

Evaluation of transportation network in AL- Fallujah city

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ABSTRACT

The city of Fallujah suffers from bad design in their network and it still dominated by the same pattern of the road and street network system that was produced by the previous stages of the development of the city, which is awaiting the necessary and appropriate solutions, which calls for planning to modernize the road network and streets in it that can accommodate the reality of the city's condition and the proposed expansions for its subsequent urban growth. The transportation network in Fallujah city was chosen as a case study, the network was divided into roads and intersections, the evaluation included two main roads and eleven sectoral roads, eleven arterial roads, and twenty-five intersections. The network was evaluated in three stages, the first stage was traffic flow and service level, the second stage was evaluating the network in terms of road and intersections marking, while the third stage concerned with evaluating the network in terms of sustainability. The HCS 2010 program was applied to evaluate the first stage, while the second and third stages were evaluated based on the field survey. The results of the first stage showed that most parts of the network in the northern zone suffer from traffic problems and have a low level of service, while most parts of the network in the southern zone have a high service level and enjoy high traffic flow. Most parts of the network were suffered from bad marking, which causes many problems for the users of this network. Related to sustainability, we note a lack of interest on the part of designers or decision-makers. It was concluded that traffic solutions should be economically feasible for some parts of the network, which would lead to improving the network's performance at the level of the three stages.

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1. Introduction

The street network has a great significance on the process of urban expansion of cities, and therefore the interest in it coincided with the development of expansion in its various spatial and temporal dimensions [1]. The transportation network in urban centers is consider as one of the most important elements for planning design of the city, because it ensures that its residents move easily between their places of residence and work from outside the city, to it or within it [2]. It is also considering as one of the important factors that lead to an increase in the link and interaction between the uses of the land. This interest comes with the emergence of some centers of the population, whose

planning efforts are aimed at developing it to become more in line with the fabric of the social life of the city's residents, as the convergence and spatial interaction works to link the parts of the city together This connection does not occur effectively unless there is a developed and wide street network that can provide service and movement for the human being in an effective manner. Hence, the city streets are likened to arteries because they provide the city with life.

1.1 Problem of the Study

Due to the uncontrolled increase in the number of cars used for the transportation network in the

city of Fallujah and what caused multiple problems in this network, this research sheds light on the traffic problems and their related issues related to the transportation network in the city of Fallujah, where the city's road network suffers from multiple problems related to capacity. Traffic and service level, in addition to other problems related to road furnishing and sustainability, which affects the flow of traffic within this network.

1.2 Importance of the Study

The importance of the study focused in identifying the most important problems and obstacles that the transportation network suffers from in the city of Fallujah, and then suggesting a number of solutions and strategies that have the duty to improve the performance of the transportation network in terms of traffic and sustainability, which contributes effectively to raising the level of service in this network to the best levels.

1.3 Aims of the Study

The most important objectives of the study can be summarized in the following points:

- The research sheds light on the traffic flow and the level of service in the transport network in the city of Fallujah by evaluating the network by calculating the traffic capacity and the delay in the network.
- Evaluating the engineering characteristics of the transportation network through evaluating the furnishing of the network, which has a significant and important impact on improving traffic flow.
- Assessment of the network's sustainability requirements that relate to the sustainability requirements of pedestrians and cyclists.

1.4 Objectives of the Study

The study depends on the descriptive and analytical approach to the transportation network in the city of Fallujah, through:

- Classification of roads in the transportation network in the city of Fallujah.
- Determining the traffic rush hours of the city's transportation network.
- Collect traffic, engineering and sustainability information related to the transportation network in Fallujah.
- Determining the level of traffic service for the city's transport network, depending on the classification of roads.
- Choosing the most important streets that suffer from traffic, engineering and sustainability problems for the purpose of evaluation.
- Suggesting the most important traffic solutions and the following strategies that will improve the level of service for the transportation network in the city of Fallujah.

1.5 Hypothesis of the Study

The study is based on a set of hypotheses

- The most important reasons that lead to a decrease in the traffic flow and the level of service in the transport network in the city of Fallujah in terms of traffic and engineering.
- The transportation network in the city of Fallujah has been divided into main streets, sectoral streets, arterial streets, collective streets and local streets, in addition to intersections.

