Traffic Assignment of Al-Kufa City Using TransCAD

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Abstract. Modern urban cities around the world suffer from high congestions due to high daily trips for different purposes. Al-Kufa city has a lot of congested roads in its road network. The main objective of this study is to evaluate the current traffic situation. Firstly, the number of links and nodes has been counted using GIS software. These links represent major and minor arterials. The collected data include flow, speed and geometric characteristics for each link and node in the network. The traffic assignment model (Stochastic User Equilibrium) in TransCAD software was adopted in this study. The results indicated that the value (v/c) for most of these roads is more than one which indicated congested roads.

Keywords: Al-Kufa city, traffic assignment, TransCAD, stochastic user equilibrium.

1. Introduction

In 1907, the first transportation mean appeared in Al-Kufa city. This was the tramway operated 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 road area for each person is 25m²; however, this value is 15.8m² per capita in 2007 and 16.03m² per capita in 2013 (Al-Kalaabee, 2017). These values are less than the standard value. Therefore, it can be concluded that there is a lack in the roads which may lead to traffic congestion.

In addition, the rate of car ownership per household increases from 0.43 in 2003 to 0.92 in 2013 for middle regions in Iraq such as Najaf, Babylon and Al-Qadisiyah cities which includes Al-Kufa city, in
addition to the annual traffic growth rate during the last 10 years is found about 11.5% which was higher corresponding the population rate 3.14% (Al-Obaedi, 2019).

Al-Jameel and Yahya (2017) reported that Al-Najaf city suffers from a lack in the road hierarchy. They found that the number of arterials and ring roads is insufficient to provide both accessibility and mobility in the city. It means that the land uses are spread over a wide area and the population density is distributed in an irregular manner, and thus the movement and access is difficult in the city. This leads to interconnected traffic with public streets within the residential areas that are not protected from the heavy traffic.

The objective of this study is to evaluate the current traffic status at the Al-Kufa network using TransCAD and GIS software in addition to field data collected by different means.

2. Literature review
In most Iraqi cities there is limited or no comprehensive published planning transportation studies or even traffic management (Qasim, 2015). Abedali and Qasim (2017) used TransCAD version 4.5 to model traffic assignment in Al-Amarah city using stochastic user equilibrium with exclusion of the local roads. The results indicated that most roads in the city with Level of Service LOS (D) in the base year (2015). However, the performance of the city network indicated that LOS (F) was found for most of the roads in the city center in 2035.

Qasim et al., (2017) evaluated the network of Nasiriyah city which the capital of Thi-Qar province in south of Iraq. This evaluation was achieved using several softwares such as TransCAD, GPS and GIS. The analyzed results demonstrated that few roads in the city centers suffered from high congestion with value of v/c was equal or more than 1.0 whereas other roads in the city with LOS (B) which represented good performance.

Alwash (2019) implemented an evaluation of Al-Hilla road networks just for major and minor arterials using GIS and TransCAD programs. The results reveal that there is a need for new roads to tackle the congestion in both current case (2018) and future case (2030).

Having reported the aforementioned studies in few Iraqi cities; Al-Kufa city has no such comprehensive study. Therefore, the current study aims to assign the flow of traffic for each major road in the city and investigate the performance of these roads.

3. Methodology
The main steps of this study could be summarized as: firstly, describe and determine the boundaries of the study area. Secondly, identify the required links and nodes in the network using GIS tool. Thirdly, collect the required traffic data and general information using field surveys and questionnaires. Finally, evaluate the current traffic condition using stochastic user equilibrium in TransCAD.

4. Study area
The city of Al-Kufa is located at the intersection of longitude (44-19)° east and latitude (31-59)° north. It is located in the southwestern part of Iraq as shown in Figure 1, the city of Al-Kufa is located in the eastern side of the province of Najaf, and is located to the western side of the Al-Kufa river, which is an important branch of the Euphrates River. The city of Al-Kufa is an important urban center for the province of Najaf. It is bordered to the north by the Kafel region (Babil Governorate), with a distance of (20 km), from the east by the Abbasiyya area, by a distance of (5 km), and from the west by the city center of Najaf, and from the south by the Manadhrah district, by a distance of (12 km). Al-Kufa city is (160 km) from Baghdad.
Figure 1. Location of A-Kufa City (Source: Directorate of Statistics Najaf Governorate, 2015).

