Evaluating Urban Streets and Public Transportation in Karbala City Using GIS

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Abstract. Because of the privilege of the city of Karbala with its religious character, this city has become a destination for all visitors from all cities of the world; as a consequence, there are now more people living in Karbala, which has increased the number of vehicles on the road and, consequently, the amount of traffic congestion. In this study, the degrees of public transportation service in the city of Karbala as well as the urban road network, were assessed using GIS. The collected data include the number of nodes, links, and the total length of Karbala's urban road network using a GIS program and traffic composition (bus and minibus). Then, a set of coefficients for evaluating the urban road network was calculated) $\boldsymbol{\beta}$- Index, $\boldsymbol{\alpha}$- Index, $\boldsymbol{\gamma}$- Index, $\boldsymbol{\eta}$-Index and GTP- Index), After determining the percentage of buses and minibusses, it became clear that public transportation in Karbala is very weak and needs development, as the percentage of buses and minibusses did not exceed 30% of the total traffic volume.

Keywords: Urban Streets, GIS, Public Transportation, and Number of Vertices.

1. INTRODUCTION

An urban street is defined as a public road with at least one traffic light every two miles [1]. Streets have many uses, including moving people and goods. Therefore, these many and varied uses must be reflected in the design and management of streets [1]. The hub of economic activity is the urban transportation system, which serves all urban areas worldwide. It thus guarantees the inhabitants' survival. Roadways, railways, airports, and waterways are all common forms of transportation in cities' mobility. These roads make up the majority of them. Most metropolitan centers' economic activity depends on the road transportation system [2]. The transportation sector is impacted by a wide range of external social and economic factors, such as population demographics, living standards, urban planning, production organization, societal structural changes, and access to transportation infrastructure [3]. Rapid urbanization in emerging nations has resulted in inadequate transportation infrastructure and amenities, which has caused traffic congestion, travel delays, high travel costs, noise pollution, and air pollution, all of which have impeded economic growth [4]. Due to the importance of the road network in daily life, it was necessary to find ways to evaluate the road network, and there are different methods for evaluating the road networks. Among these methods that were relied upon in the study to evaluate the Karbala Road network are the extraction of coefficients $\boldsymbol{\beta}$-index, $\boldsymbol{\alpha}$-index, $\boldsymbol{\gamma}$-index, $\boldsymbol{\eta}$-index, and GTP index. A study was conducted to evaluate the Karbala network and evaluation of Karbala. This research focused on the road network for Karbala city, a major center in the Arabic and Islamic world. It was necessary to apply spatial network analysis, which included determining the type of road network, analyzing accessibility between its nodes, and calculating the density of roads. Data was collected from the field and governmental institutions.

This study applied equations of elementary graph theory to the road network, evaluating models for the accessibility between nodes and calculating the density of roads according to area, population, and number of cars. The results were convergent, with the node (62) in the intersection between AL Hussain, AL Jahez, and AL Iskan districts having the first rank and the node (80) in the intersection between Al Yarmook, AL Amel, and AL Gadeer districts having the last rank. [5] Due to the increase in private cars and motorcycles causing traffic jams, excessive travel times, greenhouse gas emissions, noise, traffic accidents, and energy consumption, improving public transportation systems and raising their attractiveness. A solution to mitigate these problems [6, 7]. An effective public transportation system is a very valuable resource since it significantly contributes to meeting people's needs for carrying out their everyday activities [8.9]. The importance of public transportation enables energy conservation, reduced air pollution, improved mobility, reduced traffic accidents, and enhanced road safety. However, you do not find these privileges well available in developing countries because they are non-existent or incomplete despite the increase in the population and the growth in the number of vehicles [10]. The city of Karbala, like other cities in Iraq, lacks this type of transportation, forcing the citizens to buy expensive cars and motorcycles, which increases the possibility of traffic accidents, noise, pollution, and traffic congestion. Because the city of Karbala has a religious and tourist nature, it is visited by millions of people worldwide. To visit the shrine of Imam Hussein and his brothers, Imam Abbas [11].

