

EVALUATING TRAFFIC PERFORMANCE OF URBAN STREETS IN AL-HILLA CITY

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Abstract

The efficiency of urban street networks plays a pivotal role in ensuring sustainable urban mobility, especially in rapidly expanding cities. This study investigates the performance of six urban streets in Al-Hilla City, Iraq, utilizing Level of Service (LOS) as the principal evaluation criterion. The research identifies a gap in understanding the effects of pedestrian density, roadside activities, and infrastructure limitations on urban traffic dynamics. Comprehensive data collection methods were employed, including video recordings for traffic volume, the floating car method for travel time, and radar speed guns for free-flow speed (FFS) measurements. The analysis was conducted using the methodologies outlined in the Highway Capacity Manual (HCM 2000 and 2010) frameworks. The results revealed severe congestion, with LOS ratings predominantly ranging from D to F, reflecting critical deficiencies in traffic management and infrastructure design. The selected streets, characterized by diverse urban contexts and varying traffic densities, were systematically analysed to identify the root causes of inefficiencies. The study proposes targeted interventions, including road widening, optimization of traffic signal timings, and the implementation of public transportation systems, to alleviate congestion and enhance mobility. These findings offer actionable insights for urban planners and policymakers aiming to improve traffic flow and support sustainable urban development in Al-Hilla City. The conclusions provide a robust framework for addressing similar challenges in other developing urban contexts.

Keywords: Al-Hilla city, Highway capacity manual (HCM), Level of service (LOS), Traffic congestion, traffic flow analysis, traffic management, Urban street performance.

1. Introduction

Urban street networks are the lifelines of cities, providing essential functions that support not only transportation but also economic and social activities. In the context of Al-Hilla City, located in the heart of Iraq, the performance of these networks is critical due to the rapid population growth, increased vehicle ownership, and expanding commercial activities. These factors have collectively intensified traffic congestion, especially during peak hours, leading to significant inefficiencies in the movement of people and goods, increased pollution, and a substantial economic burden [1].

The issue of traffic congestion in Al-Hilla is a microcosm of a broader challenge faced by many developing cities globally. Urban planners and transportation engineers have long grappled with the need to balance road capacity, traffic volume, and the efficient flow of vehicles to mitigate congestion and improve the quality of urban life. Previous studies, such as those by Abbood et al. [2], have highlighted the exacerbating factors of congestion in Iraqi cities, including unregulated roadside developments, inadequate public transportation infrastructure, and insufficient traffic management strategies.

The novelty of this study lies in its comprehensive assessment of urban street performance in Al-Hilla City using both the Highway Capacity Manual (HCM 2000 and 2010) methodologies to determine the Level of Service (LOS). This dual approach allows for a more nuanced understanding of traffic dynamics and road performance under varying conditions and provides a robust framework for identifying specific bottlenecks and inefficiencies.

A unique aspect of this research is the extensive data collection undertaken from six critical urban street sites in Al-Hilla. These data encompass flow rates, travel times, free flow speeds (FFS), and traffic volumes, meticulously gathered using advanced techniques such as video recordings and radar speed guns. The integration of these diverse data sets provides a holistic view of the urban traffic scenario, enabling the accurate determination of LOS and the identification of key areas requiring intervention.

The study's findings reveal a stark reality: the majority of urban streets in Al-Hilla exhibit LOS ratings from D to F, indicating severe congestion and inadequate traffic management. This is a significant deviation from the optimal traffic conditions required for efficient urban mobility. By leveraging the HCM's detailed criteria, this research not only quantifies the extent of congestion but also highlights the specific factors contributing to the inefficiencies observed.

Moreover, the research builds on and contrasts with the achievements of other authors. For instance, while studies like those by Garber et al. [3] and Tong et al. [4] have examined traffic congestion in various urban settings, this study's focus on Al-Hilla provides new insights into the unique challenges faced by Iraqi cities. The localized approach, combined with the rigorous application of standards [5], sets this study apart, offering valuable recommendations tailored to the specific needs of Al-Hilla. In addressing the critical issue of urban traffic congestion.

This study not only contributes to the academic discourse but also provides practical solutions for urban planners and policymakers. Recommendations such as road widening, the development of external roads, adjustment of operational hours

for major traffic contributors, and enhancements in public transportation are grounded in the empirical data collected and the thorough analysis conducted.

In conclusion, this study represents a significant advancement in understanding and improving urban street performance in Al-Hilla City. By adopting a methodical approach and integrating comprehensive data analysis with established traffic management frameworks, it offers a path forward for alleviating congestion and enhancing urban mobility, thereby contributing to the overall well-being and economic vitality of the city.

The proposed solutions in this study have been developed in direct response to the severe congestion issues identified through LOS assessments and traffic flow analysis. Road widening is recommended to address capacity limitations on high-volume corridors such as Al-Atbaaba Street, aligning with HCM standards. Traffic signal optimization will improve intersection efficiency, particularly on Abo Khamra Street, using adaptive control mechanisms to reduce unnecessary delays. Enhancing public transportation, including the introduction of a Bus Rapid Transit (BRT) system, will decrease reliance on private vehicles and improve urban mobility. Additionally, the development of bypass routes will redirect through-traffic away from congested city streets, alleviating pressure on key arterials. Finally, demand management strategies such as staggered institutional hours will distribute peak-hour traffic more effectively. These recommendations are supported by previous urban traffic studies [6, 7] and best practices outlined in the HCM 2000 and 2010, ensuring their validity and applicability in Al-Hilla City.

