Evaluation of Al-Kufa City Road Networks Using GIS

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Abstract. One of the important points to develop any region is the suitable road network and understanding the relationship between land use and transportation system. To effectively develop any network, there is an urgent need to obtain proper connectivity and orientation. However, Al-Kufa road network has received significantly limited attention and studies to evaluate this network. Therefore, this study has focused on analyzing the present road network connectivity in Al-Kufa city. Furthermore, the GIS program has been adopted in this study to represent the main features in the city. Several measures have been adopted in this study to perform the evaluation for the road network such as beta index, gamma index, alpha index, spreading index, correlation index, etc. The main objective of this study is to assess how the road network is successful to containment the present road traffic and suggestions for future traffic movement performance to accommodate the growth. The results demonstrate that urgent improvements are required such as adding new roads. Finally, the network density could give better another important prediction of the road network measures.

Keywords: Al-Kufa road network; Connectivity; GIS; Network density; Spreading index.

1. Introduction

The urban road network is one of the traditional transport networks that has drawn a great deal of interest from the various research communities (Bando et al., 1995, Wang et al., 2012). The main objective of the study of urban road traffic network is to prevent or relieve traffic congestion, which has become an urgent problem to solve with the continuous growth of urban population and automobiles.

Khazaal (2009) conducted geographical analysis for paved road network in Erbil city, Iraq in order to determine the connectivity of the network. In addition, the study focused on the analysis of detour. The results mainly indicated that there are low connectivity and high detour index because of nature of the hilly nature of the area.

Aduory (2010) studied the geographical analysis for Al-Dur road network, in Salahaddin city, Iraq to
know the routes, lengths, density and the efficiency of the under study road network. The author concluded that the road density was low comparing with other cities there. The roads in the under study area were influenced by natural factors such as geographical location, water resources and also were affected by agricultural, industrial activities and population distribution.

Ogunleye (2011) studied the spatial of road networks in Ekiti city in Nigeria. The results indicated that low connectivity of roads in this city. Therefore, the recommendations of this study were to maintain the existing roads and construct the new ones for increasing the accessibility of people and goods.

Taran and Makhamra (2015) did a spatial analysis for a rural road network in Al-Mafraq city in Jordan using GIS in order to measure the connectivity and circuit. The study found that the percent of connectivity was 42% as indicated by Gamma index. Whereas, the circuit is very low as indicated by 11% of alpha index.

Taran et al., (2016) conducted structural analyses road network study in Karak city in Jordan using graphs theory and some quantitative methods to identify the reality of the road network in terms of the degree of connectivity and circuitry, accessibility and density. As well as the relationship between the lengths of the network and population distribution analysis. The authors found that the road network suffers from the low level of connectivity and circuitry in general. The study also concluded that there is a disparity in the road network distribution within the city and that the lengths of roads ratio does fit with population ratios. Therefore, the study recommended the need to develop the connectivity to ensure redistribution of the population and meet their development plans.

Al-Jameel and Abdulabas, (2017), indicated that the city network suffers from poor mobility and accessibility. Limited studies discussed the assessment of Al-Kufa road network. Therefore, the main purpose of this study is to evaluate the road network in Al-Kufa city using several indices such as connectivity and coverage.

2. Historical background

Al-Kufa is an ancient, historical and religious city which has several historical places such as Al-Kufa Mosque, Al-Sahila Mosque and Muslim Ibn Aqeel holy shrine. This city lies north east of Al-Najaf city, as indicated in Figure 1, with an area of 49.44 Km\(^2\) and population of 185232 persons in 2018.

![Figure 1. The Site of Al-Kufa city from Al-Najaf governorate and Iraq.](image-url)
Road network display both topologic and geometric variations in their structure. There are variety of indices, proposed in earlier studies applicable for evaluating road network properties. The main role of network is to connect local facilities and people. Therefore, the efficient network is an essential part of sustainable improvement in the quality of life and development of the city (Sreelekha et al., 2016).

Basically, a road network consists of links (roads) and nodes (intersections, civic center, community centers, or any natural separators such as river …etc.). The most important indicators to evaluate the network are connectivity and efficiency (Sreelekha et al., 2016). The graph theory has been developed to quantify the spatial structure of road network. Among the geographers who understand the network structure, the transportations engineers whom understanding the topology of transport network has received considerable interest. This could be attributed to different applications such as heterogeneity patterns and continuity [Xie, 2005, Gastner and Newman, 2006; and Xie and Levinson, 2007).