In recent years, spatial road network analysis has been performed using modern methods such as Geographic Information Systems (GIS). As the best tool for managing and analyzing information for many aspects of the transportation business, including both the public and commercial sectors, (GIS) is the transportation field that is growing at the fastest rate [12]. Type of the Street Network investigated the classification of road networks based on network traits that resemble trees. They assert that the four types of urban street networks shown in Figure (1) represent the majority of the city's street network designs [13.14]. 1. Purely tree-like network pattern (Figure 1-a). The area has observable backbone roads, T-type crossroads, and end roads, establishing a low-connected level network structure. Although it might be less resilient than others, this road network protects residents' privacy and traffic stability. 2. The network pattern of cul-de-sacs (Figure 1-b). Several trunk highways cross a region with several end-roads. This network provides reasonable access but may be less reliable on the inside than the others. The T-shaped network pattern 3 (Figure 1-c). This street network is similar to a purely grid-shaped network. T-type intersections, on the other hand, may increase the efficiency of trunk transportation while potentially lowering connection.4. Pure grid-like network pattern (Figure 1-d) Although this network is more connected, transportation efficiency is often lower due to the large number of intersections and short distances between them.

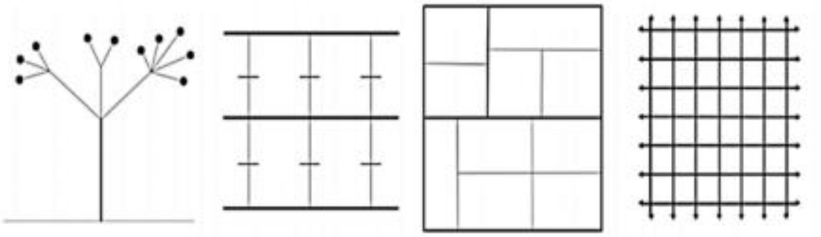

Figure 1: Tree-like structure of four types of urban street networks [14].

2. METHODOLOGY

The methodology included the following:

a. Determine the number of nodes and links tiled in the center of Karbala City and AL-Hur City using GIS.
b. The study area was divided into several regions shown in Figure 2 as area A represents agricultural areas, area B represents the newly opened residential neighborhoods that did not pave some of their streets, and area C represents the neighborhoods that will open in the future.
c. Determine the parameters ($\boldsymbol{\beta}$ (Beta) Index, $\boldsymbol{\alpha}$ (Alpha) Index, $\boldsymbol{\gamma}$ (Gamma) Index, $\boldsymbol{\eta}$ (Eta) Index, and Grid-Tree pattern index (GTP)).
d. Calculate the percentage of buses and minibusses from Al-Iskan Street, Ramadan Street, Fatima Al-Zahraa Street, Al-Abbas Street, Al-Baladiya Street, and Al-Tarbia Street. The bus and minibus ratio was calculated by installing cameras on the roads mentioned in Figure 2 for several days, and the day that contains the highest traffic volume (peak hours' volume) was determined and based on which the readings were recorded.

3. STUDY AREA

Within the Islamic community, Karbala is a well-known city. Its religious importance of it is well known. In the historic city or city center, you can visit the shrines of Imam Hussain and his brother Abbas. It is roughly 36 meters above sea level and situated between (41°, 10') and (44°, 20') longitudes as well as (32°) and (31°) latitudes. In the southwest of Baghdad, it is around 110 kilometers away. Al-Anbar province, Al-Najaf city, and Babylon city are their north, west, and south neighbors, respectively [15,16]. Figure 2 shows the location of the research region, which is the heart of the Karbala Governorate. This study focuses on a network of urban roads that connects the CBD with other commercial, industrial, residential, and educational districts. Six urban roads in Karbala city were used to collect traffic statistics. Fatima Al-Zahraa Street is a divided street in the city's heart, where a lot of business activity is concentrated. Al-Tarbia Street is home to numerous educational and retail establishments and sees heavy traffic, especially during peak hours. Al-Iskan Street is one of the busiest streets and has a lot of pharmacies and doctor's offices, especially in the evening. Ramadan Street is one of the most important commercial streets in the city of Karbala, where there are schools, universities, and shops. Al-Baladiya Street and Al-Abbas Street are also considered important commercial streets in Karbala.

