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EVALUATION OF PEDESTRIAN-VEHICLE INTERACTION ON URBAN STREETS: KUFA-NAJAF STREET

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Abstract

Interactions of pedestrians with traffic are a significant consideration in highway planning and design. Pedestrians are part of every roadway environment, and their presence should be considered in rural and urban areas. This interaction is of great interest to those seeking to achieve roadway functionality and improve safety. The main aim of this study is to determine the level of interaction between pedestrians and vehicles along Kufa-Najaf Street in Al-Najaf City. The study areas are selected at eight locations along a designated road. Video camera recordings have been used to investigate pedestrian characteristics by selecting optimal vantage points along the street. Traffic and pedestrian flows during peak hours have been collected at all selected sites in both directions. Both pedestrian crossing and walking along the street have also been investigated. The results indicate a high interaction between pedestrians and vehicles within a very high level of side friction (SF) in site No. 1, a high level of SF in sites NO. 1 and 2, and a median level of SF in the rest of the sites. Also, there is less attention to pedestrian facilities, which forces pedestrians to walk in the road, share the right-of-way with vehicles, and cross randomly wherever they find a suitable spot. This study also recommends using either a pedestrian bridge or a pedestrian tunnel along Kufa-Najaf Street, given its smooth flow and high speed. The sidewalk design should be improved with an appropriate width, a smooth, stable, and slip-resistant surface, and a separation between pedestrian and vehicular traffic. The study also emphasises a better understanding of the factors contributing to pedestrian deaths, which can lead to safer streets.

Keywords: Pedestrians, Pedestrian facilities, Pedestrian-vehicle interaction, Side friction, Urban area.

1. Introduction

Everyone has different preferences regarding transportation, but one thing common to all road users is that they are pedestrians at some stage of the trip chain [1]. Crossing or strolling along roadways is a small part of overall pedestrian walking, but it poses the greatest risk due to interactions with vehicles. Pedestrians are often considered dangerous road users, and the probability of pedestrian-vehicle collisions increases when pedestrians are distracted at roadway crossings [2]. Pedestrian safety is challenging because infrastructure is often designed for motor vehicles, with little attention paid to pedestrians, particularly in non-built-up areas [3].

Roads remain unsafe for pedestrians worldwide. Globally, pedestrian deaths have risen at nearly twice the rate of road crash deaths (12.9% increase from 2013 to 2016, compared with 6.6% increase for other road users), and, per kilometre travelled, pedestrians are nine times more at risk of death than car occupants. Based on estimated global road traffic fatalities, around 310 500 pedestrians were killed in road traffic crashes in 2016, representing around 23% of all road traffic deaths, as indicated in Fig. 1. There is a clear geographic distribution of pedestrian mortality, with the proportion of pedestrians killed in the South-East Asia Region (14%) [4]. Recent research has applied simulation and data-driven methods to better represent pedestrian–vehicle interactions and to explain crash severity, particularly at unsignalized and signalized crossings [5-10].

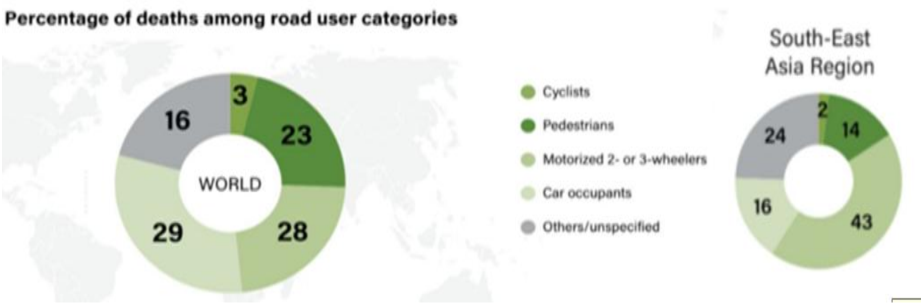

Fig. 1. Road traffic deaths by type of road user [11].

In Iraq, the frequency and severity of road accidents are a significant problem. According to the Central Statistical Organization (CSO) [12], the number of traffic accidents recorded for the year 2023 amounted to about 11,552 accidents, of which 3,262 were fatal accidents (28.2%) and non-fatal 8,290 accidents (71.8%), for all governorates except the Kurdistan Region, compared to 11,523 accidents in 2022, an increase of (0.3%). Collision accidents recorded the highest percentage during the year 2023, reaching (6519) accidents, representing 56.4% of the total number of accidents, which amounted to 11,552 accidents, followed by run-over accidents, amounting to (3912) accidents, representing (33.9%), then rollover accidents, amounting to (926) accidents, representing (8%), while other accidents amounted to (195) accidents, representing 1.7%. Al-Jameel et al. [13] found that Al-Najaf City is the second-largest city in Iraq in terms of the number of accidents, with about 1050 in 2017. Figure 2 shows all types of accidents. It shows that pedestrian collision accidents have increased rapidly over the years due to several safety shortcomings, including the absence of suitable crosswalks, footbridges/tunnels, and pedestrian traffic signals. However, the recorded number of accidents is lower than the actual number because most minor accidents are not documented [13].