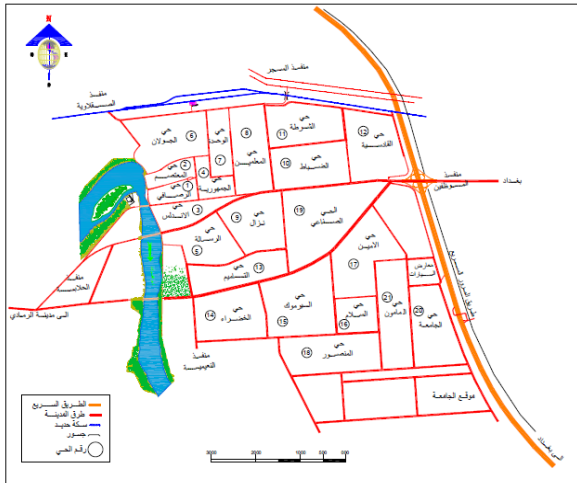
2. Study Area

Al- Fallujah (the study area) is located in Anbar Governorate, the details of areas that bordering Al- Fallujah City. From the East, Baghdad governorate, from the North Salah Al-Din governorate, from the South Karbala governorate, and from the west, the City of Ramadi, the center of Anbar governorate. This wide ramification of the borders of Fallujah City district made it occupy an area of 4205 km², which is what its 3% of Anbar Governorate, which constitutes the design area 2470 hectares of the district area (see Fig 1).

2.1. Land Use in in Al-Fallujah City

Table 1 shows the land uses in the city of Fallujah for the year 2018. It is noted through the table analysis that the majority of the land uses are

through the expansion of different land uses (see Table 2).



commercial and service as well as the residential uses, while the land uses for transportation purposes occupied an area of 633 hectares and 25% of the total city area. As for the rest of the uses it occupied different areas of the city.

Figure 1. Master Plan of Al-Fallujah City (Urban planning, Al-Anabr Government)

No.	Land Use	Area (hectares)	% Land Use to Al-Fallujah City Area
1	Residential	1250	50
2	Transportation	633	25
3	Service	230	9
4	Recreational	181	7
5	Industrial	150	6
6	Commercial	77	3
Total		2521	100

Table 1. Land Use in Al-Fallujah City for 2018 (Municipality of Al-Fallujah City)

1.1 Transportation Land Use in Al-Fallujah City

The growth and development of the city is expressed through the street network and the speed of its development, and the development of the city street network is organically linked with the functional and architectural development of the different parts of the city [3]. It can be seen that the development of land uses allocated for transportation at this stage reached 76 hectares in 1977, and increased to 128 hectares in 1987, and this development continued until it reached 342 hectares in 1997 and reached 633 hectares. In 2018, this indicates the expansion of the city's area

No.	Year	Transportation Land Use (hectares)
1	1977	76
2	1987	128
3	1994	213
4	1997	342
5	2007	510
6	2011	598
7	2015	612
8	2018	633

1.2 Transportation Network System in Al-Fallujah City

1.3 Road Classification

The road network in the city of Fallujah came as perpendicular extensions as main and commercial roads that do not reflect the future vision from any stage to another. The functional classification can be adopted as the most consistent with the principles, standards and planning foundations for the road and street network in the city, and the properties of roads and streets vary according to their functional use in a city. Table 3 shows the classification of streets for the transportation network in the city of Fallujah

Table 2. Transportation Land Use in Al-Fallujah City

Road Classification	Area (hectares)	%
Free way	36.2	5,7
Major Road	56.2	8,9
Sector Road	80.3	12,7
Arterial Road	102.3	16,2
Collector Road	142.8	22,6
Local Road	215.2	33,9
Total	633	100

- *Free way:*

The most important characteristic of these roads is that they are free from intersections, traffic spaces and traffic lights. These streets have the function of providing high traffic, which connects the city and its sectors to the external road network. It should be noted that this type is not found in the street network of the city of Fallujah. Except on the highway that passes from the northern outskirts of the city of Fallujah (the Baghdad-Jordan and Syria road on the northeastern edge of the city).

