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Integrated Congestion Analysis and Simulation-Based Improvement of the Al-Faris Al-Arabi Roundabout Using PTV VISSIM

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ABSTRACT

Rapid growth in private-vehicle use and limited upgrades to traffic infrastructure have led to chronic congestion at key intersections in Baghdad. The Al-Faris Al-Arabi Roundabout is a critical bottleneck, with long queues and unstable circulating flow during peak hours. This study applies an integrated approach that combines field traffic counts, a commuter-perception survey, and microscopic simulation using PTV VISSIM to assess existing conditions and test improvements. Baseline results show average delays of about 80 s/veh, queues exceeding 150 m, and Level of Service (LOS) D, while more than 70% of surveyed users report daily delays above 20 minutes and noticeable stress and health impacts. Two mitigation strategies are evaluated: a flyover connecting Al-Mansour and Al-Zaytoun Streets, and adaptive signal control at the roundabout entries. The flyover reduces delays by roughly 19% and queues by 38%, whereas adaptive signal control achieves delay reductions of about 14.5% and queue reductions near 30%, with lower cost and faster implementation. The findings highlight the value of combining field data, user perceptions, and simulation to support congestion-mitigation decisions in rapidly developing cities like Baghdad.

Keywords:

Traffic Congestion; PTV VISSIM; Roundabout; Adaptive Signal Control; Urban Mobility; Baghdad.

1. Introduction

Rapid urban growth and increased private-vehicle ownership have intensified congestion in many developing cities, where transport networks and traffic-management systems struggle to keep pace [1], [2]. Traffic emissions further worsen urban air quality, contributing significantly to $PM_{2.5}$ levels and associated health risks, as reported by the WHO [3]. Beyond operational factors, roadway surface performance also plays a critical role in overall network efficiency. Improvements in pavement durability reduce maintenance frequency and minimize traffic disruptions, contributing indirectly to smoother traffic flow. In this context, Sepehr and Seref demonstrated that incorporating SBS, Viatop Premium, and FRP modifiers enhances the mechanical strength and deformation resistance of Stone Mastic Asphalt mixtures [4]. Such advancements support more resilient road infrastructure, which is essential for maintaining stable traffic operations in rapidly growing urban environments.

Baghdad exemplifies these challenges. Rising population and motorization have placed continuous pressure on major intersections, many of which rely on outdated geometric designs and fixed-time signal plans [5], [6], [7]. In addition to geometric and operational limitations, pavement performance also influences traffic efficiency in congested urban corridors. Weak or moisture-susceptible asphalt surfaces deteriorate more rapidly under heavy loading, leading to surface distress, reduced driving comfort, and localized speed drops that can aggravate congestion. Saedi and Oruç demonstrated that modifying warm-mix asphalt with nano bentonite and fatty arbocel significantly improves resistance to moisture damage and rutting, thereby enhancing pavement durability under sustained urban traffic demand [8]. Strengthening pavement layers in this manner contributes to more reliable traffic operations and reduces the frequency of maintenance-related disruptions.

Enhanced pavement sustainability has also been recognized as an important factor in maintaining consistent traffic flow, particularly in high-demand networks. Materials that resist cracking and surface degradation help prevent localized slowdowns that contribute to congestion. In this context, Sepehr and Seref investigated the incorporation of roof-shingle waste fibers into Stone Mastic Asphalt mixtures and reported notable improvements in durability and deformation resistance under repeated loading [9]. Such material innovations support longer pavement service life and reduce the likelihood of maintenance interventions that often disrupt traffic operations in major urban corridors. The Al-Faris Al-Arabi Roundabout is one of Baghdad's most saturated intersections, linking four major arterial roads and serving high daily demand. Recurrent queues, long delays, and unstable circulating flow characterize both morning and afternoon peaks. Figure 1 illustrates its location within the city network.