3. Al-Kufa network

The first appearance of modern means of route used for transportation in Al-Kufa city was in 1907. This was the carriages drawn by horses as reported by Musabee (1978). Then, the first paved road network appeared in 1954 (Al-Jaboory, 2007). The number of population was increased from 13700 capita in 1947 to 157845 capita in 2013 as reported by Al-Kalaabee (2017). This increment means more area to be served by roads. According to the Directorate of planning in Iraq, the criteria of transportation and land occupied road for each person is 25m²; however, this value was 15.8m² per capita in 2007 and 16.03m² per capita in 2013, respectively (Al-Kalaabee, 2017). These values are less than the standard value. Therefore, one could conclude that there is a lack in the roads which may lead to traffic congestion.

4. Methodology

The methodology involves applying GIS for evaluating the road network of the study area as indicated in Figure 2. Urban road network evaluation based on GIS involves collecting the data resources, digitizing the network, building road network database, extracting the network structure etc. These data have been collected from different sources such as descriptive data relating to the names of roads and intersections, number of population, number of vehicles and special data such as sector maps for Al-Kufa city with scale of 1:1000, maps of fundamental design with scale of 1:60000 and satellite image (Quick Bird US Satellite) with accuracy of 60cm.

ArcGIS9.3 was used in this study. All the roads including arterial, collector streets and local streets were digitized from the satellite image. Moreover, all required lengths have been measured as indicated in Figure 3.
The required ESRI shape file format has been produced from the GIS. In this study, the GIS has an important role in representing and analyzing the road network in the city. This process of the GIS has been used to develop a map for Al-Kufa city with scale 1:1000 and 1:2000. These digital maps have been produced depending on maps from Ministry of Municipality and Public Works, Directorate of Al-Najaf Municipality and Planning Unit. Moreover, maps from fundamental design prepared by the company of Architecture Design (ADEC), Llewellyn Davies Yeang and TRIBAL Urban Studio in 2010 with scale 1:60000 have been also adopted to develop digital map produced by GIS. Finally, the satellite image for Al-Kufa city using Satellite called Quik Bird with accuracy 60cm has been used.
5. Characteristics of road network

To evaluate the road network, there are several indices which have been proposed in previous studies such as connectivity, coverage and spatial pattern. These measures have different applications in both planning and transportation practices.

6. Calculations:

6.1 Connectivity:

Connectivity refers to the directness of travel between origins and destinations. A well-connected network has many short links, numerous intersections, and minimal dead-ends providing continuous, direct routes to destinations (Sreelekha et al., 2016). To determine the connectivity for transportation network, the real network should be changed to simple network which is called topological diagram (Sreelekha et al., 2016). In the diagram, a road could be represented as a link which connects nodes. The graph theory deals with links and nodes according to network theory and data. The application of network theory in transportation network has influential effect in directing the analysis of road networks. Various indices used for evaluating connectivity pattern of road transport network are Alpha Index, Beta Index, Gamma Index, Eta Index and Grid Tree Pattern Index (Kansky, 1963; and Noda, 1996). To apply such as indications, the network has been changed to topological map as in Figure 4 using ArcGIS 10.5.

6.1.1 Beta index

This index consists of dividing the number of links by nodes. The value of this index ranges between 0 and 1 (Buyong, 2007). If this value is zero this represents no links and the value is one this means complete graph. The greater the value of β, greater is the connectivity. As transport networks develop and become more efficient, the value of β should be high (Buyong, 2007).

\[ \beta = \frac{e}{v} \]

where \( e \) - number of edges in the network, \( v \) - number of vertices in the network, and \( \beta = \frac{66}{43} = 1.53 \)

Applying such index on Al-Kufa network indicates that value is 1.53. This means that there is more
than one complete network in the city.

6.1.2. Gamma index ($\gamma$)
This is the best measurements to know the connectivity degree (Davey, 1971). This index could be determined according to Equation 2.

$$\gamma = \frac{e}{3(v-2)}$$

where; $e$ - number of edges in the network and $v$ – is the number of vertices in the network.

If there is no connectivity the value approaches from zero but if the value is one this means fully connected.

$\gamma = \frac{69}{3(43-2)} = 0.56$. The resulted value indicates that connectivity of the network is at low level. To improve the level of connectivity, there is a need to add 54 links.