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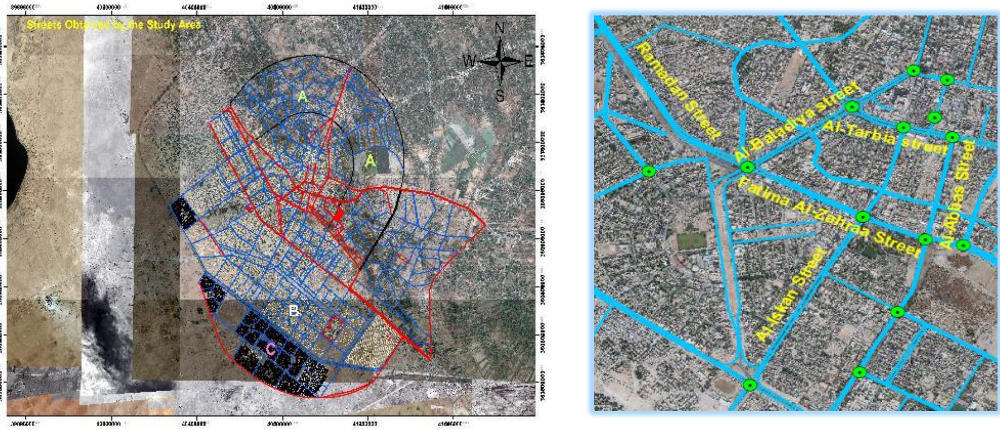


(A) (B)

Figure 2: Selected Study Area (A) and (B).

4. DATA COLLECTION AND ANALYSES OF URBAN STREET

The analyzed data for the urban road network of Karbala City are shown in the following paragraphs:

I. After calculating the number of nodes and links, the Road Network Characteristics ($\boldsymbol{\beta}$, $\boldsymbol{\alpha}$, $\boldsymbol{\gamma}$, $\boldsymbol{\eta}$, and GTP) will be calculated based on the following equations (1, 2, 3, 4, and 5), as shown in Table 1.

Where:

a) $\boldsymbol{\beta}$ (Beta) index, the $\boldsymbol{\beta}$ index is calculated according to Equation (1); the $\boldsymbol{\beta}$ index really represents the movement of the road network by being equal to one-half of the average number of links serving each node. Most route networks have a value between zero and three; a value below one implies a branching network, while a value above one shows growing complexity (a very well-connected network). Thus, the " $\boldsymbol{\beta}$ index" distinguishes between simple and complex topological systems [17].

$$\beta = \frac{e}{v} \tag{1}$$

b) $\boldsymbol{\alpha}$ (Alpha) index, the $\boldsymbol{\alpha}$ index is calculated according to Equation (2); the $\boldsymbol{\alpha}$ index measures rotation by comparing the number of closed circuits in a network (e-v+p) to the maximum number of circuits that might possibly be present (2v-5) (density of road network in a specific area). The value lies between 0 and 1. A higher value denotes a potential for greater connectedness [17].

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

c) $\boldsymbol{\gamma}$ (Gamma) index, the $\boldsymbol{\gamma}$ index is calculated according to Equation (3); the $\boldsymbol{\gamma}$ index measures the connection for a road network by comparing the actual number of edges in a network, e, to the maximum number of circuits that it may have (3(v-2)). The value lies between 0 and 1. A value closer to unity denotes a more linked network with more linkages, whereas a value closer to zero denotes a simpler network with fewer ties [17].

