Abstract: The realization of the nexus between morphological changes and road intersection performances remains a challenge in urban studies. Despite the effort spent on minimizing the traffic associated problems (such as congestion and delay) in urban intersections, namely using roundabouts, signalized intersections, and actuated traffic signal controls, there are still traffic performance inefficiencies within intersections. Traffic congestion in the intersection arises for two reasons, namely by densification formed in the surrounding area and by the lack of effective traffic management. In this paper, a morphological analytical approach was adopted to explain the urban intersection changes for a 1 sq. km study area within Jadriyah neighborhood. The study spans three historical phases (1999, 2009, and 2019) and describes the changes to urban morphology by integrating land-use development with traffic data. Problems regarding urban variation in this prominent intersection were measured and then compared in terms of the Level-of-Service (LOS). The deployment of measurement and analytical methods include two sets of measurements: firstly, the study of the morphology of urban form structures, and secondly the data analysis of volume, pedestrian movement, saturation flow, and signal timing during peak hours whilst counting the daily trips generated for each type of changed land use pattern. Analysis of the collected data revealed that the

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PUBLIC INTEREST STATEMENT

Studying the urban morphological changes has been preoccupied the attention of urban designers and town planners due to highlighting real concerns and impacts over other urban forms and structures. Development of land use and building density of urban form has impacted the performance of street network systems, in particular downtowns. One of these impacts is included, but not limited to, the performance of road intersections. It is believed that considering traffic performance problems in such intersections without taking into account the urban changes to adjacent land use and building density would not properly help to improve the LOS for some high-saturation intersections. This paper aims to raise the attention to the role of unplanned developments of urban form in interpreting the implications of the traffic generation, saturation, and delay problems at the intersection, not only at the level of intersection but also across the whole street network system of the city.
Urban morphology of transformed land use over time impacted the traffic volume for each phase on the level of intersection performance. Results thus showed a considerable decline of the urban intersection LOS in Jadriyah neighborhood; the uncontrolled land use expansion led to an increase in the peak volume at a rate of 155 veh/hr per year, whilst the percentage increase in pedestrians was 200% per hour. The paper concluded that ignoring densification and land use development at the urban design level over time has given rise to real impact, whether increasing traffic saturation or delay, on the performance of intersections and thus influence the transportation planning level.

Subjects: Transport & Vehicle Engineering; Civil, Environmental and Geotechnical Engineering; Transportation Engineering

Keywords: morphology; urban densification; land use; intersection; traffic volume

1. Introduction

Insistent morphological changes, combined with growing land use development and a significant increase in private car ownership has lead to an increase in load amongst Iraqi urban transport systems. For large and medium-sized districts in Iraq, road construction has basically been hindered between 1980 and 2003; instead, it has relied on existing street networks. Road construction cannot be a good alternative to traffic operation without optimizing traffic management. Despite the effort spent on minimizing traffic associated problems in urban intersections by using roundabouts, signalized intersections, and actuated traffic signal controls, there are still traffic performance downsides within intersections (Adeke et al., 2018) and (Sutandi, 2020). It is believed that considering traffic performance problems in these intersections without taking into account the changes to adjacent land use would not properly help to improve the LOS for some high-saturation intersections, such as those in Jadriyah.

Urban form patterns, which consider shape, size, and juxtaposition, have four basic elements: streets, plots, buildings, and land use distribution. These elements are important agents to the interpretation of the performance of urban form and structure (Silva, 2019; Rashid, 2018; Southworth & Ben-Joseph, 2013). Urban intersection performance represents one of these complex urban form patterns that have shaped and changed over time (Southworth & Ben-Joseph, 2013) and (Alobaydi, 2017). When an urban area at any given time is subject to a continuous development process, urban intersection studies require morphological analyses (Alobaydi & Rashid, 2015; Alobaydi, 2017; Rashid, 2019).

The morphology of natural and socio-economic processes influence the performance of urban intersections. Among morphological factors, urban land use development is one of the core driving forces that directly impact the performance of urban intersection. Human demand for land and the extensive land conversion for public activities accelerates movement density, building densification, and plot subdivisions. Socioeconomic and other relevant morphological data have, until recently, rarely been linked with other transport data in urban intersection studies. The study of socioeconomic-influenced intersection performances remains a research challenge.

