

# The Impact of Multi-Story Parking Facilities on Traffic Flow: The Case Study of the Al-Maidan Area in Baghdad City

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## ABSTRACT

The growth in economic activities has led to an increase in car ownership, contributing significantly to traffic congestion in modern urban areas. The study investigated the impact of multi-story parking facilities on traffic congestion and environmental performance at three critical intersections in Baghdad: Al-Khulafaa, Al-Ameen, and Al-Maidan. Under existing conditions, all intersections suffered from high congestion levels, long delays, low travel speeds, and high emissions. Field data were collected using Metro Count devices and analyzed through SIDRA Intersection v9 software under two scenarios: the existing conditions and an alternative scenario incorporating structured parking and improved traffic control measures. Comparisons were made using key performance measures, including average vehicle delay, queue length, travel speed, fuel consumption, and pollutant emissions. In the alternative scenario, the findings showed significant improvements: travel speeds virtually doubled, queue lengths decreased by over 70%, and vehicle delays decreased by up to 87%. Additionally, all sites had a greater than 70% decrease in CO<sub>2</sub>, CO, HC, and NO<sub>x</sub> emissions as well as annual fuel usage. The results show that drivers seeking open spots and on-street parking are the main causes of traffic congestion. The study concludes that incorporating multi-story parking facilities into urban traffic planning is a very successful way to increase mobility, reduce environmental impact, and boost the overall effectiveness of the road network in crowded central regions.

**Keywords-**traffic congestion; off-street parking; SIDRA simulation; Level of Service (LOS); urban mobility; Baghdad

## I. INTRODUCTION

Economic growth has led to higher household incomes and increased private car ownership, contributing significantly to traffic congestion in modern urban areas. In Baghdad, the traffic volume reached five million vehicles in 2021. However, poor public transportation services and a road network that is over 50 years old have intensified the public's reliance on private vehicles. Therefore, immediate and strategic solutions are required to enhance mobility and reduce congestion in the city [1].

One major global transportation challenge is the shortage of public and private parking, particularly in Central Business Districts (CBDs). This issue generates adverse social, economic, and environmental effects. In Baghdad, on-street

parking is often characterized by high occupancy rates and double parking, which reduces effective road width and worsens traffic flow. Meanwhile, off-street parking facilities entail high construction and land use costs. Designing efficient and sustainable parking facilities is, therefore, a critical component of modern urban planning [2].

The rising population and poor infrastructure in Baghdad have significantly increased reliance on taxis and daily commuting, further worsening congestion. Key contributing factors include inadequate public transit systems, limited parking capacity, low public awareness of traffic rules, and outdated urban planning practices. Addressing these issues requires comprehensive solutions that incorporate both policy reforms and infrastructural improvements [3, 4].

Effective roadside parking planning is particularly vital in Baghdad, where urban expansion continues to outpace the growth of transportation infrastructure. In the CBD, a noticeable shortage of parking facilities, especially at major shopping centers and public institutions, has created a growing imbalance between supply and demand [5].

Traffic simulation tools play a crucial role in transportation planning. Software like SIDRA Intersection and Highway Capacity Software (HCS) allow planners to evaluate congestion levels, test infrastructure modifications, and propose efficient traffic management strategies. These tools are invaluable for improving safety and optimizing the performance of road networks [6, 7].

This study aims to assess the impact of multi-story parking on traffic flow in the Al-Maidan area of Baghdad using the SIDRA simulation. The objectives are as follows:

- Assess existing conditions: Conduct a comprehensive field survey to analyze current parking characteristics in the study area.
- Identify key influencing factors: Determine the primary elements affecting parking efficiency at critical locations.
- Use real-world data to create a microscopic simulation approach for intelligent parking design at the Al-Ameen, Al-Khulafaa, and Al-Maidan intersections.
- Apply the analysis to a case study: Assess the feasibility and impact of the proposed parking scenarios approach in a real-life application, providing practical insights for urban planners.

Based on these objectives, the following research question is addressed in this study: "Does implementing multi-story parking significantly improve traffic performance and reduce emissions in congested urban intersections in Baghdad?". To answer this question, the study focuses on the following key aspects:

- Reduction in average vehicle delay and queue length.
- Improvement in Level of Service (LOS).
- Reduction in pollutant emissions and fuel consumption compared to current conditions.

A variety of studies have addressed parking challenges. Research has emphasized the mismatch between parking availability and demand in university settings, highlighting the lack of clear regulations and effective planning [8, 9]. Authors in [10] analyzed parking efficiency using indicators such as turnover rate and occupancy duration, revealing that some facilities were overcrowded due to mismanagement and outdated control systems. Authors in [11] recommended multi-story and smart sensor-based solutions to mitigate urban parking shortages. Innovations in smart parking have also emerged. Authors in [12] developed an Arduino-based system enabling real-time parking space reservations via smartphone apps.