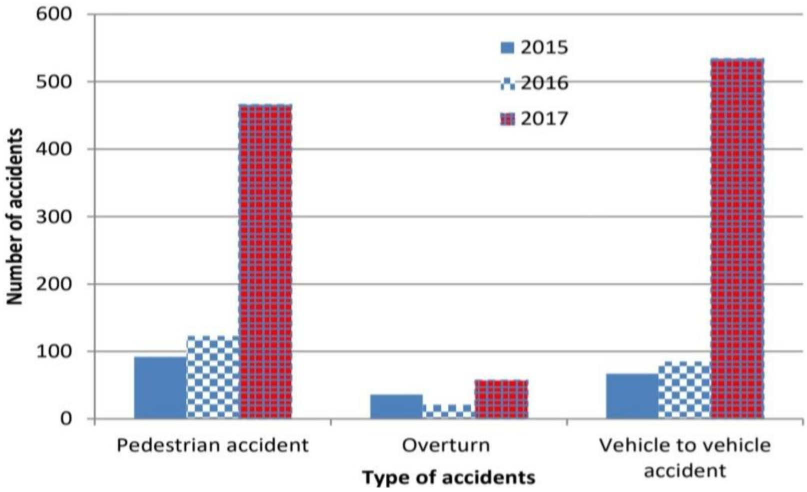

Fig. 2. Different types of accidents in Al-Najaf city [13].

Research on pedestrian crossing behaviour is an essential component of safety planning and traffic engineering. Traffic engineers are responsible for providing safe traffic arrangements for all road users and ensuring their safety. Hence, the objective of the current research is to measure pedestrian (crossing and walking-along), and vehicle flows at eight midblock sites on Kufa–Najaf Street using videographic data, classify pedestrian side-friction levels (IHCM), and identify priority locations and suitable pedestrian facilities/improvements.

2. Pedestrian as a Side Friction

Many variables affect traffic performance, including road surface, shoulder width, highway width, driver skill, side friction (SF) or side activities, terrain, and road infrastructure. In developing countries such as India, side friction significantly influences road traffic performance [14]. SF factors are defined as anything occurring on the sides of a carriageway, or even on the carriageway itself, that is likely to disrupt the usual traffic flow. In general, SFs may take various shapes, including buses at bus stops, pedestrian crossing at random, on-street parking, entry and departure from approach roads, slow-moving vehicles, and others. They impact traffic flow characteristics, restrict road capacity, and are inconvenient for commuters and other road users [15].

Based on the Indonesian Highway Capacity Manual (IHCM) [16], SF levels have been classified from extremely high to exceptionally low. The IHCM specifies the road SF elements that must be incorporated during flow and capacity calculations. The SF was divided into five categories based on the fluctuation in the speed data. Side friction does not impact the vehicles' average speed at this exceptionally low level. The percentage decrease in average speed is substantial at extremely high side friction levels. Classification of side friction levels is based on IHCM [16], as indicated in Table 1.

Table 1. SF classes [16].

SF Levels	SF events/hr	Land-use conditions
Very low	0-100	Residential location, no activities
Low	100-300	Residential location, in forms of public transportation, etc.
Medium	301-500	Residential location, in forms of public transportation, etc.
High	501-900	Commercial location, very-high roadsides activities
Very high	> 900	Industrial location, many shops on the roadsides

Mansour and Al-Jameel [17] examined the impact of SF variables on traffic performance, including speed and capacity. Four links, divided and undivided streets in Al-Najaf City, were selected. On-street parking, pedestrian activities, entry-exit manoeuvres, and temporary parking vehicles are considered side friction elements. The results show about 47% reduction in speed and 49% reduction in capacity at an extremely high side-friction level, as shown in Tables 2 and 3.

Table 2. Speed reduction at different side friction levels [17].

Section	Average Speed (km/hr)				Speed Reduction				ANOVA Test	
	Low Side Friction	**Medium Side Friction**	**High Side Friction**	**Very High Side Friction**	**Low**	**Medium**	**High**	**Very High**	**Significance Level: 0.05**	**Impact**
					Undivided Street					
I	67	50	38	-	-	24%	44%	-	0.000	Significant
II	83	64	49	44	-	23%	40%	47%	0.000	Significant
					Divided					
III	47	36	-	-	-	23%	-	-	0.000	Significant
IV	45	32	-	-	-	28%	-	-	0.000	Significant

The effect of SF elements on the stream of traffic varies depending on their location on the road (either on the side or in the centre) [18] and the dimensions of the physical element. Pedestrians are often seen as one of the sources of traffic congestion due to their illegal road occupancy [19]. Sadeq and Al-Jameel [20] noted that high pedestrian interaction with the vehicular stream in Al-Najaf city reduced the performance of this urban road network. Compared to vehicular movements, pedestrians continuously interact with one another and their surrounding environment, constantly changing their characteristics and direction, as illustrated in Fig. 3 [21].