There is considerable literature addressing traffic flow issues, organization and management, in urban intersections worldwide. Lal et al. studied the problems of traffic flow at urban intersections in Ettumanoor, India and how these could be improved sustainably; authors concluded that traffic volume, land use, and pedestrian movement significantly impacted the intersection’s performance (Lal et al., 2016). Xi et al. studied a comprehensive waiting area in an urban intersection using the simulation software PARAMICS; this was combined with programming API to effectively improve the intersection traffic operation when the traffic volume was large (Xi et al., 2013). Adeke et al. measured the layouts of the intersection in Makurdi town, including the SRS and B-Division, to
obtain the average travel demand (pcu/h) for a base year (2017) and projected year (2027) using the traffic growth rate. For both intersections, the performance results failed for the base year. The authors concluded, since the land-use features and right-of-way policies prevent further lane expansion, the existing intersection requires other kinds of design for the projected year (Adeke et al., 2018). Rouphail studied the performance of intersections by measuring the stopped and overall delays, and proposed a set of equations for full and partial stop rates, and for stopped delays that aimed to improve intersection performances. However, these equations need to be further evaluated (Rouphail, 1988). Atomode examined traffic delay problems at major urban centers in Nigeria, specifically the case of Ilorin, and suggested some proposals such as an effective traffic management method to improve traffic flow at the junctions (Atomode, 2013). Zakariya and Sherif developed a research algorithm to determine the minimum delay in optimal cycle length required for the regression analysis conducted in their study. Their numerical results showed that the proposed formulas give a better estimation for the optimal cycle length at high intersection flow ratios compared to Webster’s formula (Zakariya & Rabia, 2016). (Yue et al., 2020), used the control delay, LOS, and average stops as a method to evaluate the intersection performance. They studied the improvement of a strategy that involved two adjacent signalized intersection controllers and found that these elements reasonably evaluated the intersection’s performance (Yue et al., 2020).

In addition, morphological studies that described the spatial properties and physical qualities of city road networks, including all types of the intersection, were diverse. (Rashid, 2018) re-studied the evolution of urban structures—land use, plots, and streets—within eight study cases at the urban edges in the San Francisco Bay Area, USA (Rashid, 2018). For the street systems, his analysis described the spatial configurations and growth processes of streets (including intersections) and identified the morphological changes, which showed minor changes. Also, several studies covered the impacts of urban configurations on the mobility, accessibility, and connectivity performances of street networks (Alobaydi & Rashid, 2015, 2017; Alobaydi, 2017; Rashid, 2019).

Aside from this literature about the issue under investigation, traffic problems and relevant issues at urban intersections still need for further study in order to take local issues into account. The traffic management principles and procedures that are allocated to solve traffic problems (with or without morphological influences) can be studied, described, and implemented in the growing urban areas of developing countries but are still lacking in the literature.

In this paper, the traffic volumes at a prominent urban intersection of Jadriyah in Baghdad, Iraq are studied in relation to land use development. Field studies on traffic volume count, pedestrian traffic, private car traffic, and public transport traffic within the study area were measured during three succeeding decades to develop the spatial performance and organize the traffic flow at this urban intersection. Past traffic jams and delay data were collected from site observations by measuring the volume, saturation flow, and number of pedestrians crossing the intersection; these data were precisely analysed and described based on the LOS measure. Figure 1 shows the queues of vehicles in the four directions of the Jadriyah intersection as well as the conflict of pedestrian and the vehicle traffic during the green phase of the intersection. Impairment in operational plans and disoriented land use development planning were identified as the main reasons affecting the area.

This paper thus differs from existing literature in the way that it has conducted the morphological analyses for three sequential decades to examine the performance of Jadriyah intersection in a context that is still in flux. The main goal of this study is to measure the traffic saturation and delay of the Jadriyah intersection over three decades by increasing the awareness of unplanned urban developments for the city council and its future development project actions.
2. The case study

2.1. Location

The site of this preeminent urban intersection—so-called “Kamal Junblat Square”—is located in Jadriyah neighborhood, which is a U-shaped landform shaped by a meander of the Tigris River in the Karrada District of Baghdad. It is made of two important roads—the East Bound (EB) and West Bound (WB)—and two arterial roads including the North Bound (NB) and South Bound (SB).

The EB is known as Jamia St., while the WB forms a slight curvature in shape and runs toward Jadriyah Bridge heading into Bayaa District; this includes crowded neighborhoods and a famous industrial area in Baghdad. The NB connects the Jadriyah intersection with Karrada Dakhil St. and Abu Nuwas St. Finally, the SB runs directly towards the Tigris River bank. Two principal institutional entities—the University of Baghdad (UB) and the Ministry of Science and Technology—are located on its southwest side, while a scattered pattern of townhomes formed in the Jadriyah Orchards (Basateen) are located on its southeast side.