6.1.3 Alpha index ($\alpha$):
This is the ratio of actual number of circuits to the maximum number of circuits in the network (Dill, 2003). It ranges from 0 (no circuits) to 1 (completely interconnected network).

$$\alpha = \frac{e-v+p}{2v-5}$$

This measure should be determining the connectivity degree. The value of ($\alpha$) for Al-Kufa city is calculated as follows:

$$\alpha = \frac{69-43+3}{2(43)-5} = 0.36.$$  

This means that the connectivity is very low and there is a need for 58 links to satisfy the required connectivity degree.

![Figure 4. The topological map of the roads of A-Kufa city.](image)
6.2 Coverage

Coverage measures describe the density aspect of the elements of a network, as intersections and links (Buyong, 2007). The Coverage measures are useful in determining compactness and development. Higher the value, more the network is developed. Network density and Intersection density attribute road network coverage in an area.

Spreading degree: This index indicates how the lines of network spreading and level of access. To measure the closeness and divergence among the nodes, will be done according to the following indices:

6.2.1 Eta index(η)

This index uses for measuring the real lengths of links between the nodes as indicated below (Buyong, 2007):

\[ \eta = \frac{M}{e} \]  ……………………………………(4)

where M - total network length in km

This value starts from zero. If this value is zero, this means that no spreading for the networks in spatial urban (i.e. this network is without access).

For Al-Kufa city, \( \eta = \frac{81.012}{43} = 1.884 \)

According to this value of index, the degree of spreading is 1.884 which represents good spreading degree and there is no closeness between nodes.

6.2.2 First Betty index

This index is used to measure the level of spreading in its region. The value of this index ranges from one and more. If this value is zero, this means no spreading. This index determines from the following equation (Buyong, 2007):

Betty index= no. of links- no. of nodes +1 ……………………………………(5)

By applying this index for Al-Kufa city, its value = 69-43+1=27. This means a huge spreading for the networks in its region.

6.2.3 Detour index

The shortest distance is the straight one. So, the best roads which are straightly extended; however, most roads deviate either right or left and ascend or descend under different conditions. This leads to increase the lengths of these roads which is called detour index (Buyong, 2007).

This index is used to evaluate the efficiency of roads by knowing the lengths of roads in transportation network in addition to the straight lengths. Consequently, this will help to know where you have to add or cancel some links in the network understudy. The value of this index could be determined according to the following equation:

Detour index= \( \frac{(\text{the actual length of the road}\times\text{the straight length of the same road})}{100} \) *100 ……(6)

The value of this index is always equal or higher than 100%. If this value approaches from 100% this means that roads are straight with high efficiency. If the value exceeds 100% this refers to inadequate cases. The detour index for Al-Kufa roads is indicated in Table1 and Figure 2.