2. Literature Review

Assessing overseeing a city street network infrastructure and traffic flow management duties often involve evaluating the LOS, addressing congestion points and enhancing the traffic movement [8-11] Improving the efficiency and usability of road systems to enhance transportation in the city. Its vicinity is essential for reducing traffic congestion [12]. The road system helps in making the use of resources in various ways. In Al Najaf city there are traffic jams at spots, on the roads. In terms there are two kinds of congestion recognized: regular and irregular congestion [13]. During times traffic often builds up on the roads when their capacity decreases, usually caused by unexpected events such as bad weather, roadworks or accidents happening sporadically in the area. It's crucial to study the city road infrastructure and determine how well it can meet the demands of the future.

In a study on urban street quality and drivers' satisfaction in developing countries researchers utilized Artificial Neural Network (ANN) along with Functionally Linked Artificial Neural Network (FLANN) to simulate how drivers react on 112 urban street sections finding that 73 percent of the examined segments were categorized as "C" or below in terms of service quality [8]. The study emphasized that the condition of the pavement was identified as a factor contributing to 26.78 percent relative importance in influencing the overall experience of drivers on the roads. Moreover, it was noted that there is a lack of efforts to address traffic congestion issues within the road network specifically, in Al Najaf city.

Papageorgiou and Kotsialos [14] examined intelligent transportation systems in Al Najaf city. They recommended implementing public transport options such as

scheduled buses and Bus Rapid Transit (BRTs). Additionally, Al-Jameel and AbdAbas [15] evaluated sustainability of AL Najaf's structure involved analysing the distribution of types of roads in the city from a holistic perspective. The study revealed that the urban layout of the city was deemed inefficient due to challenges such as the absence of clear road and land use hierarchy uneven population density distribution and dense zones situated far away from the city centre. These factors contribute to commuting patterns within the city.

Al-Jameel and AbdAbas [16] conducted an evaluation of the operational performance of selected urban streets in the southern part of Al-Najaf city by utilizing methodologies outlined in the HCM 2000 and 2010. The study identified significant impacts of side friction (SF) factors, such as on-street parking and pedestrian activities, on the LOS, particularly during evening peak hours. The authors highlighted the necessity of implementing targeted traffic management measures, including the regulation of illegal parking, the management of pedestrian crossings, and the optimization of intersection operations, to enhance traffic flow and mitigate congestion effectively.

Ghanim et al. [17] conducted an in-depth analysis of Al-Matar Road (Ring Road) in Al-Najaf City, with a particular focus on the operational challenges associated with U-turn movements. Their study revealed that the frequency and design of U-turns exert a substantial impact on travel time and vehicular speed, resulting in increased traffic congestion and delays. The research categorized the road's performance using the Level of Service (LOS) framework, identifying variations ranging from Class B to Class E based on traffic flow direction. To mitigate these challenges, the authors recommended improvements in U-turn design and a comprehensive evaluation of lane capacity to enhance overall traffic efficiency.

Rwadhah and Al-Jameel [18] conducted a comprehensive evaluation of the main ring roads in the Holy City of Najaf, focusing on the operational and environmental challenges affecting traffic performance. The study highlighted significant congestion issues at critical intersections, including the airport roundabout and Muzaffar roundabout, where U-turns and high traffic volumes led to increased travel times and reduced vehicular speeds. Using the LOS framework, the analysis classified the Eastern Ring Road's performance as LOS F in certain sections, particularly during peak hours, while the Western Ring Road exhibited LOS B in most segments. The research further identified elevated noise levels and air pollution, surpassing international standards, as key environmental concerns. To address these challenges, the authors proposed targeted interventions such as intersection redesigns, lane reconfigurations, and the development of bypass routes to enhance traffic flow and sustainability.

Al-Mousawi et al. [19] conducted a study in two neighbourhoods; Al Rawan and Al Iskan streets to analyse street parking features based on field data obtained from drone video cameras and manual tallies. They found that a large portion of vehicles parked in these areas had to wait for more than 30 minutes in over 80% of cases. Also noted there were instances of parking happening on both weekdays and weekends. The research aims to assess the performance of streets in the northern section of the Al Najaf Road network based on the LOS criteria outlined in the HCM 2000 and 2010. Additionally, Al-Jameel and Muzhar [20] highlighted the significance of calculating the FFS, for designing highways and assessing their

efficiency. The aim of this study is to enhance traffic control and alleviate congestion in Hilla by evaluating the LOS.

Comparison with Current Research The findings of these prior studies provide a robust foundation for understanding urban traffic challenges in Al-Najaf City and similar contexts. This study builds on these insights by focusing on Al-Hilla City, employing advanced data collection methods, including video recordings, radar speed guns, and the floating car method, to assess six urban streets comprehensively. Unlike earlier studies, this research integrates both macro-level analyses of structural deficiencies and micro-level evaluations of traffic dynamics. The unique contribution lies in identifying severe congestion issues, with LOS ratings from D to F, and proposing strategic, context-specific interventions. These include road widening, public transportation enhancements, and optimization of traffic signal timings, tailored to the distinct challenges of Al-Hilla City's urban environment.

This integrated approach not only complements the findings of earlier studies but also addresses gaps in understanding the interplay between infrastructure design and traffic dynamics, providing actionable insights for urban planners and policymakers.

3. Urban Street class

Urban streets are classified below multilane suburban and rural roads and above local streets. Street functionality, control situations, and the type and intensity of roadside development are the key determinants of the difference. The HCM lists four different types of urban streets. These classes are categorized into I, II, III, and IV.

4. Flow characteristics

Three key elements influence vehicle speed on city streets: vehicle interaction, street surroundings, and traffic regulation, all of which influence service quality. The traffic density, the percentage of buses and trucks, and turning movements, all influence vehicle interaction. This interaction impacts on how vehicles operate at junctions and, to a lesser extent, between lights [7].

