothetical assumption of five nodes. There six typologies are discussed as follows:

i) The “Paul revere” network is a very simple network and exists where a single route connects all nodes. The major disadvantage lies in the fact that any return journey say from E to A must pass through the intervening nodes, which can be slow and tedious. This type of network is found mostly in the developing countries of the world (Fig.}
2). For example, before construction of express road, Iruekpen-Ekpoma road could illustrate Paul revere network (Okoko, 2006; Newman, 2010).

![Fig. 2: Paul Revere Network](image)

ii) The “Travelling Salesman” network is undoubtedly the shortest route around all nodes. The drawback is that journeys between nodes still involve movement through all the other nodes. In this type of network, a commuter from B to D will have to pass through C. This type of network is found mostly in less developed regions (Okoko, 2006; Newman, 2010).

![Fig. 3: Travelling Salesman Network](image)

iii) “Centre-Oriented” network is a star-like network with the links radiating from a central node. This type of network is prone to congestion at the central node since cross-country movement is impossible. As shown in Fig. 4, all traffic must pass through D resulting in congestion. In Nigeria, many towns are linked by roads to the
surrounding villages in this way such that inter-village movements must pass through the towns. Benin City represents D in the diagram, where A, B, C and E represent Ekehuwan, Warri, Ekpoma and Ore respectively (Okoko, 2006; Newman, 2010).

![Centre-oriented network](image)

**Fig. 4: Centre-oriented network**

iv) The "Circuit" network is probably the best and the most efficient since all nodes are connected to all others by the shortest route and movement between any two settlements does not have to pass through other settlements. This pattern thus offers the least cost to the user but has the disadvantage of being the most costly to construct. Roads in developed countries tend to have circuit type of network as shown in fig. 5 (Okoko, 2001).
v) The “**Branching**” network is a cost-effective network pattern. This type of network provides the shortest route connecting all the nodes in the system. Journey in this type of network by-pass all the other intervening nodes. A journey from node B to node D for example, would not involve passing through A, E or C.

(Fig. 6)

![Fig. 6 Branching Network](image)

vi) The “**Branching Circulatory**” network is developed as a compromise network between circuit and branching networks. It is fairly efficient network, and relatively cheap to construct (Fig. 7).
Understanding the Efficiency of a Network

There are available indices for the assessment of the efficiency of road network. These indices assist in measuring the level of connectivity, accessibility, and the density of road network. Efficiency is assessed in terms of Minimum travel cost in system and ratio of input and output. Input indicator is a fund spent for road handling, which can be presented national budget or city/municipal budget. Output indicator is explained by length of road, outcome indicators are presented by number of vehicle using road in a range to time (veh-km/year), and impacts are presented by several measurements like number of carbon monooxide (ton/year). The data for the output of the road handling is a road length developed and rehabilitated and the outcome data used is road network performance, presented by average speed and vehicle operating cost in those road networks (Santosa, and Joewono, 2005).

a) Connectivity: This is an index that is used to express the relationship between the number of nodes and the number of links in a single network. Kansky (1963) developed several graph theoretic indices for measuring the connectivity of various road networks. Three of the
most commonly used graph theoretic measures or indices developed by Kansky are (i) The beta (β) index (ii) the gamma (λ) index, and (iii) the alpha (α) index.

**The Beta Index (β)**

This is calculated by dividing the total number of links by the total number of nodes, i.e.

\[
β = \frac{\text{Number of links}}{\text{Number of nodes}} \quad \text{i.e. } β = \frac{L}{N}
\]

\[
β = \frac{\text{links}}{\text{nodes}} = \frac{5}{6} \quad β = 0.83
\]

This β index ranges from 0.0 for networks that consists just of nodes with no links through 1.0 and greater where networks are well connected e.g.
\[ \beta = \frac{10}{8} = 1.25 \quad \beta = \frac{4}{4} = 1.0 \]

The beta index is, however, of less value for complex networks. A beta index of 1.0 may be taken as economic dividing line: values above this level indicating advanced networks, and value below indicating less integrated networks (Papacostas, 1987).