- *Major Roads:*

These roads are divided into two directions with two outgoing lanes and two or more return lanes. The main road network forms the basis of the city's traffic system and serve as the main lines for public passenger transportation. These roads are characterized by the fact that the speed of vehicles on them is lower compared to the roads. Expressways, while accessibility is greater than highways, as the freedom of movement in them is less, and the control over the entry and exit of vehicles to and from them is moderate.

- *Sector Roads:*

These roads are responsible for linking the city's sectors with each other. These roads are divided into two directions to go and return, where they receive traffic from the main roads. Therefore, they are distributive streets that form the basis of the city's traffic system. These roads are characterized by the fact that the speed of vehicles on them is lower compared to the main roads.

Arterial Roads:

These roads are dedicated to serving the different sectors of the city and may sometimes form the boundaries of residential neighborhoods, in addition to the services they provide for traffic lanes within the commercial area and industrial and recreational areas, as they are aggregate streets. They are intended for short trips that achieve easy access to all parts of the residential neighborhood and adjacent areas.

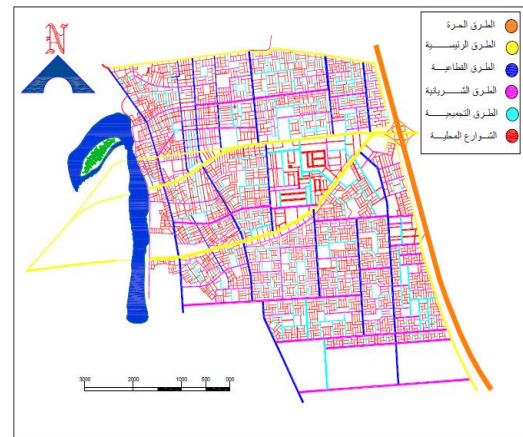
Collector Roads:

It is called collector roads, whereby the residential neighborhood is divided into several

sections whose function is to distribute the movement on the final details of the internal neighborhood network after it receives traffic from the sectoral and arterial distribution roads or streets, and it is considered the main streets in relation to the local streets. It contains crosses in its design.

Local Roads:

These roads are considered the ends of the roads network as the distributive network combined between the residential shops and its extension to



the residential units directly, and thus it takes different forms. Some are annular and others have closed ends.

Figure 2: Road Classification for Al-Fallujah City Transportation Network (Municipality of Al-Fallujah City)

1.4 Intersections

Intersections are one of the important parts of the city's roads network, as they are the element responsible for the direction of vehicle movement from one road to another. A road intersection can be defined as the area in which two or more roads are connected or perpendicular to each other.

3. Methodology

3.1 Evaluation the Level of Service for Transportation Network

3.1.1 Roads

To evaluate the level of service for the transportation network in the City of Fallujah, the network was divided into major, sector, arterial roads and intersections. A group of roads and

intersections were selected for evaluation as the congested roads in the transportation network, as shown in Figure 3.

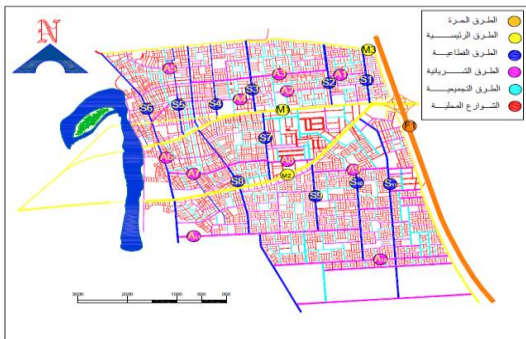


Figure 3: Selected Major, Sector and Arterial Roads for Al-Fallujah City Transportation Network as Case Study.

Table 4. Selected Major, Sector and Arterial Roads for Al-Fallujah City Transportation Network as Case Study

Road Classification	Number of Roads	Code of Roads
Major Roads	2	M1, M2
Sector Roads	11	S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11
Arterial Roads	11	A1, A2, A3, A4, A5, A6, A7, A8, A9, A10, A11

To evaluate the level of service for roads in the transportation network in Al-Fallujah City it must follow these steps [4]

- Measure the field speed.
- Measure the traffic volume.
- Calculate the density using this equation (Density = traffic volume / field speed).
- Determine the level of service for the roads based on Table 5.