Given the importance of the historical and religious center within it, the city has become a popular gathering place for a large number for visitors, which gave it a local importance that contributed directly to the city's development and urban growth.

The city of Al-kufa is one of the attractive cities for visitors because of the religious factor where the city contains a number of religious shrines, including the mosque of Al-Kufa and shrine of Muslim Ibn Aqil and Hani Ibn Erwa, as well as containing the house of Imam Ali and AL-Sahla mosque and shrine of Ibrahim AL-Gammer. The inhabitants’ growth rate is 2.5% according to (Directorate of AL-Najaf Statistic). Table 1 shows the growth in population for the last 47 years.

| Year | Population |
|------|------------|
| 1965 | 77813      |
| 1977 | 304632     |
| 1987 | 77279      |
| 1997 | 97626      |
| 2009 | 162452     |
| 2013 | 157845     |
| 2016 | 161711     |
| 2018 | 185232     |

5. Distribution of Arterials at Al-Kufa City

This study focuses on just major roads and excludes local streets and minor collectors. These main streets are:

The main streets in the city link the old city of Al-Kufa with its provinces in several directions, including:

- (Kufa –Najaf Street): which connects the city of Al-Kufa and the city of Najaf, and
- Al-Maemal Street: which starts from the bridge to the direction of the cement factory Kufa and from there to Al-Manathira.

- Airport Street: it is one of the main streets in Najaf, where it was built a few years ago and starts from the airport towards the Al-Kufa river, passing through Al-Ma'mal Street, Al-Malaab Street and Maitham Al-Tamar Street.

- Hospital Al-Sadir Street: it is the street that extends from Sadir Hospital to the Palace of Culture,
passing through the University of Kufa (Engineering Gate), and this makes it is always crowded, especially during peak times.

Main Maysan Street: it is one of the main entrances to the city of Al-Kufa, through the Mukhtar tunnel.

Whereas, the minor streets are the second phase in the city of Al-Kufa through the traffic density include:

1. Al-Jsir Street: It passes the old city in the northeast of Al-Kufa Mosque and limits the Waqf and Al-Judidat and the bridge runs through the Euphrates and has a high traffic density.
2. Sikka Street: It passes through the Al-Saray and Al-Jadidat and is linked to Muslim Bin Aqil street where it travels the Al-Jumhuria and Al-Waqq.
3. Al-Sahla Street: Consists of four lines leads from the Mosque of Al-Kufa towards the Mosque Al-Sahla.
4. Cornish Street: Starting from the southern sections of the city center along the side of the river, passes Al-Judidat and Al-Saray to the north off Al-Kufa.
5. Al-Jumhuria Street: It is characterized by less traffic density, there are main streets within the neighborhoods, often separating the neighborhoods.
6. Maitham Al-Tamar Street: it is the road between Al-Matar Street and Kufa-Najaf Street, passing through Maitham Al-Tamar neighborhood.

6. Data Collection
The main aim of collecting data is to gather all data that would be necessary to investigate the circumstances of traffic flow at the study area. The main types of these data are:

1. Geometric features (e.g., lane width for each approach, no. of lane per approach and so on).
2. Data of traffic flow which included; traffic volume of vehicles at peak period and vehicles classification (passenger car, bus, motor cycle).
3. Traffic regulator information like; the type of signal control that used in the intersection and the type of traffic control, signal cycle length and phases information.
4. The speed data at each internal link in the network.

7. GIS Analysis
Arc GIS 10.5 has been used to prepare three types of shape files. These files are links, nodes and sectors which were developed by observing the satellite image and the master plan as shown in Figure 2. Al-Kufa municipality has divided the city into four sectors according to the land use as demonstrated in Figure 2. In addition, different characteristics have been obtained from the Arc GIS such as geometric design such as length, width and number of roads as illustrated in Figure 3.