**Gamma Index** (\(\lambda\))

This index describes in numerical terms, the connectivity of network. It is the ratio of the number of arcs in a network to the maximum, which may exist between a specified number of vertices or to the maximum possible in that network. The maximum number of edges/arcs possible may be computed from the number of vertices or nodes in the system. The denominator in the expression reflects the fact that the addition of a single vortex necessarily increases the number of possible edges/arcs by three e.g. three arcs are required to join three vertices but six arcs may be drawn when a fourth vertex is added.

The gamma index is represented by the formula:

\[ \lambda = \frac{\text{No. of arc}}{\frac{3}{3} \times (\text{no. of nodes} - 2)} \]

It could also be expressed in percentage form as:

\[ \lambda = \left( \frac{a}{\frac{3}{3(n-2)}} \right) \times 100 \quad \text{(Okoko, 2006)} \]

With reference to the figure below (fig. A), it is seen that the network scores better (67%) than the more elementary network of Fig. B that achieves only 42% of maximum connectivity.
\[ \lambda = \left( \frac{10}{3(8-2)} \right) \times 100 \]
\[ = 66.7\% \]
\[ \lambda = 55.6\% \]

**Alpha Index \((\alpha)\)**

This is closely related to the gamma index, but its ratio is based on the number of circuits in a network rather than the number of edges/arcs. It is one of the most useful, and perhaps the best measure of the connectivity of a network, especially a fairly complex network. This index expresses the ratio of the number of fundamental circuits to the maximum possible number of circuits, which may exist in the network. It is represented by the formula:

\[ \alpha = \frac{\text{actual circuits}}{\text{Maximum circuit}} = \frac{e - v + 1}{2v - 5} \times 100 \]

Where; \( e \) = The number of links (i.e. edges or arcs) in the network

\( v \) = the number of nodes or vertices in the network.

E.g. for Fig. A, \( \alpha = \frac{10 - 7 + 1}{2 \times 7 - 5} \times 100 = 44\% \)

For Fig B, \( \alpha = \frac{10 - 8 + 1}{2 \times 8 - 5} \times 100 = 27.3\% \)

*Note: All figures above are hypothetical and are used for explanatory purposes.*

The alpha index gives the range of values from 0.0 to 1.0 or from 0.0% to 100%. The higher the value of the alpha index, the greater the degree of connectivity in the network. A value of 1 or 100% is indicative of a highly integrated network in which every possible link exists between the various nodes (Papacostas, 1987).

**Accessibility of Network**

While the three techniques explained above are designed to measure the degree of completeness of links between nodes in the network (i.e. connectivity), other techniques are
available to measure the degree of accessibility within networks. Any node that is well connected to other nodes in a network is said to be accessible, for instance, in Figure C below, there are 5 nodes linked together by a series of arcs. The accessibility matrix for Figure C is shown in table 1. Accessibility is measured using either the Shimbel index or the König number.

![Figure C](image)

**Table 1: Accessibility Matrix**

<table>
<thead>
<tr>
<th>From</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>Shimbel Index</th>
<th>König No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>E</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>9</td>
<td>3</td>
</tr>
</tbody>
</table>

(Adapted from Okoko, E (2006) *Urban Transportation Planning and Modelling*)

Konig number is used to find the centrality of nodes. It is the maximum number of links from each node to the other nodes in the network. Lower values indicate greater centrality. Shimbel index is derived from the shortest path matrix and it indicates the number of arcs needed to
connect any node with all the other nodes in the network by the shortest path. The Shimbel index is superior to the Konig number as a measure of accessibility. With reference to Figure C, node A is the most accessible since it is easier to reach all the other nodes from A, and it is also easier to reach A from other nodes. Accordingly, A has the lowest Shimbel index (Table 1) and also one of the lowest Konig values. The superiority of the Shimbel index over Konig number is glaring here (Okoko, 2006).