Regional case studies further demonstrate the benefits of better parking management. For example, authors in [2]

reported that removing on-street parking in Jember, Indonesia, increased road capacity by 25% and improved traffic speed by 11%. In Baghdad, authors in [5] used VISSIM simulation to show that eliminating on-street parking on Al-Rasheed Street improved traffic flow by 46.6% and cut delays by 69%.

Other Iraqi studies have consistently pointed to the shortage of legal off-street parking and outdated infrastructure in cities like Al-Maidan (Baghdad), Al-Hilla, Al-Mansour (Baghdad), and Al-Najaf [13-17]. They advocate for the integration of smart technologies, expansion of off-street facilities, and enforcement of parking regulations as key strategies for sustainable urban mobility.

The use of simulation tools such as SIDRA for traffic analysis and intersection performance improvement has been validated by several recent international studies. SIDRA's ability to improve traffic flow and decrease delays at both signalized and unsignalized crossings, for instance, has been shown in experiments conducted in Ethiopia and Iraq [18, 19]. Kenya implemented AIMSUN to assess methods for reducing emissions along urban roadways [20]. Other studies also concentrated on merging traffic and emission models to minimize overall journey duration and environmental impact [21] and optimizing Park-and-Ride systems through multi-criteria approaches [22]. These studies provide a solid basis for the present investigation, particularly in bolstering the application of SIDRA and defending the design approach chosen for the Al-Maidan region.

## II. METHODOLOGY AND DATA COLLECTION

Car parking is crucial in Baghdad due to its impact on traffic flow, congestion, and environmental pollution. Effective parking planning requires a clear understanding of the city's unique characteristics, such as parking supply and demand, trip generation, and land use patterns. This paragraph presents the data collection and analysis process for a proposed underground multi-story parking garage in Maidan Square, Baghdad, based on both local and international experience.

### A. Study Area

The study area, located in the Al-Rusafa district of Baghdad, experiences severe congestion due to road blockages, the presence of street vendors, the absence of effective regulatory enforcement, and an old network of pavement. Key intersections, such as Al-Khulafaa, Al-Ameen, and Al-Maidan, are particularly impacted, as illustrated in Figure 1. The survey aims to analyze these challenges and propose improvements for parking management in these heavily congested zones. The area was selected due to its central location, high commercial activity, and critical importance for traffic planners and daily commuters. Secondly, the area includes commercial zones and shopping centers with diverse land uses, which necessitate a detailed investigation to assess their influence on traffic patterns and urban infrastructure. In addition, the region is characterized by high traffic volumes, especially during daytime hours, underscoring the need for robust traffic and parking management solutions. Lastly, the area suffers from disorganized parking patterns and a shortage of designated spaces, highlighting the need for structured parking facilities.

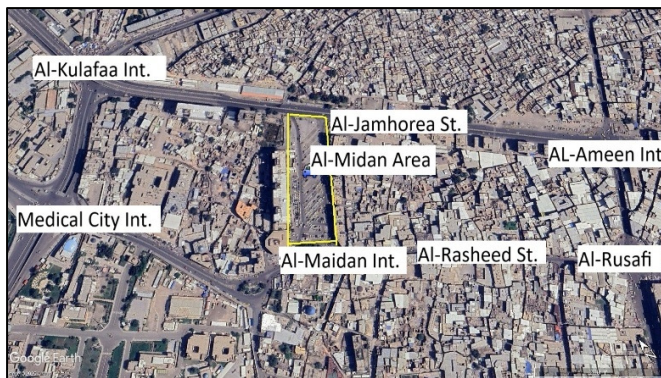


Fig. 1. Location of the study area, © Airbus, Maxar Technologies.

### B. Data Collection

The study investigated traffic conditions in a defined area using Metro Count devices to assess road performance. The collected data were categorized into three main types: traffic flow measurements, parking surveys, and questionnaire/interview-based surveys. The Metro Count devices comprised a data logger connected to pneumatic tubes installed at major intersections. Sensors were installed at key locations and tested to ensure accurate data recording. The pneumatic tubes were connected to the data logger, which automatically recorded data each time a vehicle passed over the tubes, as illustrated in Figure 2. After a 24-hour data collection period, the recorded information was retrieved and analyzed using Metro Count Traffic Executive software. The device's built-in battery enabled continuous operation without requiring an external power source.

### C. Peak Hours Determination

The peak hour refers to the time of day with the highest traffic volume, typically influenced by fluctuations in vehicle demand, congestion levels, and variations in traffic flow. To identify these peak traffic periods, data were collected using Metro Count devices, direct observations, and reports from traffic officers. The findings reveal a distinct morning peak in the study area occurring between 8:30 AM and 11:00 AM. Table I presents a summary of the identified peak periods at the intersection under study.

