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Analyzing Movement Densities in AlKarkh Districts: A Comparative Study

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ABSTRACT

In recent years, many city centers have experienced severe traffic congestion due to focusing on personal transportation, with cars being the easiest and fastest means of travel. The excessive use of cars has led to neglect of social and environmental aspects, further exacerbating the issue. Historical city centers are particularly affected as they are often commercial hubs with an organic network of roads that increase the difficulty of access and movement. As a result, congestion has intensified, and cars have become the only means of transportation between different parts of the city. This research aims to analyze the effects of traffic congestion in city centers by focusing on a case study of AlKarkh. The study relied on observing and collecting information available at the site, calculating movement densities during peak times on five busy days, and analyzing the data. Additionally, the study compared the results with data from 2014 to assess changes in movement densities. The findings from this research can provide evidence for urban planning that aims to develop the road network in historical city centers and improve transportation policies.

Keywords: Movement densities, Historical fabric, Street vitality, Street networks, Transportation, Street planning

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تحليل كثافات الحركة في مناطق الكرخ: دراسة مقارنة

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الخلاصة

في السنوات الأخيرة ، عانى العديد من مراكز المدن من ازدحام مروري حاد بسبب التركيز على وسائل النقل الشخصية ، حيث أصبحت السيارات أسهل وأسرع وسيلة للسفر. أدى الاستخدام المفرط للسيارات إلى إهمال الجوانب الاجتماعية والبيئية ، مما أدى إلى تفاقم المشكلة. تتأثر مراكز المدن التاريخية بشكل خاص لأنها غالبًا ما تكون محاور تجارية بها شبكة عضوية من الطرق تزيد من صعوبة الوصول والحركة. ونتيجة لذلك ، اشتد الازدحام ، وأصبحت السيارات هي الوسيلة الوحيدة للتنقل بين مختلف أجزاء المدينة. يهدف هذا البحث إلى تحليل آثار الازدحام المروري في مراكز المدن من خلال التركيز على دراسة حالة الكرخ. اعتمدت الدراسة على مراقبة وجمع المعلومات المتوفرة في الموقع ، وحساب كثافات الحركة خلال أوقات الذروة في خمسة أيام مزدحمة ، وتحليل البيانات. بالإضافة إلى ذلك ، قارنت الدراسة النتائج ببيانات عام 2014 لتقييم التغيرات في كثافة الحركة. يمكن أن تقدم نتائج هذا البحث أدلة على التخطيط الحضري الذي يهدف إلى تطوير شبكة الطرق في مراكز المدن التاريخية وتحسين سياسات النقل.

الكلمات المفتاحية: كثافات الحركة، النسيج التاريخي، حيوية الشوارع، شبكات الشوارع، النقل، تخطيط الشوارع

1. INTRODUCTION

Cities are vibrant hubs of social life and events, where the urban space provides opportunities for people to connect and engage with each other. Historical city centers, in particular, are the epicenters of socio-economic activities and commercial exchanges due to their historical and central significance within the city. The street network facilitates movement and communication, a crucial element of the city's urban spaces. It also plays a vital role in commercial activities and the movement of goods. Streets have proven to be more durable than buildings and have continued to serve as essential transportation arteries, supporting the growth and development of cities **(Hillier, 1996; Mumford, 2007; Roukouni et al., 2023).** Many city centers face the problem of high movement densities, which can be attributed to various factors, including the changes in the city’s morphology, especially the planning of the street network **(Yang and Qian, 2023; Al Hashimi and Alobaydi, 2023).** The street network changes with different social and economic conditions, which can increase movement densities. Furthermore, movement densities and land use distribution are closely linked, as land use distribution within an area largely determines movement patterns **(Hillier et al., 1993; Alsaffar and Alobaydi, 2023).**

Many studies have extensively examined the impact of spatial configuration on movement distribution behavior in city centers by investigating the spatial characteristics of an old town in Algeria and analyzing the data collected through field surveys to understand movement activity within walking areas. The study aimed to provide insights to urban planners to design more appropriate streets that improve the city’s functionality **(Fareh and**

Alkama, 2022). Similarly, studied public spaces and their usability in the historical region of Villanova in Italy. They found that well-designed public spaces enhance active mobility and promote social interactions, thus contributing to urban redevelopment **(Garau and Annunziata, 2022)**. **(Ajay et al., 2020)** discussed traffic congestion challenges in urban areas and proposed an intelligent eco-friendly transport management system based on IoT technology. It addressed the negative consequences of private vehicle traffic, such as increased fuel consumption, pollution, accidents, and time wastage. The paper emphasizes the potential of IoT in managing traffic congestion through features like organization, monitoring, and data analysis. **(Mazloumian et al., 2010)** focused on the spatial variability of vehicle densities as a determinant of urban network capacity. It presented a macroscopic simulation approach to studying congestion spreading in urban road networks and highlighted the importance of accurately capturing fluctuations in traffic variables. The study uncovers fundamental relationships between average flow, average density, and the variability of vehicle densities, offering insights into urban traffic performance. Hillier's publication on "Cities as Movement Economies" provides no specific information about its content or relevance in this context **(Hillier, 1996)**.

