Evaluation of Al-Najaf road networks connectivity and Spatial Pattern

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Abstract. Road network development is a key factor in developing any region in these days. The correct connectivity and the right orientation are needed in an urgent way in order to make a development to road network. However, the attention that is given to the development of the road network especially in the urban areas is insufficient. Thus, the analysis of the road network in the city of Al-Najaf is the main focus of this paper. Beta, Gama, Eta indices and other measures such as spreading index, correlation index were adopted in this study in order to assess the road network for the city. The main findings of this study are that there is an urgent need to improve the road network, and one way to do this is constructing new roads. Lastly, a better prediction to the network can be given by measuring the density of the city road network.

Keywords: Road network, connectivity, Al-Najaf network

1. Introduction

The structure of the road network can show topologic variation as well as geometric variation. Different indices that can be applied for the evaluation of the road network were found in many past studies [1, 2]. Connecting the people with the local facilities is the principal role of the road network. So, the more efficient the network is, the more the developed and sustainable the life is [3]. Actually, a road network is made of two parts: links (which are the roads) and nodes (which are the intersections) [3]. To quantify the spatial structure of any network, the graph theory comes in role. A great interest was given to the understanding of the topology of the road network when compared to other geographic aspects. Continuity and heterogeneity patterns are among a variety of applications that can be attributed by this [4, 5, 6].

Weak mobility and bad accessibility are two of many aspects that Al-Najaf city suffers from in terms of road network [7]. Assessing the road network of this city was taken into consideration in very limited studies, thus, the evaluation of this road network by using several different measures and indices (e.g., connectivity and coverage) is the main purpose of this paper.

2. Methodology

The use of the GIS system/software is involved as a method in the evaluation of the network of the study area, which in turn involves data resources collection, network digitizing, building of the network database, network structure extraction, etc. To characterize the road network and determining the variation in its patterns, ArcGIS 10.5 was utilized depending on different indicators. The satellite image was used in digitalizing all diverse types of roads: arterial, sub-arterial, collector, and local streets. Then, the GIS was used to produce the needed (Environmental System Research Institute) ESRI shape file format. ArcGIS is then used in...
georectify both maps to geographic coordinate for which the ground control points were used. Then, connectivity and coverage are used in order to evaluate the road network.

The GIS plays a vital role in this study in analyzing and displaying the city road network. Scales of 1:1000 and 1:2000 were used in GIS for developing of the city. Maps from Ministry of Municipality and Public Work, Directorate of Al-Najaf Municipality and Planning Unit were relied on in producing the digitalized maps. Moreover, maps from fundamental design prepared by Architecture Design company (ADEC), Liewelyn Davies Yeang and TRIBAL Urban Studio in 2010 with scale of 1:60000 have been also adopted in the development of the digital map that is produced by GIS. Quick Bird Satellite was chosen for the satellite image of the city with accuracy of 60 cm.

3. Characteristics of road network
Coverage, connectivity, and spatial pattern are some of the indices that were proposed in many previous studies when evaluating road networks. These indices can be applied in various applications for transportation practice as well as planning.

4. Connectivity
The directness of travel path between destinations is referred to by connectivity. A network can be considered a well-connected one when it has short links, many intersections, and minimum number of dead-ends [3]. A simple network (called topological diagram) is obtained from the real network in order to determine the connectivity index for the network [3]. In this diagram, roads are referred to by links which connect the nodes, and both the links and the nodes are dealt with by the graph theory and data. The analysis of the road network is massively affected by the application of the network theory in the transportation network. Alpha, Beta, Gamma, Eta, and Grid-Tree indices were used in the evaluation of the connectivity pattern of the road network [8, 9]. The road network has to be changed to the topological map (as in Figure 1) by utilizing ArcGIS ver. 10.5 in order to apply the mentioned indices.

Beta index: The value of this index can be calculated by dividing the number of links by the number of nodes. The range of this value is from 0 to 1, if it is zero, it means that there are no links whereas if it is one, it means the graph is complete [8, 9]. The larger the value of Beta, the higher connectivity in the network. The Beta value increases as transport networks become more developed and efficient.

\[
\beta = \frac{e}{v} \quad \text{(1)}
\]

where:
- \(e\) - number of links in the network
- \(v\) - number of nodes.