Jadriyah intersection provides two main access points to the UB and Ministry of Science and Technology; however, these two accesses are restricted by checkpoints, which only allow mobility to students, faculty members, and employees (Figure 2). Yet, the flow of pedestrians/vehicles of the other three roads is easy-to-access.

2.2. Descriptive data

The Jadriyah intersection is one of the most important intersections in Baghdad and serves more than 12 million vehicles per year, according to the General Directorate of the Traffic of Baghdad. Baghdad has been divided into 14 administrative municipalities. From the total population of Baghdad Governorate, which is 8,402,000 capita, 5% live in Karrada District, with a gender factor of 50% male (Khatib and Alami, 2014). The housing density of Karrada is seven houses per hectare (hph), which is lower than that of Baghdad at 15 hph; however, the population density is 151 persons per hectare (pph) compared to the average population density of Baghdad at 115 pph. The average gross domestic product (GDP) per capita for Karrada is approximately 80% higher than the average GDP for the Iraqi capita at 5,165 USD.
Jadriyah intersection has been selected for several reasons:

- It provides the main access points to the UB and the Ministry of Science and Technology. Users of the two aforementioned institutions pass through it either by vehicle or as a pedestrian. For more clarification, see Table 1.
- In the last decade, Jadriyah neighborhood has experienced rapid urbanization, socioeconomic change, and an increased level of motorization (number of vehicles per 1000 people). Moreover, the average motorization level in Iraq is 141 whereas for Jadriyah it is approximately 200, see (Albayati & Lateef, 2019).

Land use in the vicinity of intersection area includes bus stops, a shopping center, print shops, restaurants, and the university.

3. Method
The LOS measure was employed to evaluate the performance of the intersection. It was based on the geometry, traffic, and intersection signals. The method was based on the Highway Capacity Manual (HCM) (Highway Capacity Manual, 2000). Data were collected for the four directions of the Jadriyah intersection in terms of the traffic volume, field estimate of the saturation flow, and pedestrian crossings for the three examined urban morphological decades (1999, 2009, and 2019). For each examined phase, observers were distributed on four sides of the intersection in order to collect the required data. Durations of these observations were carried out at the morning peak hours (7:30–9:30 AM) and at the afternoon peak hours (2:30–4:30 PM). The data were classified based on the history and study topics. Data were analysed and used as input data to the Highway Capacity Software 2000 (HCS2000) to estimate the delay for each side and for the intersection. The flow chart shown in Figure 3 describes the process used to evaluate the performance of the intersection.

The saturation flow was defined as the maximum flow rate during the green time. It was measured after 10 to 14 seconds of the beginning of the green light, which corresponded to the passage of the front axle of the 4th to 6th vehicle after the green began. The average control delay

| Institute                          | Year | 1999 | 2009 | 2019 |
|-----------------------------------|------|------|------|------|
| University of Baghdad             | Staff| 3522 | 5461 | 6530 |
|                                   | Students| 13,591| 17,583| 19,866|
| Ministry of Science and Technology| Not established| 7344 | 9200 |
time per vehicle using the observed intersection was calculated according to the following equation, as stated by the (Highway Capacity Manual, 2000):

\[ d = d_1(PF) + d_2 + d_3 \]

where:

- \( d \): average control delay per vehicle (s/veh),
- \( d_1 \): uniform delay assuming uniform arrivals (s/veh),
- \( PF \): delay progression adjustment factor,
- \( d_2 \): incremental delay (s/veh),
- \( d_3 \): initial queue delay (s/veh).

The calculation of \( d_1 \), \( d_2 \), and \( d_3 \) are dependent on different intersection factors such as: the cycle time, effective green time, saturation flow, and lane group capacity.

LOS parameter was then calculated based on the criteria shown in Table 2.

Morphological changes focused on studying the historic development of four main structures: land use development, streets, plot subdivisions, and the building forms of a 1 sq./m study area within Jadriyah neighborhood. The analysis was based on cartographic techniques which were founded by M.R.G. Conzen and adopted by urban morphologists and geographers studying urban form and structures, see (Alobaydi, 2017) and (Alobaydi & Rashid, 2017). Studying morphological changes influenced by socioeconomic developments were cartographically described by the four previously stated structures, including how they significantly impacted traffic volumes at the intersection based on the data analysis.