Beta (β) index
The main part of spatial analysis of road network is to develop graph theories depending on links (edges), nodes (vertices), etc. It is possible to compute the degree of complexity of road network as follows:

- Number of edges (e) =69
- Number of vertices (v)= 45
- Number of separate non-connecting sub-graphs (p) =3

The beta β index, which is also called as the link-node ratio, determines the "completeness" of a graph.
The index determines the level of connectivity of the transport network. The $\beta$ index is found as follows: (Buyong, 2007)

$$\beta = \frac{e}{v} \quad \cdots \quad \cdots \quad (1)$$

**Figure 2. Sectors Divisions of Al-Kufa City**

The $\beta$ index is in fact $1/2$ of the average number of links servicing each node and it represents the circulation of road network. It varieties between (0) and (3) for most route networks. If a value of $\beta$ is less than one, this means a branching like network. If a value of $\beta$ is greater than one, this indicates an increasing complication (very well connected network). Hence; $\beta$ index discriminates simple topological structures from complex topological structures. The value of $\beta = \frac{e}{v} = \frac{69}{45} = 1.533$

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

The alpha index utilizes the conception of a circuit- a finite, closed path starting and ending at a single node (Dill, 2003). This index for connectivity is the ratio of the number of fundamental circuits to the maximum possible number of circuits which may be in a network. This alpha index is a measure of the redundancy or duplication in the system. This index determines the ratio of the number of observed fundamental circuits in a graph to the maximum number of fundamental circuits which may occur (Morlock, 1967). This index is calculated as follows (Buyong, 2007):

$$\alpha = \frac{e-v+p}{2v-5} \quad \cdots \quad \cdots \quad (2)$$

The $\alpha$ index compares the number of closed circuits in a network ($e-v+p$) against the maximum possible number of circuits which it might have ($2v-5$) and it is measuring of rotation (density of road network in specific area). The value ranges between zero and unity. A higher value of $\alpha$ Indicates a higher possible level of connectivity. $\alpha = \frac{69-45+3}{2*45-5} = 0.317$. These values will be used in the TransCAD software. This means that the connectivity is very low and there is a need for (61) links to satisfy the required connectivity degree.
8. Determination of Peak Hour Periods

The most congested period for traffic data collection predicted by various individual observations and survey, using video camera, was implemented in the selected area. Many personal interviews; interviewing people face to face, have also been achieved with many concerned people such as; policemen, owners of shops and offices at the study area and different road users. These observation and survey showed that there were two peak periods at (7:30-9:30 A.M.) and (1:30-4:30 P.M.) for typical weekdays (Sunday, Tuesday, Thursday and Friday). Intersections were collected by field measurement that data was collected during morning peak hour (7:30-8:30 A.M.).

It could be noticed that the traffic volumes passing through selected intersections (that located in entertainment places and shopping centers) were approximately equal during all the weekdays. Whereas there were big differences in the traffic volumes between the workdays and the weekend in the intersections located at the school zones and governmental buildings.

9. Data Collection and Implementation

In order to achieve the aims of the study, different types of data from different sources were needed. There are:

1. Official data:

These data collected from different organizations and they are:

- The number of household and population and growth factor for each year obtained from Directorate of AL-Najaf statistics.
- The number of vehicles and classification according to type which is obtained from AL-Najaf Traffic Police Directorate.
- Maps for AL-Kufa city provided by Municipality Directorate.
2. Socioeconomic data:

These data can be collected using design questionnaire forms which include socioeconomic characteristics such as income, household size, vehicle ownership.

3. Manual count

The manual count method utilized in the traffic data collection reflects the existing traffic characteristics of the study area. Traffic volume studies are implemented to find the degree, movements and classification of road vehicles in the significant location.

These data can help in determining critical flow times, or determining the effect of large vehicles or the flow of pedestrian traffic, or document traffic trends. The length of the sampling period bases on the kind of count taken and the intended use of the recorded data. For example, the interactive count is performed during the peak flow period where the manual count can be used with 5-minute intervals to get traffic flow data.