Table 5. Level of Service for Major, Sector and Arterial Roads for Al-Fallujah City Transportation Network [5]

Free Flow Speed	Criteria	LOS				
		A	B	C	D	E
100 km/h	Maximum density (pc/km/ln)	7	11	16	22	25
	Average speed (km/h)	100	100	98.4	91.5	88
	Maximum volume to capacity ratio (v/c)	0.32	0.50	0.72	0.92	1.0
	Maximum service flow rate (pc/h/ln)	700	1100	1575	2015	2200
90 km/h	Maximum density (pc/km/ln)	7	11	16	22	26
	Average speed (km/h)	90.0	90.0	89.8	84.7	80.8
	Maximum volume to capacity ratio (v/c)	0.30	0.47	0.64	0.89	1.0
	Maximum service flow rate (pc/h/ln)	630	990	1435	1860	2100
80 km/h	Maximum density (pc/km/ln)	7	11	16	22	27
	Average speed (km/h)	80.0	80.0	80.0	77.6	74.1
	Maximum volume to capacity ratio (v/c)	0.28	0.44	0.64	0.85	1.0
	Maximum service flow rate (pc/h/ln)	560	880	1280	1705	2000
70 km/h	Maximum density (pc/km/ln)	7	11	16	22	28
	Average speed (km/h)	70.0	70.0	70.0	69.5	67.9
	Maximum volume to capacity ratio (v/c)	0.26	0.41	0.59	0.81	1.0
	Maximum service flow rate (pc/h/ln)	490	770	1120	1530	1900

3.1.2 Intersections

25 intersections will be evaluated, 17 intersections in the northern sector of Fallujah and 8 intersections in the southern sector of Fallujah. To evaluate the level of service for roads in the transportation network in Al-Fallujah City it must follow these steps:

- Collect the traffic, geometric and signal data for each approach in the intersection.
- Measure the traffic volume for each approach in the intersection.
- Determine the capacity for each approach in the intersection.
- Calculate the delay for each approach in the intersection.
- Determine the level of service for the intersections based on Table 6.

Table 6. Level of Service for Intersections for Al-Fallujah City Transportation Network [5]

LOS	Control Delay per Vehicle (s/veh)
A	≤ 10
B	> 10-20
C	> 20-35
D	> 35-55
E	> 55-80
F	> 80

3.2 Road Furniture's

In this step, roads and intersections will be evaluated based on the road marking and other services, including evaluating sidewalks, median islands, lighting, traffic signals, and planning streets and parks.

3.3 Sustainability

The transportation network related to sustainability will be evaluated, such as the presence of lanes designated for pedestrians or bicycles, the presence of places designated for

public transportation, or the presence of green spaces designated for the transportation network.

24 Arterial A11 B

4. Evaluation the Transportation Network

4.1 Existing Level of Service

Highway Capacity System 2010 (HCS) program was approved to determine the level of service for roads and intersections. Table 7 shows the level of service for the major, sector and arterial roads While Table 8 shows the level of service for intersections in the transportation network in the City of Fallujah.

Through the results obtained for the level of service for the streets in the transportation network for the city of Fallujah in Table 7, the following can be summarized:

Table 7. Existing Level of Service for Major, Sector and Arterial Roads for Al-Fallujah City Transportation Network

No.	Road Classification	Road Code	Level of Service
1	Major	M1	B
2	Major	M2	B
3	Sector	S1	E
4	Sector	S2	E
5	Sector	S3	F
6	Sector	S4	E
7	Sector	S5	E
8	Sector	S6	E
9	Sector	S7	B
10	Sector	S8	C
11	Sector	S9	B
12	Sector	S10	B
13	Sector	S11	B
14	Arterial	A1	E
15	Arterial	A2	F
16	Arterial	A3	E
17	Arterial	A4	E
18	Arterial	A5	C
19	Arterial	A6	C
20	Arterial	A7	B
21	Arterial	A8	A
22	Arterial	A9	B
23	Arterial	A10	B