Moreover, by investigating the street network's inclusiveness in the city center of Tehran, focusing on three pedestrian movement paths. **(Shobeiri, 2021)** aimed to revive pedestrians' presence despite vehicles' dominance in downtown Tehran. The research compared how the streets of central Tehran can fully respond to different age groups using direct assessment, imaging, and point-based analysis. His study conducted direct observation on three days of the week to cover movement activities in the street, emphasizing the contribution of these paths to activate social communication and city center business activities**.** By highlighting the research Evaluation of Pedestrians Walking Speeds in Baghdad City, Using the established methodology, the counts of pedestrians were performed using manual and video counting. It has been found that pedestrians walk slower than others in developed countries or regions with a minimum walking speed of 29.85 m/min **(Sarsam and Abdulameer, 2014).** In general, areas with high concentrations of land uses that attract many people, such as commercial and cultural activities, tend to have higher movement densities. On the other hand, areas that have low movement densities are primarily used for residential purposes **(Mohamad et al., 2020)**.

Historic cores are known for having a mix of land uses that co-exist within the same area, including residential, commercial, and cultural activities. This can result in complex movement patterns as people move between activities and destinations. Typically, movement densities in historic cores are characterized by high pedestrian traffic, limited vehicular access, and a mix of land uses. These changes embody the physical aspects of public space and social inclusion by promoting people's participation in the political, economic, cultural, and social spheres. However, they can also create unique challenges for urban planners and designers, who must balance the needs of different users and stakeholders while preserving the area's historic character. The study analyzed the current movement densities in the historical AlKarkh region. The study mainly examines the road network and land uses to understand the traffic flow in the area. To collect data, the research suggests conducting site observations of the traffic density in the road network. The collected data will be compared with the available data in the AlKarkh development project for 2014 by the Baghdad Municipality. Movement densities will be limited to the movement of vehicles and pedestrians during the working day from Sunday to Thursday, specifically during peak times from 8 am to 6 pm. The final results covered the period from 2014 to 2023, identifying the similarities and differences between variables that impact the formation of the street

network and its impact on traffic density. The study aims to provide insights into the current situation of movement densities in the historical AlKarkh region and help inform future urban planning and development decisions. The main objective is to gather knowledge and expertise from theoretical calculations and practical designs to present a street network as a sustainable, efficient, and safe mobility system. Also, it aims to demonstrate that a properly implemented street network system can be adaptable to local historical conditions. Unfortunately, local pressure and political reasons often lead to the overriding of such systems, with dire consequences.
The investigation focused on specific locations but used theoretical calculations and generalization to allow for broad implementations. The paper's first section introduces the changes in street networks and their impact on traffic density in historic city centers. The second section presents the theoretical framework for previous studies that deal with the main research areas to identify knowledge gaps. The third section focuses on practical framework methods and techniques based on data collection and analysis through site observation by counting the number of movements of vehicles and pedestrians. The fourth section presents the results and discussion. Finally, the last section concludes the research. This paper aims to provide insights into sustainable and efficient street networks that can be adapted to local historical conditions. By analyzing the data from site observations, the research highlights the impact of street network design on traffic density. The paper calls for adaptable street network systems and suggests that local pressures and political reasons should not override such methods.

2. BACKGROUND OF STREET NETWORK DESIGN

AlKarkh's street patterns and community designs have significantly changed in the last century. The traditional tree-like street networks transitioned to gridded street layouts, becoming more dendritic. The rapid development of cities has necessitated the study of street network design, patterns, and characteristics to understand the dynamics of the city. This study aims to understand the structural characteristics of street networks used in historic city centers.
(Buchanan, 1963) highlighted the unsustainable nature of private car-based transportation over half a century ago in his book "Traffic in Towns." He proposed a traffic intensity limit of 200 cars/hour in both directions for local streets, allowing high traffic intensity and traffic jams only on thoroughfares with appropriate parameters. It's worth noting that Buchanan used the phrase "street environment" to focus on the social environment with urban and historical values rather than biology and air pollution. Buchanan's study aims to understand the impact of street network design on urban environments and its historical importance. The study hopes to encourage sustainable transportation practices and promote healthy urban development by setting traffic intensity limits and considering the social environment. By examining the effect of accommodating traffic in four locations, including Newbury (a small town), Leeds (a large town), Norwich (a historic town), and a Central London block (essentially Fitzrovia), the study aims to understand the impact of street network design on urban environments and historical values. One aspect followed by chance, perhaps more than design, was that the inner circulation problems should be resolved before building a major bypass. In Leeds, some innovative possibilities included three alternative arrangements for distributor roads in the central area, including a hexagonal road pattern. The study of the historic town Norwich is disappointing, but its conclusion that heritage needs protection even at the cost of the car is probably one we still support.

(Buchanan, 1963) recognized that only in small towns could daily life co-exist with full car use. In other situations, the action was necessary. Integrated transportation plans would not only coordinate land use but also control demand. Some of the proposals are still valid, such as a system of permits to control the entry of vehicles to defined zones, electronic road pricing, and subsidizing public transport to make it cheaper than car travel, but changing work patterns seemed too complicated. Buchanan suggested improving the capacity of the primary system and parking, moving some uses out of central areas, and extending the length of the peak period. None of these solutions was fully satisfactory, and the problem remains today. Buchanan concluded that the scale of primary roads needed to accommodate total car usage was so great that the nation's fabric could not easily assimilate them: 'These roads must be located about broader considerations of environment, well-designed, and visually attractive from all angles.

The shape and characteristics of urban networks can greatly influence many mobility aspects, such as travel distance, mode choice, and safety. For example, a tram can be a real competition to the car. Definitely, yes, if the car is stuck in a traffic jam and the tram has priority, but not only in such cases! With proper system design, a tram may offer faster travel to the city center than a car. On the other hand, if the tram provides faster travel than the car only during several peak hours, it is usually enough to provide better service for most people travelling in such a direction. Streets serving residential or commercial areas should be livable. To reach that goal, nonmotorized and public modes of transport should be competitive with car traffic **(Gehl, 2010; Currie and Delbosc, 2011; Wachs, 2013)**.