TABLE I. PEAK HOURS OF KEY STREETS IN THE STUDY AREA

Street name	Peak hours
Al-Khulafaa intersection	10:30 – 11:30
Al-Maidan intersection	7:00 – 8:00
Al-Ameen intersection	15:00 – 16:00

### D. Simulation Tool: SIDRA Intersection v9

SIDRA Intersection v9 was chosen for this study because of its established dependability and widespread acceptance for evaluating the performance of both signalized and unsignalized intersections. SIDRA provides precise, deterministic calculations of several traffic performance metrics, including LOS, average delay, fuel consumption, pollutants, and queue length. The accuracy of SIDRA in real-world scenarios has been confirmed by numerous research studies. Authors in [23],

for example, showed that SIDRA performed better than other methods, such as HCS, when calculating delays at Jordanian signalized crossings. Similarly, SIDRA's efficacy in assessing various intersection control types in New Zealand was validated by authors in [24]. Furthermore, because of SIDRA's dependability and regular results, traffic authorities in wealthy nations like Canada and Australia have formally adopted and certified it [6]. Specifically, version 9 offers improved tools for simulating public transportation movements, multi-lane road segments, and pedestrian and vehicle interactions—all of which are highly relevant to the complex traffic conditions in the Al-Maidan region. Because of these features, SIDRA was the best instrument for achieving the goals of this study, guaranteeing both practical application and scientific validity.



Fig. 2. Data collection using pneumatic tubes in the study area.

### E. Evaluation Scenarios

Two scenarios were analyzed:

- Original scenario – Base case evaluation (without multi-story parking): In this scenario, the current traffic conditions of the study area are evaluated using SIDRA v9 software without the addition of a multi-story parking facility.
- Alternative scenario – Estimating demand for the parking facility via questionnaire: In this scenario, a field questionnaire is conducted targeting taxi drivers, bus drivers, shop owners, residents, etc., to determine the number of vehicles that would likely use the proposed multi-story parking facility.

The goal is to estimate the demand for the proposed multi-story parking facility. The results help predict how many vehicles would be diverted from the street network to the

parking structure, thereby reducing congestion and pressure on the road system.

### III. EXPERIMENTAL RESULTS AND DISCUSSION

The results discussion is arranged according to the three crossings examined in this study: Al-Khulafaa, Al-Ameen, and Al-Maidan. Following the installation of the planned multi-story parking structure, traffic performance metrics and environmental effects are examined for each intersection. The evaluation's findings and consequences are shown in the following subsections.

#### A. Analysis and Results of Original Scenario

##### 1) Al-Khulafaa Intersection—Current Condition

The analysis of the Al-Khulafaa intersection under the current scenario reveals severe operational deficiencies. Figure 3 and Tables II and III show that the intersection handles a total traffic volume of 7,053 veh/h, with the highest congestion observed in the approaches from Al-Khulafaa Street. The average control delay reaches 434 s/veh, indicating critical oversaturation and excessive wait times for drivers. The Degree of Saturation (DoS) is recorded at 1.85, significantly above the acceptable threshold, confirming that the intersection is operating far beyond its design capacity. In terms of LOS, the intersection performs at LOS F, representing the worst performance category in traffic analysis standards. Furthermore, the environmental indicators show high fuel consumption of approximately 885,289 L/year and CO<sub>2</sub> emissions of about 2,100,626 kg/year, which emphasize the negative environmental impact of current congestion levels.

TABLE II. VEHICLE MOVEMENT PERFORMANCE AT AL-KHULAFAA INTERSECTION UNDER THE ORIGINAL SCENARIO

Movement	Demand flow (veh/h)	v/c	Average delay (s/veh)	LOS	Average speed (km/h)
South (S.B) Al-Jamhorea approach	1678	1.81	433	LOS F	6.9
East (E.B) Al-Fadhil approach	1767	1.83	445	LOS F	6.9
North (N.B) Abo Talib approach	1808	1.85	448	LOS F	6.7
West (W.B) City of Medicine St. approach	1799	1.80	409	LOS F	7.1
All vehicles	7053	1.85	434	LOS F	6.8

a. v/c: volume-to-capacity ratio.

