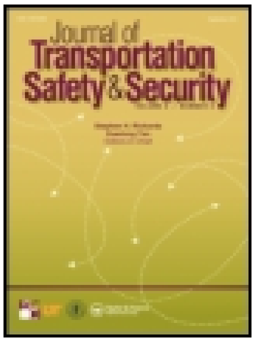

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Journal of Transportation Safety & Security

ISSN: 1943-9962 (Print) 1943-9970 (Online) Journal homepage: https://www.tandfonline.com/loi/utss20

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To cite this article: Khaled Shaaban, Deepti Muley & Abdulla Mohammed (2019): Modeling pedestrian gap acceptance behavior at a six-lane urban road, Journal of Transportation Safety & Security, DOI: 10.1080/19439962.2019.1691100

To link to this article: https://doi.org/10.1080/19439962.2019.1691100

Published online: 27 Nov 2019.

JOURNAL OF TRANSPORTATION SAFETY & SECURITY
https://doi.org/10.1080/19439962.2019.1691100

Modeling pedestrian gap acceptance behavior at a six-lane urban road

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ABSTRACT

The illegal crossing behavior of pedestrians at unmarked mid-block sections is unsafe, risky, and increase the potential of severe conflicts and crashes, especially in the case of multilane roads. This paper investigates the pedestrians' gap acceptance while crossing the road illegally at an unmarked mid-block segment of a six-lane divided urban road. A multiple regression model was developed to estimate the size of the accepted gaps as a function of the demographics, crossing behavior, and traffic-related characteristics. The model suggested that waiting time, crossing point, rolling gap, vehicle speed, critical distance, and vehicle position have a strong influence on the size of the gap. The findings of this study can be useful for simulation modeling, enforcement efforts, and education and training programs.

KEYWORDS

Illegal crossing; unmarked crossing; pedestrian crossing; multiple regression models; jaywalking

Introduction

Pedestrians' illegal crossing is defined as crossing at a location where crossing is not allowed according to the traffic regulations. This behavior usually occurs at intersections or mid-block sections to reduce walking distance or save time (Demiroz, Onelcin, & Alver, 2015) and has a significant effect on the pedestrians' safety, especially at unprotected crosswalk locations (Zhang, Zhou, Qiu, & Liu, 2018). At these locations, pedestrians are at greater risk when they cross the road illegally particularly at multilane roads due to the much wider crossing distance and the high speed of vehicles.

The pedestrian's decision to cross the road illegally depends on many factors, including the pedestrian characteristics and the traffic flow. Generally, a pedestrian observes the approaching vehicles in the travel lanes, analyzes them, then selects a particular gap to cross. During the

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/utss.

crossing process, the gap acceptance behavior and the pedestrians' speed are important for a safe crossing and must be understood in detail. Moreover, the number of crossing lanes has a major effect on the pedestrian–vehicle conflicts. As the pedestrians cross a higher number of lanes, the number of conflicts and speeds increase accordingly. Consequently, six-lane divided roadways have more severe vehicle-pedestrian conflicts in comparison with four and two-lane roadways (Zhang, Chen, & Wei, 2019).

Furthermore, illegal pedestrian crossing situations at uncontrolled mid-block crosswalks are more hazardous in developing countries as compared to developed countries, due to the inadequacy of proper infrastructure and the aggressive driver behavior (Kadali & Vedagiri, 2016). The purpose of this study is to investigate the pedestrians' gap acceptance behavior while illegally crossing a six-lane urban road (the most critical type of facilities for pedestrians) in Doha, the capital of Qatar (a developing country in the Arabian Gulf region).

In Qatar, many pedestrians were killed in traffic crashes. Most pedestrian fatalities take place in urban areas and mid-block locations. Most of the road sections do not have marked mid-block crossings, either signalized or unsignalized. Additionally, this region has its own unique behaviors and attitudes. Many pedestrians were observed crossing illegally along long and short road sections, where marked and signalized crosswalks are available at the signalized intersections within an easily walkable distance. In general, the pedestrians' attitude, extreme weather conditions, low yielding rate of vehicles, and lack of infrastructure increase the risk of this type of behavior in Qatar.