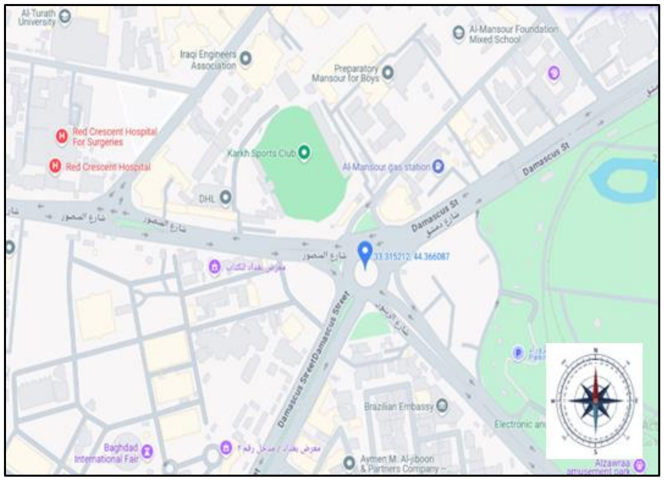

Figure 1. Geographic context of Baghdad and the Al-Faris Al-Arabi Roundabout.

In addition to material-based enhancements reported in prior studies, recent research has emphasized the importance of pavement durability and systematic monitoring in maintaining efficient urban traffic operations. Saedi [10] demonstrated that incorporating biomass fibers into hot-mix asphalt significantly improves moisture resistance under freeze–thaw and wet-weather conditions, reducing stripping potential and delaying structural deterioration. These improvements directly support more stable traffic flow by minimizing surface distress and reducing the frequency of maintenance-related closures—an important consideration for high-demand corridors feeding into the Al-Faris Al-Arabi Roundabout. Complementing these material advancements, Aburqaq et al. [11] showed that UAV-based pavement inspection using georeferenced control points (GCPs) provides a reliable and rapid tool for monitoring surface conditions in urban networks. Their findings highlight how early detection of pavement defects can prevent localized speed reductions and emerging bottlenecks. Together, these studies reinforce the broader conclusion that both pavement resilience and data-driven inspection methods contribute meaningfully to maintaining consistent flow at critical intersections such as the Al-Faris Al-Arabi Roundabout.

Studies from nearby regions also demonstrate that improving geometric design can significantly reduce congestion. For instance, Tarhuni et al. [12] showed that converting conventional roundabouts into turbo-roundabouts can reduce delays by more than one-third by eliminating conflict points and enforcing better lane discipline. Although such solutions offer strong operational benefits, they often require considerable right-of-way and construction resources. In addition, recent environmental assessments in Baghdad indicate that traffic-related emissions remain one of the primary contributors to deteriorating air quality, with measurable increases in $PM_{2.5}$ levels during peak traffic periods [13]. Although these studies focus mainly on pollution trends, they reinforce the need for operational improvements that reduce prolonged idling and stop-and-go movement.

Globally, several studies emphasize that roundabouts and multi-leg intersections often act as bottlenecks, and microscopic tools such as PTV VISSIM are essential for diagnosing operational deficiencies [14], [15]. In the MENA region, congestion is additionally driven by high private-car dependency and underdeveloped public transport systems [16]. Although simulation research exists in Iraq, few studies integrate survey data with calibrated models or compare structural and operational solutions.

In addition to regional analyses, several recent simulation-based studies offer insights relevant to saturated intersections. Akula Prakash et al. [17] showed that applying VISSIM to evaluate operational strategies can lead to measurable reductions in delay, especially when adaptive control mechanisms are introduced. Their findings highlight the practical value of testing alternative scenarios virtually before implementing them in the field.

Similarly, Erpek et al. [18] explored how advanced modeling techniques support intelligent transport applications, demonstrating that detailed microscopic representations can capture both driver behavior and system-level interactions. Although their work centers on ITS communication frameworks, the emphasis on high-fidelity simulation underscores its importance for complex urban traffic environments such as Baghdad.

Key research gaps include:

1-Limited mixed-method analyses combining surveys with microscopic simulation.

2-Very few applications of adaptive signal control in Baghdad.

3-Weak integration of environmental and health dimensions.

4-Limited comparison between long-term geometric improvements and short-term operational strategies.