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

d) $\boldsymbol{\eta}$ (Eta) index, the $\boldsymbol{\eta}$ index is calculated according to Equation (4), the ε index, which determines the overall length, offers some indications of geographic scale; the edge length will shorten as a network is packed more densely into a region and has more connections. Consequently, it is anticipated that it will be high in underdeveloped networks and low in developed ones [17].

$$\eta = \frac{m}{e} \tag{4}$$

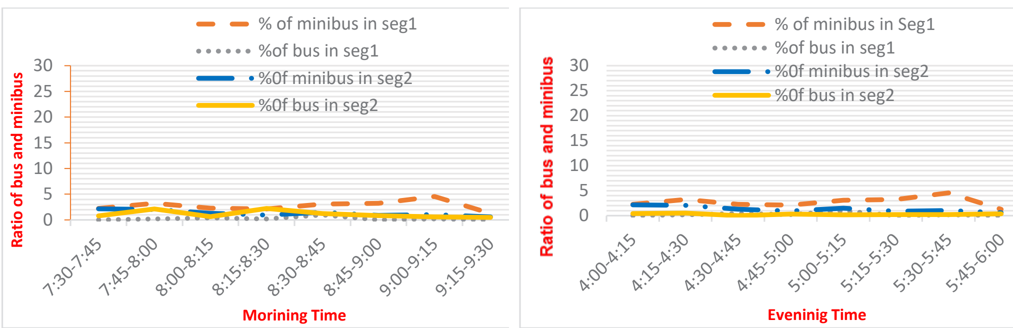
e) Grid-Tree Pattern Index (GTP) is calculated according to Equation (5); it is a measure of the network's pattern, with values ranging from 0 for tree patterns to 1 for grid patterns [18, 19]. Analyzed the connection between pedestrian-bicyclist collisions and found that more connectedness is associated with fewer non-motorized road user accidents [20]. Used graph connectivity metrics and road density to examine the geographic variation of West Bengal's road network layout. GIS-based technologies [21]. Utilized connectivity indexes to examine India's transportation networks.

$$\mathrm{GTP} = \frac{e-v+p}{(\sqrt{v}-1)^2} \tag{5}$$

Table 1: Road Network Characteristics in urban street of Karbala City.

Parameter	Value
v: The number of vertices (nodes)	V=82
e: The number of edges (links)	e=121
p: The number of separate non-connecting sub-graphs	P=18
m: The total network length	m=756.175km
β (Beta) Index	β=1.44
α (Alpha) Index	α=0.358
γ (Gamma) Index	γ=0.504
η (Eta) Index	η=6.249
Grid-Tree pattern index (GTP)	GTP =0.878

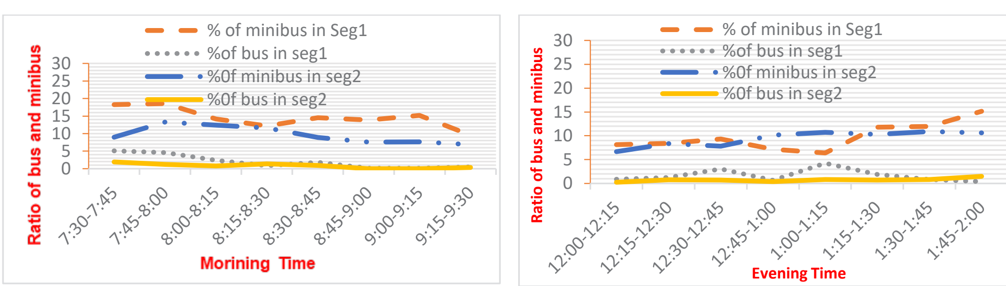
II. The bus and minibus ratio was calculated for the road shown in Figure 2 by calculating the traffic volume based on video recording for several days and choosing the peak hour during the morning and evening. The results are shown in Figures 3 to 7.



(A) (B)

Figure 3: The ratio of bus and minibus in Seg 1 and Seg 2 for Al-Iskan Street, (A) at Am time, (B) at PM time.