Literature review

The factors affecting the pedestrians' decision to cross illegally have been analyzed by numerous studies and using different methods such as crash records (King, Soole, & Ghafourian, 2009; Kim, Ulfarsson, Shankar, & Kim, 2008) and field measurements (Yannis, Papadimitriou, & Theofilatos, 2013 ; Shaaban, Muley, & Mohammed, 2018; Zhao, Malenje, Tang, & Han, 2019). In general, there are many benefits of using field measurements, especially if crash data are not available, difficult to obtain, or do not have sufficient information.

From the perspective of gap acceptance behavior for pedestrians making illegal crossings, field measurements studies have focused on identifying the significant factors affecting behavior such as pedestrian attributes (gender, age, etc.), pedestrian behavioral attributes (pedestrian path, waiting time, etc.), and traffic-related attributes (vehicle speed, lane change, etc.).

The significance of many of these factors has been a debatable topic, according to previous studies. For the pedestrians' attributes, some studies showed that gender is a significant factor contributing to pedestrian behavior. Female pedestrians were found to violate traffic rules less frequently than males (Guo, Gao, Yang, & Jiang, 2011; Hamed, 2001; Rosenbloom, 2009; Rosenbloom, Nemrodov, & Barkan, 2004; Tiwari, Bangdiwala, Saraswat, & Gaurav, 2007; Tom & Granié, 2011). Other studies showed a different finding, where females were found to be less likely to comply with the traffic rules (Ren, Zhou, Wang, Zhang, & Wang, 2011).

Additionally, some studies showed that older pedestrians comply more with the traffic rules than younger pedestrians, (Granié, Pannetier, & Gueho, 2013; Ren et al., 2011; Rosenbloom et al., 2004). They also wait longer than younger pedestrians at signalized crossings (Guo et al., 2011). On the other hand, other studies indicated that older pedestrians violate more the traffic rules compared to younger pedestrians (Dommes, Cavallo, Dubuisson, Tournier, & Vienne, 2014; Dommes, Cavallo, & Oxley, 2013; Dommes & Cavallo, 2011; Holland & Hill, 2010; Oxley, Fildes, Ihsen, Charlton, & Day, 1997; Oxley, Ihsen, Fildes, Charlton, & Day, 2005). In some studies, age did not indicate any significant difference in the behavior of violating the traffic rules (Avinash, Jiten, Shriniwas, Gaurang, & Manoranjan, 2018; Rosenbloom, 2009).

For pedestrian behavioral attributes, some studies indicated that the gap size decreases as the waiting time increases (Cherry, Donlon, Yan, Moore, & Xiong, 2012; Das, Manski, & Manuszak, 2005). Other studies demonstrated that the increase in waiting time resulted in an increase in the gap size (Kadali & Vedagiri 2013a). Some studies did not indicate any significance for the waiting time (Wang, Wu, Zheng, & McDonald, 2010, Yannis et al., 2013). Several studies also suggested that the size of the accepted gap was not affected by whether a pedestrian was crossing unaccompanied or in a group (Kadali & Vedagiri 2013b, 2013c; Serag, 2014). However, other studies showed that the gap size increases with the increase in the size of the group (Sun, Ukkusuri, Benekohal, & Waller, 2002).

For traffic-related attributes, it has been reported repeatedly that the vehicles' speeds have a significant influence on the gap size. Pedestrians usually tend to accept smaller gaps in the case of higher speeds (Lobjois & Cavallo, 2007, 2009; Oxley et al., 2005).

In summary, although many studies have investigated this type of behavior, there are many outstanding issues that need to be investigated. Most of the studies investigated two or four-lane roads. Limited studies investigated this type of behavior on major urban roads with a high number of lanes and high speeds. In addition, most of the previous studies were conducted in developed countries. Limited studies were conducted in developing countries, especially the Arabian Gulf region. Countries in this region have observed a significant number of crashes in the past years, where many pedestrians lost their lives or got injured. A high percentage of these crashes involve pedestrians crossing illegally.