This study aims to fill these gaps by integrating field traffic counts, commuter perceptions, and VISSIM modeling to evaluate baseline conditions and assess two improvement scenarios: a flyover and adaptive signal control. Table 1 summarizes recent literature related to congestion and simulation-based analysis.

Table 1. Summary of recent literature (2023–2024).

Study / Year	Focus Area	Methods Used	Key Findings	Identified Gaps
UN-Habitat [1]	Global urban congestion	Global mobility assessment	Urbanization intensifies congestion	No intersection-level modeling
World Bank [2]	Economic impact	Economic analysis	Congestion increases fuel & time loss	No microsimulation
WHO [3]	Air quality	Health data	Traffic contributes heavily to $PM_{2.5}$	No traffic modeling
Talib & Nassrullah [6]	Baghdad signals	VISSIM modeling	Signal timing can reduce delays	No survey integration
Mohammed [7]	Baghdad intersections	VISSIM calibration	Aggressive local behavior modeled	No improvement scenarios
Tarhuni et al. [12]	Turbo-roundabouts	Geometric redesign	Large delay reductions	High cost
Rabie [13]	$PM_{2.5}$ in Baghdad	Field measurements	Vehicles contribute ~40% of $PM_{2.5}$	No scenario testing
Akomolafe & Adedeji [16]	MENA congestion	Regional analysis	High car dependency worsens congestion	No micro-simulation
Akula Prakash et al. [17]	Adaptive signals	ITS + VISSIM	Reduces delay by 10–30%	Not applied in MENA
Yang et al. [19]	AI-based signals	Deep learning + VISSIM	Improves flow & stability	Complex deployment

2. Methodology

This research adopts a structured, five-phase methodology to evaluate congestion at the Al-Faris Al-Arabi Roundabout and to test potential improvement strategies. The overall framework is illustrated in Figure 2 and consists of: (1) traffic data collection, (2) commuter-perception survey, (3) VISSIM model development and calibration, (4) scenario testing, and (5) performance evaluation using standard indicators.

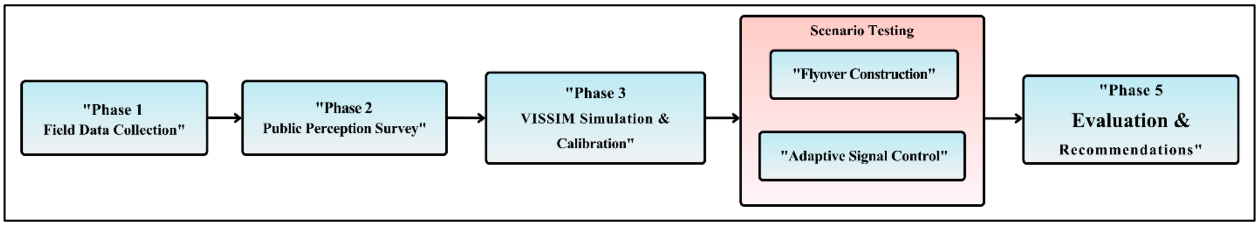

Figure 2. Methodological framework of the study.

2.1. Study Area

The Al-Faris Al-Arabi Roundabout is located in western Baghdad and connects four major arterial corridors: Al-Mansour, Al-Zaytoun, Al-Nusour, and Damascus Streets. The roundabout serves a mixture of residential, commercial, and institutional land uses, resulting in high traffic volumes during both morning and afternoon peaks. Field visits were carried out to document geometric characteristics, including entry and exit lane configurations, circulating lanes, and typical turning movements.

2.2. Traffic Data Collection

Manual traffic counts were conducted on three typical weekdays in January 2025 during the morning peak (8:00–9:00 AM) and the afternoon peak (2:00–3:00 PM). Observers recorded approach-specific flows, turning movements, and vehicle classifications. The data were subsequently aggregated to obtain hourly volumes for each movement. Vehicles were grouped into two broad classes: passenger vehicles (cars and taxis) and heavy vehicles (trucks, buses, and service vehicles). The approximate share of each class is summarized in Table 2.

Table 2. Vehicle classification and approximate share.