4. Results and discussion

4.1. Urban morphological influences

The main landform of Karrada District is Jadriyah neighborhood where preeminent orchid and agricultural areas have formed the dominant uses for many years. However, the development of this neighborhood has long been characterized by a slow and steady growth pattern, in which green and agricultural subdivisions were transformed to residential use. However, in the last

| LOS | Control Delay (s/veh) |
|-----|-----------------------|
| A   | ≤ 10                  |
| B   | 10–20                 |
| C   | 20–35                 |
| D   | 35–55                 |
| E   | 55–80                 |
| F   | >80                   |
decade, and due to the investment opportunities gained by the Municipality of Baghdad, commercial and mixed-use activities have been increasingly taken place in Jadriyah and so many green areas have been turned into built up areas. The four main urban form structures—land use, streets, plots, and the buildings of the intersection—have changed dramatically from 1999 to 2009 up to 2019, as shown in Figure 4.

These urban structures include streets that are mostly steady elements in Jadriyah neighborhood and have not changed over time. Plot subdivisions, which have generated new small land percolations, allow new opportunities for investment. In general, the shape of the plot subdivisions is often rectangle or semi-rectangle and the size is middle or large when the uses are dedicated to commercial and institutional activities, and distributed around main roads. Small plot subdivisions were often allocated to residential uses and thus formed around arterial roads to meet safety and privacy criteria. Large-size plot subdivisions included industrial activities and agricultural areas and were founded at the urban edges of districts (Alobaydi & Rashid, 2017) and (Alobaydi & Rashid, 2015). Building forms have become dense when open spaces, gardens, courts, and courtyards, inside urban clusters have been turned into built up areas. Changes have been concentrated in the northwest and northeast sides of the intersection. Land use development processes at the urban core of Baghdad are organized and managed by the Municipality of Baghdad in collaboration with other local municipalities. Changing land use was granted through a difficult bureaucratic process.
during the 1990s and was always based on the master-plan. However, some urban violations or unplanned developments occurred in a limited manner.

After 2003, that process of change witnessed a lack of control and has since relied on the developers’ agenda. Many land use changes were conducted by the interventions of a pressure group, the special elite, and elected officials that influenced the regulations and norms of the planning process and policy-making (Alobaydi, 2017). Land uses in Jadriyah have transformed from clusters of residential activities into commercial and institutional uses, in particular in the northwest, northeast, and southeast sides of the intersection (Alobaydi & Rashid, 2017). In addition to that change, many green areas dedicated to residential clusters were turned into residential areas and filled by building forms. Building forms thus have become dense.

Change in these urban structures, in particular involving land use, has impacted the number of generated trips; the increased number of trips during the examined decades was shown in Figure 5. For more clarification, Figure 6 demonstrates the total resulting number of trips generated by each land use activity during the growth processes.

It can be noted that the institutional land use, located on the southwest side, has the most generated trips per day and the rate of increase from 1999 to 2009 was 194 trips/day per year, and for 2009 to 2019 was 122 trips/day per year. It was expected that this rate would be higher for the period 1999–2009 because of the establishment of the Ministry of Science and Technology. The rate of increase for commercial land use was higher for 2009–2019 because of the change to commercial activities, which started in the last decade, see Figure 4. To a lesser extent, the effect of mixed-use activities in the total generated trips was 63 trips/day compared to the base year in 1999 which was null.

4.2. Intersection performance
The LOS method was applied to examine the three historical phases, 1999, 2009, and 2019, to measure the change in intersection performance. The change in volume (veh/hr) was measured and Figure 7 shows a significant increase in the number of vehicles from the four vicinity areas of the intersection. It could be seen that, in 1999, there was no big difference in the volumes between EB and WB, which are both three-lane arterial roads, whereas this started to increase significantly in 2009 and 2019. The rate of increase in traffic volume from 1999 to 2009 and from 2009 to 2019 for the EB was 155 and 125 veh/hr per year, respectively. The south vicinity area also revealed a greater volume and rate of change for the same periods, which were 60 and 30 veh/hr per year, respectively. The reason behind the high difference found between 1999 and 2009 was the large number of vehicles after 2003 due to improvements in the annual income per capita. The NB showed very little rate increase due to the closure of the end of the road.

The number of pedestrians increased reaching a maximum of 1261 ped/hr in 2019 crossing the EB and heading to the UB; in comparison, it was 631 in 2009 and 286 in 1999, as shown in Figure 8. This increase originated from the change in building the Research Center of the Ministry of Science and Technology after 2003. Furthermore, there was a clear increase in the number of users at the UB, which resulted from the addition of several new colleges to the UB campus (Al-Mosawe et al., 2018). The EB and WB showed higher numbers of pedestrian due to the existence of a main public transport stop (see Figure 1).