Moreover, several pedestrian characteristics were not studied or sufficiently addressed in previous studies, including the pedestrians' clothing, mobile phone use, carrying bags, and group size. Some of these factors may have a significant effect on the behavior of pedestrians. Therefore, the objective of this study is to investigate the gap acceptance behavior of pedestrians making illegal crossings on a six-lane mid-block section in Qatar. Furthermore, the study assesses the relationship between the accepted gap size and different attributes. Lastly, the study develops the best model to predict the accepted gap size.

Methods

Site selection

A six-lane mid-block section with a speed limit of 80 km/h was used in this study. The section is spanned 368.50 m in length between the crosswalks of two signalized intersections (390 m center to center) and is located in Doha, Qatar. The section width is 12 m in each direction with a 4.95 m raised median. Each direction has three lanes at 3.65 m each in addition to a 1.05 m verge. The site details are shown in Figure 1. Both signalized intersections are equipped with pedestrian signals where pedestrians can cross during the pedestrian walk phase.

Data collection and extraction

Data were collected using four video cameras on two typical weekdays. The view of each camera was selected to ensure an overlap between the cameras. A total of 12 consecutive hours were recorded from 6:00 a.m. to 6:00 p.m. each day. The data extraction revealed a total of 2766 observations. Only 972 observations involved a vehicle–pedestrian conflict and were included in the analysis. Different traffic and pedestrian attributes were extracted. A description of the different characteristics is given in Table 1 and Figure 2. It should be noted that the effect of the upstream and downstream traffic signals was not considered as the cameras were placed far from the junctions.

Pedestrian characteristics

The pedestrian characteristics were determined based on the physical appearance of the pedestrians. The age was determined based on the judgment of the observer according to three broad categories; elderly, middle age, and children. The clothing of the pedestrians was noted to indicate the differences in crossing behavior between locals and expatriates. In Qatar,