Traffic count was achieved on 1/12/2019 for the period from 7:00 am to 9:00 am. The count was implemented on normal working days: Sunday, Monday and Tuesday, which are the typical count days. The data were categorized according to the class of vehicle and according to the direction. For each movement, traffic volume was categorized into five kinds by the vehicle type. The first category refers to private cars. The second kind represents buses, inclusive of all vehicles with passenger capacity of 22 persons. The third kind refers to minibuses. A truck is any vehicle with two or more axles and it represents the fourth kind. The fifth kind refers to bikes and motorcycles; this is shown in Table 2.

The traffic volumes accounted per hour and per maximum 15 minute for each link in both directions in the network for peak hour. As shown in Table 3 and Figure 4 shown number of each link.

10. Traffic Volume Data for Intersections and roundabout

These data include counting the traffic volumes extracted from a video recording for each leg at the intersections and roundabout in the chosen network, also, traffic composition and the volume of turning movements. The data are required for this software for each intersection alone. Many runs were implemented to exclude the bias data. SIDRA INTERSECTION 5.1 software was used to analyze the existing traffic flow patterns for intersections roundabouts as isolated at the study area. Table 4 indicate the output results of simulation runs include the degree of saturation, total delay, and level of service for each intersection in the study area for peak hour. All the output results are categorized by medium to high total delays, thus the level of service for these intersections are shown in Figure 5 (a, b and c).
Table 2. Part of Numbers and Percentages of Transportation used in the Study Area.