4.1. Free flow speed (FFS)

The FFS is the intended average speed adopted by the driver when not restricted by other cars in the stream under a given set of road circumstances [8]. The presence of traffic lights or other traffic control systems disrupts traffic flow on city streets. Therefore, FFS in metropolitan areas is essential [8]. Leong et al. [21] developed and assessed free-flow speed models under heterogeneous traffic in Malaysia, highlighting that the free-flow speed is influenced by various factors such as vehicle type, road characteristics, and traffic control conditions.

4.2. Travel time

The time required to travel a route between any two sites of interest is referred to as travel time. By traveling the path(s) that links any two or more locations of interest, travel time may be accurately calculated. Running time, or the amount of time that the means of transportation is in motion, and paused delay time, or the amount of time that it is stopped (or travelling at a speed that is sufficiently slow to be stopped, usually less than eight mph or five mph), make up travel time [22]. The average travel speed (ATS) is the speed factor that best represents the impact of traffic management [5].

4.3. Level of service for urban street

The LOS is a way to qualitatively assess how well traffic flows in a given street considering factors like speed, travel time, ease of movement disruptions, comfort and convenience. Various methods have been employed to determine the LOS for streets as outlined in HCM 2000.

In this manual the ATS serves as an indicator for evaluating the service quality of streets. It involves collecting real time travel data to calculate the LOS for each street segment. Table 1 presents the criteria for LOS levels based on street class and travel speed. The six levels range from LOS A (flow with manoeuvrability) to LOS F (congested conditions) when traffic volume exceeds street capacity.

Additionally, the LOS can also be evaluated using the volume to capacity ratio (V/C ratio). This method helps determine capacity based on HCM 2000 guidelines and calculates flow rates from field observations as detailed in Table 1.

Table 1. Urban streets LOS by classes (HCM2000).

Urban street class	I	II	III	IV
Range of FFS	90 to 70 km/h	70 to 55km/h	55 to 50 km/h	55 to 40 km/h
Typical FFS	80 km/h	65 km/h	55 km/h	45 km/h
LOS	ATS (km/h)			
A	> 72	> 59	> 50	> 41
B	> 56-72	> 46-59	> 39-50	> 32-41
C	> 40-56	> 33-46	> 28-39	> 23-32
D	> 32-40	> 26-33	> 22-28	> 18-23
E	> 26-32	> 21-26	> 17-22	> 14-18
F	≤ 26	≤ 21	≤ 17	≤ 14

According to HCM 2010, two criteria have been suggested to measure the LOS for a direction of a road segment, in car mode. The initial criterion is the speed of travel for through movements, which helps highlight factors influencing how efficiently the link operates and the delays experienced by vehicles at the intersection. The second criterion is the V/C ratio, for traffic passing through the junction. Table 2 outlines the LOS standards used to reflect traffic conditions on a road with calculations of V/C involving field observations to determine actual flow rate and capacity based on HCM 2000.

Table 2. LOS thresholds for vehicle mode on urban streets (HCM 2010).

Travel speed as a percentage of Base Free-Flow Speed (%)	LOS by V/C Ratio	
	≤1.0	> 1.0
> 85		A
> 67-85		B
> 50-67		C
> 40-50		D
> 30-40		E
≤ 30		F

5. Capacity

Depending on the composition of the traffic, capacity is expressed in units of specific objects (cars, people, etc.). Additionally, capacity analysis is influenced by the

surrounding circumstances. It is a probabilistic measure that changes depending on the moment and the location. As a result, it is sometimes difficult to fully derive the capacity analytically. Observations made in the field are primarily how it is obtained [23].

The advancement of industry and the increase, in traffic volume and speed there is a growing need to focus on enhancing road durability and their capacity to withstand vehicle weights. It is also crucial to pay attention to road specifications and design for comfortable travel [24-26].

Alongside advancements in construction machinery and project management, as well as traffic control, road design and maintenance have become more efficient and cost effective. Road intersections are points in the road network where traffic from directions converges influencing both traffic flow efficiency and vehicle safety [27, 28]. The peak hour factor (PHF) indicates when the total hourly volume occurs within a 15-minute interval. In terms PHFs range from 0.70 in areas with low traffic density to 0.98 in congested urban zones with high traffic volumes.

6. Methodology

In transportation engineering, evaluating urban street performance necessitates a structured and comprehensive methodology. This study focused on assessing the LOS of six urban streets in Al-Hilla City. These streets were chosen based on their strategic importance within the city's transportation network, diverse traffic conditions, and surrounding land uses. The methodology, including data collection techniques, analytical framework, and limitations, is detailed below.

6.1. Data collection method

Traffic data collection was conducted on Sunday, Monday, and Wednesday to provide a comprehensive representation of urban mobility in Al-Hilla City. These days were selected based on their ability to capture varying traffic conditions across the workweek, ensuring robust LOS assessment. Sunday marks the start of official activities, resulting in peak congestion, while Monday reflects stabilized mid-week traffic flow. Wednesday provides insights into pre-weekend travel patterns influenced by increased commercial activity. This approach aligns with the guidelines outlined in the HCM, 2000 and 2010 and methodologies applied in previous studies on urban transportation analysis [6, 7].

6.2. Travel time measurement

The floating car method was employed to measure travel time. A test vehicle traversed each road segment repeatedly under normal traffic conditions. GPS-enabled devices were used to record the start and end times of trips, ensuring accurate calculations of travel time. Each segment was assessed through six runs in both directions, and average travel times were calculated to ensure statistical reliability.

6.3. Free flow speed (FFS) measurement

FFS was measured using a Bushnell radar speed gun. Measurements were conducted during off-peak hours to eliminate external interference, allowing an accurate determination of the maximum speed achievable under ideal conditions. FFS data were essential for classifying LOS according to the HCM standards.

6.4. Statistical analysis tools

The statistical analysis was conducted using IBM SPSS Statistics v30 and GraphPad Prism v10.3.1. These tools enabled the precise calculation of correlation coefficients, regression models, and significance tests, ensuring robust analysis of traffic flow and performance data.