| Table 1. Detour index for The main streets in the Kufa City |
|-----------------|-----------------|-----------------|-----------------|-----------------|
| no. of links    | Street          | Actual length (m) | Theoretical length (m) | Detour index% |
| 1               | Airport Street 1 | 1233.196          | 1233.196          | 100            | 0               |
| Airport Street 2 | 1341.988 | 1341.988 | 100 | 0 |
|-----------------|----------|----------|-----|---|
| Airport Street 3 | 692.482 | 692.482 | 100 | 0 |
| Airport Street 4 | 329.457 | 329.457 | 100 | 0 |
| Airport Street 5 | 1229.382 | 1216.559 | 101.054 | 12.823 |
| AL-Hawlee 4-2 | 3413.011 | 3413.011 | 100 | 0 |
| AL-Hawlee 4-3 | 2331.596 | 2331.596 | 100 | 0 |
| AL-Maamel Street 1 | 1541.985 | 1541.985 | 100 | 0 |
| AL-Maamel Street 2 | 928.729 | 923.724 | 100.541 | 5.005 |
| Najaf- Kufa3 Street | 969.647 | 969.647 | 100 | 0 |
| Najaf- Kufa5 Street | 710.743 | 709.437 | 100.184 | 1.306 |
| Najaf- Kufa6 Street | 399.292 | 390.328 | 102.2965 | 8.964 |
| Najaf- Kufa4 Street | 1446.331 | 1446.331 | 100 | 0 |
| Najaf- Kufa8 Street | 639.510 | 638.966 | 100.0851 | 0.544 |
| Najaf- Kufa7 Street | 274.629 | 274.629 | 100 | 0 |
| Airport Street 6 | 361.402 | 361.402 | 100 | 0 |
| AL-Delal Street | 1065.482 | 1064.707 | 100.0728 | 0.775 |
| AL-Syahe1 Street | 2828.370 | 2808.028 | 100.6532 | 18.342 |
| AL-Esaa Street | 2695.236 | 2549.690 | 105.7084 | 145.546 |
| AL-Hila1 Street | 1476.325 | 1476.325 | 100 | 0 |
| AL-Hila2 Street | 640.827 | 573.027 | 111.8319 | 67.8 |
| Kufa-Abasya1 Street | 320.503 | 320.503 | 100 | 0 |
| Kufa-Abasa2 Street | 1071.704 | 1053.007 | 101.7756 | 18.697 |
| Kufa-Abasya3 Street | 958.296 | 940.912 | 101.8476 | 17.384 |
| AL-Syahe2 Street | 939.960 | 939.960 | 100 | 0 |
| AL-Syahe3 Street | 1186.886 | 1181.043 | 100.4947 | 5.843 |
| Kufa-institute1 Street | 1885.754 | 1679.170 | 100.3504 | 6.584 |
| Kufa-institute2 Street | 2778.588 | 2778.588 | 100 | 0 |
| AL-Imam Ali bridge | 1570.198 | 1563.304 | 100.440 | 6.894 |
| Mesan- ALImam Ali bridge | 1584.183 | 1579.504 | 100.296 | 4.679 |
| WFaa-Mesan | 1724.460 | 1630.207 | 105.7817 | 94.253 |
| WFaa-Mesan 1 | 434.909 | 434.909 | 100 | 0 |
| WFaa-Mesan 2 | 540.988 | 540.988 | 100 | 0 |
| WFaa-Mesan 3 | 572.736 | 572.736 | 100 | 0 |
| AL-Mocktar 1 | 931.830 | 931.830 | 100 | 0 |
| AL-Mocktar 2 | 1710.089 | 1710.089 | 100 | 0 |
| AL-Boheedaree1 | 2652.339 | 2801.797 | 101.803 | 50.542 |
| AL-Tejare 1 Street | 586.087 | 586.087 | 100 | 0 |
| AL-Tejare 2 Street | 1721.218 | 1721.218 | 100 | 0 |
| Steen1 Street | 586.783 | 586.783 | 100 | 0 |
| Steen2 Street | 1733.022 | 1733.022 | 100 | 0 |
| Tamoz1 | 1455.767 | 1455.767 | 100 | 0 |
| Tamoz4 | 736.844 | 736.844 | 100 | 0 |
| Tgawez1 | 1287.108 | 1287.108 | 100 | 0 |
| AL- Taqaa Street | 1518.455 | 1518.455 | 100 | 0 |
6.3 Correlation index

This index represents the correlation degree between links in the network. This index is calculated as follows (Buyong, 2007):

\[
\text{Correlation index} = \frac{\text{no. of links}}{\text{max. no. of possible links}}.
\]

Where; The max possible links

\[= \frac{1}{2}(n^2-n) \]

\[\text{...(7)}\]

\[n=\text{no. of nodes.}\]

If the value for this index is zero which represents there is no link in the network. Whereas, when the value is one this represents that the number of links is the max possible number. By applying the above equation, the value of this index is:

The max possible links= \[\frac{1}{2}(43^2-43) = 903\]

Correlation index= \[
\frac{66}{903} = 0.073
\]

This value is so low and the degree of correlation is so weak.