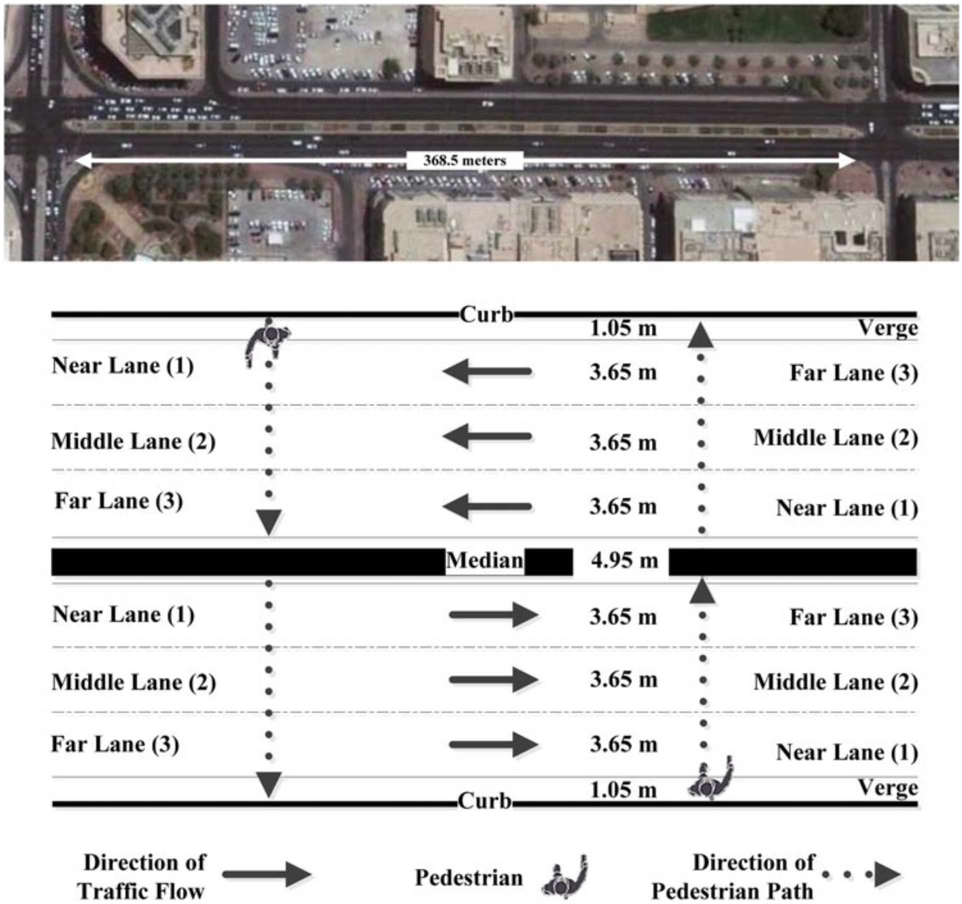

Figure 1. A Sketch of the study site. (Source Shaaban, Muley, & Mohammed, 2018).

locals wear traditional clothes while expats (people from other countries) wear normal clothing. It should be noted that Qatar is home for people from diverse nationalities from over 50 countries. To reduce bias during the data extraction process, the videos were processed by two investigators. If there was any disagreement in judgment regarding specific records, both investigators exchanged views until reaching an agreement.

Moreover, it was observed whether pedestrians are using mobile phones or carrying bags while crossing or not. Furthermore, walking in a group was observed to determine whether the pedestrian is accompanied by someone or walking alone. The group size denotes the number of people walking together. For a group of two, two separate observations were recorded. This approach was adopted because the behavior and attributes of the different pedestrians in the same group can be similar or different. In some cases, many attributes were different, including crossing speed, crossing path, running versus walking, changing speed, etc.

Table 1. Description of variables.

Category	Type	Variable	Description
Pedestrian characteristics	Categorical	Gender	0 if pedestrian is male 1 if pedestrian is female
	Categorical	Age	0 if children 1 if middle age pedestrian 2 if elderly pedestrian
	Categorical	Type of clothing	0 if pedestrian wears normal clothes 1 if pedestrian wears traditional clothes
	Categorical	Mobile phone use	0 if pedestrian does not use a mobile phone while crossing 1 if pedestrian uses a mobile phone while crossing
	Categorical	Carrying bags	0 if pedestrian does not carry bags/luggage 1 if pedestrian carries bags/luggage
	Categorical	Group size	Number of pedestrians crossing in a group (1 if the pedestrian crosses alone)
Pedestrian behavioral characteristics	Continuous	Accepted gap	Gap between two vehicles at the pedestrian crossing point in seconds
	Continuous	Critical distance	Distance of critical vehicle from pedestrian crossing line in meters
	Categorical	Crossing point	1 if pedestrian crosses from curb 0 if pedestrian crosses from median
	Continuous	Waiting time	Time waiting for a suitable gap in seconds A time of zero indicates that there is no waiting
	Categorical	Near lane	1 if pedestrian accepts gap in near lane 0 if pedestrian accepts gap in any lane other than near lane
	Continuous	Crossing time	Time is taken by a pedestrian to cross one direction of the road in seconds
	Categorical	Pedestrian path	1 if pedestrian uses oblique path for crossing 0 if pedestrian uses a perpendicular path for crossing
	Continuous	Pedestrian speed	Speed of pedestrian while crossing the road in m/s
	Categorical	Pedestrian speed change	1 if pedestrian reduces speed while crossing 0 if pedestrian does not reduce speed while crossing
	Categorical	Rolling gap	1 if pedestrian accepts a rolling gap 0 if pedestrian does not use a rolling gap
	Categorical	Running	1 if pedestrian runs while crossing the road 0 if pedestrian does not run while crossing the road
	Continuous	Number of attempts	Number of unsuccessful attempts for crossing the road
	Categorical	Gap type	0 if pedestrian accepts lag gap while crossing the road 1 if pedestrian accepts gap while crossing the road
	Continuous	Density	Total number of pedestrians present when a pedestrian crossed the road
Traffic-related characteristics	Categorical	Yield	1 if there is either lane change or speed reduction by driver 0 if there is no lane change or speed reduction by the driver
	Categorical	Flow against	1 if another pedestrian crosses in the opposite direction 0 if no pedestrian crosses in the opposite direction
	Categorical	Flow with	1 if another pedestrian crosses in the same direction 0 if no pedestrian crosses in the same direction
	Continuous	Vehicle speed	Speed of approaching critical vehicle in m/s