TABLE III. FUEL CONSUMPTION AND GAS EMISSIONS AT AL-KHULAFAA INTERSECTION UNDER THE ORIGINAL SCENARIO

Parameter	Unit	Value
Fuel total	L/year	885,289
CO <sub>2</sub> total	kg/year	2,100,626
CO total	kg/year	1,748
HC total	kg/year	268
NO <sub>x</sub> total	kg/year	2,859

Colour code based on Level of Service

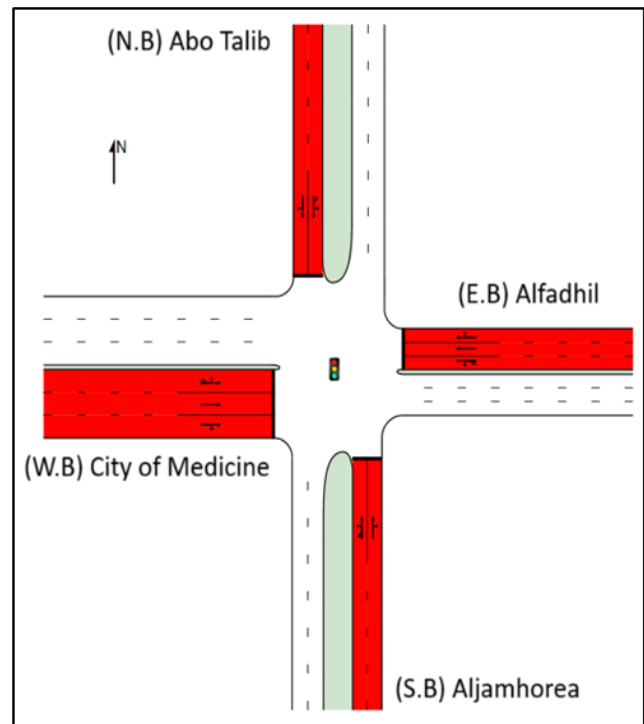


Fig. 3. Simulation of the Al-Khulafaa intersection in SIDRA software under the original scenario.

Overall, the Al-Khulafaa intersection suffers from excessive fuel consumption, elevated emissions, and high operational costs, primarily driven by intense vehicle delays and oversaturated traffic conditions. The findings suggest that traffic signal optimization and geometric redesign could be effective strategies for improving intersection performance, such as signal timing optimization, geometric redesign, or the implementation of traffic demand management strategies.

##### 2) Al-Ameen and Al-Maidan Intersections—Current Condition

The Al-Maidan and Al-Ameen crossroads both performed poorly in the original scenario. Al-Maidan recorded a LOS F and an average delay of 89.6 s/veh, whereas Al-Ameen displayed even more critical conditions with an LOS F and an average delay of 174 s/veh. Congestion at the crossings resulted in high levels of emissions and fuel usage in both situations. These findings highlight how important it is to put in place structured parking facilities and enhance traffic control to relieve the strain on these critical urban nodes. The simulation analysis of the Al-Ameen and Al-Maidan intersections reveals significant congestion levels and suboptimal traffic performance across multiple vehicle movements, as illustrated in Figures 4 and 5 and Tables IV, V, VI, and VII.

The results indicate an urgent need for strategic interventions to enhance both the operational efficiency and overall traffic flow at this key junction. The intersection

operates under highly oversaturated conditions. Evidence from the simulations suggests the critical need for traffic management strategies or infrastructure upgrades aimed at reducing delays, enhancing flow efficiency, and mitigating environmental impacts at the Al-Ameen and Al-Maidan intersections.

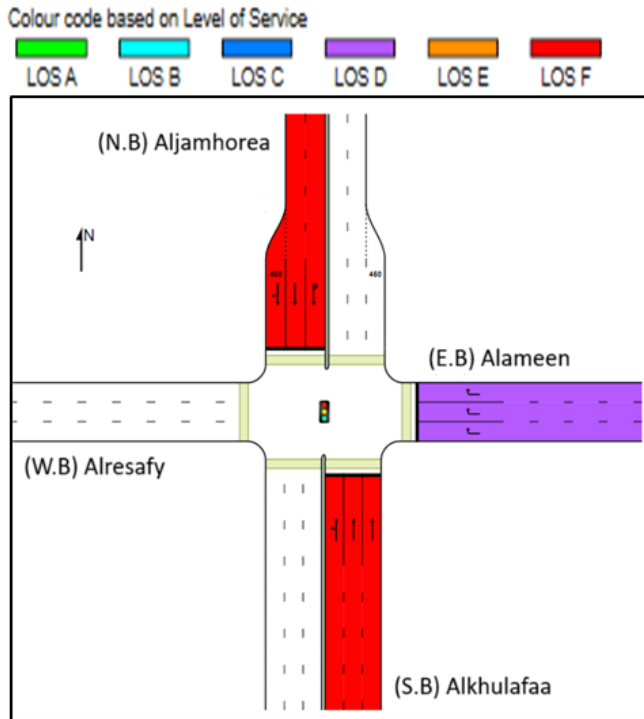


Fig. 4. Simulation of the Al-Ameen intersection in SIDRA software under the original scenario.

