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SPATIOTEMPORAL FEATURES OF MOSUL CITY ROAD NETWORK

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Abstract

Mosul is the second-largest city in Iraq, the movements of people within the city have become more restricted by the crowded streets during rush hours. This issue has also become critical since it impacts most of the life aspects of the city (e.g., going to work, schools, etc.). Therefore, there is a need to mitigate this issue using low-cost strategies and solutions due to the current economic issues in the country. In this work, a network-based model is generated that represents the road network of both sides of the city (east and west coasts). The generated network is analysed based on its spatial and temporal features. Then, the elite intersections (crossroads) are extracted, which represent the most effective factors in the road network of the city. After that, low-cost sensor technologies are suggested and can contribute to mitigating the traffic jam issue in the city. Finally, the proposed solutions and suggestions can be generalized to any city that is close in the nature to the considered city in this study.

Keywords: Road Networks, Traffic Jams, Mosul City, *Network Science.*

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1. Introduction

1.1 Overview

Recent decades have witnessed significant population growth over all the world. This leads cities to be expanded and developed aiming to contain the current growth in population. One of the important aspects of this development is to ease the movements of people within and across cities. To this end, the transportation systems around the world have been developed and there exists a paradigm shift that yields having different kinds of transportation such as trains, cars, busses, subways, trams, etc. that are used to transport people from/to different places (e.g., work and home). In this context, the concept of "*Road Networks*" has been introduced to refer to the roads (e.g., streets) that connect different regions within a city or across cities. The main issue in road networks is the intersections of these roads that lead to a severe delay in reaching a particular destination, especially in crowded and metropolitan cities. In fact, humans try to convert the global road network of 14 million kilometres of the total 19 million hectares of the earth's surface into paved transportation roads [1].

Engineers and researchers around the world deal with road networks in many different ways [2]. Some of them try to build mathematical or statistical models for analysing road networks. Furthermore, the most recent way to model road networks is to use graph theory and concepts from network science. This kind of approach models road networks as nodes to represent the intersections, and edges to represent streets. Practically, this approach proves as one of the efficient ways in analysing road networks.

This work tries to consider the second largest city in Iraq, Mosul city, as our targeted Road Network. The city of Mosul, the centre of the Nineveh Governorate, located in northern Iraq, is one of the largest Iraqi governorates, with an area of 180 km^2 and a population of more than 4 million people [3]. The city is, geographically, divided into Eastern and Western coasts as the Tigris River splits the city into two coasts. The city is linked by many streets and intersections that connect the areas within the two coasts, and 5 bridges connect them. In recent years, the city struggled with major traffic jams as a result of the extensive destruction of infrastructure during the recent war against ISIS [4]. In the recent years, the population has been significantly increased. Adding to that, the phenomenon of a large number of rural residents moving to the city due to their low-level living conditions as a result of climate changes. Another issue in Mosul city, that is, there is a server lack in international and highway roads that are used for transporting goods from the neighbouring countries such as (e.g., Turkey and Syria). This lack caused the within-streets to be highly loaded. Also, the city of Mosul plays a significant role as a bridge between the middle/south Iraqi cities and the tourism cities in the north. All these reasons together make traffic jams an important issue in Mosul city.

1.2 Literature Review

Several approaches proposed by researchers consider road networks as their target problem to analyze and this is due to the importance of such issues. Most of the available studies use mathematical or statistical methods for modelling road networks. On the other hand, the complex networks approach proved its efficiency in instigating and analysing road networks. The study of Tian et al. (2016) [5] proposed a weighted network model for urban road traffic by taking into consideration the functional characteristics of the road network and the concept of traffic efficiency for the road section in the urban road traffic network. Another study performed by Sayed et al. (2017) [6] tried to identify the best path between the accident location to healthcare service providers in the Greater Cairo metropolitan area depending on the capabilities of the Geographic Information System (GIS). Debashis et al. (2019) [7-3] suggested a method to find the shortest path between two points in Guwahati city of India by analysing and digitizing its road network system to solve the traffic jam problem. The analysis of this study was done based on some features such as traffic density, waiting time in traffic light, barriers, and traversing distance.