When Beta index is applied on Al-Najaf city, it gives a value of 1.47 which indicates that there is more than one network in the city.

\[
\beta = \frac{87}{59} = 1.47
\]

Gamma index (\(\gamma\)): This index is considered one of the most reliable measurements by which the connectivity degree can be determined. The value of this index can be calculated using the following equation [8, 9].

\[
\gamma = \frac{e}{3(v-2)} \quad \text{(2)}
\]

When the value approaches to zero, it means that there is no connectivity, whereas if the value equals to one, it means the network is fully connected.

\[
\gamma = \frac{87}{3(59-2)} = 0.50
\]

The resulted value indicates there is a need for adding 84 links.

Alpha index (\(\alpha\)): This index is the ratio of the actual to the maximum number of circuits. The range of this index is 0 to 1 (zero means no circuits and 1 means the network is thoroughly interconnected) [8, 9].

\[
\alpha = \frac{e-v+p}{2v-5} \quad \text{(3)}
\]
Figure 1. The topological map of the roads of the holy Najaf city.
This index can be used in determining the degree of connectivity. For Al-Najaf city, this index can be calculated as follow\cite{8, 9}: 
\[ \alpha = \frac{x+y+p}{2v-5} = 0.25, \]
which means that 21 links are needed so that the required connectivity degree is satisfied.

5. **Coverage**

The coverage measure is used to describe the density of the network elements such as links and intersections. It is beneficial in finding the development and compactness of a network. The greater the value of coverage, the more developed the network is \cite{8, 9}. The coverage of a road network in an area is attributed by the intersection density and the network density.

Spreading degree. This index determines the access level and how the network lines are spread. The divergence and closeness among nodes can be measures by the following indices:

**Eta index** ($\eta$): The Eta index is used in the measurement of the real lengths of links between nodes as expressed below\cite{8, 9}:
\[ \eta = \frac{M}{e} \]
where; $M$ - total network length in km

The value of this index starts from zero and has no upper limit, and if it equals to zero, then it means that the network lacks spreading in the special urban (there is no access in the network).

For Al-Najaf city, \[ \eta = \frac{1244.67}{87} = 14.30 \]
The result of this index indicates that there is no closeness among the nodes and the network is spreading widely.

**First betty index:** This index is used in the measuring of the spreading level in its region. The value of this index starts from 1 but if it is equal to zero then it means that there is no spreading. It can be calculated using the below equation.

\[ \text{Betty index} = \text{no. of links} - \text{no. of nodes} + 1 \]

For Al-Najaf city, this index value will be \[ 87 - 59 + 1 = 27 \]
which indicates that the network is highly spread in its region.

6. **Detour index**

The straight distance gives the shortest distance, therefore, the roads that extend straightly are the best roads. However, under different conditions, roads could deviate either right or left and ascend or descend. As a result, the lengths of these roads will be increased which is called detour index\cite{8, 9}.

This index can be applied when the efficiency of the roads is needed. This can be done by knowing the lengths of the roads in the network and the straight lengths as well. In consequence, adding or canceling links in the network can be easily known if needed.

This index value can be calculated by using the below equation:

\[ \text{Detour index} = \left( \frac{\text{the actual length of the road}}{\text{the straight length of the same road}} \right) \times 100 \]

The value of this index is always equal or higher than 100%. The roads are straight and have high efficiency if the value of this index approaches to 100% whereas if the value is greater than 100%, this means that the roads lack the efficiency and even the increment for positive causes.

For Al-Najaf city roads, the detour index values are shown in Table 1 and Figure 2.

102.36% is the average value for the detour index. The 2.36% increment form the ideal 100% value indicates that the city is with an efficient network that can be due to the level terrain.

22 roads were found to have the value of 100% while 19 roads were found to have the value 101% - 120%.