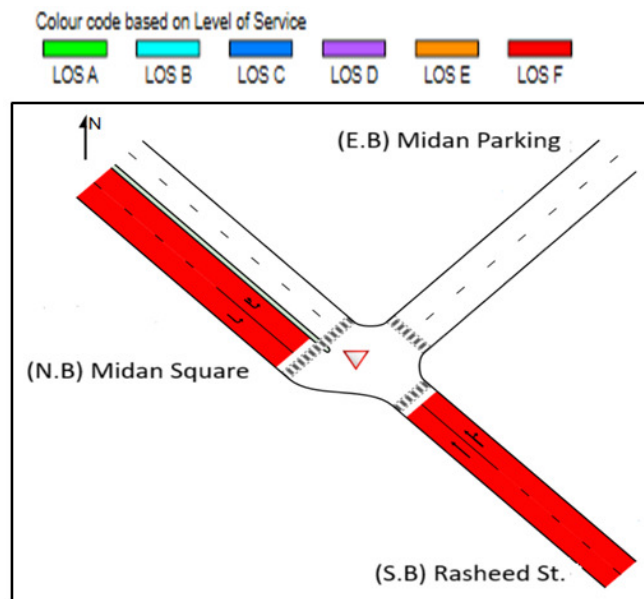


Fig. 5. Simulation of the Al-Maidan intersection in SIDRA software under the original scenario.

TABLE IV. VEHICLE MOVEMENT PERFORMANCE AT AL-AMEEN INTERSECTION UNDER THE ORIGINAL SCENARIO

Movement	Demand flow (veh/h)	v/c	Average delay (s/veh)	LOS	Average speed (km/h)
South (S.B) Al-Khulafaa approach	1964	1.39	247	LOS F	11
East (E.B) Al-Ameen approach	621	0.19	46	LOS D	32.4
North (N.B) Al-Jamhorea approach	1626	1.14	135	LOS F	16
All vehicles	4212	1.39	174	LOS F	14.1

TABLE V. FUEL CONSUMPTION AND GAS EMISSIONS AT AL-AMEEN INTERSECTION UNDER THE ORIGINAL SCENARIO

Parameter	Unit	Value
Fuel total	L/year	348,137
CO <sub>2</sub> total	kg/year	834,300
CO total	kg/year	752
HC total	kg/year	100
NO <sub>x</sub> total	kg/year	2,076

TABLE VI. VEHICLE MOVEMENT PERFORMANCE AT AL-MAIDAN INTERSECTION UNDER THE ORIGINAL SCENARIO

Movement	Demand flow (veh/h)	v/c	Average delay (s/veh)	LOS	Average speed (km/h)
South (S.B) Rasheed St. approach	371	0.80	36	LOS E	18
North (N.B) Maidan square approach	663	1.18	119	LOS F	8.7
All vehicles	1034	1.18	89	LOS F	10.5

TABLE VII. FUEL CONSUMPTION AND GAS EMISSIONS AT AL-MAIDAN INTERSECTION UNDER THE ORIGINAL SCENARIO

Parameter	Unit	Value
Fuel total	L/year	39,099
CO <sub>2</sub> total	kg/year	92,949
CO total	kg/year	77
HC total	kg/year	11
NO <sub>x</sub> total	kg/year	175

3) Summary

One of the key underlying causes of this degraded performance is the presence of on-street parking, illegal parking, and insufficient designated parking facilities in the area. On-street parking and illegal parking reduce the effective width of roadways, thereby limiting capacity and creating bottlenecks, particularly during peak hours. This not only disrupts traffic flow but also causes conflicts between moving and parked vehicles, increasing delay and accident risk. Illegal parking exacerbates the situation by blocking turning lanes, pedestrian crossings, and intersections, further impeding vehicle and pedestrian movement. Moreover, the lack of sufficient off-street parking options forces drivers to circle the area in search of space, increasing traffic volume and contributing to unnecessary congestion. These parking issues,

combined with outdated signal timings and inadequate road geometry, result in a severely compromised intersection performance. To mitigate these challenges, it is essential to implement a comprehensive parking management strategy that includes enforcement against illegal parking, conversion of on-street parking to off-street facilities, and possibly the introduction of smart parking solutions. Alongside signal optimization and geometric improvements, addressing these parking-related issues is critical to improving overall intersection efficiency and safety.

### B. Questionnaire Survey

An analysis of a questionnaire-based interview was conducted in the research area to collect data. The interview was conducted on working days (five days per week) between 8:00 am and 4:00 pm for off-street parking drivers and between 10:00 am and 1:00 pm for on-street parking drivers. User feedback is essential in parking studies to understand behavior, challenges, and support for proposed solutions. The questionnaires relied on commonly used questions to design a straightforward form that allows the user to provide detailed responses. The parking area accounted for 1,572 bays (capacity), according to [15]. The sample size was determined by estimating it based on capacity, which is less than 50,000, as described in [17]. Hence, 314 surveys were distributed for on-street and off-street parking.