Shi et al. (2019) [8] used the spatiotemporal dynamics of urban roads growth in Nanjing city in China. Spatial statistical models have been used for describing their spatial patterns in cities development. Their goal was to enhance the performance of the network in case of scalability. Kerekes (2018) [9] performed a study for analysing the road network for one of the largest cities in Romania, which was Cluj-Napoca city. The study aimed to generate an optimal route model for faster and more reliable access to medical services and this is due to the high rate of accidents in the city. Idhoko 2016 [10] suggested a spatial analysis for accessing places and facilities of

Yenagoa city roads. The geospatial datasets were georeferenced and link with the attribute database using the ArcGIS software.
The analysis included a spatial search for a particular road and the shortest route between two locations. The study was concentrated on ascertaining the minimum path travel, distance, time for effective emergency response services aiming to improve the standard of life within the study area. Faka et al. (2018) [11] presented a methodology for calibrating and validating the raw results of a GIS-based spatiotemporal analysis from direct sunlight around a country road using spatial video in Rethimno, Greece. The factors used in this study were the topography, the road network, and the sun position for a specific time during summer. The study suggested solutions for this kind of issue. A recent study performed by Hasan [12] (2021) suggested an approach for modelling road networks that is based on forming intersections as nodes and the leading streets as edges. The author used network measurements in the analysis of the network.

1.3 Problem Statement and Contribution

According to the previous studies, many works do not consider the cost of the solutions for road networks. Also, few studies focused on spatial and temporal aspects in analysing road networks. Hence, in this work, we try to suggest low-cost strategies that mitigate the traffic jams issues in Mosul city considering the spatial and temporal aspects.
The rest of this work is organized as follows: the next section presents the research method in terms of dataset collection, network formation, network measurements used, and the analysis approach. Section 3 demonstrates the obtained results, discussions, and recommendations. The whole work is concluded in Section 5.

1. Research Method

This section provides the details of the research method followed in this work. This includes the dataset used in creating the road network of Mosul city. The dataset collection was performed in two stages as follows:

- **Stage 1**: This stage includes using Google Earth to collect the coordinates of the intersections of the city. Each coordinate consists of two parameters: *Latitude* and *Longitude*.
- **Stage 2:** Information from the Traffic Directorate of Nineveh about loads of each intersection was collected. In the data, loads of the intersections can be in five levels (1-5). Therefore, we considered that load of 1 referred to a low load intersection, while 5 referred to the highest load level. These levels reflect how crowded a particular intersection is compared to the other intersections.
- **Stage 3:** The distance between intersection pairs was collected and used as the weight between two intersections.

After completing the dataset collection process, we converted the data into two excel files. The first one is for nodes (intersections) including all their attributes (e.g., intersection ID, name, load, latitude, longitude, and coast ID). The second file includes the edges that represent the streets connecting the intersections.
The network creation was performed as follows: the road network is represented as a graph of two tuples $G(I, S)$, where I denotes the intersections and S denotes the streets that connect the intersections. The edges creation strategy was based on the following: given that two intersections i and j. An edge e is created between i and j *if and only if* there exists a direct street that connects them. In fact, some intersections have three to four leading streets, which means the average degree of the intersections in the network will not be 4.
During the data collection process, we considered only the main official intersections, which are 65 (number of nodes) and connected by 129 streets (number of edges). After preparing the dataset files, the road network is ready to be visualized and analysed. The visualization was performed using Gephi software.
Furthermore, the generated road network of Mosul city is analysed using network measurements. These measurements can provide facts about the networks in terms of their intersections and streets. The goal of this process is to extract the most important intersections in the network and use them in suggesting strategies that lead to mitigating the traffic jams in the network. The measurements were used in two levels: *network* and *nodes* level. The network-level measurements are diameter, density, average clustering coefficient, and average shortest path

length [13]. The nodes level measurements used in the analysis are; *Eccentricity*, *Betweenness*, and *Eigen* centralities.
The *Eccentricity (E)* in the context of our work reflects the maximum distance from an intersection to any given intersection in the network. The eccentricity values of all the intersections (I) were calculated using the following equation [13]:

$$E_t = \frac{1}{max(dist(k,t): k \in T)} \quad (1)$$

The *Between ness* $B(i)$ of an intersection means how many times an intersection appears in the shortest paths of network pairs of intersections. This is important since it reflects how influential a particular intersection is in the flow of traffic within the network. The following equation is used to calculate the betweenness of a particular intersection [14][15]:

$$B(i) = \sum_{j \neq i \neq k} \frac{\sigma_{jk}(i)}{\sigma_{jk}} \quad (2)$$

Where σ_{jk} denotes the shortest path between the intersection *j* and *k* and *σ(i)* denotes the number of streets that pass through intersection *j*.
The Eigen centrality shows how well-connected an intersection is to the highly connected intersections in the network. It can be calculated using the following formula [13][16]:

$$x_i = \frac{1}{\lambda} \sum_{j \in N_i} x_i = \frac{1}{\lambda} \sum_{j \in G} A_{i,j} x_j \quad (3)$$

Where *i* denoted to an intersection, N_i the neighboured intersections, $a_{i,j}$ is set to 1 when intersection *i* has a direct street to intersection *j*, and *0* otherwise. The term λ is constant and *x* is the obtained score for a particular intersection. The above equation can be written as follows [17]:

$$Ax = \lambda x \quad (4)$$

The reason behind choosing these measurements is that we believe they can reveal the most important facts about the importance and the influence of a particular intersection within the network. This enables us to define the elite intersection as explained in the next section.

2. Results and Discussion

2.1. Network Characteristics

The geographical characteristics of the network are presented in Table 1. These characteristics are based on the geographical nature of the Mosul road network.

Table 1: Geographical characteristics of Mosul road network.

Metric	Value
Average Distance	1.31 km
Standard Deviation	0.92 km
Magnitude	76.55 km
Direction	NW (310.30 degrees' clock-wise from North)

Furthermore, after generating the road network of Mosul city, the characteristics of the network were extracted as shown in Table 2. As mentioned in the previous section, the number of main intersections in Mosul city is 65 connected by 129 streets. According to the table, the network reflects a high diameter level of 11. This means to move between the farthest two intersections in the city it is required to cross 11 streets, which is not sufficient and reflected in the average shortest path of the network (4.506). Also, the average clustering coefficient shows a weak tendency of the intersections to cluster with each other.
As mentioned, the visualization of the network was performed based on projecting each intersection on the exact coordinates on the map. Therefore, the visualization reflects a real

projection of the intersection on the network. The nodes in the network show two colours, the red colour represent the east coast of the city, while the green represents its west coast. Nodes size represents the load level of the intersection (the bigger the size, the heavy load of the intersection).

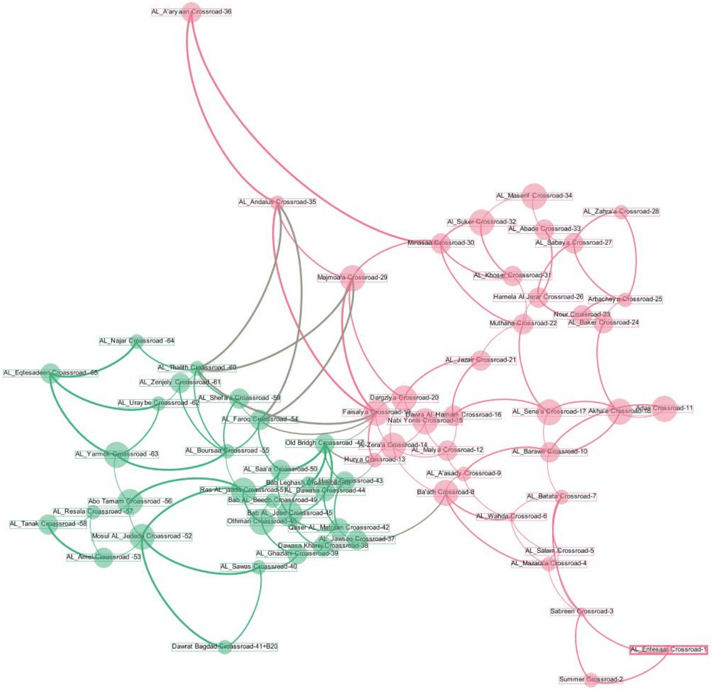

Figure 1: Visualization of Mosul road network.