Wide lanes encourage drivers to gain speed, but the drivers face hazards from low-speed traffic **(Kang and Fricker, 2013)**. Turning to side streets or searching for a parking space. Cyclists, fearing heavy and fast car traffic, often ride on sidewalks, endangering pedestrians; a comparison can be made to observations of Pedestrians getting narrow sidewalks close to traffic noise or are encroached on by parking. Inhabitants face a deterioration of the environment and fragmentation of the area, including children crossing dangerous streets on their way to school. Professional drivers cannot find a place to stop their taxi or delivery van. A solution can be found in reducing the capacity and speed of cars **(Marks, 1957; Broach et al., 2012).** An early road safety study from the 1950s by Marks is one of the first to address the perceived safety problems of grid street patterns compared to hierarchical designs **(Marks, 1957).**

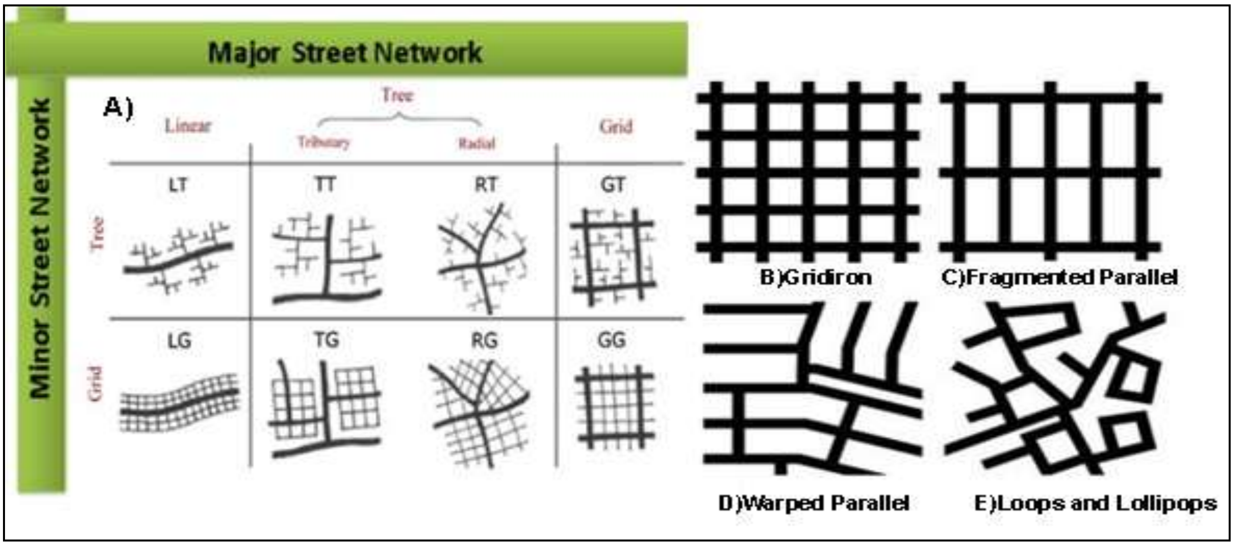


Figure 1. Street Configuration Classifications **(Marshall, 2005)**

Based on five years of crash data for 86 residential areas, Marks found almost eight times more crashes on the gridded streets and 14 times more at the four-way intersections in a grid design than at the T-intersections found in dendritic arrangements. The reason for these results was the relationship between increased residential street connectivity and the probability of increased traffic at higher speeds **(Handy et al., 2003)**. It adopts a chart from Stephen Marshall's book Streets and Patterns that emphasizes the major street network structure separately from the minor street network depicted in **Fig. 1 (Marshall, 2005)**.

In his book "Streets and Patterns" Marshall used the A B C D classification system to describe different types of street networks and their corresponding trends, such as gridiron, fragmented parallel, warped parallel, and loops and lollipops. These street network types have varying effects on the frequency of walking, cycling, and transportation usage, as illustrated in **Fig. 1.**

The A B C D classification proposed by Stephen Marshall provides a useful framework for understanding the street network and its development. By categorizing streets into different types and patterns, such as gridiron, fragmented parallel, warped parallel, loops, and lollipops, we can gain insights into how they affect the frequency of walking, riding, and transportation usage. For instance, with its regular and connected street network, the gridiron pattern encourages more walking and cycling while reducing car usage.

Moreover, these patterns may appear alone or in combination, depending on the level of centralization in urban areas. For instance, in densely populated cities, we may see a mix of different patterns that reflect the unique urban structure of the city. Understanding these patterns and their densities can help us predict changes in the usage of the streets and plan accordingly to ensure safe and efficient transportation for all users.

It's worth noting that studies have shown that street widening projects, which are often proposed to improve safety and reduce congestion, may lead to reduced safety. Therefore, it's crucial to consider the impact of street design and development on various modes of transportation and the safety of users.

3. METHODS AND TECHNIQUE

The objective of the proposed approach is to conduct a comparative analysis of the movement densities in the AlKarkh districts, which serves as the focus area of the study. The aim is to develop a methodology that can effectively evaluate the differences in the levels of movement within and between the districts. By doing so, this study aims to provide insights into the factors that influence movement patterns and densities in the area, which can inform future urban planning and transportation initiatives.