Table 3. Capacity reduction with different side friction levels [17].

Secti	Clas	Type	Side Friction Level	SF Events/hr	Observed capacity pcu/hr	Standard capacity pcu/hr	Reduction
I	II	Undivided	High	500-1000	1689	2500	32
II	I	Undivided	Very High	>1000	2137	4200	49
III	II	divided	Medium	200-500	2191	2500	13
IV	III	divided	Medium	200-500	1972	2500	21

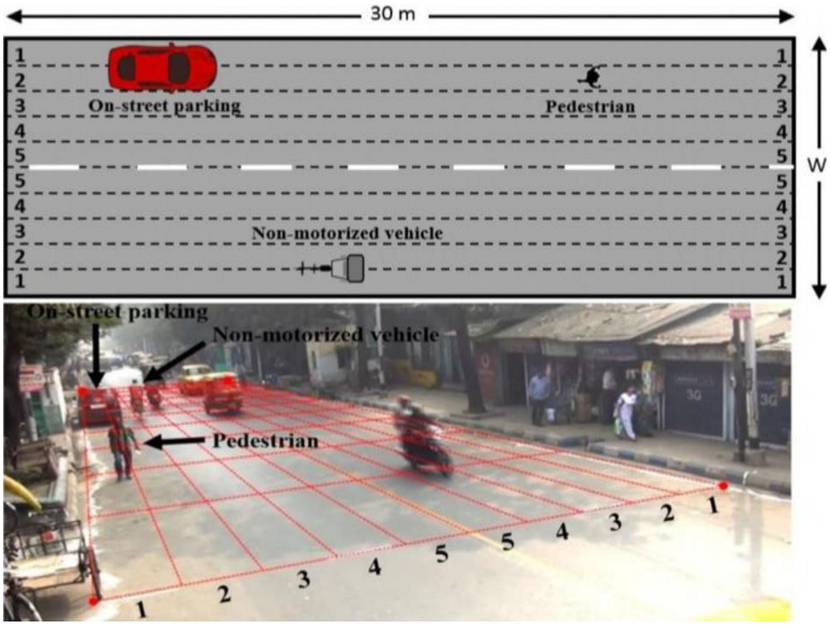

Fig. 3. Side friction data on the carriageway [21].

3. Methodology

3.1. Survey area

Najaf is one of Iraq's most prominent cities, located southwest of the capital, Baghdad. This city has a religious, cultural, historical, and manufacturing background, represents different population groups, and has several business and trading districts. Kufa-Najaf Street was chosen as a case study; this road is classified as an arterial road (Class I).

In the second step, the volumes of pedestrians and vehicles traversing the study locations were counted manually from field-recorded videos. Then, all data were aggregated to determine the hourly flow rates for both vehicles and pedestrians.

3.2. Data collection

A videographic survey was conducted at each selected location for 2 hours during peak periods. All required data, including traffic and geometric data, were collected at the selected road locations on typical weekdays under excellent, precise weather conditions. Geometrical data include physical features in the roads, such as roadway width, median width, sidewalk width, pedestrian facilities, and the number of lanes in each direction. For all sites, the number of lanes in each direction is three with a divided median, and the width of each direction is 12 m. Table 4. Illustrates the geometrical details of the study area.

Traffic data were collected at mid-block urban road segments in the study area. At all selected sections, vehicle- and pedestrian-related data were manually counted from recorded field videos at 5-minute intervals. Vehicles passing an imaginary line were counted, and all data were aggregated to determine hourly traffic and pedestrian volumes.

Table 4. Road network's geometric details.

Site No.	Study Location	Section length (m)	Median width (m)	Sidewalk width (Kufa dir.)	Sidewalk width (Najaf dir.)	Type of crossing facility
1	Under the bridges of the twentieth revolution	200	18	2	3	No
2	Opposite Najaf Court	200	2.5	3	2.8	Foot bridge
3	Facing the Najaf Education Directorate	200	6.3	2.4	(2.2-4)	Foot bridge
4	Opposite the College of Basic Education	200	6.3	20	2.43	Cross walk
5	Opposite the University of Kufa	200	6.3	3	3.2	No
6	Facing Khawkha Restaurant	200	6.2	8	7	No
7	Opposite Kufa Court)	200	6.2	5	5.6	No
8	Facing Kufa Market	200	No	3	3	Cross walk

3.3. Selected sites

Eight different midblock locations on selected roads were chosen to understand the pedestrian characteristics under the bridges of Thawrate Al-Eishrin, opposite Najaf Court, opposite Najaf Education Directorate, opposite Faculty of Basic Education, opposite University of Kufa, opposite Khawkha Restaurant, opposite Kufa Court, and opposite Kufa market, as shown in Fig. 4.