| Investigated Street | Dir. | PC % | BUS % | MB % | HV % | MT % | % |
|---------------------|------|------|-------|------|------|------|---|
| Kufa-Najaf1         | AB   | 77.2 | 43    | 1.8  | 411  | 17.3 | 12 | 0.5 | 75  | 3.2 |
| BA                 | 2914 | 79   | 37    | 1    | 457  | 12.3 | 90 | 2.4 | 194 | 5.3 |
| Kufa-Najaf2         | AB   | 67   | 40    | 2.8  | 250  | 17.4 | 100| 7   | 150 | 10.4|
| BA                 | 864  | 63.3 | 30    | 2.2  | 250  | 18.3 | 100| 7.33| 120 | 8.8 |
| Kufa-Najaf3         | AB   | 67   | 40    | 2.8  | 250  | 17.4 | 100| 7   | 150 | 10.4|
| BA                 | 864  | 63.3 | 30    | 2.2  | 250  | 18.3 | 100| 7.33| 120 | 8.8 |
| Al-Kornich          | AB   | 945  | 82.7  | 1    | 0.08 | 56   | 4.9 | 82  | 7.2 | 59  | 5.2 |
| BA                 | 969  | 85.6 | 1     | 0.08 | 45   | 3.9  | 72 | 6.4 | 44  | 3.9 |
| Al-Sikaa            | AB   | 250  | 74    | 0    | 0    | 12   | 3.5 | 20  | 6   | 56  | 16.5|
| BA                 | 185  | 70.6 | 0     | 0    | 38   | 14.5 | 16 | 6.1 | 23  | 8.7 |
| Al-Sahla            | AB   | 457  | 66.6  | 2    | 0.3  | 103  | 15  | 49  | 7.1 | 75  | 11  |
| BA                 | 436  | 73   | 1     | 0.2  | 88   | 14.7 | 38 | 6.4 | 34  | 5.7 |
| Al Memail           | AB   | 894  | 66.9  | 5    | 0.4  | 197  | 14.7| 106 | 7.9 | 133 | 9.9 |
| BA                 | 862  | 72.5 | 4     | 0.3  | 122  | 10.3 | 111| 9.3 | 89  | 7.5 |
| Al-Takaa and Al-Mutanabe | AB | 382  | 82.5  | 3    | 0.65 | 27   | 5.8 | 35  | 7.5 | 16  | 3.45|
| BA                 | 301  | 84.5 | 1     | 0.3  | 18   | 5.1  | 14 | 3.9 | 22  | 6.2 |
| Kure Saada          | AB   | 1996 | 82.6  | 5    | 0.2  | 120  | 4.96| 164 | 6.8 | 131 | 5.4 |
| BA                 | 1309 | 82.8 | 8     | 0.5  | 99   | 6.3  | 91 | 5.7 | 74  | 4.6 |
| Maysan Al Rayiysi   | AB   | 1942 | 77.8  | 5    | 0.2  | 322  | 13  | 71  | 2.8 | 154 | 6.2 |
| BA                 | 855  | 62   | 6     | 0.43 | 283  | 20.5 | 119| 8.6 | 115 | 8.3 |
| Hospital            | AB   | 1628 | 84.8  | 9    | 0.47 | 48   | 2.5 | 112 | 5.8 | 121 | 6.3 |
| Al-Sadir            | BA   | 1473 | 92.7  | 12   | 0.75 | 47   | 2.9 | 18  | 1.1 | 39  | 2.4 |
| Al Sharit           | AB   | 104  | 70.2  | 2    | 1.4  | 13   | 8.7 | 12  | 8.1 | 17  | 11.5|
| BA                 | 104  | 70.2 | 2     | 1.4  | 13   | 8.7  | 12 | 8.1 | 17  | 11.5|
| Muslim bin Aqeel    | AB   | 760  | 65    | 5    | 0.42 | 285  | 24.4| 68  | 5.8 | 51  | 4.3 |
| BA                 | 979  | 61.3 | 2     | 0.12 | 340  | 21.3 | 113| 7.1 | 162 | 10.2|
| Al-Jiser and bridge | AB   | 1004 | 76    | 1    | 0.07 | 135  | 10.2| 78  | 6   | 103 | 7.8 |
| BA                 | 955  | 70.5 | 0     | 0    | 198  | 14.6 | 92 | 6.8 | 108 | 7.98|
| Imam Ali and bridge | AB   | 2190 | 81.4  | 4    | 0.15 | 187  | 7   | 128 | 4.7 | 181 | 6.7 |
| 1.2                | BA   | 1326 | 78.5  | 3    | 0.2  | 60   | 3.5 | 119 | 7   | 180 | 10.6|
| Almazari            | AB   | 440  | 61.6  | 4    | 0.56 | 100  | 14  | 90  | 12.6| 80  | 11.2|
| 1.2                | BA   | 380  | 63    | 4    | 0.66 | 86   | 14.3| 53  | 8.77| 81  | 13.4|
| Sahla               | AB   | 466  | 50    | 5    | 0.5  | 200  | 21.4| 112 | 12  | 150 | 16.1|
| Maysan              | BA   | 1215 | 66.1  | 4    | 0.22 | 328  | 17.8| 139 | 7.55| 153 | 8.32|
| Sahilia             | AB   | 443  | 62.1  | 4    | 0.56 | 112  | 15.7| 78  | 10.9| 76  | 10.5|
| BA                 | 392  | 64   | 3     | 0.48 | 84   | 13.7 | 53 | 13.5| 81  | 20.6|

*PC= passenger car, **MB= mini bus, TR=Truck, ***MT= motorcycle), *AB and *BA mean trips in direction AB and BA.
### Table 3. Samples of links flows of Al-Kufa network.