- Traffic flow on the main streets, depending on the level of service, is considered very well, as the service level was B.
- There is a problem in the traffic flow in the sectoral streets, depending on the level of service for the northern sector, which is more crowded, as most of the sectoral streets have a service level E, as this level is a low level, which negatively affects the traffic flow and causes a lot of congestion that causes a lot of problems traffic on the transport network. On the contrary, we note that the rest of the sectoral streets in the southern sector are characterized by a high level of service B, which positively affects the traffic flow.
- The same previous observation was observed in evaluating the level of service in the arterial streets, as the arterial streets in the northern sector have service level E, while the arterial streets in the southern sector have service level B.

Table 8. Existing Level of Service for Intersections for Al-Fallujah City Transportation Network

Intersection No.	Level of Service
1	E
2	E
3	D
4	E
5	D
6	E
7	F
8	C
9	E
10	D
11	E
12	F
13	B

14	D
15	E
16	C
17	E
18	B
19	C
20	C
21	C
22	B
23	B
24	B
25	B

- The majority intersections in the northern sector have a low level of operation, and most of the intersections have a service level of E, which indicates that there are traffic problems in most of these intersections, which negatively affects the traffic flow and the transport network in the city.
- The majority intersections in the southern intersection have an acceptable or good level of operation, and most of the intersections have a service level C, which indicates that the traffic flow in the southern intersection is high and there are no congestions at those intersections.

Through the results obtained for the level of service for the intersections in the transport network for the city of Fallujah in Table 8, the following can be summarized:

4.2 Road Furniture's

Table 9. Existing Road Furniture's for Major, Sector and Arterial Roads for Al-Fallujah City Transportation Network

No.	Road Classification	Road Code	Road Signs	Road Marking	Lighting	Parking
1	Major	M1				X
2	Major	M2				X
3	Sector	S1	X			X
4	Sector	S2	X			X
5	Sector	S3	X			X
6	Sector	S4	X	X		X
7	Sector	S5	X	X		X
8	Sector	S6	X	X		X
9	Sector	S7	X	X	X	X
10	Sector	S8	X	X	X	X
11	Sector	S9	X	X	X	X
12	Sector	S10	X	X	X	X
13	Sector	S11	X	X		X
14	Arterial	A1	X			X
15	Arterial	A2	X			X
16	Arterial	A3	X			X
17	Arterial	A4	X			X
18	Arterial	A5	X			X
19	Arterial	A6	X	X		X
20	Arterial	A7	X	X		X
21	Arterial	A8	X	X		X
22	Arterial	A9	X	X	X	X
23	Arterial	A10	X	X	X	X
24	Arterial	A11	X	X	X	X

Table 10. Table 10: Existing Road Furniture's for Intersections for Al-Fallujah City Transportation Network

Intersection No.	Traffic Signals	Road Signs	Road Marking	Lighting
1	X	X	X	X
2	X	X	X	X
3	X	X	X	X
4	X	X	X	X
5	X	X	X	X
6	X	X	X	X
7	X	X	X	X
8	X	X	X	X
9	X	X	X	X
10	X	X	X	X
11	X	X	X	X
12	X	X	X	X
13	X	X	X	X
14	X	X	X	X
15	X	X	X	X
16	X	X	X	X
17	X	X	X	X
18	X	X	X	X
19	X	X	X	X
20	X	X	X	X
21	X	X	X	X
22	X	X	X	X
23	X	X	X	X
24	X	X	X	X
25	X	X	X	X

By noting the results obtained for Road Furniture's of major, sector, arterial and intersections from Tables 9 and 10, the following can be noted:

- Most of the roads and intersections have not road signs, road marking and traffic signals which causes a lot of conflict between vehicles in the traffic flow which has a negative impact on

the traffic operation and the level of service in the transportation network.

- Most of the roads and intersections are without lighting, which causes a lot of unclear vision at night and may lead to many accidents.
- It was noticed that there are no designated parking spaces in the major, sector, arterial roads, which causes a lot of congestion in these

roads, especially roads that have many commercial or recreational activities.