Table 2: The characteristics of the road network of the city of Mosul.

Nodes	Edges	Diameter	Density	Average Clustering Coefficient	Average Path Length
65	129	11	0.062	0.368	4.506

2.2. Network Measurements

3.2.1 Eccentricity Centrality Measurement

Table 3 presents the highest eccentricity levels of the intersections. The reason behind choosing the top 4 is that the eccentricity level was significantly dropped after the value of (11). As can be seen in the table, 4 intersections are considered the closer ones to all the intersections in the city. Figure 2 depicts the visualization of the network where node colours reflect different loads of intersections (Blue=5, Pink=4, Green=3, Orange=2, and Dark Green=1 of loads), and node size is based on the value of the eccentricity of intersections.

Table 3: Top eccentricity intersections in the network.

#	Crossroad	Eccentricity	City Coast	Load	Degree
1	AL_Baker	11	East	4	3
2	Arbacheya	11	East	3	4
3	AL_Zahra'a	11	East	3	2
4	AL_Tanak	11	West	4	2

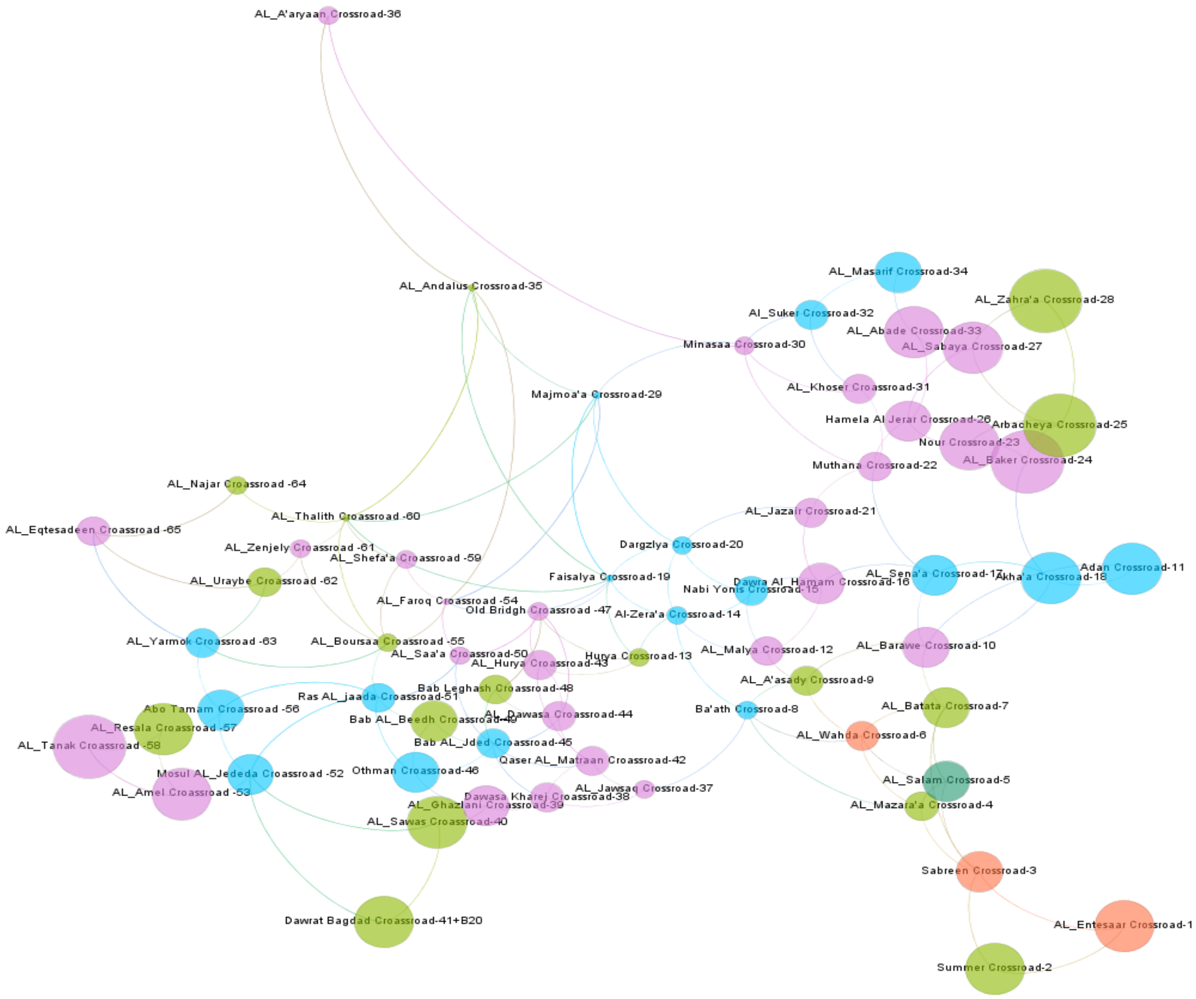

Figure 2: Visualization of Mosul road network where node size reflects the eccentricity level.

3.2.2 Betweenness Centrality Measurement

Using the same of the previous strategy, the highest betweenness centrality levels of the intersections are presented in Table 4. The intersections presented in the table are considered the most effective ones in the network in terms of controlling the traffic flow. The visualization where the node size corresponds to the level of betweenness of the intersection is shown in Figure 3.

Table 4: Top eccentricity intersections in the network.

#	Crossroad	Betweenness	City Coast	Load	Degree
1	Ba'ath	0.2148	East	5	5
2	Majmoa'a	0.2050	East	5	6
3	Minasaa	0.1981	East	4	5
4	Muthana	0.1944	East	4	5
5	Faisalya	0.1880	East	5	8