| Investigated Street   | Direction | flow (veh/hr) | Link Number |
|-----------------------|-----------|---------------|-------------|
| Kufa-Najaf1           | AB*       | 3044          | L6          |
|                       | BA*       | 4092          |             |
| Kufa-Najaf2           | AB        | 1464          | L22         |
|                       | BA        | 1392          |             |
| Kufa-Najaf3           | AB        | 1464          | L23         |
|                       | BA        | 1392          |             |
| Al-Kornich            | AB        | 1256          | L28, L33    |
|                       | BA        | 1264          |             |
| Al-Sikaa              | AB        | 420           | L67         |
|                       | BA        | 332           |             |
| Al-Sahla              | AB        | 776           | L8, L26     |
|                       | BA        | 720           |             |
| Al Meamal             | AB        | 1488          | L20, L21    |
|                       | BA        | 1324          |             |
| Al-Takaa and Al Mutanabe | AB       | 652           | L7, L25     |
|                       | BA        | 560           |             |
| Kare Saada            | AB        | 2648          | L4, L24     |
|                       | BA        | 1744          |             |
| Maysan Al Rayiysi     | AB        | 2756          | L66         |
|                       | BA        | 1720          |             |
| Hospital Al-Sadiri t  | AB        | 2072          | L5          |
|                       | BA        | 1960          |             |
| Al Sharit             | AB        | 150           | L1          |
|                       | BA        | 150           |             |
| Muslim bin Aqeel      | AB        | 1332          | L49, L51    |
|                       | BA        | 1724          |             |
| Al-Jiser              | AB        | 1416          | L52         |
|                       | BA        | 1420          |             |
| Imam Ali and bridge   | AB        | 2756          | L31, L32    |
|                       | BA        | 1720          |             |
| Kofa-Abasya           | AB        | 550           | L34, L55, L62, L64 |
|                       | BA        | 500           |             |
| Almazarie 1, 2        | AB        | 800           | L48, L65    |
|                       | BA        | 700           |             |
| Sahla Maysan          | AB        | 1904          | L3          |
| Sahilia               | AB        | 800           | L10         |
|                       | BA        | 700           |             |
Figure 4. Number of links in Al-Kufa city.

Table 4. Results of Analysis Intersections and Roundabouts by SIDRA 5.1 Intersections for Existing Condition.

| Intersection Code | Intersection Name       | Max. Degree of saturation (V/C) | Average Delay (sec/veh) | LOS |
|-------------------|-------------------------|---------------------------------|-------------------------|-----|
| 1                 | Al-Najaf Hospital       | 6.085                           | 463.7                   | F   |
| 2                 | Al Shahrstani Roundabout| 1.654                           | 278.1                   | F   |
| 3                 | Habib Al Raash Roundabout| 1.087                           | 46.9                    | D   |
Figure 5. LOS analysis of intersection (T-intersection) and Roundabouts.

11. Public Transport at Al-Kufa City

The structure of public transportation varies from place to place and according to the transportation infrastructure and means of transportation that the population can travel. As for the city of Al-Kufa, public transportation depends on minibuses, whose passenger numbers range from 11-14 passengers. These buses do not have private parking spaces, but according to the desire of the passengers. Other significant things are absence of timetable for these public transportation lines. Actually, no suitable stations are available through the city. Furthermore, all these vehicles utilized as public transportation are for private sector (each vehicle has private owner not belong to the government) therefore, no uniform label (such as bus No.) for these buses even the distributed lines and routes of these buses are out of control. Subsequently, no control on the public transportation could be forced. Moreover, the
characteristics enjoyed by minibuses of capacity between 11 to 14 passengers are the deficiency of stops, speed and freedom to maneuver in traffic at traffic jams and exceeding the time taken to complete the number of passengers provided it many sources of attraction. These minibuses provide flexibility for public transportation than buses because the number of passengers is less than buses. Moreover, they can stop anywhere without depending on regular stops.

12. Existing problems of Al-Kufa Roads Network

The existing conditions issues concerning transportation system in Al-Kufa included the following:

- Extreme obstruction of traffic at peak hours due to lack of traffic management;
- Illegal parking and lack of rules on parking.

The main road to Al-Kufa-Najaf, there are a lot of vehicles standing parallel parking on road side, these vehicles leads to reducing the street capacity from three lanes to two lanes. Therefore, just one lane is used for traffic movement in the following sections:

1. Section from Al-Najaf hospital to the holy shrine Maitham Al-Tamar.
2. Section close to Muslim-Tunnel to the Al-Kufa old bridge.
3. Al-Sikah street.
4. The section between Al-Raash Roundabout to Al-Shahristani Roundabout.