The field saturation flow was measured, and Figure 9 showed a dramatic drop in the values during the three examined decades. This figure displayed close values for the saturation flow for the WB and EB during these decades. The rate of decrease between 1999 and 2009 and 2009–2019 were 12 and 21 veh/hr per year for EB and 14.5 and 16 veh/hr per year for the WB, respectively. This is mainly due to the large number of pedestrians crossing the intersection and
due to the increase in traffic volume and bus stop maneuvers for loading and unloading in the
downstream and upstream intersection vicinities

Thus, the delay was influenced by changes that occurred in the intersection during two decades. Figure 10 shows how the vehicle delay changed throughout that period. It could be noted that the
WB had the maximum delay time during the whole period. The reason was due to the public transport stops, which resulted in the semi-closure of the right lane. The NB had a little delay time, which changed over time because of the closure of the road end. As a result, it was noted that the performance of the intersection, which was represented by the LOS, was recorded as F in 2009 and 2019 but as D in 1999, as shown in Figure 11.

Results of the current study combined two sets of data derived from the field of urban design and transportation engineering; this included urban morphological developments and traffic facts and statistics. By using morphology measures and GIS technology, these results were different from the study by (Yue et al., 2020), which only used transportation engineering models, and from Rashid's research that focused on the evolution of urban form structures (streets, land use, and plots). The interpretation could, therefore, cover various topics and issues within the two aforementioned and interrelated data sets. For example, urban densification and land use development (from residential to commercial) around the Jadriyah intersection involved the generation of new car trips, traffic saturation, and delays. However, the new generated trips have raised the land value in Jadriyah neighbourhood and turned many residential and green areas into commercial and institutional uses.
5. Conclusions
This paper adopted an evidence-based approach to consider the possibility of cause and effect relationships and interdependencies between morphological changes over time in the city and variations in the traffic volumes of road intersections. Many previous scientific efforts that studied the influence of urbanization on intersection performance only relied on traditional measures like LOS; therefore, they fall short of achieving their targets due to the exclusion of road intersections, in which urban morphological changes shape and influence the flow of pedestrians/vehicles. The influential role of land uses, buildings, and plot subdivisions on road intersection performances within an urbanized area had implications for the quality of urban life. One of the most important changes in the urban life of Jadriyah district was the huge delay in traffic flow during the working week, yet daily traffic noise and visual urban pollution have become inherent characteristics of the area.

The important findings of this research can be summarized as follows: firstly, the study has shown how the distribution of land use has oftentimes inconsistently changed in relation to the current approved master plan throughout the three historical phases (1999, 2009, and 2019).
Commercial uses have increased in the vicinity areas of the intersection as well as the institutional uses. Secondly, changes to the socioeconomic values have caused an increase in the generated trips per day. This number reached to 4300 veh/day in 2019 but was around 1260 veh/day in 1999; this comes from institutional uses located on the southwest side of the Jadriyah intersection. In the same manner, the change in commercial buildings has increased in number from 41 to 1488 veh/day. Moreover, another impact of urban morphological change was the volume of vehicles, which increased from 2851 veh/hr to 9217 veh/hr, and measured the four vicinity areas of the intersection. Likewise, the number of pedestrians also increased from 614 to 3028 ped/hr. Finally, these changes increased the controlled delay time per vehicle from 36 sec/veh in 1999, to 184 sec/veh in 2009, up to 432 sec/veh in 2019. The increased delays within the Jadriyah intersection led to a failure in the LOS measure that dropped from class D in 1999 to F in 2019.

Results raise attention that the unplanned developments of urban form impacted the traffic generation, saturation, and delay problems at the intersection and influenced the traffic volume, not only at the Jadriyah Intersection but also across the whole Karrada District.
The study has shown that intersection performance, pedestrian/vehicle conflict, daily generated trips and traffic volume can mainly be explained and described by understanding the morphology of changes to the urban form. Such changes for similar road intersections in urban areas can be controlled by the pre-actions of urban design and planning regulations and practices, which are developed by the city council. By adopting these pre-actions, changes to the neighbouring intersection land use will not fundamentally impact the performance of intersections in the future.

Further research could focus on those road intersections where conflicts among various road users (pedestrians, cyclists, transit vehicles, and private vehicles) are expected.

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