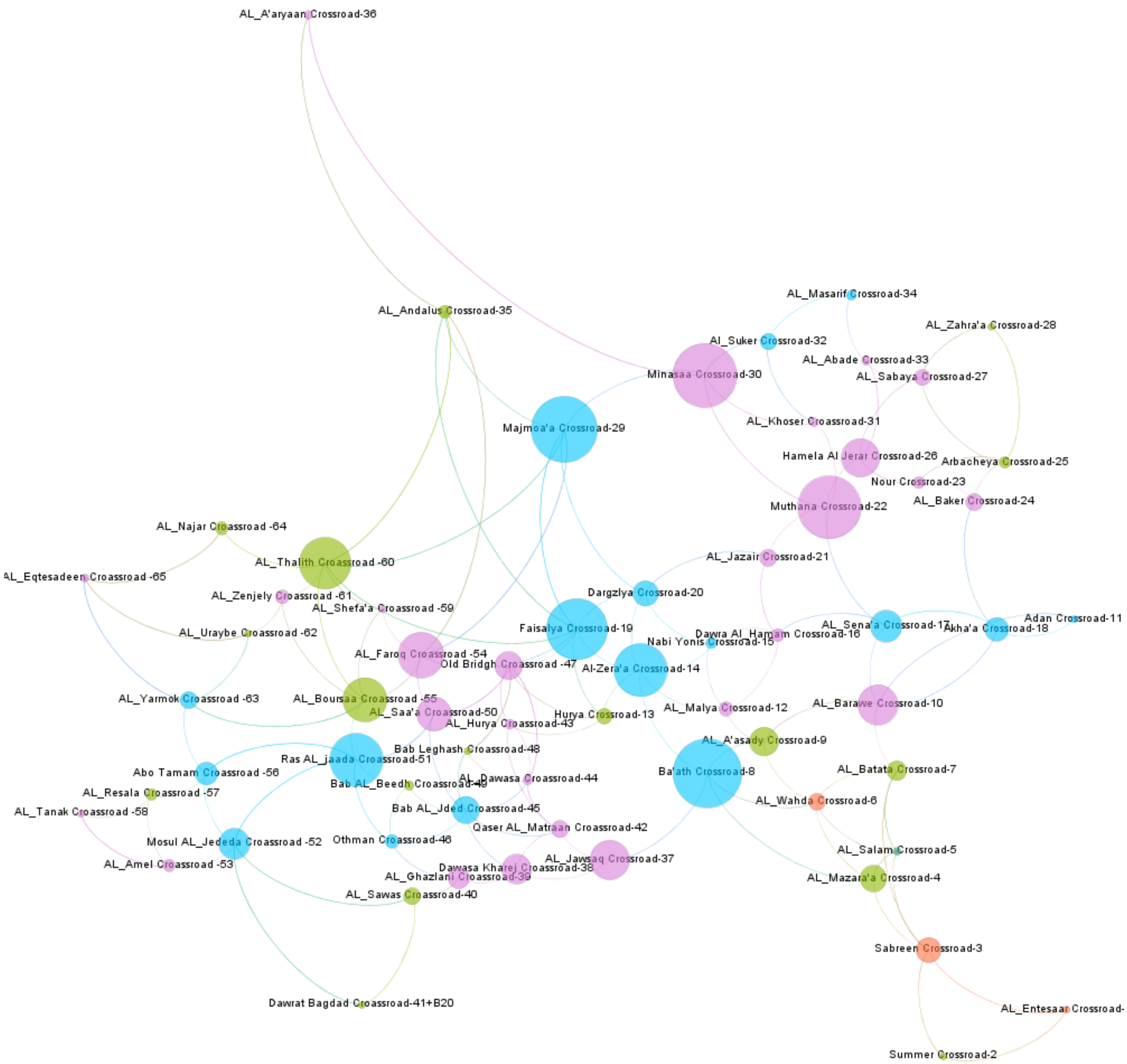

Figure 3: Visualization of Mosul road network where node size reflects the eccentricity level.

3.2.3 Eigen Centrality Measurement

Table 5 presents the highest Eigen Centrality intersections in the network. These intersections represent the most dependent intersections that lead to highly connected intersections. The visualization of the network according to the Eigen Centrality of the intersections is depicted in Figure 4.

Table 5: Top Eigen centrality intersections in the network.

#	Crossroad	Eigen centrality	City Coast	Load	Degree
1	Faisalya	1.0	East	5	8
2	Majmoa'a	0.7737	East	5	6
3	AL_Thalith	0.7415	West	3	7
4	AL_Faroq	0.7378	West	4	6
5	AL_Andalus	0.6574	East	3	5