Class	Description	Approximate Share
Passenger Cars	Private cars, taxis, small vehicles	75–80%
Heavy Vehicles	Trucks, buses, service vehicles	5–10%

The results confirm a strong dominance of passenger vehicles, consistent with the high private-car dependency reported in regional studies [16].

2.3. Commuter-Perception Survey

To complement the field data, a structured questionnaire survey was administered to users of the Al-Faris Al-Arabi Roundabout. A total of 250 valid responses were collected. The survey focused on travel purpose, mode choice, average travel time during peaks, perceived congestion severity, satisfaction with public transport, and health-related impacts such as stress and respiratory symptoms. Respondents were grouped into three main categories: daily commuters, students, and local residents. Their proportional shares are shown in Table 3.

Table 3. Survey respondent categories and percentages.

Respondent Type	Percentage of Total Sample (%)
Daily Commuters	71%
Students	18%
Local Residents	11%

The survey results provide an important user-based perspective that is later compared with simulation outputs.

2.4. Simulation Model Development

A detailed PTV VISSIM model of the Al-Faris Al-Arabi Roundabout was constructed based on the documented geometry and field-measured traffic volumes. The Wiedemann 74 car-following model was selected due to its suitability for urban traffic and prior successful use in Baghdad [7]. Driver parameters related to standstill distances, following behavior, and lane-change aggressiveness were calibrated to reflect observed local driving patterns. Key performance indicators (KPIs) used to evaluate traffic conditions in the simulation are summarized in Table 4.

Table 4. Traffic performance indicators used in VISSIM analysis.

Indicator	Description
Travel Time (s)	Average time required to traverse the roundabout approaches; used as a primary congestion measure
Queue Length (m)	Maximum and average extent of queues, indicating bottleneck severity
Throughput (veh/h)	Number of vehicles served per hour, reflecting flow efficiency
Level of Service (LOS)	Qualitative category of operational performance (A–F) based on delay and flow conditions

2.5. Scenario Design

To examine potential improvements, two alternative scenarios were designed and compared with the baseline (existing conditions). Both scenarios use the same demand levels as the calibrated baseline model to ensure consistent comparison.

Table 5. Improvement scenarios.

Scenario	Description	Objective
Scenario 1: Flyover	Grade-separated link between Al-Mansour and Al-Zaytoun Streets, removing through traffic from the roundabout	Reduce circulating volume and alleviate internal conflicts
Scenario 2: Adaptive Signal Control	Real-time, traffic-responsive signal plan controlling entries to the roundabout	Reduce delay and balance flows between approaches

The flyover scenario represents a long-term geometric intervention, while adaptive signal control represents a more immediate, lower-cost operational strategy.

3. Integrated Results: Commuter Perceptions and Simulation Outcomes

This section presents an integrated analysis of congestion at the Al-Faris Al-Arabi Roundabout, combining survey findings with baseline VISSIM results and scenario-based improvements. The goal is to examine how perceived congestion, health impacts, and measured performance relate to each other.

3.1. Travel Patterns, Mode Choice, and Peak-Hour Behavior

Survey responses confirm that users of the Al-Faris Al-Arabi Roundabout are a diverse group that includes daily employees, university and school students, and nearby residents. Most trips during peak hours are work- or education-related, which is consistent with typical daily mobility patterns in Baghdad. The mode-choice distribution, illustrated in Figure 3, shows that more than 70% of respondents rely on private cars, about 20% use public transport, and less than 10% walk or cycle. These values closely match the observed vehicle classification in Table 2, where passenger cars represent approximately 75–80% of traffic. Such a high share of private vehicles means that even moderate increases in demand can quickly lead to queuing and unstable circulating flow at the roundabout.