### C. Driver Feedback Summary

A quick poll of nearby drivers was conducted in addition to simulation modeling to get their opinions on the suggested installation of a multi-story parking structure. More than 75% of respondents said they supported the initiative, pointing out that it would help ease traffic and cut down on the amount of time required to find parking. This feedback demonstrates the high level of public approval for the suggested design and supports the simulation results. Figure 6 reveals that 25% of drivers are merely passing through the area, circulating, and looking for a parking spot. These circulating vehicles create unnecessary traffic and congestion on already busy roads.

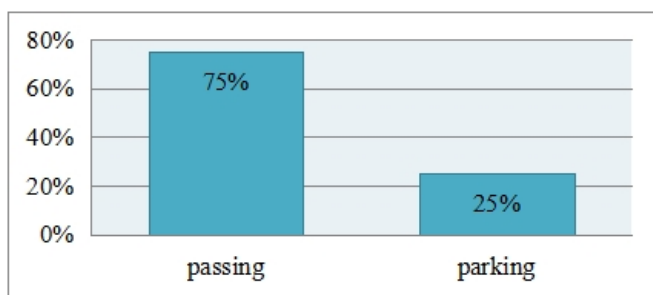


Fig. 6. Percentage of drivers searching for parking spots in the area.

### D. Analysis and Results of Alternative Scenario

In this scenario, an Al-Maidan multi-story parking facility was added, based on survey responses indicating an expected reduction in traffic volume of up to 20%. This decrease is attributed to the improved circulation while searching for parking and reduced on-street and illegal parking. In addition, geometric modifications were applied at each intersection,

including the provision of a separate right-turn lane and the addition of a U-turn in all directions. These improvements aimed to enhance traffic flow, reduce conflict points, and improve overall intersection performance.

#### 1) Al-Khulafaa Intersection—Optimized Scenario

A comparison was made between conditions before and after adding a multi-story parking facility in the study area and making some adjustments to the intersection geometry at the Al-Khulafaa intersection, as shown in Figure 7. A key geometric intervention was the removal of the through movement from Abu Talib Street (NB) toward Al-Jamhorea (SB), forcing vehicles to use the overpass. This change significantly reduced internal conflicts and lowered the volume processed at the surface level of the intersection.

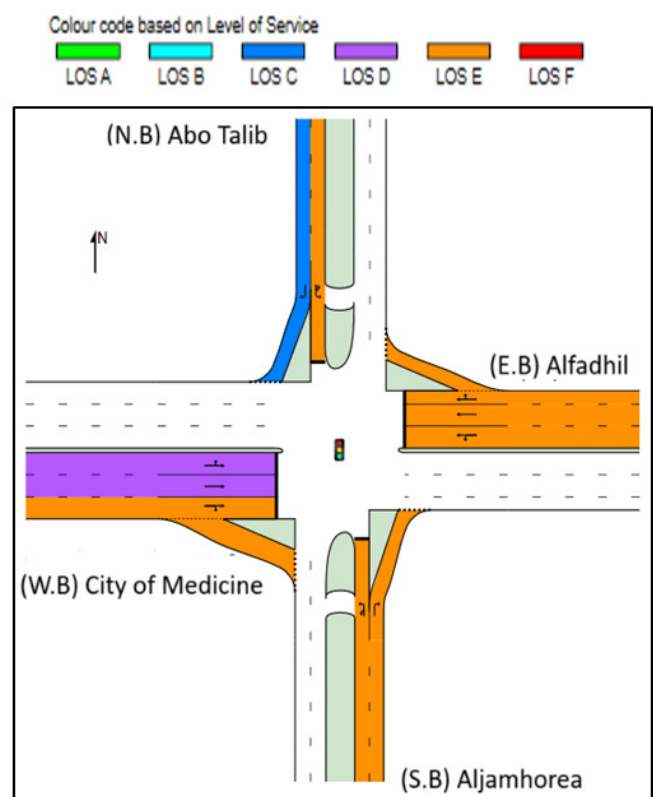


Fig. 7. Simulation of the Al-Khulafaa intersection in SIDRA software under the alternative scenario.

Significant improvement in both traffic performance and environmental impact was observed in the alternative scenario, as shown in Tables VIII and IX. The alternative scenario showed clear enhancements: the demand flow was reduced to 4,925 veh/h, the v/c ratio dropped to 0.95, and the average delay decreased significantly to 54 s/veh. The LOS improved to D, and average speeds nearly tripled to 25.2 km/h. Each intersection approach experienced lower delays, shorter queues, and increased travel speeds.