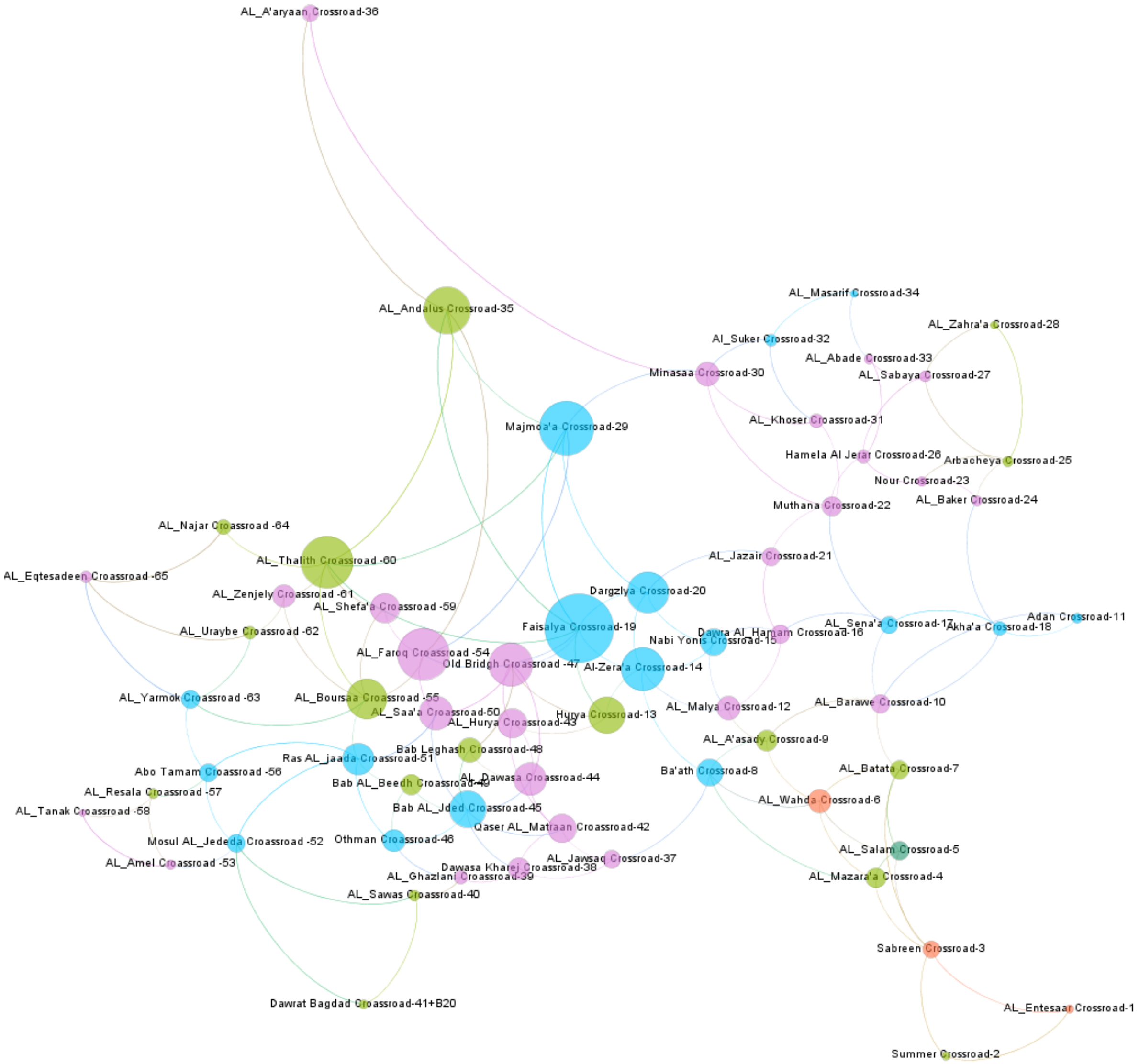

Figure 4: Visualization of Mosul road network where node size reflects the Eigen centrality.

3.2.5 Sensors Technology Solution

The next step in our analysis is to provide low-cost recommendations and solutions in the Mosul road network. For this purpose and according to the Traffic Directorate of Nineveh, the rush hours of the intersections mentioned in Tables 3, 4, and 5 (we call them *Elite Intersections*) were collected. Table 6 shows the rush hours of the most important intersections (according to the aforementioned measurements) in Mosul city.

Our focus in providing suggestions and recommendations is based on the elite intersections. This means the suggestions can only be applied to these intersections aiming to reduce the cost of improving the network and minimize the traffic jams delays. To this end, we suggest adopting low-cost hardware technologies that are considered the cheapest effective solutions. Practically, many techniques can be used for this particular purpose. For instance, the engineers in [18] suggested adaptive traffic lights timing by calculating the traffic density depending on the image processing technique of several road patterns. Their method was based on using digital cameras and processing the captured images. This solution can be adopted on some or all the elite intersections in the Mosul city road network. Another cheap solution that was used in [19] adopted a PIC microcontroller based on IR sensors to achieve a dynamic timing slot with different levels. As another solution suggested in [20] using a fuzzy logic controller with the IoT sensors at a junction. Also, the developers in [21] tried an intelligent system for controlling vehicles in traffic lights based on machine learning and microcontroller circuit-based. The system adjusts the time of traffic signal to reduce traffic congestion.

Table 6: Rush hours of the most important intersections in Mosul road network.