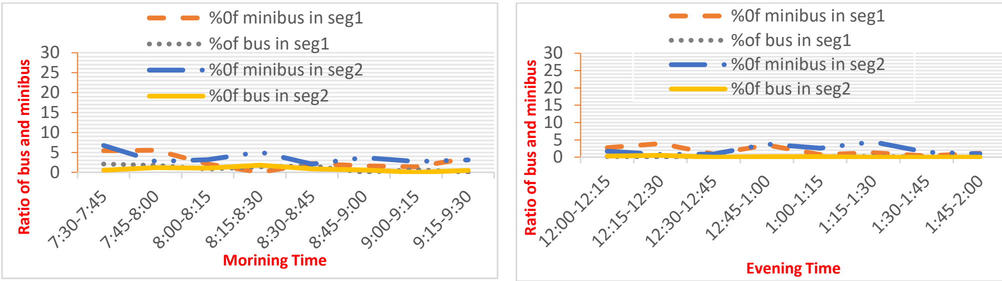
Figures (A) and (B) show the percentage of buses and minibusses in Al-Iskan Street and that the percentage of buses and minibusses did not exceed 10% of the total traffic volume at the morning and evening peak time. Although this street is one of the important streets in which doctors' clinics and commercial centers abound.



(A) (B)

Figure 4: The ratio of bus and minibus in Seg 1 and Seg 2 for Ramadan Street, (A) at Am time, (B) at PM time.

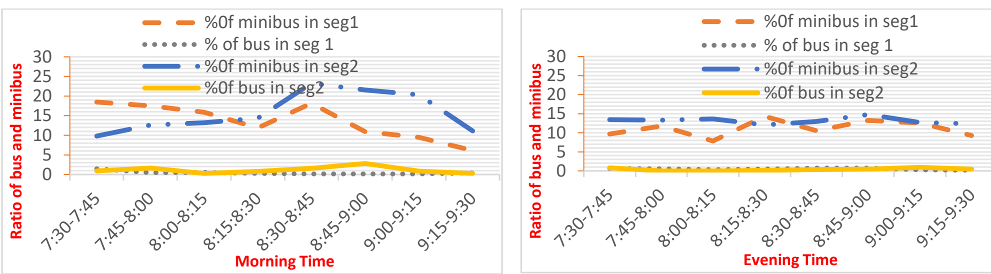
Figures (A) and (B) show the percentage of buses and minibusses on Ramadan Street and that the percentage of buses and minibusses did not exceed 20% of the total traffic volume during the morning and evening peak time. Although this street is one of the important streets in which commercial centers and schools abound, there are two universities, the University of Karbala and the University of Al-Sibtain.



(A) (B)

Figure 5: The ratio of bus and minibus in Seg 1 and Seg 2 for Fatima Al-Zahraa Street, (A) at Am time, (B) at PM time.

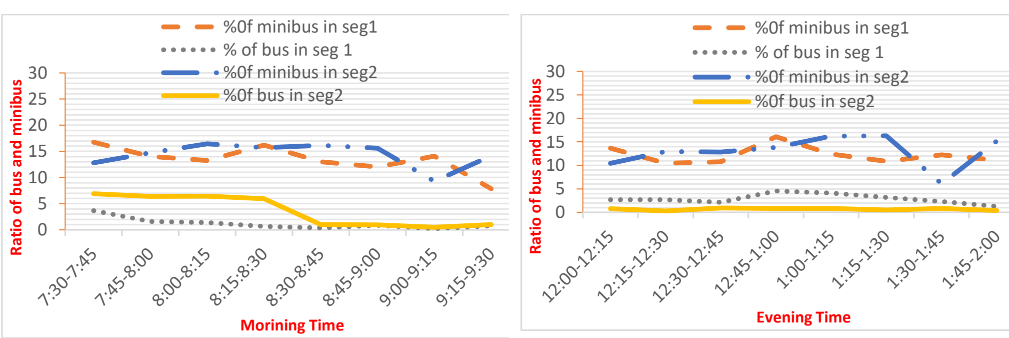
Figures (A) and (B) show the percentage of buses and minibusses on Fatima Al-Zahraa Street and that the percentage of buses and minibusses did not exceed 10% of the total traffic volume during the morning and evening peak time. Although this street is one of the important streets in which commercial centers abound, it is called Al-Sanater Street because of the large number of shopping complexes and restaurants.