Therefore, on-street parking (using strict traffic enforcement) along the main road network must be prevented parking vehicles and adequate off-street parking spaces (parking and garages) must be installed.

13. Traffic assignment model

The traffic assignment model, which is available in the TransCAD Software 4.5, stochastic user equilibrium model was adopted in this study.

A. Input parameters

The main inputs required for this model are road network file and origin-destination (O-D) matrix file. Firstly, the road network file can have imported from GIS software as in this study which has the characteristic of the road network such as Identify Data (ID), length, width, number of lanes, direction of flow, capacity, flow and speed for each link. Furthermore, the characteristics of each node, which represents intersection, such as ID and x-y coordinates.

Secondly, the O-D matrix is the simplest way to represent the travel demand between the selected sectors which are Sectors 1, 2, 3 and 4. Without such matrix, TransCAD can't operate in addition to starting and ending trips at some discrete points in the city network. That is why centroid nodes have been employed to overcome this problem. The centroid point is the geographic center of a sector. Therefore, these centroids will not be connected to the road network, a new set of links, call centroid connectors are created to make connection. Table 5 represents Al-Kufa city peak hour O-D matrix among sectors.

Another type of data is required for traffic assignment, the external- external traffic volume; trips start and end outside the study area; which should be located on the road network links. Then, the external and internal matrixes are combined together into one matrix.
Table 5. Al-Kufa City Peak Hour O-D matrix (vph)

|       | Sector 1 | Sector 2 | Sector 3 | Sector 4 |
|-------|----------|----------|----------|----------|
| Sector 1 | 0        | 4367     | 5615     | 1787     |
| Sector 2 | 421      | 0        | 10029    | 1137     |
| Sector 3 | 2046     | 4806     | 0        | 1828     |
| Sector 4 | 1081     | 3559     | 2746     | 0        |

B. Performing a traffic assignment

After preparing the O-D matrix with the suitable ESRI shape files (with all required data as mentioned above), the execution of the program using stochastic user equilibrium with a default number of iterations which are 20 per assignment is performed. The outputs of the program are exported to specific files.

Mainly, trips for each O-D pair are then allocated to the links in the minimum path and the trips are added up for each link as indicated in Figure 6. The allocated flow is then compared with the capacity of each link to find out if it congested or not. If a link is congested the travel time is adjusted to result in a longer travel time on that link. Consequently, changes in travel time means that the shortest path may change. This process is replicated several iterations until there is an equilibrium between travel demand and travel supply. The results of stochastic user equilibrium model indicated the LOS for each link in terms of (v/c) according to the value demonstrated in Table 6.

Figure 6. Flow map for Kufa network morning peak.
Table 6. Relationship between v/c ratio and LOS for Urban Roads (HCM, 2010)

| LOS | V/C Ratio | Operating Condition                      |
|-----|-----------|------------------------------------------|
| A   | 0.00-0.50 | Free flow conditions                     |
| B   | 0.51-0.70 | Reasonably unimpeded operations          |
| C   | 0.71-0.80 | Generally stable operations              |
| D   | 0.81-0.90 | Approaching unstable conditions          |
| E   | 0.91-0.99 | Significant delays and low average speed |
| F   | ≥1        | Severe congestion and delays             |

Therefore, a lot of links with (v/c>1.0) LOS F have been observed as indicated in Figure 7. These roads with (v/c>1.0) are always for roads carrying trips towards University of Kufa. These links need more improvements to mitigate traffic congestion such as preventing parking and convert some of these intersections discussed above to interchange.

Figure 7. Stochastic User Equilibrium Method Assignment Model Result.
14. Conclusions
The main significant points of this study could be summarized as following:

1. The activities of the network have two main centers: the first is the University of Kufa in Sector 1 and the second is the city center of Al-Kufa which is close to the river.
2. The network suffers from high congestion with links of (v/c) close and higher 1.0 especially Al-Kufa-Najaf and Najaf-Miasan Roads.
3. There is a need for adding more road to satisfy the network connectivity along with reducing the congestion.

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