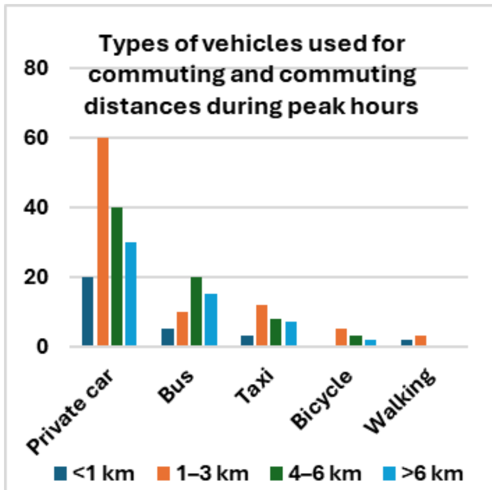

Figure 3. Mode choice and commuting distances for users of the Al-Faris Al-Arabi Roundabout.

3.2. Congestion Severity and Delays

3.2.1 Survey-Based Perception of Delay

Survey results indicate that commuters perceive congestion at the roundabout as both severe and persistent. As summarized in Figure 4, more than half of respondent's report spending over 30 minutes in congested conditions during peak periods, while roughly 38% indicate delays between 15 and 30 minutes. Only a small minority around 10% experience less than 15 minutes of delay. These findings suggest that the roundabout functions as a major bottleneck in the local network, increasing total corridor travel time for a large share of users.

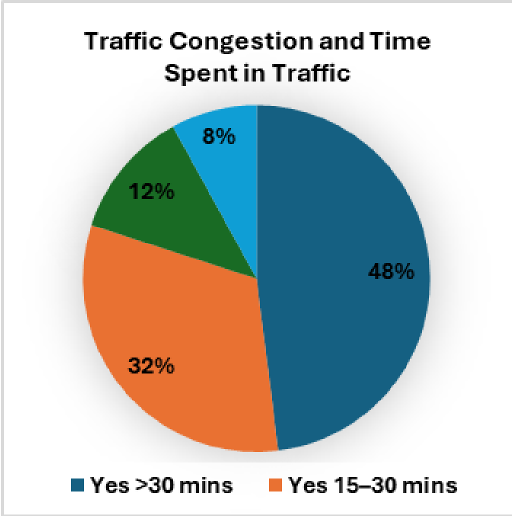

Figure 4. Reported time spent in congestion during peak hours.

3.2.2. Baseline Simulation – Morning Peak

The baseline VISSIM model for the morning peak (8:00–9:00 AM) confirms that the intersection operates under congested conditions. Average delay at the roundabout is 80.58 s/veh, corresponding to LOS D. Long queues form on all approaches, particularly along Al-Mansour and Al-Nusour Streets, where queues can extend well beyond the immediate roundabout area.
Key performance indicators for the morning peak are summarized in Table 6.

Table 6. Baseline simulation indicators for morning peak (8:00–9:00 AM).

Performance Indicator	Value	Interpretation
Average Travel Time (s)	80.58 s	High delay; unstable flow
Average Queue Length (m)	162 m	Long queues on major approaches
Average Speed (km/h)	12.7 km/h	Stop-and-go conditions
Vehicle Throughput (veh/h)	2,184 veh/h	Demand close to capacity
Level of Service (LOS)	D	Congested operation
Maximum Delay (s/veh)	>120 s	Severe delay at critical movements

3.2.3. Baseline Simulation – Afternoon Peak

The afternoon peak (2:00–3:00 PM) exhibits slightly shorter queues but similar average delays. The intersection remains in LOS D, indicating sustained congestion.

Table 7. Baseline simulation indicators for afternoon peak (2:00–3:00 PM).

Performance Indicator	Value	Interpretation
Average Travel Time (s)	79.84 s	Comparable to morning peak
Average Queue Length (m)	158 m	Persistent queues
Average Speed (km/h)	12.5 km/h	Stop-and-go movement
Vehicle Throughput (veh/h)	2,156 veh/h	High demand, near capacity
Level of Service (LOS)	D	Congested operation
Maximum Delay (s/veh)	>118 s	Long delays for certain movements

3.2.4. Alignment Between Survey and Simulation Results

Survey responses and simulation results describe different aspects of the same phenomenon: the survey reflects corridor-level experience, while VISSIM quantifies intersection-level performance. Nevertheless, several consistencies emerge:

1-Reported "very slow movement" and long waiting times match simulated speeds of 12–13 km/h. The fact that 92% of respondents characterize congestion as "heavy" is consistent with LOS D in the baseline model.
2-Estimated queue lengths from field observations (~150–160 m) correspond closely to simulated average queues of 158–162 m.
3-These consistencies indicate that the calibrated VISSIM model accurately represents observed conditions and perceived congestion at the roundabout, providing a reliable base for testing improvement scenarios.