6.5. Street selection criteria

The six streets analysed in this study were selected based on the following criteria:

- **Strategic Importance:** Streets play critical roles in connecting key urban areas and facilitating mobility.
- **Traffic Dynamics:** Each street exhibits unique characteristics such as varying pedestrian densities and traffic volumes.
- **Urban Context:** Surrounding land use includes commercial, educational, and residential zones, providing a holistic representation of urban traffic challenges.

6.6. Analytical framework

The analytical framework involves the following analysis:

- **Traffic Flow and Volume Analysis:** Traffic flow rates were calculated from video data to assess congestion levels and identify bottlenecks.
- **LOS Classification:** The study utilized HCM 2000 and 2010 methodologies to classify LOS. Metrics included ATS, V/C ratios, and comparisons between FFS and actual travel speeds.
- **Congestion Analysis:** Relationships between traffic flow, travel time, and density were analysed to identify segments with severe delays and operational inefficiencies.

6.7. Limitations

Limitations of the study are as follows:

- **Temporal Constraints:** Data collection occurred on Sunday, Monday, and Wednesday during morning and evening peak hours. While these days represent typical workweek conditions, weekend and off-peak variations were not captured.
- **Environmental Variability:** Adverse weather or unexpected incidents may have influenced traffic patterns, introducing variability in the data.
- **Sample Size:** The study focused on six streets. Expanding the sample size could provide broader insights into urban traffic dynamics.
- **Manual Data Processing:** Vehicle counts and classifications were performed manually, which may introduce minor errors despite rigorous validation procedures.
- **Visual Aids:** The absence of illustrative images for each street may limit the contextual understanding of traffic conditions. Future studies should incorporate photographic documentation.

7. Study Area

The six streets analysed in this study were selected based on their strategic role in Al-Hilla City’s transportation network, ensuring a diverse representation of traffic and land-use conditions. The selection criteria included variations in traffic volume, pedestrian activity, and the influence of roadside factors, aligning with methodologies outlined in the HCM 2000 and 2010. The streets encompass key urban functions, such as commercial zones (Abo Khamra Street, Al-Mahkamh Street), medical service areas (Al-Atbaaba Street), major arterial roads (Street 60), and mixed-use residential corridors (Imam Ali Street). These selections enable a comprehensive evaluation of congestion dynamics and LOS variations across different urban contexts. The diversity of geometric configurations, surrounding land use, and traffic demand ensures that the findings contribute valuable insights for improving traffic management strategies in developing cities like Al-Hilla.

The selected streets provide a comprehensive representation of Al-Hilla City’s urban transportation dynamics, encompassing critical medical, commercial, and high-density pedestrian zones. Al-Atbaaba Street is a prime example of this complexity, featuring a high concentration of medical clinics and roadside vendors that significantly disrupt traffic flow. The intense pedestrian movement further contributes to congestion, particularly during peak hours, resulting in a LOS rating of F. Similarly, Abo Khamra Street experiences severe traffic congestion due to its narrow road width and the presence of densely packed commercial establishments. The lack of properly designated parking areas and unregulated pedestrian crossings exacerbate the traffic inefficiencies, leading to substantial delays and a deteriorated LOS. These streets illustrate the broader transportation challenges faced by Al-Hilla City, highlighting the urgent need for strategic urban mobility solutions.

The chosen streets offer a comprehensive representation of Al-Hilla City’s transportation challenges, encompassing commercial zones, educational hubs, and residential areas. Their locations are illustrated in Fig. 1, providing spatial context, and highlighting their significance within the city’s urban and transportation landscape.

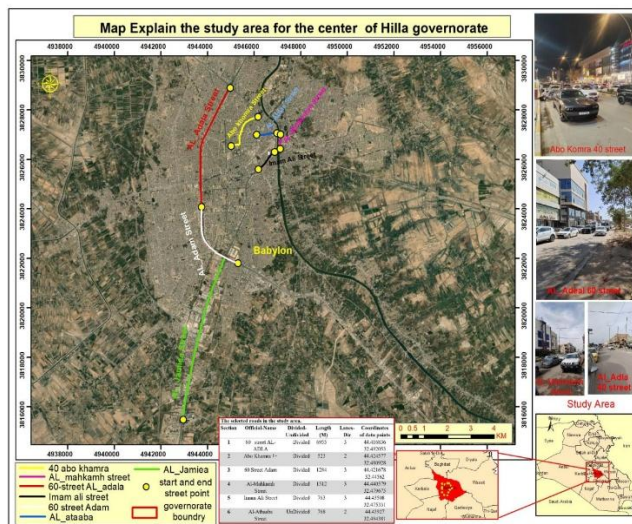


Fig. 1. Hillah governorate (location of the selected data point).

8. Data Collection

Traffic data collection was strategically conducted on Sunday, Monday, and Wednesday to ensure a representative sample of traffic patterns across typical working days. These days were selected based on their ability to reflect varying traffic conditions: Sunday marks the start of the workweek in Iraq, characterized by heightened activity as schools, businesses, and government offices resume operations. Monday offers insights into mid-week traffic dynamics, while Wednesday provides a snapshot of traffic conditions as the workweek approaches its end, often marked by a mix of regular and preparatory activities for the weekend.

Data was gathered during both morning and evening peak periods to capture fluctuations in traffic flow. Video cameras were mounted at elevated positions along the roadsides, enabling a comprehensive view of traffic movement and ensuring accurate data capture. Six urban streets in Hilla City were identified for this study, each selected for its unique characteristics and significance within the city's transportation network. The roadways were divided into mid-block sections to examine their distinctive features systematically.