The number of roads, which are higher than 120%, is four which is 4.59% from the total number of roads. These roads are ring road no.1 and Al-Suwer road. Accordingly, the roads of Al-Najaf city are efficient.
| NO. | Street            | Actual length (m) | Theoretical length (m) | Detour index % | Increase (m) |
|-----|-------------------|-------------------|------------------------|----------------|--------------|
| 1   | AL-Uroba AL-Gated - 1 | 761.196          | 761.196                | 100            | 0            |
| 2   | AL-Uroba AL-Gated - 2 | 1293.72           | 1293.72                | 100            | 0            |
| 3   | AL-Gameea          | 2019.343          | 2019.343               | 100            | 0            |
| 4   | AL-Yarmok         | 1914.715          | 1914.715               | 100            | 0            |
| 5   | ARTS University   | 1456.048          | 1456.048               | 100            | 0            |
| 6   | AL-Imam Ali 1     | 764.507           | 764.507                | 100            | 0            |
| 7   | AL-Imam Ali 2     | 354.037           | 354.037                | 100            | 0            |
| 8   | AL-Esken 1        | 1009.043          | 1009.043               | 100            | 0            |
| 9   | AL-Esken 2        | 887.201           | 887.201                | 100            | 0            |
| 10  | Mualmeen Association | 1438.587         | 1438.587               | 100            | 0            |
| 11  | Ahmed AL - Safi Najafi | 1811.406       | 1811.406               | 100            | 0            |
| 12  | AL-Salam         | 1938.416          | 1938.416               | 100            | 0            |
| 13  | AL-GENSEEAA       | 1511.639          | 1511.639               | 100            | 0            |
| 14  | AL-Wafaa 1        | 659.380           | 659.380                | 100            | 0            |
| 15  | AL-Wafaa 2        | 1322.05           | 1322.05                | 100            | 0            |
| 16  | Airport 1         | 644.988           | 644.988                | 100            | 0            |
| 17  | Airport 2         | 740.888           | 740.888                | 100            | 0            |
| 18  | Airport 3         | 690.928           | 690.928                | 100            | 0            |
| 19  | Airport 4         | 1626.581          | 1626.581               | 100            | 0            |
| 20  | AL-SHorta 1       | 1090.269          | 919.950                | 118.513        | 170.319      |
| 21  | AL-SHorta 2       | 1995.16           | 1708.499               | 167.778        | 286.661      |
| 22  | AL-Gawahere 1     | 1001.246          | 1001.246               | 100            | 0            |
| 23  | AL-Gawahere 2     | 867.351           | 867.351                | 100            | 0            |
| 24  | AL-Gaemaa 1       | 1803.611          | 1748.646               | 103.143        | 54.965       |
| 25  | AL-Gaemaa 2       | 2584.497          | 2401.537               | 107.618        | 182.96       |
| 26  | cemetery          | 1023.275          | 1023.275               | 100            | 0            |
| 27  | AL - Haboubi - 1 | 941.1331          | 941.1331               | 100            | 0            |
| 28  | AL - Haboubi - 2 | 1071.707          | 1071.707               | 100            | 0            |
| 29  | AL - Haboubi - 3 | 1200.584          | 1200.584               | 100            | 0            |
| 30  | AL-Shahed AL- Sader 1 | 512.768          | 512.768                | 100            | 0            |
| 31  | AL-Shahed AL- Sader 2 | 1065.277        | 1065.277               | 100            | 0            |
| 32  | AL-Shahed AL- Sader 3 | 1302.807        | 1302.807               | 100            | 0            |
| 33  | AL-Hawlee 1-1     | 384.991           | 384.991                | 100            | 0            |
| 34  | AL-Hawlee 1-2     | 3325.088          | 3277.670               | 101.446        | 47.418       |
| 35  | AL-Hawlee 1-3     | 1093.603          | 1093.603               | 100            | 0            |
| 36  | AL-Hawlee 1-4     | 5227.435          | 3960.260               | 131.997        | 1317.175     |
| 37  | AL-Hawlee 1-5     | 2594.609          | 2095.945               | 121.644        | 498.664      |
| 38  | AL-Hawlee2- 1     | 6267.978          | 6072.972               | 103.211        | 195.006      |
| 39  | AL-Hawlee 2-2     | 1751.05           | 1751.05                | 100            | 0            |
| 40  | AL-Hawlee 3-1     | 1680.829          | 1680.829               | 100            | 0            |
| 41  | AL-Hawlee 3-2     | 1651.949          | 1651.949               | 100            | 0            |
| 42  | AL-Hawlee 3-3     | 914.9971          | 914.9971               | 100            | 0            |
| 43  | AL-Hawlee 3-4     | 1053.876          | 1053.876               | 100            | 0            |
| 44  | AL-Hawlee 4-1     | 1558.526          | 1558.526               | 100            | 0            |
| 45  | AL-Hawlee 4-2     | 1866.046          | 1866.046               | 100            | 0            |
| 46  | AL-Hawlee 4-3     | 1300.584          | 1300.584               | 100            | 0            |
| 47  | AL-Hawlee 4-4     | 692.269           | 692.269                | 100            | 0            |
| 48  | AL-Hawlee 4-5     | 1684.086          | 1684.086               | 100            | 0            |
| 49  | AL-Hawlee 4-6     | 4452.615          | 4452.615               | 100            | 0            |
| 50  | AL- Soor 1        | 647.578           | 634.292                | 102.094        | 13.286       |
The max possible links = $\frac{1}{2}(n^2-n)$