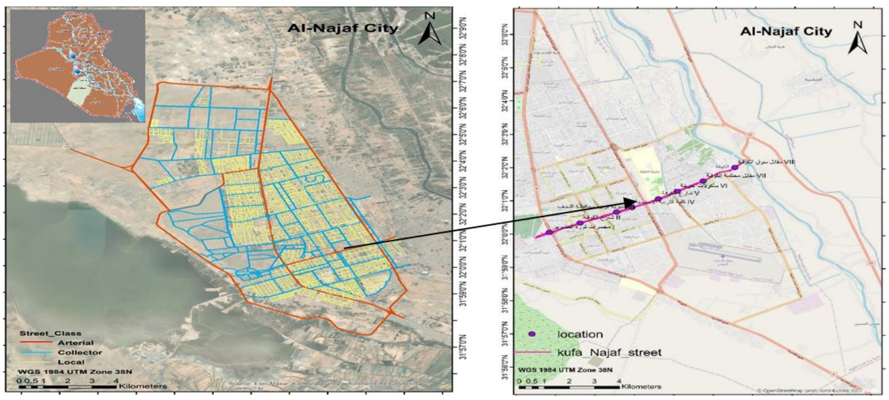

Fig. 4. The study area was selected within Al-Najaf city.

3.3.1. Site no. 1 Kufa- Najaf Street

This site, located under the bridges of Thawrate Al-Eishrin, is considered the city centre of Najaf and the starting point of Kufa-Najaf Street, where pedestrian traffic is substantial, as shown in Fig. 5. The orange line indicates the direction of vehicle movement from Kufa to Najaf, while the blue line indicates the opposite direction. The grey line indicates the number of pedestrians randomly crossing the street. At the same time, the red line indicates pedestrians walking along the road course due to the lack of suitable sidewalks. It was found that the friction between pedestrians and traffic flows was extremely high in Site No. 1, where the number of pedestrians exceeded the number of vehicles present, and the number of pedestrians crossing the street during the morning peak hours reached 3124 ped/hr. Figure 6 shows some of the flow conditions observed under study.

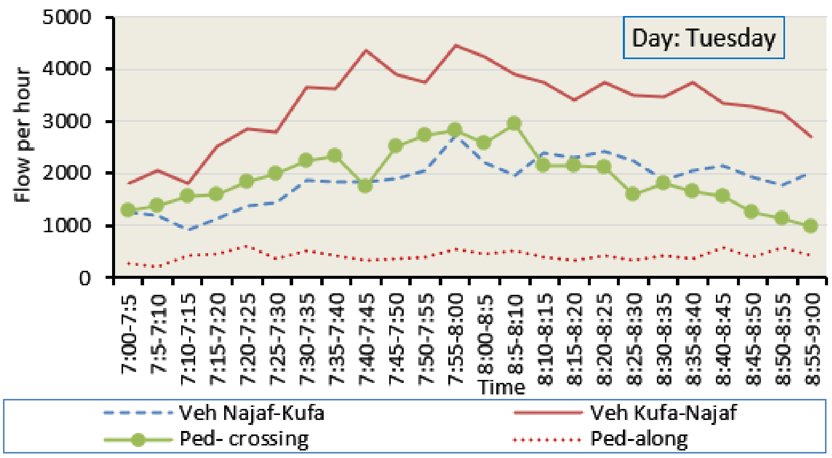

Fig. 5. Pedestrians and vehicles flow in site no. 1.

Fig. 6. Pedestrian flow conditions observed under study in site no.1.

3.3.2. Site no. 2, Kufa-Najaf Street

The second, located opposite Najaf Court, location is opposite the Najaf Court, where many government institutions and educational centres are represented by Al-Hakim Hospital, the Najaf Court, Al-Farahidi School, commercial centres for selling furniture, and residential areas.

A field survey was conducted, and data were collected for two hours on Monday during peak hours, considering that peak hour was between 7 and 9 am. This location has a pedestrian bridge (FB1) and an iron fence extending 500 meters to prevent pedestrians from crossing the road. Figure 7 shows the vehicle flow rate in both directions, along with the number of pedestrians who used FB1 and those who crossed the road at random. Figure 8 displays some of the observed flow conditions under study.