For instance, Street 60, a divided road in the city centre, serves as a hub of commercial activity and experiences significant congestion during peak hours. Street 40, home to numerous educational institutions and retail centres, witnesses heavy traffic flows, particularly during school hours. Another undivided street, known for its concentration of clinics and pharmacies, is heavily congested in the evenings. Al-Atbaaba Street, one of the most significant thoroughfares in Hilla, also demonstrates unique traffic dynamics.

Table 3 outlines the selected streets along with their geographic coordinates, providing a framework for detailed analysis of traffic conditions and their broader ecological implications. This methodical approach ensures that the data accurately captures the city's transportation dynamics, offering insights into effective urban traffic management and planning.

Table 3. The selected roads in the study area.

Section	Official-Name	Divided/ Undivided	Length (m)	Lanes (Dir)	Coordinates of data points
1	60 street Al-Adla	Divided	6955	3	44.424577 32.480928
2	40 Abo Khamra	Divided	523	2	44.421678 32.44562
3	60 Street Adam	Divided	1284	3	44.440579 32.47967
4	Al- Mahkamh Street	Divided	1512	3	44.43508 32.475331
5	Imam Ali Street	Divided	763	3	44.43508 32.47533
6	Al-Atbaaba Street	Undivided	768	2	44.43927 32.4843

The data collection process relied on two primary tools: a Sony Handycam and a Bushnell radar speed gun, as illustrated in Fig. 2. These tools were essential for ensuring accurate and reliable traffic data collection.

The Sony Handycam was chosen for its high-definition recording capability, wide-angle lens, and ability to capture detailed footage under various lighting conditions. This camera was used to record traffic volumes between 7:00 A.M. and 7:00 P.M., covering both morning and evening peak hours. Its mobility and cost-effectiveness made it an ideal choice compared to other options, such as fixed-loop detectors or advanced surveillance systems, which were either less practical or significantly more expensive.

The Bushnell radar speed gun was employed to measure free-flow speeds and spot Speeds of vehicles. Known for its precision and ease of use, this tool provides real-time Speed data essential for analysing vehicle dynamics on urban streets.

Both tools were selected based on their suitability for capturing the necessary traffic parameters while balancing cost, practicality, and reliability. The images shown in Fig. 2 are original and were taken during the fieldwork conducted specifically for this study, providing visual documentation of the equipment utilized.



Fig. 2. Tools used to collect data.

9. Travel Time Data

To determine the speed, the ratio of the segment's length to the travel time taken was calculated. Travel time refers to the time required to navigate a stretch of road considering any delays due to stops. The segments length is specifically defined as the distance, between its connecting intersections [5]

The information gathered involves monitoring how long it takes to travel on each road section within a network. The roads are split into parts before determining the travel durations. Details, about the lengths of the selected road segments and the average travel times for each part can be found in Table 4. To calculate travel times sections for each road were defined following HCM 2000 guidelines and measurements were taken using the floating car method. This method involved tracking vehicles travel time to collect data on measurements and traffic congestion levels.

The process was repeated times with the final recorded time being used as the result. Various statistical factors such as confidence level, standard deviation and acceptable error were taken into consideration to determine the required number of operations for results. In this research six runs of travel times were conducted for each segment in both directions based on guidelines outlined by Ghanim et al. [17] regarding sample size calculations for road surveys. Delays commonly experienced

during peak hours were factored in when measuring travel times while non-recurring delays such as maintenance activities or unexpected incidents were not included in the analysis. Table 4 shows the calculated travel times for each road section.

Table 4. Analysis of travel time data for morning and evening periods.

Road no.	Road name	Lanes (Dir)	Direction no.	Length (m)	Average travel time (s)	
					Morning period	Evening period
1	60 Street Al-Adla	3	1	6955	1240	1132
			2	6950	1142	942
2	40 Abo Khamra	2	1	523	175	235
			2	520	161	195
3	60 Street Adam	3	1	1284	136	122
			2	1279	149	138
4	Al-Mahkamh Street	3	1	1512	253	196
			2	1514	236	188
5	Imam Ali Street	3	1	763	195	182
			2	759	186	189
6	Al-Atbaaba Street	2	1	786	183	202

10. Road Class Based on FFS

The obtained speed is given by the following sub-sections for each road based on the FFS data collected by the Radar speed gun: The FFS was used to establish the class for each of the roads specified in Table 5.

Table 5. Classes for the chosen roads based on HCM 2000.

Road name	Seg. No.	FFS (km/h)	Class by FFS
60 street Al-Adla	1	73.53	I
	2	64.23	II
40 Abo Khamra	1	68.41	II
	2	71.62	I
60 Street Adam	1	80.37	I
	2	72.61	I
Al-Mahkamh Street	1	58.41	II
	2	62.00	II
Imam Ali Street	1	59.34	II
	2	63.38	II
Al-Atbaaba Street	1	64.82	II

11. Results and Discussion

This study utilized advanced mathematical and statistical techniques to interpret traffic congestion patterns and assess LOS. Statistical computations were conducted using IBM SPSS Statistics v30 and GraphPad Prism v10.3.1, applying a range of analytical methods to enhance the precision and reliability of the findings.

Spearman's rho correlation was used to analyse the relationship between traffic volume and travel time, providing insights into congestion trends. Multiple regression analysis quantified the influence of pedestrian density, roadside friction, and free-

flow speed on LOS. Additionally, descriptive statistics were employed to summarize travel time variations and congestion severity across different urban corridors.

The LOS classification adhered to the methodologies outlined in the HCM, 2000 and 2010. The ATS method was applied to evaluate congestion severity and roadway efficiency, while the V/C ratio method was used to determine the functional performance of urban streets under varying traffic conditions.

Furthermore, a multiple logistic regression model was developed to predict LOS, achieving an R^2 value of 95.4% indicating a high level of predictive accuracy. The model identified critical factors influencing urban congestion, including traffic flow, travel time, pedestrian density, and roadside parking activities.