Relevance of Network Analysis to Transportation Planning and Economic Development of a Region

The accessibility values obtained in the network studies could be used as a framework within which to plan the spatial distribution of development (Adesina, 2004). Accessibility values are not only used for the planning of the spatial distribution of development, it also shows low and high accessibility of node and of network and to locate an industry. Understanding the accessibility of network in an area, the cost of transporting the raw materials from the source to the industry is reduced.

From the study of accessibility matrix carried out in Iyoba Ward in Orhionmwon local government, it is clear that facility that will be located for general use by the inhabitants of the ward should be located at Evbodobian because it is most centrally located with Konig value of 7 and has the highest accessibility in the area.

It is of note that the following relevance are drawn outside the study area. Transportation planning and network analysis has helped Lagos State and Abuja in the construction of overpasses, underpasses, and one-way links at different locations. The Third Mainland Bridge in Lagos is a very good example of where network analysis has played a crucial role during
planning of transportation network. How cumbersome it would have been for commuters in Lagos with the numbers of car today?

Intersection and junction attributes have been refined especially in Benin City metropolis with the help of network analysis. Areas where traffic volume is high traffic lights are installed to check and control the movement vehicles. For example, the ever busy First East Circular and Second East Circular junctions have been sanitized of standstill traffic jam.

Intermodal or interline terminals, transfer points, and delay functions are other areas where transportation planning and network analysis has also contributed to the development of countries especially in the Advanced part of the World. An intermodal network can be defined as an integrated transportation system consisting of two or more modes. Modes on intermodal networks are connected through facilities which allow travellers and/or freight to transfer from one mode to another during a trip from an origin to a destination (Boile, 2010).

It is possible to use connectivity and network density as measures of economic development. The greater the density (or the lower the ETA index), the more advanced is the economic prosperity of the country or region concerned (Santosa, and Joewono, 2005).

Another relevance of network analysis is that it helps in the development of a new road in a depressed part of the region (rural areas) to ginger up economic development. The depressed area is normally an area that has been by-passed by railway or motorway development. The decision to construct new roads in the depressed regions is usually promoted by government policy.

Transportation planning and network analysis has contributed in the development of TransCAD by those in Geographic Information System. Networks are stored in a highly-efficient way, enabling TransCAD to solve routing problems very quickly.
A case study of accessibility matrix in Iyoba ward in Orhionmwon Local Government

The first assignment was to transform the road network into a graph. In a more complex network involving a larger number of nodes and with possible alternative routes between nodes (Figure D), it is less easy to make assumptions with respect to accessibility. The way to tackle this type of problem is to prepare an accessibility matrix with the rows representing origins of movement while the columns represent their destinations (Table 2). The most accessible node is Ebvodobian with the lowest Konig number (7) and one of the lowest Shimbel index values (2).

Table 2: Accessibility Matrix in Iyoba Ward in Orhionmwon Local Government

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>Shimbel Index</th>
<th>Konig. No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evbokabua (A)</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Evbobemwen (B)</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Ebvodobian (C)</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Owe (D)</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Egboro (E)</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Ugbohhirima (F)</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>-</td>
<td>3</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Otobaye (G)</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>-</td>
<td>3</td>
<td>14</td>
</tr>
</tbody>
</table>

Source: Fieldwork, August, 2012.
Conclusion

The study of network analysis in transportation planning build a more comprehensive approach to explain the input, output, outcome, and impact of any road network. The short term benefit of the study is an application in practical use to allocate the limited budget, especially when the efficiency of the road network is understood.

Network analysis has provided the basis of solving most of traffic challenges both in the rural and urban areas as this can be seen in Benin City and other parts of the country.
REFERENCES
Boile, M.P. (2010). Intermodal Transportation Network Analysis - A Gis Application