Pedestrian behavioral characteristics

Different categorical and continuous variables for the pedestrian's crossing behavior were extracted as indicated in Table 1. The accepted gap was estimated as the time gap taken by the critical vehicle to reach the crossing point of a pedestrian. To identify the critical vehicle, the safety distance for

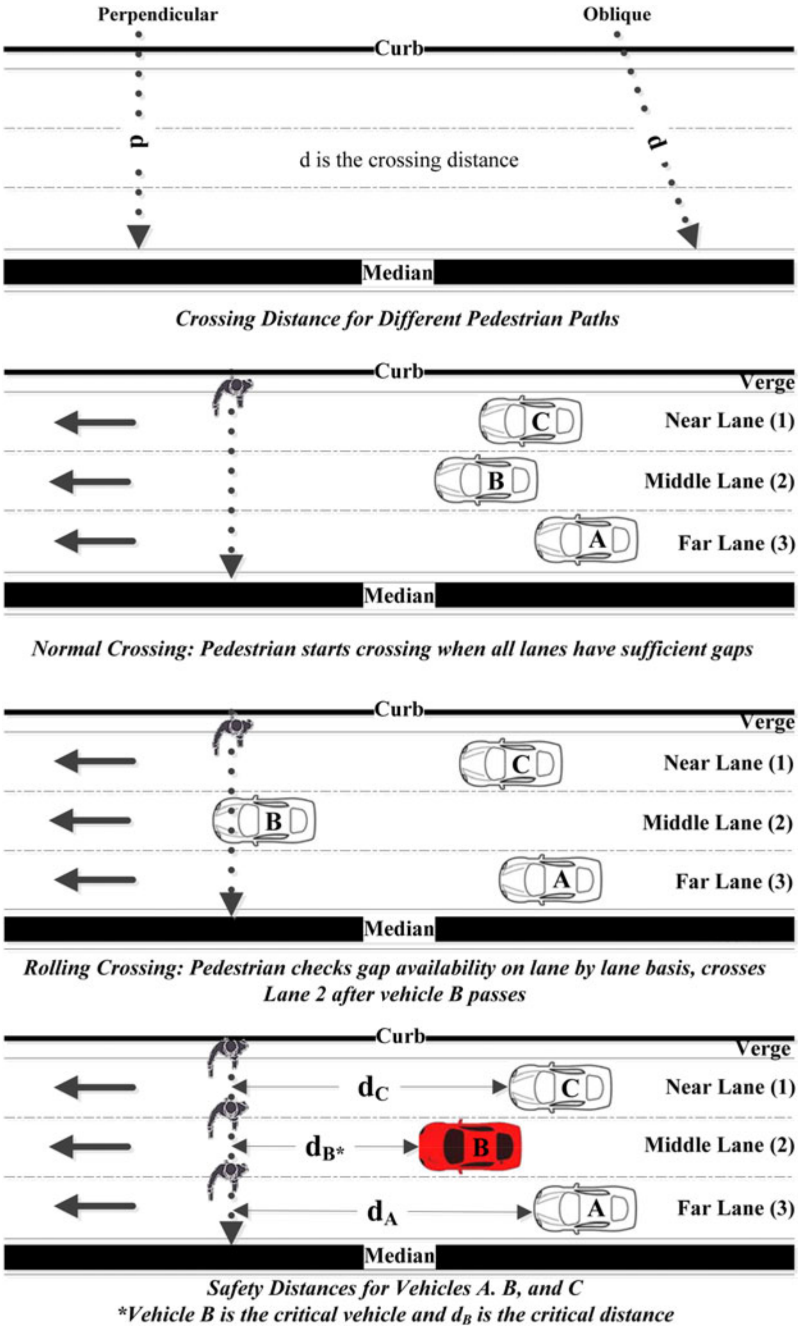

Figure 2. Illustration of several variables. (Source: Shaaban, Muley, & Mohammed, 2018).