3.1. Case Study (AlKarkh-Historic Center)

AlKarkh is a historic neighbourhood located on the west bank of the Tigris River in Baghdad, Iraq. It is one of the city's oldest and most densely populated areas, with a rich history that dates back to the 8th century. Narrow winding streets, traditional architecture, and vibrant local culture characterise the neighbourhood. AlKarkh is home to many significant cultural and religious landmarks. The neighborhood contains several historic markets, such as Al Rahmaniyah and Al Shawaka market, known for their traditional handicrafts, textiles, and food. Despite its historical significance, AlKarkh faces numerous challenges, including overcrowding, ageing infrastructure, and environmental degradation. The neighbourhood has experienced significant urbanization in recent decades, with many traditional buildings replaced by high-rise apartment blocks and modern commercial buildings. To address these challenges, the local government has launched several initiatives to preserve the neighbourhood's cultural heritage and improve living conditions for residents. These initiatives include restoring historic buildings, creating public green spaces, and implementing new transportation infrastructure to ease congestion and improve mobility. AlKarkh remains an important cultural and historical center in Baghdad, with a unique character and identity that continues to attract visitors and residents alike **(Alobaydi and Rashid, 2017);** see **Fig. 2.**

Figure 2. Urban fabric plan of the historic core of AlKarkh. Reference: Municipality of Baghdad.

3.2. Research Method And Technique

The researchers aimed to determine the movement densities for both vehicles and pedestrians in AlKarkh, Baghdad, Iraq. They used the gate count observation technique, which involved counting the average number of movements in the road network of the study area. Thirteen station points were chosen according to the degree of people's attendance and use of street spaces, and an imaginary crossing line was drawn on the road network at the selected points. The counting was conducted during working days and peak times on traffic axes, including main streets and intersections (**Fig. 3**).

Data was collected for 15 minutes every hour from 8:00 am to 6:00 pm, and the number of moving vehicles and pedestrians was recorded in a table using the Excel program for data analysis. The focus was on peak hours, when commercial activity and movement of pedestrians and vehicles increase, especially during times of going to work and the end of the working day and school.

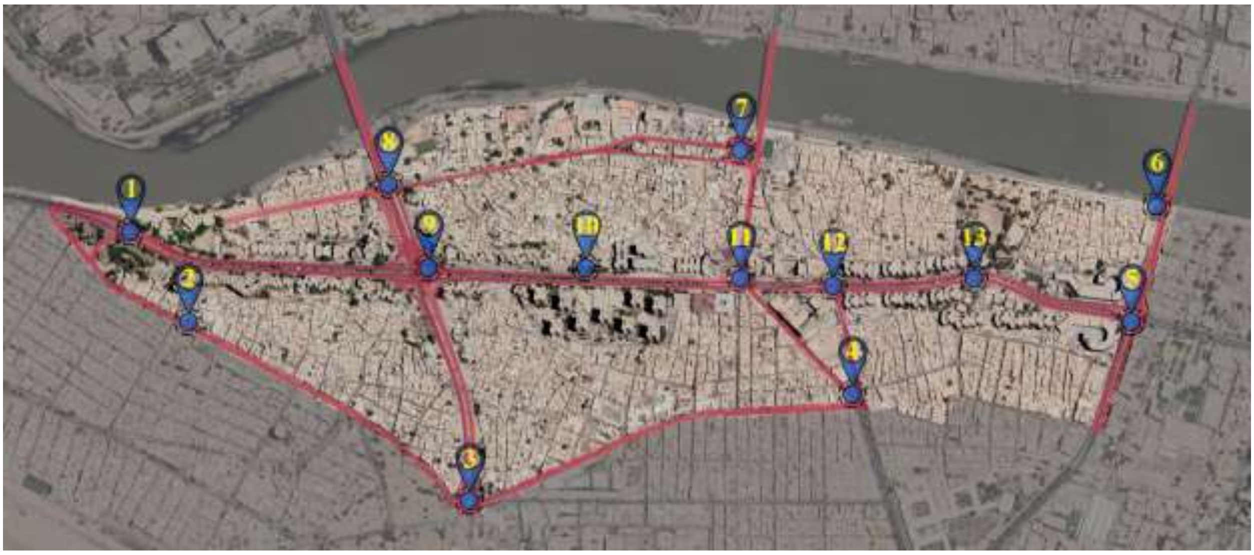


Figure 3. Map of the site observation survey for Alkarkh, yellow dots are the 13 selection stations.

Table 2 shows the data analysis for the movement densities for AlKarkh, based on site observation surveys using a questionnaire form to count the movement of vehicles and pedestrians in the case study area.

The study aimed to provide insights into the traffic and pedestrian movement patterns in AlKarkh, which could help urban planners make informed decisions about infrastructure and development projects in the area. It is hoped that the findings will improve the quality of life for the local community and make the area safer and more accessible for pedestrians and vehicles. See **Tables 1 to 3**.

Table 1. Descriptive statistics of the movement densities for the site observation survey in 2014. according to the Alkarkh development project. **(Baghdad Municipality)**

Traffic Surveys Locations	Total vehicles (/10hr)	Total vehicle's peak time (/10hr)	Total pedestrians (/10hr)	Total pedestrian's peak time (/10hr)
Station 1 (Ahmad AlWaeli park)	17828	8456	324	163
Station 2 (Sheikh Maruf street)	3919	1045	334	157
Station 3 (Sheikh Maruf square)	6181	1295	395	246
Station 4 (Allawi street)	8775	3261	543	218
Station 5 (king Faisal 1 square)	4135	1983	255	127
Station 6 (AlAhrar Bridge)	2456	864	854	442
Station 7 (Al Shuhada square)	4527	1896	785	435
Station 8 (Bab AlMoatham Bridge)	17732	5991	465	231
Station 9 (AlTalae'a square)	28809	14530	533	254
Station 10 (Haifa street)	26074	15014	236	184
Station 11(Haifa street square)	12230	4445	316	185
Station 12 (Haifa street)	2645	945	351	142
Station 13 (Haifa street)	1898	826	210	75

Table 2. Descriptive statistics of the movement densities for the site observation survey in 2023.