3.3. Environmental and Health Impacts

Survey data also shed light on how congestion at the Al-Faris Al-Arabi Roundabout affects commuters' health and well-being. As illustrated in Figure 5:
1-Approximately 68% of respondents report breathing difficulties or respiratory irritation.
2-Around 45% indicate increased stress, fatigue, or irritability linked to daily congestion.
3-Nearly 25% mention recurrent headaches or general discomfort while travelling through the area.
These perceptions are consistent with findings from WHO reports and regional studies that link traffic-related emissions and prolonged exposure to congested environments with adverse health outcomes [3], [19], [21]. Long queues and low speeds (≈12.5 km/h) increase idling time and stop-and-go cycles, which in turn raise emissions of $PM_{2.5}$, NO_x, and CO_2 at and near the roundabout [3], [20].

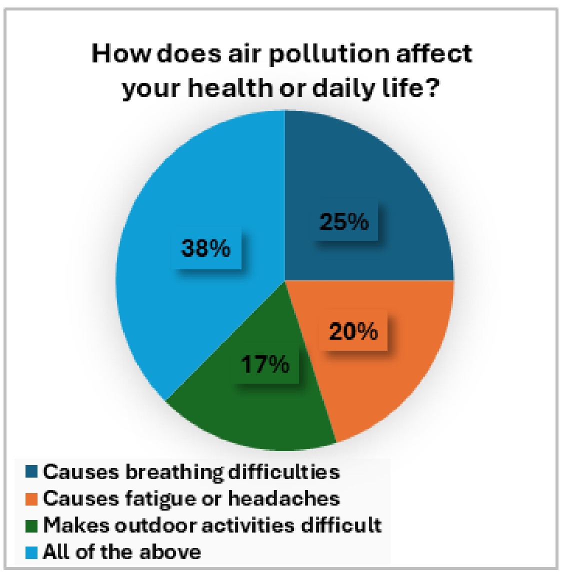

Figure 5. Commuter-reported impacts of air pollution and congestion around the Al-Faris Al-Arabi Roundabout.

Taken together, these results suggest that improving traffic operations at this location can yield not only mobility benefits but also sizeable health and environmental co-benefits.

3.4. Visualizing Baseline Queues and Flow

Simulation screenshots (Figures 6 and 7) depict the spatial distribution of queues and the evolution of flow throughout the peak hours. Both figures clearly show that queues frequently spill back along all four approaches, sometimes reaching adjacent intersections.

Advance Researches in Civil Engineering
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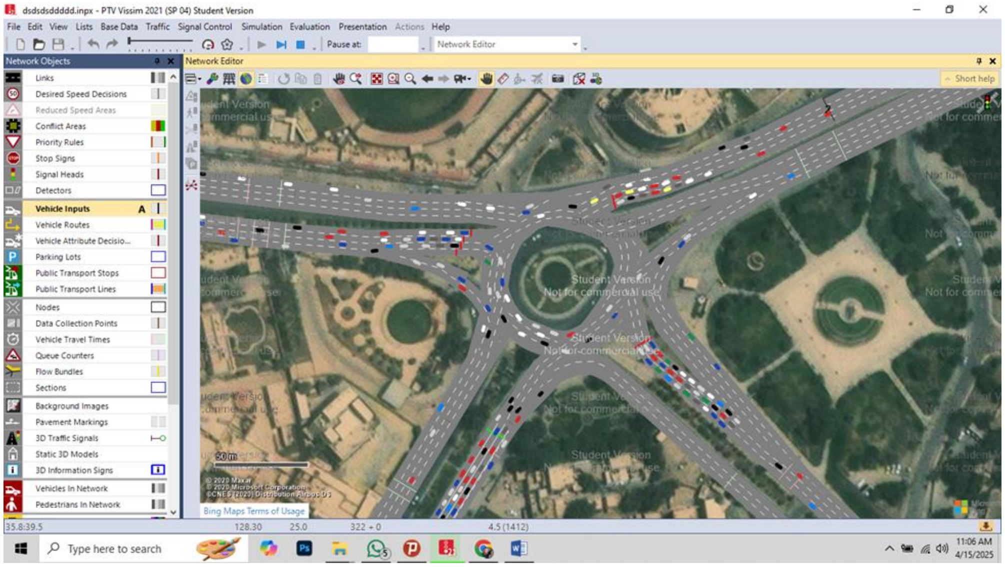