the vehicles available in each lane was calculated, which is defined as the distance between the vehicle in each lane and the pedestrian at the time of crossing this lane. The critical vehicle is then identified as the vehicle with the minimum safety distance. To calculate the speed of the critical vehicle, the time required by the critical vehicle to arrive at the crossing point at the critical lane was measured, then the ratio of the critical distance to this time provided the speed of the critical vehicle. The type of gap, lag versus gap, was also identified in the study. The lag gaps occur when a pedestrian crosses the road before the first vehicle arrives.

The number of rejected gaps was obtained by counting the number of vehicles passing in different lanes while the pedestrian waits for the availability of a suitable gap. Furthermore, the waiting time of the pedestrian at the curb or median was measured. The pedestrian crossing speed was estimated using the crossing time and distance traveled by the pedestrian (either perpendicular or oblique) for each direction of the road. It was also recorded if the pedestrians used a rolling gap to cross the road or not. In these cases, the pedestrians check the gap availability on a lane by lane basis then cross the road on multi-stages by anticipating that the lanes will be clear as they cross, as shown in Figure 2. The gap, in this case, is called a rolling gap.

Traffic-Related characteristics

Traffic-related characteristics were studied to understand their impact on the gap acceptance behavior for pedestrians. Several attributes were recorded, including speed, speed change, and lane changing after sighting a pedestrian. These characteristics gave an indication regarding the yielding behavior of the drivers. In order the calculate speed change for a vehicle, two trap length of 20 meters were used to calculate the speed at the beginning of the pedestrian crossing and at the pedestrian location. These two speeds were used to identify any speed reduction cases. Vehicle types were not considered in this study because commercial vehicles are not allowed to use this road segment.

Some cases were not included in the analysis, such as large gaps. If traffic volume is low, large gaps can occur, and pedestrians can cross easily during these large gaps. However, these cases were not applicable to this study due to the characteristics of the study site. First, the distance between the two intersections is short. Second, the presence of two signalized intersections upstream and downstream the segment controls the traffic entering the segment and provides cases with no conflict for pedestrians. These cases are classified as no-conflict cases and were not investigated in this paper. Other cases such a pedestrian crossing when the queue was backed up to the crossing point, a pedestrian crossing while holding a bicycle in hand, a pedestrian who changed his/her mind during the crossing process and returned back, and when a taxi stops in the pedestrian path for picking up a customer. All the collected data were compiled in spreadsheets and analyzed using the IBM SPSS statistical package. The following section presents the results of the analysis.

Results

Overview of data

The minimum accepted gap was 1.78 s with a mean of 6.52 s and a standard deviation of 3.29 s. The overall 85th percentile value of accepted gaps was 9.25 s. Different continuous variables were determined for each pedestrian, including waiting time, pedestrian speed, and pedestrian crossing time. The minimum, maximum, average, and standard deviation values for each variable are presented in Table 2. The same table also shows the number of observations, the average gap, and the 85th percentile gap for various categorical pedestrian attributes in addition to the vehicle speed and critical distance.

The gender distribution showed that only a few female pedestrians crossed illegally in the study segment (2.4%). The average gap for male pedestrians was 6.51 s compared to 6.81 s for female pedestrians indicating that female pedestrians accept slightly larger gaps. Looking at the age group distribution, most of the pedestrians who crossed illegally were from the middle age group. The average and 85th percentile accepted gap size for the middle-age groups were 6.45 s and 9.07 s compared to 8.61 s and 17.21 s for the elderly group.