Traffic Surveys Locations	Total vehicles (/10hr)	Total vehicle's peak time (/10hr)	Total pedestrians (Person/10hr)	Total pedestrian's peak time (Person/10hr)
Station 1 (Ahmad AlWaeli park)	22314	10875	511	231
Station 2 (Sheikh Maruf street)	6423	3255	1136	554
Station 3 (Sheikh Maruf square)	7743	4329	913	408
Station 4 (Allawi street)	19432	11563	1306	632
Station 5 (king Faisal 1 square)	26224	10986	1719	774
Station 6 (AlAhrar Bridge)	25805	12378	1227	542
Station 7 (Al Shuhada square)	6765	3012	3994	2405
Station 8 (Bab AlMoatham Bridge)	30795	18543	743	445
Station 9 (AlTalae'a square)	50251	27869	834	454
Station 10 (Haifa street)	26254	16026	751	409
Station 11(Haifa street square)	18353	12390	1255	682
Station 12 (Haifa street)	23159	13555	1144	614
Station 13 (Haifa street)	22957	10421	1163	497

4. RESULTS AND DISCUSSION

This study aimed to analyze traffic densities in the AlKarkh area of Baghdad using the gate count observation technique. The approach involved selecting 13 traffic count points in the study area and counting the number of moving vehicles and pedestrians every 15 minutes for 10 hours. The counting was conducted during working days and peak hours, with a focus on main streets and intersections with high people attendance and street usage.

The results of the traffic density analysis showed a significant increase in traffic densities in the study area after nine years, especially in Haifa Street **Fig. 4**., which is the main motor path that divides the region into two parts and is linked by three bridges to the rest of Baghdad. The study found that car traffic was the highest on this street, while pedestrian traffic decreased over time. However, pedestrian traffic increased in station 7 (Shuhada square), a traditional market area with low car traffic **Fig. 5**.

Table 3. The correlation coefficient for data from 2014-2023

Total vehicles (per10hr)	Total vehicle's peak time (per10hr)	Total pedestrians (per10hr)	Total pedestrian's peak time (per10hr)
0.64014	0.711109	0.49922	0.54918

Figure 4. Haifa Street (station 9) intersection high density for vehicles area

The findings of the current study are presented in **Fig. 6, 7, 8, and 9**, which illustrate the traffic densities for the two different periods of the study area. The results revealed that the development project by the Municipality of Baghdad in 2014 did not improve the traffic densities in the area, and traffic densities increased over time. The study provides valuable insights into the traffic patterns in the AlKarkh area of Baghdad, which urban planners and policymakers can use to develop more effective transportation policies and strategies. Generally, the study highlights the importance of continuous monitoring and analysis of traffic densities in urban areas, especially in highly populated and commercially active regions. The results can help urban planners and policymakers identify the areas that require improvements and develop more effective transportation policies and strategies that prioritize the needs of both pedestrians and vehicles. See **Figs. 10 , 11**.

Figure 5. AlShuhada Square (station 7) high density for the total pedestrian area

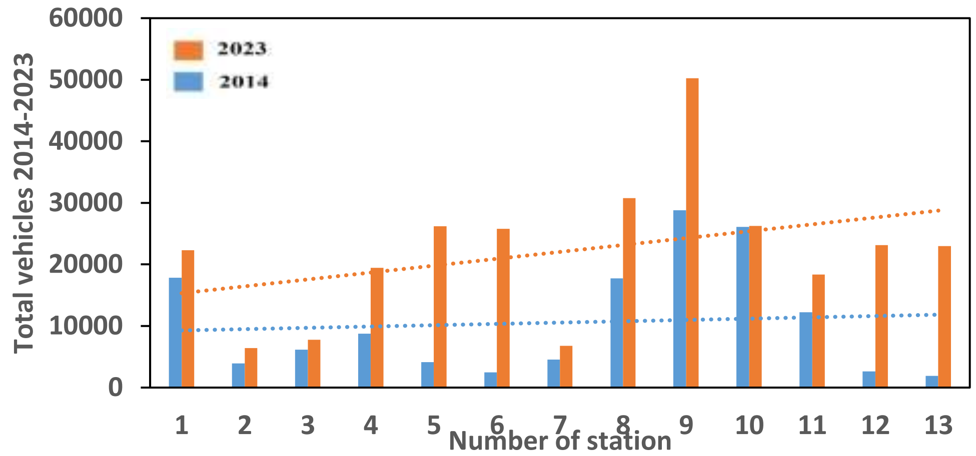


Figure 6. Statics Graph results for total vehicles in Alkarkh, 2014-2023, the highest rate of vehicle movement in Station (9).