Figure 6. VISSIM snapshot and analysis for morning peak.

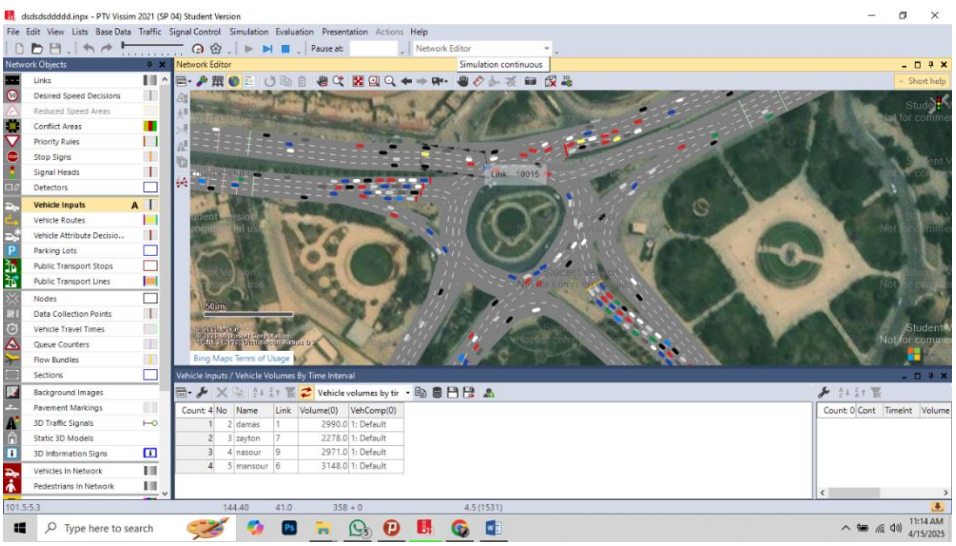

Figure 7. VISSIM snapshot and analysis for afternoon peak.

Such patterns indicate that the roundabout acts as a major constraint, limiting corridor performance in a wider network area.

3.5. Scenario Results: Flyover vs. Adaptive Signal Control

3.5.1. Scenario 1 – Flyover (Al-Mansour → Al-Zaytoun)

The first improvement scenario introduces a flyover linking Al-Mansour and Al-Zaytoun Streets, effectively removing a significant portion of through traffic from the roundabout. Simulation results show:

1-Delay reduction of approximately 19% relative to the baseline.
2-Queue length reduction of about 38%.
3-LOS improvement from D to B.
4-Higher average speeds and smoother circulating flow inside the roundabout.

The flyover scenario thus delivers the strongest operational improvement among the tested options, but it entails high construction costs and longer implementation time.

3.5.2. Scenario 2 – Adaptive Signal Control

The second scenario introduces an adaptive signal-control system governing entries to the roundabout. Green times are adjusted in response to observed volumes, aiming to balance queues and reduce delays without altering geometry. The main outcomes are:
1-Delay reduction of roughly 14.5%.
2-Queue length reduction of about 30%.
3-LOS improvement to B.
4-More stable flow at both morning and afternoon peaks.
Although performance gains are smaller than those of the flyover scenario, this approach requires considerably less capital investment and can be implemented more quickly, making it attractive as a short- to medium-term solution.