Environmentally, the alternative scenario achieved dramatic reductions in fuel consumption and emissions. Annual fuel use decreased to 342,313 L (a 58.8% reduction), whereas CO<sub>2</sub>

emissions dropped to 813,983 kg. Similar reductions were recorded for CO, HC, and NO<sub>x</sub> emissions, all declining by more than 50%. Overall, the alternative scenario presents a more sustainable and efficient solution for managing traffic at the intersection, offering significant benefits in terms of mobility, travel time, and environmental protection.

TABLE VIII. VEHICLE MOVEMENT PERFORMANCE AT AL-KHULAFAA INTERSECTION UNDER THE ALTERNATIVE SCENARIO

Movement	Demand flow (veh/h)	v/c	Average delay (s/veh)	LOS	Average speed (km/h)
South (S.B) Al-Jamhorea approach	992	0.95	57	LOS E	24.6
East (E.B) Al-Fadhil approach	1391	0.90	60	LOS E	24.2
North (N.B) Abo Talib approach	1124	0.87	42	LOS D	27.4
West (W.B) City of Medicine St. approach	1419	0.81	55	LOS E	25
All vehicles	4925	0.95	54	LOS D	25.2

TABLE IX. FUEL CONSUMPTION AND GAS EMISSIONS AT AL-KHULAFAA INTERSECTION UNDER THE ALTERNATIVE SCENARIO

Parameter	Unit	Value
Fuel total	L/year	342,313
CO <sub>2</sub> total	kg/year	813,983
CO total	kg/year	551
HC total	kg/year	76
NO <sub>x</sub> total	kg/year	1,300

2) Al-Ameen and Al-Maidan Intersections—Optimized Scenario

A comparison was made between conditions before and after adding a multi-story parking facility in the study area and making some adjustments to the intersection geometry at the Al-Ameen and Al-Maidan intersections, as shown in Figures 8 and 9, respectively. The analysis reveals a significant improvement in both traffic performance and environmental impact in the alternative scenario. Tables X and XI summarize the major traffic performance metrics and environmental effects at the Al-Ameen and Al-Maidan intersections.

The findings show a notable improvement at the Al-Ameen intersection, where the average speed virtually doubled to 28.2 km/h, the LOS improved to D, and the average delay decreased to 39 s/veh. At the Al-Maidan intersection, the average delay decreased to 22 s/veh, the v/c ratio improved to 0.48 (indicating more efficient traffic handling), and the average speed increased to 23.4 km/h. The LOS improved to C. Fuel consumption and emissions also significantly decreased, according to environmental data.

3) Summary

The alternative scenario achieves notable environmental improvements and a dramatic reduction in delay. This scenario demonstrates better efficiency for selected routes and significantly improved sustainability, making it a strategically

favorable outcome if balanced traffic distribution is further optimized. This enhancement was not solely attributed to the estimated 20% reduction in traffic volume, based on the survey data, but also to the strategic geometric improvements implemented in the design. Specifically, the inclusion of dedicated right-turn lanes and designated U-turn facilities played a crucial role in easing traffic movement. These modifications effectively diverted turning vehicles away from through lanes, thereby reducing conflict points and overall intersection load. As a result, vehicle delays were minimized, and traffic flow became smoother and more continuous, reflecting a substantial gain in operational efficiency.

TABLE X. VEHICLE MOVEMENT PERFORMANCE AT AL-AMEEN AND AL-MAIDAN INTERSECTIONS UNDER THE ALTERNATIVE SCENARIO

Intersection	Demand flow (veh/h)	v/c	Average delay (s/veh)	LOS	Average speed (km/h)
Al-Ameen (all vehicles)	3319	0.68	39	LOS D	28.2
Al-Maidan (all vehicles)	427	0.48	22	LOS C	23.4

TABLE XI. FUEL CONSUMPTION AND GAS EMISSIONS AT AL-AMEEN AND AL-MAIDAN INTERSECTIONS UNDER THE ALTERNATIVE SCENARIO

Intersection	Fuel consumption (L/year)	CO <sub>2</sub> emissions (kg/year)
Al-Ameen (all vehicles)	188,369	452,792
Al-Maidan (all vehicles)	8,143	20,496