(A) (B)

Figure 6: The ratio of bus and minibus in Seg1 and Seg2 for Al-Abbas Street, (A) at Am time, (B) at PM time.

Figures (A) and (B) show the percentage of buses and minibusses in Al-Abbas Street and that the percentage of buses and minibusses did not exceed 25% of the total traffic volume during the morning and evening peak time. Although this street is one of the important streets in which government departments abound, there is Al-Husseini Hospital.



(A) (B)

Figure 7: The ratio of bus and minibus in Seg1 and Seg2 for Al-Tarbia Street, (A) at Am time, (B) at PM time.

Figures (A) and (B) show the percentage of buses and minibusses on Al-Tarbia Street and that the percentage of buses and minibusses did not exceed 20% of the total traffic volume during the morning and evening peak time. Although this street is one of the important streets in which government departments and restaurants abound, it is considered one of the most active streets in Karbala. The above Figures 3 to 7 show the ratio of bus and minibus at the morning and evening peak hours. The ratio of bus and minibus did not exceed 25% of Total flow rate in the morning peak and evening peak.

III. Average ratio values for bus and minibus have been drawn up in GIS, as shown in Figures 8 to 13.

Figure 8: The average ratio of bus and minibus in GIS for Al-Iskan Street at AM and PM.

The Al-Iskan Street consists of two segments, and as shown in Figure 8, the average ratio of bus and minibus at morning and evening peak using GIS for each segment.

Figure 9: The average ratio values of bus and Minibus in GIS for Ramadan Street at AM and PM.

Ramadan Street consists of four segments, and as shown in Figure 9, the average ratio of bus and minibus at morning and evening peak using GIS for each segment.

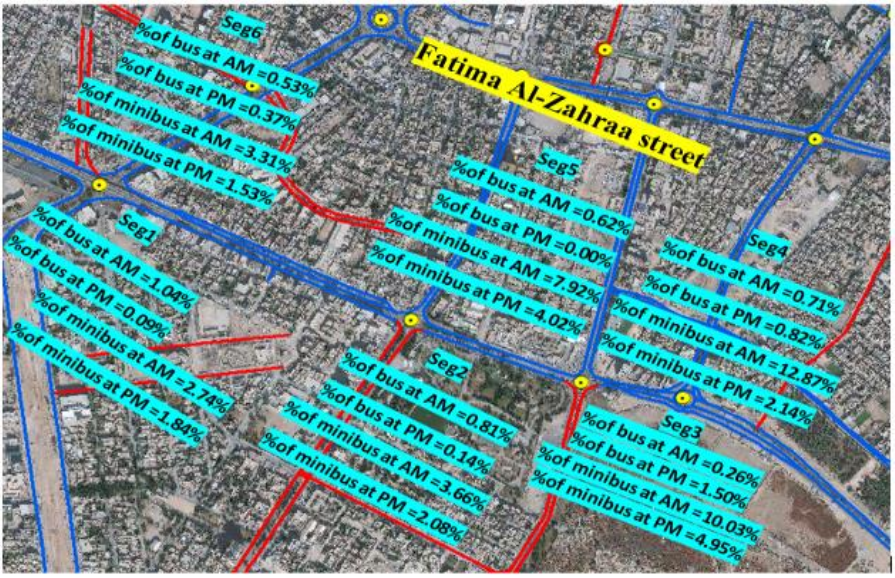


Figure 10: The average ratio values of bus and minibus in GIS for Fatima Al-Zahraa Street at AM and PM.

Fatima Al-Zahraa Street consists of six segments, and as shown in Figure 10, the average ratio of bus and minibus at morning and evening peak using GIS for each segment.