3.6. Comparative Assessment of Scenarios

A side-by-side comparison of the baseline and both scenarios shows clear benefits from each intervention:
1-Average delays decline from around 80 s/veh in the baseline to the range of 65–69 s/veh in the improvement scenarios.
2-Average queue lengths drop from about 158–162 m to approximately 90–110 m.
3-LOS improves from D to B in both the flyover and adaptive signal-control scenarios.
These improvements align with commuter priorities expressed in the survey, particularly the desire for shorter waiting times, smoother movements, and more predictable travel conditions.

4. Discussion

The integrated analysis confirms that the Al-Faris Al-Arabi Roundabout currently operates under severe congestion, mainly driven by high private-vehicle dependency, limited geometric capacity, and aggressive driving behavior. The strong correspondence between survey responses and simulation results increases confidence in the calibrated VISSIM model and supports its use in scenario testing.
Both improvement scenarios substantially enhance performance, but they differ in their implementation requirements and strategic roles:
1-The flyover scenario yields the largest technical improvements, particularly in reducing queue lengths and elevating LOS.
2-The adaptive signal-control scenario achieves slightly smaller operational gains but can be deployed more rapidly and at much lower cost.
From a planning perspective, this suggests that adaptive signal control may serve as an effective short-term intervention, while the flyover could be considered a long-term structural enhancement if funding and right-of-way are available.

Advance Researches in Civil Engineering
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4.1. Comparative Table of Baseline and Improvement Scenarios

Table 8. Comparison of baseline conditions and improvement scenarios.

Performance Indicator	Baseline	Scenario 1: Flyover	Scenario 2: Adaptive Signal Control	Best Performance
Average Delay (s/veh)	~80 s	~65 s (≈−19%)	~69 s (≈−14.5%)	Flyover
Queue Length (m)	158–162 m	~100 m (≈−38%)	~110 m (≈−30%)	Flyover
Average Speed (km/h)	12–13 km/h	17–18 km/h	16–17 km/h	Flyover
Level of Service (LOS)	D	B	B	Tie (Flyover & Adaptive)
Construction Cost	None (existing)	High	Low	Adaptive Signal
Implementation Time	—	Long	Short	Adaptive Signal
Suitable for Short Term	—	No	Yes	Adaptive Signal
Suitable for Long Term	—	Yes	Possibly as complement	Flyover

The table illustrates that while the flyover provides the strongest operational relief, the adaptive signal-control strategy offers clear advantages in terms of cost and speed of implementation. A realistic policy roadmap could therefore prioritize adaptive signal control as a near-term solution while planning for possible grade separation in the longer term, depending on financial and spatial constraints.

5. Conclusion

This study presented an integrated assessment of congestion at the Al-Faris Al-Arabi Roundabout in Baghdad using a mixed-method framework that combines field traffic data, commuter-perception surveys, and calibrated PTV VISSIM simulation. The baseline analysis reveals that the roundabout operates under congested conditions (LOS D) during both morning and afternoon peak hours, with average delays near 80 s/veh, queues exceeding 150 m, and operating speeds around 12–13 km/h. Survey data confirm high levels of commuter dissatisfaction, long perceived delays, and notable health impacts related to congestion and air pollution.

Two improvement strategies were evaluated: a flyover connecting Al-Mansour and Al-Zaytoun Streets and an adaptive signal-control system regulating entries to the roundabout. Simulation results show that both scenarios substantially improve performance, with the flyover providing the greatest delay and queue reductions, and adaptive signal control offering significant benefits at lower cost and with shorter implementation time.

The findings suggest that:

1-Immediate deployment of adaptive signal control could deliver meaningful congestion relief and health co-benefits.

2-A flyover may be justified as a long-term investment, especially if integrated into a broader corridor-level improvement plan.

3-Mixed-method approaches that integrate field observations, user perceptions, and microscopic simulation offer a robust evidence base for decision-making in congested urban networks.

Future work could extend the analysis to adjacent intersections and corridors, incorporate explicit emission modeling within the simulation environment, and explore coordinated control strategies that combine adaptive signals and geometric modifications.

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