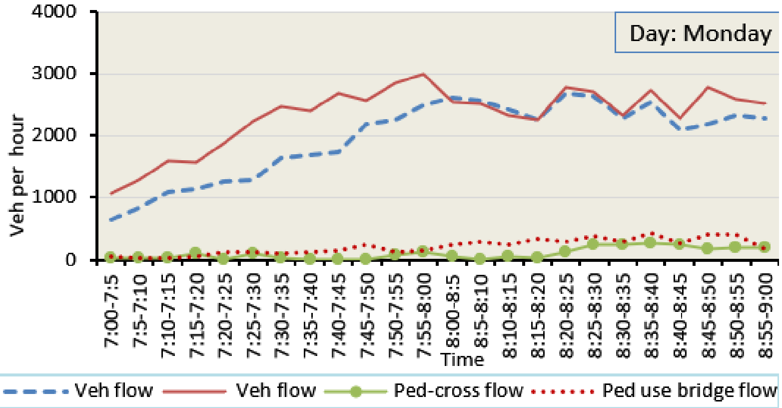

Fig. 7. Pedestrians and vehicles flow in site no. 2.

Fig. 8. Pedestrian flow conditions observed under study in site no. 2.

3.3.3. Site no. 3, Kufa-Najaf Street

The third location is opposite the Najaf Education Directorate. This location contains many government institutions that are frequented by many employees, visitors, and students. Pedestrian movement is active on the road and its sides, with 704 ped/hr pedestrians crossing the road during peak morning hours. Figure 9 shows the high traffic flow at this location on the road, the number of pedestrians who use the bridge, and the number of pedestrians crossing the road. Although there is a pedestrian bridge, most pedestrians do not use it. In addition, the sidewalk discourages walking, as it is used for lampposts, billboards, government filters, waste containers, etc., as shown in Fig. 10.

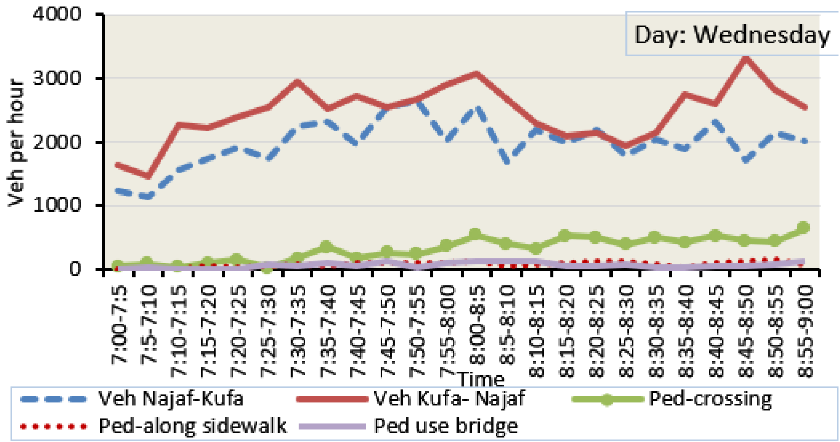

Fig. 9. Pedestrians and vehicles flow in site no. 3.

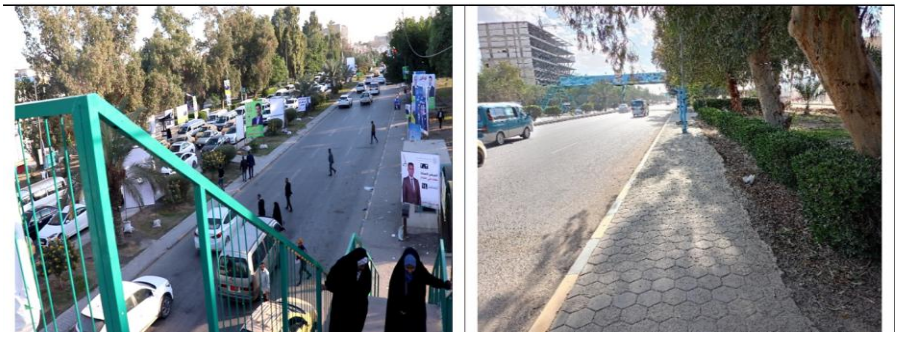

Fig. 10. Pedestrian flow conditions observed under study in site no. 3.

3.3.4. Site no. 4 Najaf-Kufa Street

The fourth location is located opposite the College of Basic Education. There are many educational centres in this location, such as the College of Basic Education, Al-Alamein Institute, Jaber Bin Hayyan University of Medical Sciences, and Al-Mamil School, in addition to several streets overlooking the main street.

There is a pedestrian crossing with a traffic police officer to ensure safety. However, this crossing creates long queues due to the high traffic flow on this road. As shown in Fig. 11, high traffic flow occurs, with the number of vehicles during morning peak hours reaching 3600 veh/hr, while pedestrian crossing rate reaches 972 ped/hr. Figure 12 shows the interaction between people and vehicles at the field site.