Figure 11: The average ratio of bus and minibus in GIS for Al-Abbas Street at AM and PM.

Al-Abbas Street consists of four segments, and as shown in Figure 11, the average ratio of bus and minibus at morning and evening peak using GIS for each segment.

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Figure 12. The average ratio values of bus and Minibus in GIS for Al-Tarbia Street at AM and PM.

Al-Tarbia Street consists of four segments, and as shown in Figure 12, the average ratio of bus and minibus at morning and evening peak using GIS for each segment.

Figure 13: The average ratio values of bus and Minibus in GIS for Al-Baladiya Street at AM and PM.

Al-Baladiya Street consists of four segments, and as shown in Figure 13, the average ratio of bus and minibus in morning and evening peaks using GIS for each segment.

The figures above show average bus and minibus ratio values at peak hours during the morning and evening periods using GIS.

5. DISCUSSION

According to Figure (1), the type of street network in Karbala city is (T-type). According to the range of $\boldsymbol{\beta}$ value (0-3), a value of $\boldsymbol{\beta}$ below one indicates a branching-like network. In contrast, more than one value indicates an increasing complexity (very well-connected network) [17]. The $\boldsymbol{\beta}$ value is 1.44, $\boldsymbol{\beta}$ value more than one that indicates the increasing complexity of the urban road network of Karbala city. That means the urban road network of Karbala is very well-connected, according to the range of α value between zero and unity. A higher value of **α** indicates a higher possible level of connectivity [17]. The α value is 0.35, and α value more than zero indicates a higher possible level of connectivity in the urban road network of Karbala city, according to the range of $\boldsymbol{\gamma}$ value between zero and unity. A value closer to zero indicates a simpler network with fewer links, whereas a value closer to unity indicates a better-connected network with more Links [17]. The γ value is 0.504. The γ value more than zero indicates a connected network with more links in the urban road network of Karbala city. The $\boldsymbol{\eta}$ index calculates the total length and introduces some notices of geographic scale; the more densely a network is packed into a region, and the greater the number of junctions, the shorter the edge length becomes.

Therefore, $\boldsymbol{\eta}$ is expected to be high in ill-developed networks and low in well-developed networks [17]. In 2013, the $\boldsymbol{\eta}$ was 0.812 [13], while in 2023, the $\boldsymbol{\eta}$ is 6.249, which means the density of the urban road network of Karbala is a good comparison with 2013. According to the Grid-Tree Pattern Index (GTP) range, the range value is (0-3); if the GTP is less than 1, then the network format is not desirable, and if it is greater than 1, the network format is desirable. The value of GTP is 0.878. A higher GTP index indicates that the urban road network in Karbala City is more connected. In Figures 3 to 7, the ratio of bus and minibus did not exceed 30% of the Total flow rate in the morning peak and evening peak, meaning the need to develop public transportation. As shown in Figure 2, area (A), an agricultural area, has been mostly converted into residential areas and lacks a node and connection. In areas (B) and (C), these are residential neighborhoods that were established recently and are poor in node and link.

6. CONCLUSIONS

The most significant conclusions of the research:

- The shape of the urban road network in Karbala is (T-type).
- The $\boldsymbol{\beta}$ value is 1.44, which means the urban road network of Karbala is a very well-connected network.
- The α vale more than zero indicates a higher possible level of connectivity in the urban road network of Karbala city.
- The γ value more than zero indicates a connected network with more links in the urban road network in Karbala city.
- The $\boldsymbol{\eta}$ value is 6.249, which means the density of the urban road network of Karbala is good compared with the year 2013.
- The value of GTP is 0.878; a higher GTP index indicates that the urban road network in Karbala City is more connected.
- After calculating the percentage of buses and minibusses in the street, it was found that the percentage of buses and minibusses is very small, meaning that public transportation must be developed in Karbala.
- The number of nodes and connections must be increased in agricultural areas that have been converted into residential areas, as well as newly established areas, to increase the efficiency of the road network.

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