Where:

$\text{N} = \text{no. of nodes}$

The value of this index ranges from 0 to 1 (zero means the network does not have links, and a value of one means the network has the maximum number of links). For Al-Najaf city, the value of this index can be found by applying the mentioned equation:

The max possible links = $\frac{1}{2}(59^2-59) = 1711$

Correlation index = 87/1711 = 0.05

This is a very low value and indicates that the correlation degree is very weak.

7. Correlation index

The degree of correlation among links can be represented by this index which can be calculated by the following equation [8, 9]:

Correlation index = no. of links/max. no. of possible links.

Where:

The max possible links = $1/2(n^2-n)$

$\text{N} = \text{no. of nodes}$

The value of this index ranges from 0 to 1 (zero means the network does not have links, and a value of one means the network has the maximum number of links). For Al-Najaf city, the value of this index can be found by applying the mentioned equation:

The max possible links = $1/2(59^2-59) = 1711$

Correlation index = 87/1711 = 0.05

This is a very low value and indicates that the correlation degree is very weak.

8. Density of roads to the area and the number of population

The economic development for an area is presented by this indication which also provides an idea about how many roads are sufficient for the geographical area when evaluating its roads performance.
The density of roads to the area = lengths of the roads (km)*1000/(the area served by roads (km²))
For Al-Najaf city, the density of roads = 1244.672*1000/183.785=6772.435 km/1000km².
Thus, the standard specification (105km/1000km²) is lower than the calculated one for the city.
The calculation of roads with respect to the population is as follows:
The density of roads to population = lengths of roads (km)*100000/population
Therefore, for the year (2011) the density is 182.628 km/100000 people which is fewer than the standard specification (496 km/100000 people) [10].

9. Discussion the results
Having all connectivity indices predetermined, from the results of Beta index (1.47), it can be concluded that there is more than one network in the city. And from the results of Gamma index (0.5), this means that the city needs 84 links, but the result of Alpha index indicates that only 21 links are needed. These differences are attributed to each type of measuring. Henceforth, all connectivity indices indicate that the network needs more links.

When it comes to the spreading degree, Eta index and first beta index equal to 14.30 and 27 respectively which means that the network has a widespread and the nodes are spaced far among each other. Additionally, the results of the detour index roughly show that the roads are mostly straight. The result of the correlation index demonstrates that the network is badly correlated and the result of the ratio of the road density to the area and population (6772.435 km/1000km² and 182.628 km /100000 respectively) show that the former is greater than the standard value (105km/1000km²) and the later is smaller than the standard value (496km/100000people) [10]. Lastly, the number of roads to the number of vehicles ratio equals to 8.80 m. This value can be calculated from dividing the number of vehicles(1244672) by the lengths of all roads (141303 m).

10. Conclusion and recommendation
The main conclusions of this study could be summarized as:
1. For Al-Najaf city, the connectivity measurements indicate that the connectivity is weak due to the results of its indices which are α, β and γ that are equal to 0.25, 1.47 and 0.5, respectively.
2. Based on the result of Eta index, the coverage indication shows that the network is widely spread, and it lacks closeness among the nodes.
3. Al-Najaf roads can be considered efficient due to the results of the detour index.
4. The correlation among roads (links) is very weak which is indicated by the correlation index.
5. The ratio of the roads density to the city area is found greater than the standard value, while the ratio of the roads density to the population is found to be smaller than the standard value.
6. In order to avoid any lack aspect in the network, a plan has to be made that correspondingly will increase the road network efficiency.

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