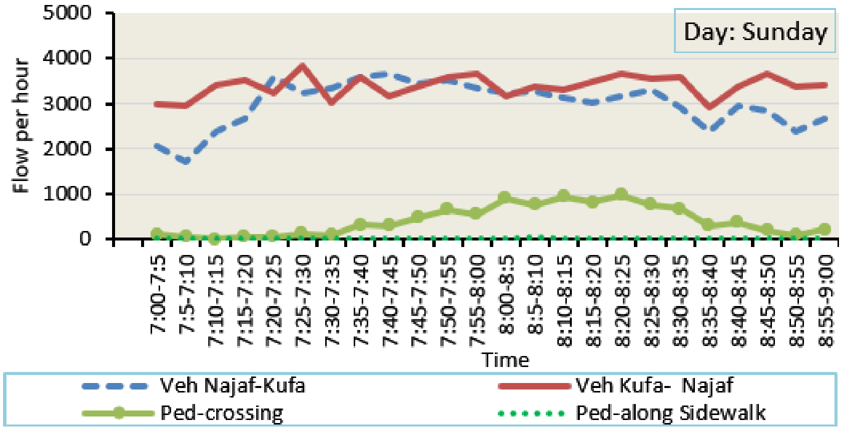

Fig. 11. Pedestrians and vehicles flow in site no. 4.

Fig. 12. Pedestrian flow conditions observed under study in site no. 4.

3.3.5. Site no. 5 Najaf-Kufa Street

This site, opposite the University of Kufa, is located between an educational centre represented by the University of Kufa, which includes more than 18 colleges and where more than 30,000 male and female students' study, according to site data and the website of the statistics system affiliated with the University of Kufa, and a commercial centre represented in the industrial zone, as shown in Fig. 13.

Pedestrian traffic is active at this location, and traffic congestion and pedestrian interactions increase because pedestrians cross the street at random, as there is no pedestrian facility opposite the university. This interaction increases during the morning hours from 7:00 to 9:00 am, with vehicle volume reaching 4464 veh/hr and pedestrian crossing volume reaching 1572 ped/hr. Figure 14 shows some of the flow conditions observed under study.

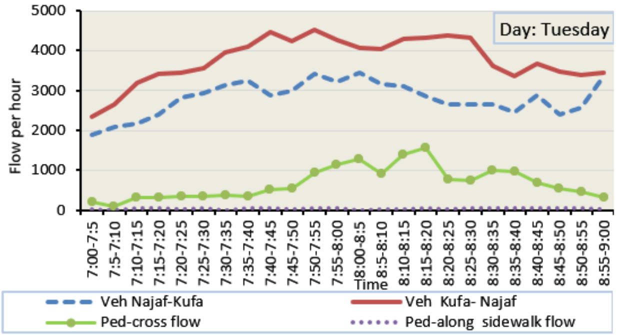

Fig. 13. Pedestrians and vehicles flow in site no. 5.

Fig. 14. Pedestrian flow conditions observed under study in site no. 5.

3.3.6. Site no. 6, Kufa-Najaf Street

This site, opposite Khawkha Restaurant, is characterised by commercial, economic, and shopping activities, as well as many restaurants, cafes, shopping centres, and others, which mainly increase traffic demand and affect traffic flow, as pedestrian traffic is active in the evening. The data were collected in this section of the road in the evening peak period from five to seven PM. Figure 15 shows that the number of vehicles during the evening peak period reaches 2,352 veh/hr, and the number of pedestrians crossing the road reaches 720 ped/hr. It is worth noting that this section of the road has beautiful, illuminated central islands and paved side sidewalks, but most restaurant and commercial mall owners encroach on the sidewalks. This forces pedestrians to use the road lanes to walk. Whereas Fig. 16 represents the actual reality of the site.

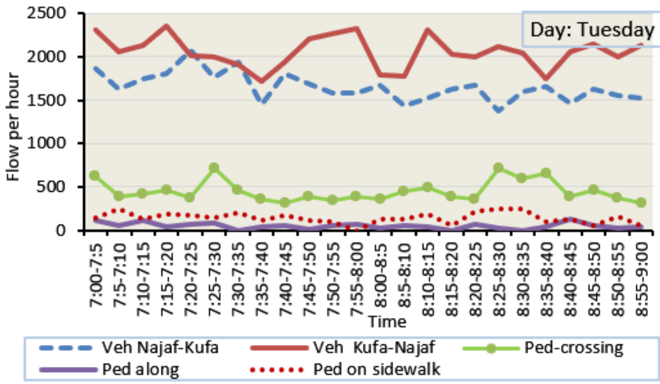

Fig. 15. Pedestrians and vehicles flow in site no. 6.

Fig. 16. Pedestrian flow conditions observed under study in site no. 6.