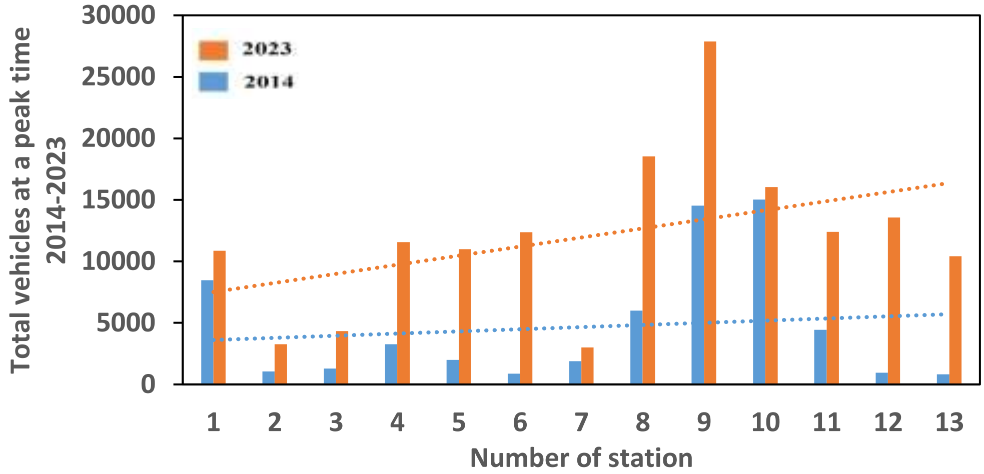


Figure 7. The statical graph results for movement densities for total vehicles at peak time in Alkarkh, 2014-2023, the highest rate of vehicle movement in Station (9).

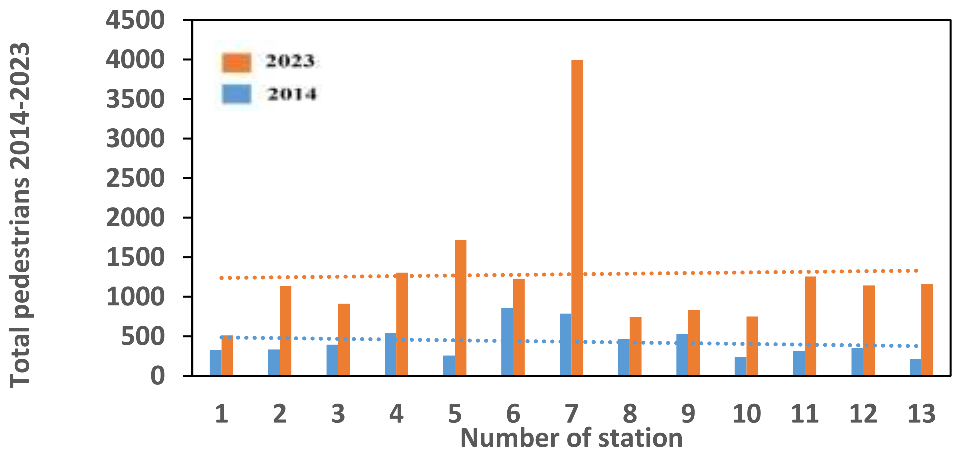


Figure 8. The statical graph results for movement densities for total pedestrians in Alkarkh, 2014-2023, the highest rate of pedestrian movement in Station (7).

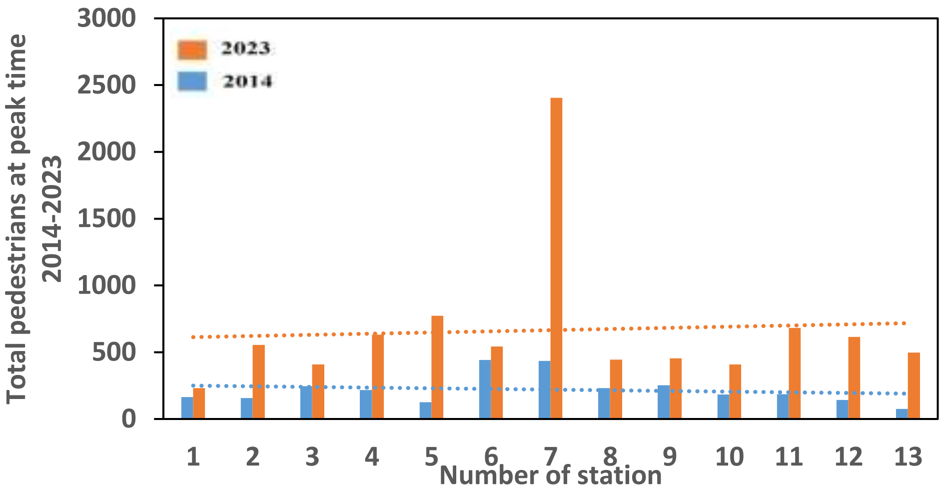


Figure 9. Statics graph results for movement densities for total pedestrians at peak time in Alkarkh, 2014-2023. The highest rate of pedestrian movement in Station (7).