To further enhance the clarity of results, graphical representations such as scatter plots and regression models have been incorporated to visualize data trends. These enhancements ensure that the analysis is not only empirically robust but also statistically validated, thereby strengthening the credibility and reliability of the study's conclusions.

11.1. LOS according to ATS

Urban streets are evaluated using the ATS after segment classification based upon FFS as it represents a key indicator of service quality, in urban areas and is determined through field collected travel time data analysis.

As shown in Table 6, the analysis of traffic flow on different roads uncovers a blend of inefficiencies. On Al-Adla Street as an example – Sections 1 and 2 showcase elevated FFS standing at 73.53 km/h and 64.23 km/h respectively. Despite these speeds both sections operate at a LOS indicating noticeable congestion or other factors that notably hinder smooth travel experience.

Abo Khamra Street demonstrates challenges in traffic flow. Both segments on this street show moderate to high FFS values of 68.41 and 71.62. However, they consistently suffer from a poor LOS of F, indicating substantial delays and density that negatively affect travel times and could potentially deter efficient transportation.

Adam Street showcases a situation compared to others in the area with an impressive FFS reaching 80 the highest observed so far in its first segment. However, the travel experience is graded as E, a small improvement from neighbouring streets indicating less than ideal journey conditions despite the potential for high speeds, on Adam Street.

On Al-Mahkamh Streets parts marked by FFS values of 58.41 and 62.43 experience an LOS of E which shows a slightly improved flow compared to roads with an F rating but still reflects ongoing challenges, in travel efficiency This trend implies that congestion and inefficiencies persist even on streets designed for lower speeds.

Finally, the situation on Imam Ali Street and Al-Atbaaba Street underscores a widespread issue across different road classifications and traffic speeds. Most segments on these streets exhibit poor levels of service, rated as E and F. This consistent poor performance across various streets likely results from multiple factors such as road design, traffic volume, or regulatory challenges, although these are not explicitly detailed in the data but can be inferred from the ongoing traffic conditions.

Based on the provided traffic data Table 7, the analysis reveals significant disparities between the (FFS) and the actual (ATS) during the evening period across

various urban street segments, resulting in suboptimal (LOS) leading to generally poor (LOS). Street Al-Adla's first segment has a high FFS of 73.53 km/hr but a low ATS of 22 km/hr, resulting in a LOS of F due to significant congestion.

Table 6. LOS Based on ATS Using HCM 2000 for the morning period.

Road No.	Seg. No.	FFS	Class	ATS (km/h)	LOS
60 street AL-ADLA	1	73.53	I	20	F
	2	64.23	II	20	F
40 Abo Khamra	1	68.41	II	11	F
	2	71.62	I	12	F
60 Street Adam	1	80.37	I	33	E
	2	72.61	I	31	E
Al-Mahkamh Street	1	58.41	II	22	E
	2	62.43	II	23	E
Imam Ali Street	1	59.34	II	14	F
	2	63.38	II	15	F
Al-Atbaaba Street	1	64.82	II	15	F

The second segment shows some improvement with an FFS of 64.23 km/hr and an ATS of 27 km/hr, achieving a LOS of D. Abo Khamra Street experiences severe inefficiencies, with both segments enduring a LOS of F, with ATS figures significantly lower than their FFS values, suggesting extensive delays and congestion.

Adam Street and Al-Mahkamh Street manage slightly better conditions with a LOS of D across their segments, despite high FFS values not translating into proportionately high ATS, indicating ongoing traffic flow issues. Imam Ali Street and Al-Atbaaba Street display the most severe inefficiencies, with all segments languishing at a LOS of F, where even moderate FFS values do not mitigate extremely low ATS figures, reflecting major structural or regulatory challenges in traffic management. Overall, these observations highlight the urgent need for interventions to resolve the gap between potential and actual traffic speeds to improve traffic efficiency across the network.

Table 7. LOS Based on ATS Using HCM 2000 for the evening period.

Road No.	Seg. no.	FFS	Class	ATS (km/h)	LOS
60 street AL-ADLA	1	73.53	I	22	F
	2	64.23	II	27	D
40 Abo Khamra	1	68.41	II	8	F
	2	71.62	I	10	F
60 Street Adam	1	80.37	I	38	D
	2	72.61	I	33	D
Al-Mahkamh Street	1	58.41	II	28	D
	2	62.43	II	29	D
Imam Ali Street	1	59.34	II	15	F
	2	63.38	II	14	F
Al-Atbaaba Street	1	64.82	II	14	F

11.2. LOS based on V/C

Table 8 displays an analysis of the Level of Service (LOS), for road sections in the morning showing a variety of traffic conditions on the roads under study. The

analysis points out that certain sections face congestion while others maintain a consistent flow of traffic

Segments such as Abo Khamra Street, Al-Mahkamah Street and Imam Ali Street show signs of traffic with LOS F indicating congestion due to traffic exceeding the roads capacity limits. For example, the initial stretch of Al-Mahkamah Street has a Volume to Capacity (V/C) ratio of 1.11 indicating a situation where traffic demand surpasses the infrastructures capabilities. This high level of congestion highlights the urgency, for implementing traffic management solutions in these areas

On the hand areas like Adam Street exhibit performance with LOS B noted in its initial segment. In this case the V/C ratio stays below 1.0 (0.95), indicating traffic flow and efficient road operation near capacity with minimal delays. Similarly, the first part of Abo Khamra Street also shows LOS B with a V/C ratio of 0.79 suggesting that it can handle traffic without congestion, for a driving experience.

Some sections of the road such as parts of Imam Ali Street and Al-Atbaaba Street fall under the category of LOS C. Indicating that there is traffic moving with delays but generally in good conditions overall. To illustrate further; The beginning segment of Imam Ali Street has a V/C ratio of 0.79 which suggests that while traffic is nearing capacity it remains under control. Likewise, the initial stretch of Al-Atbaaba Street has a V/C ratio of 0.34 indicating traffic flow, with some congestion.