3.3.7. Site no. 7 Najaf-Kufa Street

This site, located opposite Kufa Court, is characterised by high commercial activity and the presence of vital government institutions, such as the Kufa, as well as an essential religious centre (the Maitham Al-Tamar shrine), an educational centre such as Al-Kafeel College, Al-Tamar School, and Al-Rahman School, all directly overlooking the street. In addition to many commercial activities, such as shops and pharmacies, this increases pedestrian activity in this location. The survey was conducted on Tuesday during the morning peak hours, where it was observed that there was a large number of pedestrians randomly crossing the road due to the lack of special facilities for pedestrian crossing, in addition to high pedestrian activity on both sides of the road (sidewalk), as shown in Figs. 17 and 18.

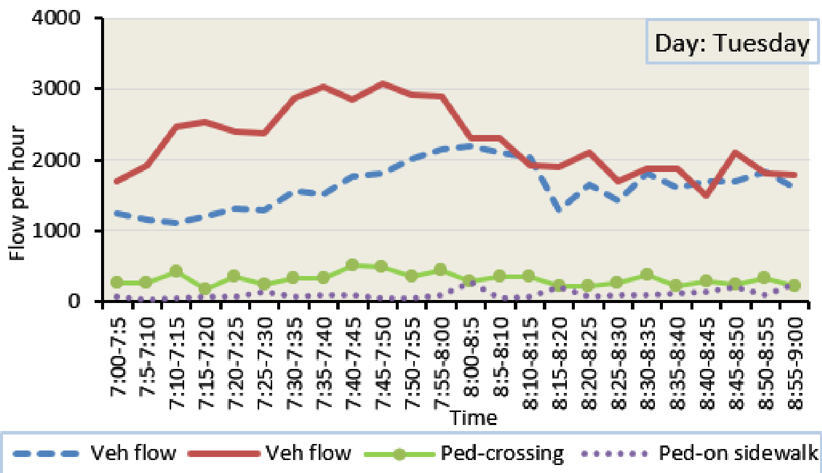

Fig. 17. Pedestrians and vehicles flow in site no. 7.

Fig. 18. Pedestrian flow conditions observed under study in site no. 7.

3.3.8. Site no. 8 Kufa-Najaf Street

This site, facing Kufa Market, is characterised by high shopping and commercial activity, educational centres, important government departments, and a concentration of public transport stops.

Another location is crowded with traffic of up to 3,000 ve/hr in each direction and has a high density of pedestrians, as shown in Fig. 19. In this location, pedestrian movement on the sidewalk is obstructed by shop owners, hawkers, and vehicle owners who use the sidewalk as a parking lot for cars and vehicles. In addition, they need to be addressed regarding cleanliness and arrangement, forcing pedestrians to use the road lanes for walking. In addition, there is a pedestrian crossing, but it needs to be equipped with signals or controls, and pedestrians do not care to cross through it. Figure 20 shows some flow conditions observed under study.

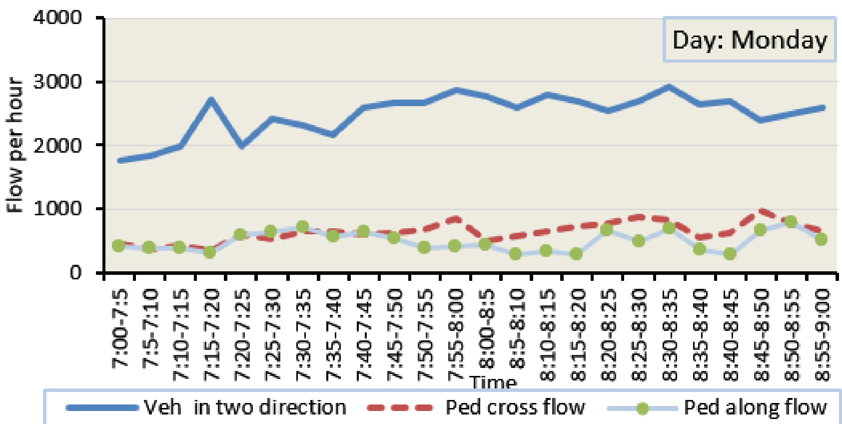

Fig. 19. Pedestrians and vehicles flow in site no. 8.