| No. | Street                  | X1     | X2     | Value | Calculation |
|-----|-------------------------|--------|--------|-------|-------------|
| 46  | AL-Mutanabe Street      | 1445.103 | 1445.103 | 100   | 0           |
| 47  | Sahlaa-kufa 1           | 720.875 | 720.875 | 100   | 0           |
| 48  | Sahlaa-kufa 2           | 1324.868 | 1324.868 | 100   | 0           |
| 49  | AL-Sahalea Street       | 735.216 | 735.216 | 100   | 0           |
| 50  | Medicine college street 1 | 651.326 | 651.326 | 100   | 0           |
| 51  | Medicine college street 2 | 796.516 | 796.516 | 100   | 0           |
| 52  | Sahlaa-SulAL kufa 1     | 1157.454 | 1157.454 | 100   | 0           |
| 53  | Sahlaa-SulAL kufa 2     | 485.668 | 485.668 | 100   | 0           |
| 54  | Sahlaa-Mesan            | 1194.011 | 1130.351 | 105.631 | 63.66      |
| 55  | Ibn Blal 1 Street       | 642.034 | 642.034 | 100   | 0           |
| 56  | Ibn Blal 2 Street       | 1255.248 | 1255.248 | 100   | 0           |
| 57  | AL-Sekaa                | 752.551 | 670.288 | 112.272 | 82.263     |
| 58  | AL-Shahrstane           | 436.801 | 436.801 | 100   | 0           |
| 59  | AL-Mdares 1             | 692.233 | 692.233 | 100   | 0           |
| 60  | AL-Mdares 2             | 555.213 | 555.213 | 100   | 0           |
| 61  | AL-Szwenea              | 2760.702 | 2736.989 | 100.866 | 23.713     |
| 62  | Mesan-Askaree 1         | 486.116 | 486.116 | 100   | 0           |
| 63  | Mesan-Askaree 2         | 548.338 | 548.338 | 100   | 0           |
| 64  | Mesan-Askaree 3         | 850.476 | 850.476 | 100   | 0           |
| 65  | Tjawez 2                | 1185.095 | 1185.095 | 100   | 0           |
| 66  | AL-Senaee 1             | 1438.993 | 1438.993 | 100   | 0           |
| 67  | AL-Senaee 2             | 563.270 | 563.270 | 100   | 0           |
| 68  | Kornesh street 1        | 1774.815 | 1765.770 | 100.512 | 9.045      |
| 69  | AL-Kornesh street 2     | 1323.030 | 1252.614 | 105.621 | 70.416     |

Source: Depending on the spatial database
6.4 Grid Trip Proportion GTP

The grid-tree proportion (GTP) (Sreelekha et al., 2016) index for road connectedness and the crossing factor (CF) (Xie and Levinson, 2007) for road density are selected from existing pattern indexes. Various indexes describing the relationship between the number of roads and the number of intersections has been proposed in the field of quantitative geography (Gastner and Newman, 2006). An index for connectedness is expanded to make it possible to assess the relationship in a square grid road network, and is defined as the GTP index as

$$\text{GTP index} = \frac{e^{p} - v + p}{(\sqrt{v} - 1)^2} = 0.841$$

The relationship between the total length of road and the number of intersections has been studied mainly by using a random line model based on integral geometry, in which random straight lines are treated as a road network.

6.5 Density of roads to the area and the number of population

This indication represents the economic development for the area and it also gives an idea about the number of roads whether it is sufficient with the geographical area in order to evaluate the performance of these roads in the area understudy (Buyong, 2007).

The density of roads to the area= lengths of the roads (km)*1000/(the area served by roads (km²)) ……..(9)

The density of roads in Al-Kufa City = 117.3965*1000/49.4422=2374.419 km/1000km².

Therefore, this density in the city is higher than the standard specification (105km/1000km²)

The density of roads to the population could be determined as:

The density of roads to population=lengths of roads (km)*100,000/population………………(10)

=117.3965*100,000/185,232

So, the density for 2018 is 63.3 km/100,000 people. This value is less than the standard specification which is (496km/100000people) (Buyong, 2007).

7. Discussion of the results

Having determined the results of connectivity, the Beta index is 1.53 which means that more than one network in the city. Whereas, Gamma index was found to be 0.53 which indicate there is a need for 26 links. However, the alpha indicates there is a need for 4 links. Therefore, all indices of connectivity demonstrate that there is a need for more links in the network.

On the other hand, the spreading degree indicates that there is a wide spread in the network and nodes are away from each other because Eta index is 14.30 while first betty index is 27. In addition, detour index is approximately demonstrating that most roads are straight. Among other measures, correlation index shows very weak correlation of the network. On the contrary, the density of roads in the city to the area and the number of population is 6772.435km/1000km² which is too much higher than standard value (105km/1000km²) whereas, the density of roads to population (182.628km/100000) is less than standard value (496km/100000people). Finally, the ratio of roads to vehicles is 8.80m which is inadequate.

8. Conclusion and recommendation

The main conclusions of this study could be summarized as:

1. The connectivity indications for Al-Kufa city show weak connectivity according to its indices. The values of α, β and γ are 0.25, 1.47 and 0.5, respectively.
2. The coverage indication of the network shows, according to Eta index, widely spread and there is no closeness among nodes. This indication, according to first Betty index, demonstrates a huge spreading for the network in its region.
3. The detour index states that Al-Kufa roads are efficient.
4. The correlation index indicates that the degree of correlation among roads (links) is weak.
5. The density of roads to the area of the city is higher than the ideal value; whereas the density of roads to population is less than the ideal value.
6. There is a need for putting a plan for the city to avoid the lack of the network which in return will help increasing the efficiency of road network.

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