	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Ba'ath	08:00am-10:00am	08:00am-10:00am	08:00am-10:00am	08:00am - 10:00am	08:00am-10:00am	04:00pm-07:00pm	04:00pm-07:00pm
Majmoa'a	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	08:00am 09:30am	04:00pm-09:00pm	04:00pm-09:00pm
Minasaa	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	04:00pm-09:00pm	04:00pm-09:00pm
Muthana	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	04:00pm-07:00pm	04:00pm-07:00pm
Faisalya	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	04:00pm-07:00pm	04:00pm-07:00pm
AL_Baker	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	04:00pm-08:00pm	04:00pm-08:00pm
Arbacheya	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	04:00pm-07:00pm	04:00pm-07:00pm
AL_Zahra'a	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	08:00am-09:00am	04:00pm 06:00pm	04:00pm-06:00pm
AL_Tanak	07:00am-11:00am	07:00am-11:00am	07:00am-11:00am	07:00am-11:00am	07:00am-11:00am	04:00am-06:00am	04:00am-06:00am
Faisalya	08:00am-10:00am	08:00am-10:00am	08:00am-10:00am	08:00am-10:00am	08:00am-10:00am	04:00am-07:00am	04:00am-07:00am
Majmoa'a	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	04:00am-08:30am	04:00am-08:30am

AL_Thalith	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	04:00am-07:30am	04:00am-07:30am
AL_Faroq	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	08:00am-09:30am	04:00am-07:30am	04:00am-07:30am
AL_Andalus	04:00am-09:30am	04:00am-09:30am	04:00am-09:30am	04:00am-09:30am	04:00am-09:30am	04:00am-11:00am	04:00am-11:00am

Hence, in this article, we generated a network model to implement a road network and suggested several low-cost sensors in the elite intersections. These sensors count the number of vehicles that cross through these intersections (see Figure 5). A controller that connects these sensors can be used to control the traffic light time (red and green) based on the current load of that intersection. For instance, when a street is loaded with many cars, a signal will be sent to the controller indicating that a load will occur. Also, a signal should be sent to the next intersections informing them that a load will be happening in the next minutes. Practically, a threshold should be used on the number of cars that a street can handle and are considered as a heavy load. This specific threshold is based on the capacity of that street, which can be easily obtained. The proposed strategy uses the temporal and spatial aspects of the streets to control the traffic lights of the intersections in terms of time. Figure 6 provides an example of how the counting sensors can be used in particular streets. As shown in the figure, for each intersection, it is needed to plant almost 8 sensors. The maximum estimated cost for each intersection is summarized in Table 7. According to this table, it can be observed that the cost is sufficient enough for the proposed temporary solution on the elite intersections.

Table 7: The estimated cost of using low-cost sensor technology in one intersection.

PRODUCT	PRICE	QUANTITY	TOTAL
WVD-130X VEHICLE DETECTION SENSOR	10$	8	80 USD
WAP-348X WIRELESS ACCESS POINT	70$	1	70 USD
INSTALLATION COST	40 USD		
TOTAL PRICE			190 USD

Figure 5: Sensors that count the number of passing vehicles through a street.

Figure 6: Example of how sensors can be used in streets that are directly connected to intersections.

3. Conclusions and Future Works

In this work, the intersections and roads of Mosul city were modelled using concepts inspired by complex networks. The generated model represents the road network of Mosul city. The nodes represented the intersections, while the edges represented the streets that connect the intersections. The analysis approach was based on three main centrality measurements, namely, eccentricity, betweenness, and Eigen centralities. These measurements are used to distinguish the elite intersections within the network. The proposed strategies aimed to minimize the cost and delay time in the network. Also, we suggest using low-cost sensor technologies that can be adopted easily. We also suggest using these sensors with the elite intersections only aiming at having low development costs. The suggested solution can be generalized to all the intersections

in Mosul city. However, we believe the current economic situation of the country does support this plan, and, therefore, we performed this study and provide information about the optimal intersections that need to be developed in the city.
As future work, we plan to perform simulations about the proposed method and prove the effectiveness of the suggested strategy. We also plan to include the external roads of the city that connect it to the other neighbouring cities.

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