Fig. 20. Pedestrian flow conditions observed under study in site no. 8

4. Results and Discussion

4.1. Pedestrian-vehicle interaction

Field data recorded by a video camera at various locations along an area with a 200-meter border. Figure 21 indicates that Site 1 has the highest crosswalk interaction for all sites, while Site 2 has the lowest. The presence of a pedestrian bridge and an iron fence in the middle median at Site 2 forced the largest number of pedestrians to use it. It helped reduce interaction between vehicles and pedestrian traffic on this section of the road. In contrast to Site 3, although there is a pedestrian bridge, only some people use it, preferring to risk crossing the street. At site 8, pedestrian movement on the sidewalk is obstructed by shop owners, hawkers, and vehicle owners who use the sidewalk as a parking lot. Therefore, pedestrians walking in the road, with a flow of 720 pedestrians/hr. In addition, the sidewalks need more maintenance and cleaning, forcing pedestrians to use the road lanes. The same applies to Site 1, where the lack of pedestrian infrastructure along and across the street (paving, proper markings, refuge islands, pedestrian crossings) resulted in pedestrians walking inside the road and crossing randomly, ultimately leading to interaction between pedestrians and vehicular traffic. In the two locations, 7 and 4, the presence of broad, neat, and clean sidewalks helped people walking along the road use them and prevented them from encroaching into the road lanes. Site No. 4 and Site No. 8 have a pedestrian crosswalk. However, the current crossing area must be equipped with traffic signals and well-marked, as most pedestrians cross randomly from wherever they see fit without using the crossing area.

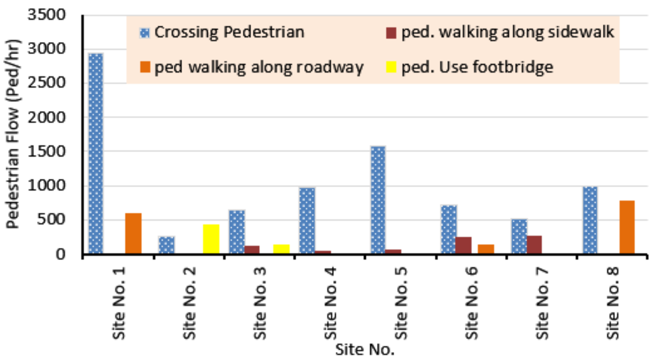

Fig. 21. The maximum flow rate of pedestrians for all sites.

4.2. Pedestrian as a side friction

The study monitored the lateral friction between pedestrians and vehicle traffic at eight locations on Kufa-Najaf Street in the city of Najaf and compared it with a classification of lateral friction levels based on the IHCM (1997). The result was a high level of SF across different locations on Kufa-Najaf Street, as shown in Table 5. There is also a need for more organized pedestrian walkways along the street. Based on the analysis, the total pedestrian flow under the bridges of the Twentieth Revolution reaches 3,456 peds per hour, while the fifth and eighth sections reach 1608 and 1644, respectively.

In the first section, based on previous studies, the speed will decrease by 47% at a very high SF level, while in the fifth and eighth sections, at a high SF level, the decrease is 44%. On the other hand, at a medium level of SF in Sections 2, 3, 4, 6, and 7, the reduction reaches 28%. Although the last sections are at the same level as SF, the reduction in section four is higher than in section three. This may be due to differences in the street's speed and carrying capacity from one section to another.

Table 5. Level of SF.

Site No.	Segment Length(m)	Max. pedestrian crossing (ped/hr.)	Level of side friction
I	200	3124	Very high
II	200	564	Medium
III	200	704	Medium
IV	200	900	Medium
V	200	1208	High
VI	200	752	Medium
VII	200	484	Medium
VIII	200	1456	High

5. Conclusions

This study investigated pedestrian side friction at eight urban sites in Iraq, focusing on two dominant components: crossing-related interactions and walking along the street, and examined their influence on traffic performance indicators. Based on field observations and comparative site analysis, the main findings can be summarised as follows:

- The eight sites have two types of pedestrian-side friction: crossing and walking along the streets. Site 1 has the highest crosswalk interaction, while Site 2 has the lowest level of side friction. Other sites represent the moderate effect of the level of side friction.
- Sites No. 1, 5, and 8 have the highest crossing interactions between pedestrians and vehicles, which are 3124 ped/hr, 1456 ped/hr, and 1208, respectively.
- Compared to the average street crossing of 11 m, the typical pedestrian bridge spans 103 m because ramps or stairways are needed to elevate it above street level. These bridges are built with steep stairs or steep sloped ramps, which are particularly challenging for people with disabilities, children, older adults, and anyone carrying goods.
- Suggestion of erecting a fence in the middle median, or by placing a fence on both sides of the road of sufficient length (approximately 500 meters), which

might prevent pedestrians from crossing the highway at any point and widen the pedestrian path to use crossings.

This study recommends either a footbridge or a tunnel for pedestrians along Kufa-Najaf Street due to high traffic volume and speeds. In addition, road safety education programs are recommended in schools (especially primary schools) with a fixed grade level.

Nomenclature

FB	Footbridge/pedestrian bridge
IHCM	Indonesian Highway Capacity Manual
LOS	Level of Service
Midblock	Road segment between intersections
pcu/h	Passenger car units per hour
ped/h	Pedestrians per hour
PV	Pedestrian–vehicle (interaction)
SF	Side friction
V/C	Volume-to-capacity ratio
veh/h	Vehicles per hour

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