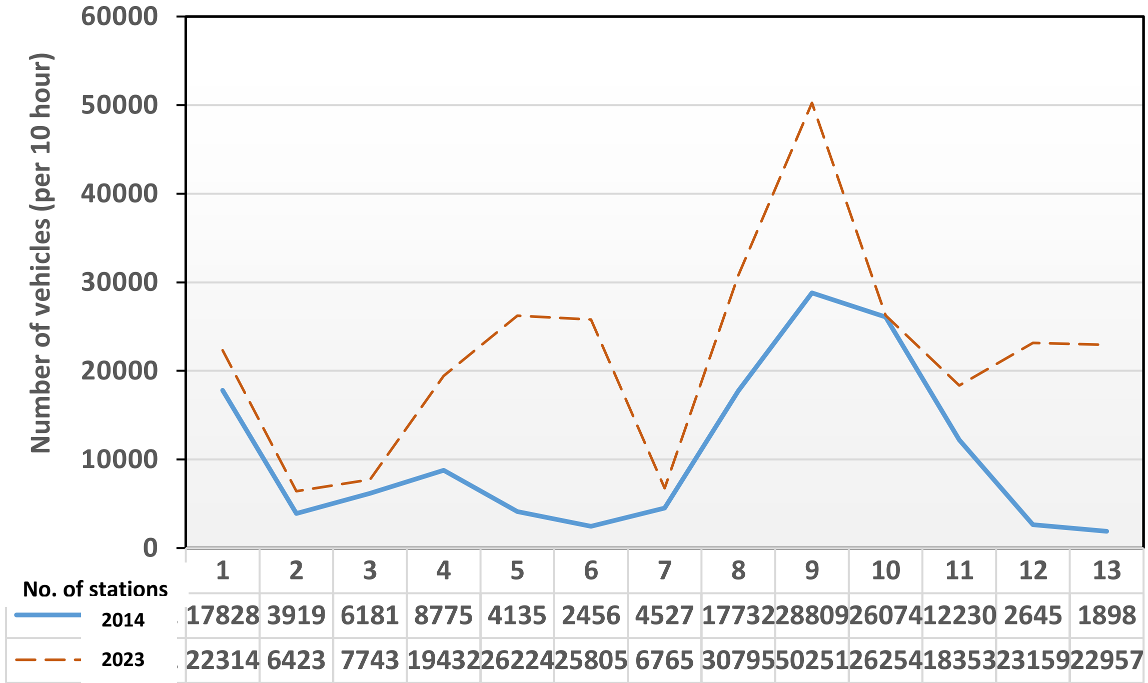
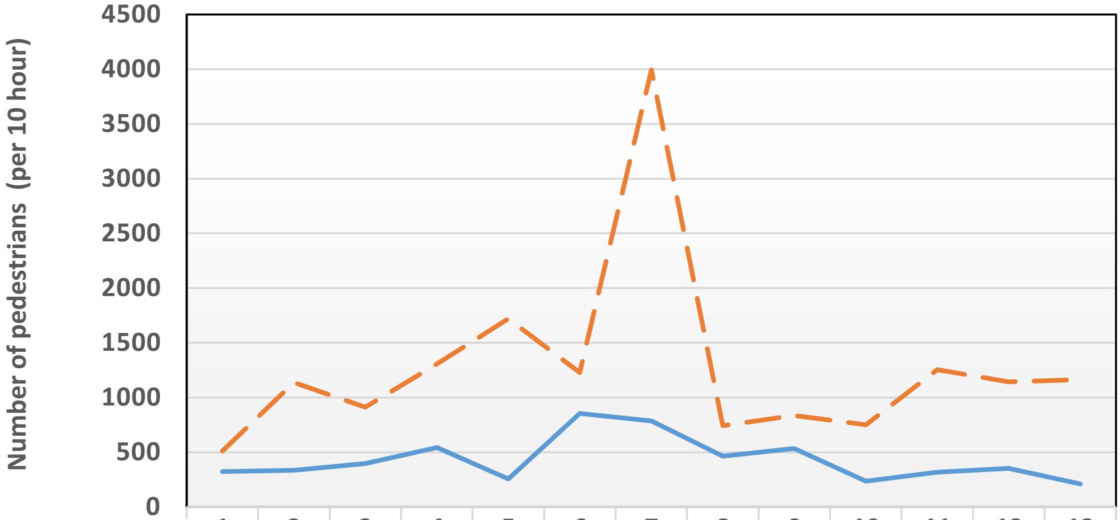


Figure 10. Correlation results for movement densities for total vehicles 2014-2023.



No. of stations	1	2	3	4	5	6	7	8	9	10	11	12	13
2014	324	334	395	543	255	854	785	465	533	236	316	351	210
2023	511	1136	913	1306	1719	1227	3994	743	834	751	1255	1144	1163

Figure 11. Correlation results for total pedestrians 2014-2023.

One effective way to measure traffic density is by using a mathematical equation.
Traffic density = No. of vehicles / Longest tiled road

$$T = \frac{N}{L} \quad (1)$$

where T is the Traffic density, N is the number of vehicles, L is the longest tiled road (km).
By measuring the traffic density of Haifa Street, as it is the longest street and has the most traffic density, according to the data in **Tables 1 and 2,** the traffic density of Haifa street (2014) is

$$T = \frac{28{,}809}{2{,}55} = 11$$

While the traffic density of Haifa street in (2023)

$$T = \frac{50{,}251}{2{,}55} = 20$$

In 2023, there has been a significant increase in movement in Baghdad, Iraq's capital city. This can be attributed to the substantial population growth over the past eight years, with the population increasing from (7.665) million in 2014 to (8.556) million in 2023. This is a notable difference of 0.891 million people.
AlKarkh experienced significant population growth and saw population rise from (31,040) people in 2014 to (67,844) people in 2023. Additionally, the number of vehicles in Baghdad has increased from (2,087,039) in 2014 to (2,730,880) in 2023, according to data from the statistical center of the Ministry of Planning **Table 4. (Albayati and Lateef, 2019)**.
These population and vehicle increases have led to significant movement throughout the city. As a result, urban designers, planners, and policymakers need to consider the impact of

this growth on transportation infrastructure, public transportation, and road safety to ensure that the city can accommodate the needs of its residents and visitors.