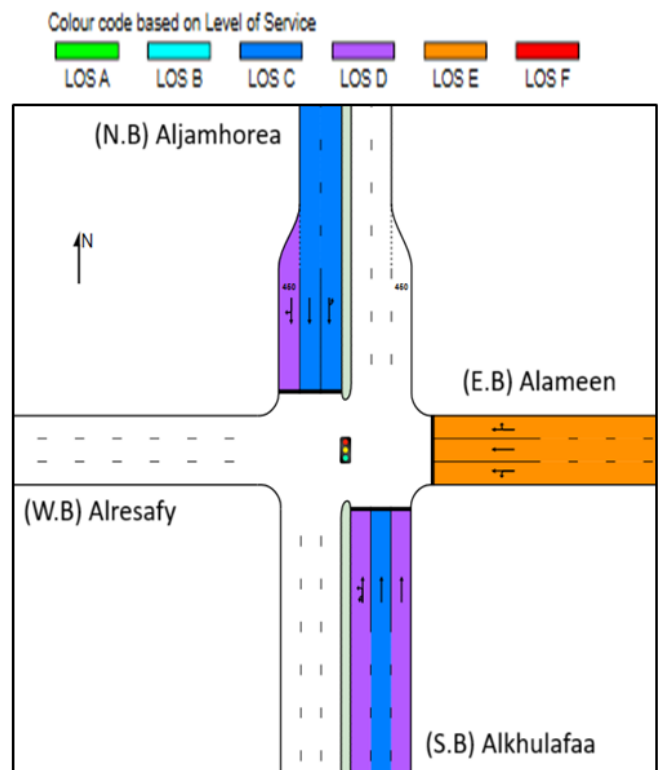


Fig. 8. Simulation of the Al-Ameen intersection in SIDRA software under the alternative scenario.

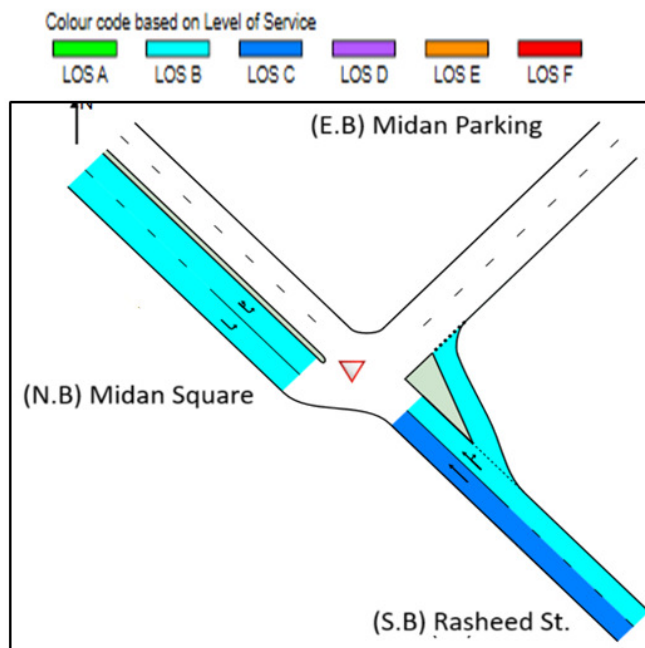


Fig. 9. Simulation of the Al-Maidan intersection in SIDRA software under the alternative scenario.

#### IV. CONCLUSION

This study examined the effects of installing multi-story parking structures on environmental performance and traffic congestion at three significant Baghdad junctions. The results demonstrated notable improvements in vehicle delay, queue length, travel speed, and emission levels using SIDRA Intersection v9 software and field data. The following points summarize the key outcomes:

- All three intersections suffered from severe congestion. At Al-Khulafaa, the v/c ratio reached 1.85, with an average delay of 434 s/veh and LOS F across all movements. Al-Ameen and Al-Maidan also experienced LOS F, with delays up to 174 s and speeds below 10 km/h due to geometric constraints and excessive demand.
- Environmental impacts were substantial. Al-Khulafaa alone emitted over 2,000,000 kg of CO<sub>2</sub> and consumed 885,289 L of fuel annually. Furthermore, there were high levels of CO, HC, and NO<sub>x</sub> emissions across all intersections. The overall system was inefficient due to excessive idling, long queues, and stop-and-go traffic.
- The alternative scenario, incorporating multi-story parking, targeted demand reduction, and geometric improvements, produced substantial operational and environmental benefits. Average vehicle delay decreased by up to 87%, average speed increased by up to 270%, and annual fuel consumption and emissions decreased by over 70% at certain intersections.
- The implementation of multi-story parking facilities is also anticipated to improve pedestrian safety and urban walkability by mitigating automobile congestion. This strategy enhances accessibility and safety for non-

motorized users in the city center by reducing roadside parking and vehicle-pedestrian interactions at key crossings.

The results are consistent with those of both domestic and foreign studies. Authors in [25] reported a 30–35% decrease in CO<sub>2</sub> emissions and traffic congestion after installing automatic parking garages. Authors in [19] observed a 32% delay reduction in Karbala using SIDRA. These comparisons validate the validity and efficacy of the employed approach. Future research could expand on this approach by investigating its integration with public transportation systems, evaluating its financial viability, and using microsimulation tools (such as VISSIM) to analyze vehicle behavior in depth.

#### DATA AVAILABILITY

The datasets generated and analyzed during the current study are not publicly available due to internal restrictions, but they are available from the corresponding author upon reasonable request.

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