- All intersections lack a traffic signals to operate the intersection in an optimal way, as all intersections are managed by traffic police and sometimes without traffic men, which causes a

4.3 Sustainability

Regarding to the results obtained for the level of

No.	Road Classification	Road Code	Road Signs	Road Marking	Lighting	Parking
1	Major	M1				X
2	Major	M2				X
3	Sector	S1	X			X
4	Sector	S2	X			X
5	Sector	S3	X			X
6	Sector	S4	X	X		X
7	Sector	S5	X	X		X
8	Sector	S6	X	X		X
9	Sector	S7	X	X	X	X
10	Sector	S8	X	X	X	X
11	Sector	S9	X	X	X	X
12	Sector	S10	X	X	X	X
13	Sector	S11	X	X		X
14	Arterial	A1	X			X
15	Arterial	A2	X			X
16	Arterial	A3	X			X
17	Arterial	A4	X			X
18	Arterial	A5	X			X
19	Arterial	A6	X	X		X
20	Arterial	A7	X	X		X
21	Arterial	A8	X	X		X
22	Arterial	A9	X	X	X	X
23	Arterial	A10	X	X	X	X
24	Arterial	A11	X	X	X	X

lot of congestion at some intersections.

sustainability of the main, sectoral, arterial streets and intersections from Table 11, the following can

Table 11. Existing Road Furniture's for Major, Sector and Arterial Roads for Al-Fallujah City Transportation Network

be noted:

All major, sector, arterial roads lack lanes designated for pedestrians due to the exploitation of all sidewalks for commercial purposes or recreational activities, or due to the narrowness of the sidewalks, forcing pedestrians to use the pedestrian river, which

poses a great danger to pedestrians and exposes those to run-over accidents.

There are no lanes designated for cyclists in the transportation network in Fallujah, which causes the use of the street river by cyclists, which causes a lot of confusion to car traffic, especially because cyclists do not comply with traffic rules and traffic safety.

There are no places designated for public transport users to disembark or ride in the transport network, as most owners of private or public transport buses, as well as their users, do not have any commitment to traffic safety or traffic rules, which causes many cases of collision or run-over between users of these modes.

Although there are some green spaces allocated in the major, sector, arterial roads, in general, they are few or insufficient spaces, or they are incorrectly allocated that contradict the engineering design of the streets, which can block the vision and cause many accidents.

Regarding to the results obtained for the level of sustainability of the main, sectoral, arterial streets and intersections from Table 11, the following can be noted:

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Although there are some green spaces allocated in the major, sector, arterial roads, in general, they are few or insufficient spaces, or they are incorrectly allocated that contradict the engineering design of the streets, which can block the vision and cause many accidents.

5. Conclusions and Recommendations

Through evaluating the transportation network in the city of Fallujah through three axes, the first axis is traffic flow and the level of service, the second axis is the furnishing of the transport network, and the third axis is the level of sustainability, the following conclusions were reached:

- On the level of traffic flow and the level of service, it was noted that most of the streets and

intersections in the northern sector suffer from traffic problems at the level of traffic flow, which

requires a lot of traffic solutions. No traffic problems at the moment.

- Most parts of the transport network in the city of Fallujah lack adequate and appropriate furnishing to serve the traffic movement, which fits the international specifications for road design, which negatively affects the network's performance correctly.

- One of the most important problems that most transportation networks suffer from is neglecting the sustainability factor. Through a field

survey of the transportation network in the city of Fallujah, it was noted that most parts of the network lack lanes designated for pedestrians or bicycles, or places designated for public or private transport users, or the presence of properly designated places for green spaces.

The most important recommendations reached by this study to improve the reality of the transportation network in the city of Fallujah:

- Improving the level of service for the transport network by finding appropriate and economical traffic solutions to solve the problem of congestion in some parts of the network and not adopting traditional solutions that would solve the problem in a particular part and their agreement in another part of the network.
- Furnishing roads and intersections with traffic signals and indicative signals, in addition to the presence of sidewalks, medians and street lighting correctly, with an emphasis on educating drivers to read traffic signs to avoid accidents and congestion.
- The necessity of taking into consideration the importance of sustainability for the transport network and the necessity of paying attention to this factor by the designers and decision makers due to the importance of this factor in the transport networks.

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