Table 8. LOS for selected road segments based on V/C ratio according to HCM 2010 for morning period.

Road No.	Seg. No.	FFS	Class	Max V. (veh/h)	Capacity (veh/h)	(V/C)	LOS
60 street Al-Adla	1	73.53	II	3364	2670	1.25	F
	2	64.23	II	3576	2670	1.33	F
40 Abo Khamra	1	68.41	I	2736	3430	0.79	B
	2	71.62	I	3004	3430	0.87	B
60 Street Adam	1	80.37	I	3260	3430	0.95	B
	2	72.61	II	3368	2670	1.26	F
Al-Mahkamah Street	1	58.41	I	3807	3430	1.11	F
	2	62.43	II	3252	2670	1.19	F
Imam Ali Street	1	59.34	II	3476	3560	0.97	C
	2	63.38	IV	3672	3250	1.12	F
Al-Atbaaba Street	1	64.82	II	616	1780	0.34	C

Table 9 displays an examination of evening traffic conditions, on road sections using the measurements detailed in the HCM 2010. The table offers an evaluation of the LOS and V/C ratios for the streets studied, providing insights into their effectiveness and congestion levels during busy evening periods

The first segment of Al-Adla Street faces traffic despite its FFS being 73;53 km/h and a V/C ratio of 1:53 resulting in a LOS classification as F which indicates that the traffic volume exceeds the road capacity causing delays and inefficient traffic flow. Similarly, the second part of Al-Adla Street also encounters congestion with a V/C ratio of 1;31 underscoring the need for traffic management strategies to alleviate the burden on the infrastructure.

On Abo Khamra Street the first segment performs adequately with a V/C ratio of 0.94 corresponding to an LOS rating of B indicating traffic flow and minimal congestion.

In contrast the following section displays signs of pressure as the number of vehicles approaches a ratio of 1.02 resulting in a grade of F LOS suggesting that this particular stretch is either operating at or, above its capacity and experiencing traffic congestion.

Adam Street also shows signs of traffic congestion as indicated by a V/C ratio of 1 with an LOS grade of F despite its FFS of 80 km/h, in the section. In contrast the second segment faces higher traffic challenges during evening rush hours with a V/C ratio of 1 and an LOS grade of F.

The initial segment on Al-Mahkamh Street performs well with a V/C ratio of 0.92 and an LOS rating of C indicating traffic conditions with manageable congestion. In contrast the subsequent segment faces congestion with a V/C ratio reaching 1.39 and resulting in an LOS grade of F suggesting the necessity for infrastructure or regulatory adjustments to handle the traffic flow efficiently.

Imam Ali Street and Al-Atbaaba Street exhibit varying levels of congestion. The third segment of Imam Ali Street shows a V/C ratio of 0.97 and an LOS of C, indicating stable traffic conditions. However, the fourth segment suffers from an LOS of F due to a V/C ratio of 1.12, indicating congestion problems that require attention. Meanwhile, Al-Atbaaba Street performs relatively well with a V/C ratio of 0.68 and an LOS of C, suggesting that traffic flows smoothly in this segment despite being in an urban area.

Table 9. LOS for selected road segments based on V/C ratio according to HCM 2010 for evening period

Road No.	Seg. No.	FFS	Class	Max V. (veh/h)	Capacity (veh/h)	(V/C)	LOS
60 Street Al-Adla	1	73.53	II	4104	2670	1.53	F
	2	64.23	II	3504	2670	1.31	F
40 Abo Khamra	1	68.41	I	3240	3430	0.94	B
	2	71.62	I	3524	3430	1.02	F
60 Street Adam	1	80.37	I	3468	3430	1.01	F
	2	72.61	II	3224	2670	1.20	F
Al-Mahkamh Street	1	58.41	I	3172	3430	0.92	C
	2	62.43	II	3725	2670	1.39	F
Imam Ali Street	3	59.34	II	3476	3560	0.97	C
	4	63.38	IV	3672	3250	1.12	F
Al-Atbaaba Street	1	4.82	II	1228	1780	0.68	C

11.3. Statistical analysis of urban street performance

This section presents a detailed statistical analysis of the traffic performance of urban streets in Al-Hilla City, emphasizing the relationships between traffic volume, travel time, and their implications for LOS.

11.3.1. Correlation between traffic volume and travel time

The relationship between traffic volume and travel time was analysed using Spearman's rho correlation test. The findings are summarized in Table 10:

Table 10. Correlation between traffic volume and travel time.

Street	No. of Observations	Correlation Coefficient (ρ)	Significance (p-value)
40 Abo Kharma	60	0.501	<0.001
60 Street Adam	36	0.446	0.006
Al-Mahkamh Street	72	0.709	<0.001
Al-Atbaaba Street	72	0.080	0.503

- Abo Kharma Street: Moderate positive correlation ($\rho = 0.501$), statistically significant, indicates increasing travel time with traffic volume.
- 60 Street Adam: Moderate positive correlation ($\rho = 0.446$), statistically significant, reflects controlled traffic flow challenges.
- Al-Mahkamh Street: Strong positive correlation ($\rho = 0.709$), highlights severe congestion.
- Al-Atbaaba Street: Weak, statistically insignificant correlation ($\rho = 0.080$), suggests minimal congestion impact.

Figure 3 illustrates the correlation between traffic volume and travel time across the studied streets. Abo Kharma and Al-Mahkamh Streets exhibit strong positive correlations, suggesting significant congestion during peak traffic hours, while Al-Atbaaba Street shows minimal correlation.