Table 4. Indicators of population density and vehicle density during two periods of 2014-2023

Indicators	Year 2014	Year 2023
Population in Baghdad	7,665,852	8,556,756
Population in AlKarkh	31,040	67,844
vehicles in Baghdad	2,087,039	2,730,880

The current study differs from previous works **(Alobaydi and Rashid, 2015, 2017; Al-Saaidy and Alobaydi, 2019; Alobaydi et al., 2020; Alsaffar and Alobaydi, 2023; Al Hashimi and Alobaydi, 2023)** that have primarily followed metric and morphological approaches to understand the properties of street networks. In addition, there is a set of studies that analyzed the urban forms and structures of street layouts and organizations **(Farhan et al., 2022; Mohammed and Alobaydi, 2020a; Al-Mosawe et al., 2018; Aziz et al., 2020; Mohammed and Alobaydi, 2020b)**.

The current study aims to raise awareness that increasing traffic volumes not only impacts traffic densities but also influences the patterns of urban life as pedestrians and car drivers begin to alter their route paths to avoid traffic jams. This shift in transportation modes significantly affects the character of nearby areas, particularly residential areas, as it impacts privacy.

5. RESEARCH LIMITATIONS

- The current study does not involve a visual analytic approach like space syntax, which is dedicated to capturing the integrated (the most accessible) and segregated (the least accessible) paths that influence the interpretation of the current findings.
- The current study does not include a metric network analysis like Urban Network Analysis (UNA), which is employed to analyze an urban area in relation to a set of centralities, including reach, betweenness, closeness, gravity, and straightness measures. These measures influence the interpretation of the current findings and open up other kinds of correlations, explaining the physical-spatial qualities of the given urban area.
- The environmental factors, which are essential in impacting the mobility of pedestrians in hot-arid climates, were excluded from the analysis. This exclusion might not reveal the influences of human comfort in determining the route pedestrians take.

6. CONCLUSIONS

The current study differs from the existing studies regarding methods and techniques employed. Unlike **(Ajay et al., 2022),** focusing on IoT-based solutions, and **(Mazloumian et al., 2010)**, utilizing macroscopic simulation approaches, the current study relies on site observations and field survey techniques. The researchers directly observe and gather data from the study area, employing comparative strategies to analyze and understand the traffic dynamics. The study aims to provide a unique perspective on the subject matter by utilising on-site observations and field surveys, contributing distinctly to the existing body of knowledge. The study's main goal was to identify the road network surrounding the study area, including streets and alleys, and to develop a general framework for urban growth based on traffic surveys. The study aimed to ensure the continuity of movement in the study area, promote urban sustainability, and facilitate the balanced movement of vehicles and pedestrians without any accidents or issues between traffic flows.

The traffic surveys showed that Haifa Street had the highest flow of vehicular traffic during peak hours, with a traffic volume of 28,809 and a traffic density of 11 in 2014. However, in 2023, the traffic flow increased significantly to 50,251, with a traffic density of 20. This increase was due to a rise in population and personal transportation, including taxis and minibuses, since there were no infrastructure services for public transport, such as the metro or tram. The study also found that areas with high vehicle density had a noticeable decrease in pedestrian traffic. In contrast, areas with high pedestrian rates were those where cars were not allowed to enter, such as public places, traditional markets, and retail areas. These narrow streets and alleys with traditional organic textures were more pedestrian-friendly and safer.

The broad and long linear urban streets that divided the region into parts caused problems as they did not match the traditional fabric of the area. These streets became challenging to reach pedestrians and caused the region to lose its privacy. They also failed to consider human factors, and the high vehicle densities in these streets made them unsafe for pedestrians. The study showed that promoting a more pedestrian-friendly environment in urban areas is crucial to ensure urban sustainability and safety. This can be achieved by improving public transportation infrastructure and promoting traditional organic textures that prioritize pedestrian movement. This is a set of recommendations:

- To alleviate traffic congestion on busy streets such as Haifa Street, secondary streets must be provided to accommodate vehicles. This can be achieved by creating alternative routes that connect major destinations, allowing drivers to avoid congested main streets. By reducing the number of cars on main roads, traffic flow can be improved, and the overall driving experience can be more efficient.
- The development of public spaces and green areas can effectively encourage pedestrian activity, reduce reliance on cars, and make the environment more livable. By creating walkways, bike lanes, and other pedestrian-friendly infrastructure, people can move around more easily and safely, leading to improved physical health and well-being. In addition, parking areas should be designed in a way that does not impede pedestrian pathways.
- Improving public transport infrastructure is key to reducing traffic and carbon emissions. This can be achieved by developing new routes, improving existing services, and integrating different modes of transport such as buses, light rail, and trains. By making public transport more convenient and accessible, people can leave their cars at home, reducing traffic congestion and improving air quality.
- Implementing transportation services such as metro, trams, and trains can significantly reduce traffic congestion, especially during peak hours. These services can provide fast and efficient transportation to major destinations and reduce the number of cars on the road. Additionally, the implementation of these services can help to reduce carbon emissions, which can have a positive impact on the environment.
- Providing designated parking spaces for vehicles and minibuses can help to reduce road congestion and improve traffic flow during peak times. By providing off-street parking, drivers can avoid obstructing traffic flow on main roads, reducing overall travel times and

improving the driving experience. This can also help reduce carbon emissions by reducing vehicles' time idling in traffic.

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Credit Authorship Contribution Statement

Saif Albabely contributed primarily to developing the research methodology and digital simulation processes, in addition to analyzing and interpreting digital data, designing and executing the numerical simulations, as well as the analysis and interpretation of the data and writing. Dhirgham Alobaydi provided significant support in analyzing and interpreting the data, formulating it, validating the simulation results and providing critical insights during the manuscript preparation and editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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