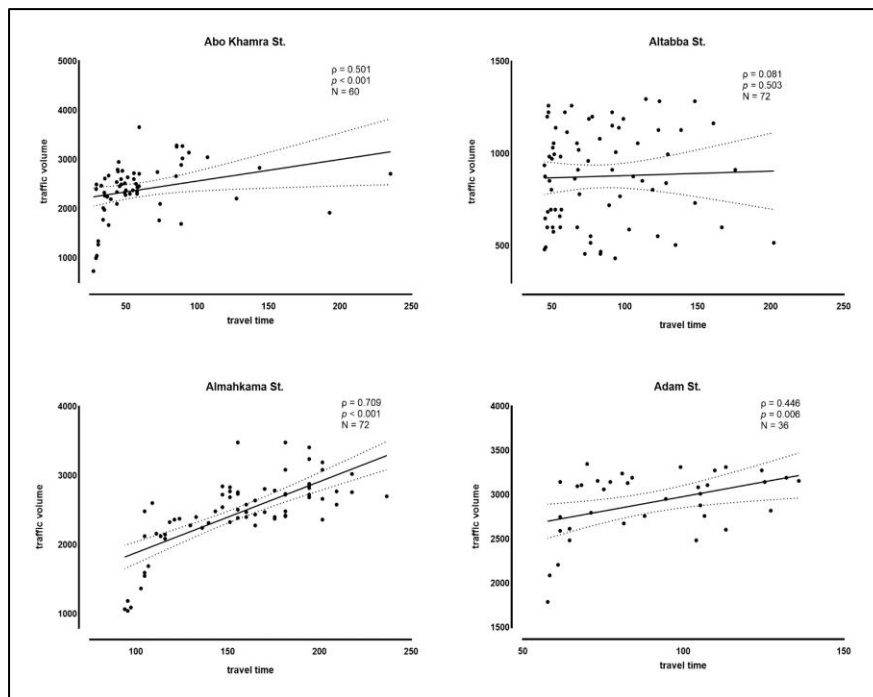


Fig. 3. Correlation between traffic volume and travel time among four different streets.

11.3.2. Regression analysis of factors influencing LOS

The LOS equation for urban streets was derived using statistical regression analysis incorporating key urban traffic parameters. The final model is represented as follows:

$$\text{LOS} = -15.7096 + (2.0548 \times \log(\text{Flow}_V)) + (0.0012 \times C) - (0.2436 \times (1/\text{SF})) \quad (1)$$

where Flow_V represents traffic flow in vehicles per hour, C refers to roadway capacity in vehicles per hour, and SF accounts for external factors affecting traffic movement, such as pedestrian activity and roadside obstructions.

The logarithmic transformation applied to Flow captures the non-linear impact of increasing traffic volume on congestion. Initially, as traffic volume increases, the LOS improves due to efficient utilization of road capacity. However, at higher volumes, congestion effects become dominant, leading to a decline in LOS. Capacity has a direct positive effect on LOS, as roads with higher capacity can accommodate more vehicles before experiencing congestion. On the other hand, SF negatively affects LOS, as increased roadside activities, parked vehicles, and pedestrian movements reduce the available lane width, leading to frequent disruptions in vehicle flow. The inverse transformation ($1/\text{SF}$) applied in the model effectively represents this negative impact, ensuring a more realistic estimation of LOS in urban environments.

The regression model achieved an R^2 value of 0.954, indicating that 95.4% of LOS variations are explained by the selected independent variables. This high explanatory power confirms the model's reliability in estimating LOS under varying urban traffic conditions.

12. Conclusions

The analysis, based on methodologies outlined in the HCM 2000 and 2010, revealed significant congestion issues, with most street segments operating at LOS D to F. These findings highlight substantial inefficiencies in traffic flow, underscoring the need for strategic interventions to improve urban mobility.

The study confirms that high traffic volume, pedestrian density, roadside activities, and inadequate road infrastructure are major contributors to congestion. Streets such as Abo Khamra and Al-Atbaaba recorded LOS F, indicating severe operational inefficiencies and unacceptable delays. Unlike previous studies, this research employed a multi-method approach, integrating video recordings, the floating car method, and radar speed gun measurements. Statistical analysis was conducted using IBM SPSS and GraphPad Prism, strengthening the reliability of LOS assessments.

To address the identified issues, targeted interventions have been proposed. Road widening projects on high-traffic corridors such as Abo Khamra Street and Street 60 are expected to alleviate congestion by increasing roadway capacity, potentially improving LOS by one to two levels. Signal optimization strategies, including adaptive traffic control systems, will enhance intersection efficiency and reduce delays by approximately 15–25%, based on global benchmarks. The introduction of a structured Bus Rapid Transit (BRT) system is recommended to decrease dependency on private vehicles, potentially shifting 10–20% of daily commuters to public transport. Additionally, the development of bypass routes to divert through traffic away from congested city centres will further improve overall traffic flow and reduce peak-hour congestion by up to 30%.

Nomenclatures

C	Roadway capacity, vehicles/h
Flow_V	Traffic Flow, vehicles/h
V/C	Volume to capacity ratio

Greek Symbols

β_0	Intercept in Regression Model
β_1	Coefficient for Flow_V in Regression Model
β_2	Coefficient for Capacity in Regression Model
β_3	Coefficient for 1/SF in Regression Model
ε	Error Term in Regression Model
ρ	Spearman's Correlation Coefficient

Abbreviations

ATS	Average Travel Speed (km/h)
BRT	Bus Rapid Transit
CBD	Central Business District
Dir	Direction
FFS	Free Flow Speed (km/h)
GIS	Geographic Information System
GPS	Global Positioning System
HCM	Highway Capacity Manual
LOS	Level of Service
Max V.	Maximum Volume (veh/h)
SF	Side Friction
SPSS	Statistical Package for the Social Sciences

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