Moreover, fewer pedestrians with traditional clothes (6.5%) were observed crossing the road illegally. They accepted larger gaps than pedestrians with normal clothes. The mean and 85th percentile accepted gap size for people with traditional clothes was 7.27 and 12.84 s, respectively, compared to 6.47 and 9.08 s for pedestrians with normal clothes.

Few pedestrians (2.0%) were found using their mobile phone while crossing. The average gap size of pedestrians using their mobile phones was 7.31 s versus 6.50 s for pedestrians without mobile with a difference of 0.8 s. Almost one-fifth of the pedestrians were carrying bags while crossing. These pedestrians accepted slightly higher gaps (6.78 s versus 6.46 s) than pedestrians crossing without bags.

More than 80% of the pedestrians were crossing alone. The remaining was crossing in groups of two, three, or four. The average gap for individual pedestrians (6.44 s) was less than those crossing in a group (6.86 s). Also, the pedestrians crossing from the curb accepted smaller gaps.

Approximately 58% of the pedestrians accepted the first gap without waiting. The average accepted gap size was lower for pedestrians who accepted a gap without waiting. The minimum, maximum, and average waiting times were estimated as 0, 81.78, and 6.99 s, respectively. When the

Table 2. Descriptive statistics of accepted gaps.
(a) *Descriptive statistics for continuous variables*

Variable	Minimum	Maximum	Average	Std Dev
Vehicle speed (km/h)	19.18	93.19	49.10	10.47
Critical distance (m)	22.95	119.55	69.38	17.53
Waiting time (s)	0	81.78	6.99	13.12
Pedestrian speed (m/s)	0.78	3.69	1.68	0.44
Crossing time (s)	3.29	17.99	7.73	1.82

(b) *Descriptive statistics for categorical variables*

Attribute	Category	Number	Percentage	Average gap (s)	85^{th} Percentile (s)
Gender	Male	949	97.6	6.51	9.32
	Female	23	2.4	6.81	8.75
Age	Child	1	0.1	5.33	5.33
	Middle age	952	97.9	6.45	9.07
	Elderly	19	2.0	8.61	17.21
Type of clothing	Normal	909	93.5	6.47	9.08
	Traditional	63	6.5	7.27	12.84
Mobile phone use	No	953	98.0	6.50	9.11
	Yes	19	2.0	7.31	9.54
Carrying bags	No	787	81.0	6.46	9.07
	Yes	185	19.0	6.78	9.50
Crossing in a group	No	789	81.2	6.44	8.96
	Yes	183	18.8	6.86	10.12
Crossing point	Curb	421	43.3	6.26	8.61
	Median	551	56.7	6.72	9.50
Near lane	No	813	83.6	6.24	8.42
	Yes	159	16.4	7.96	12.12
Wait	No	567	58.3	5.70	7.46
	Yes	405	41.7	7.67	11.56
Pedestrian path	Perpendicular	602	61.9	6.43	9.01
	Oblique	370	38.1	6.67	9.52
Rolling gap	No	660	67.9	5.31	6.96
	Yes	312	32.1	9.09	13.66
Running	No	792	81.5	6.79	9.49
	Yes	180	18.5	5.32	7.02
Flow against	No	955	98.3	6.52	9.34
	Yes	17	1.7	6.28	7.77
Flow with	No	753	77.5	6.39	8.70
	Yes	219	22.5	6.98	10.04
Gap type	Gap	382	39.3	7.49	10.96
	Lag	590	60.7	5.89	7.66

critical vehicle was present in the near lane, the size of the accepted gap was larger. More than 60% of the pedestrians accepted lag gaps. The average gap size for lag gaps was 20% less the average size of normal gaps. Moreover, the majority of the pedestrians utilized the shortest available path for crossing. These pedestrians accepted slightly smaller gaps compared to the oblique path.

More than 30% of the pedestrians used a rolling gap to cross. The average gap size was approximately 40% lower for pedestrians accepting normal gaps. The pedestrians who were running while crossing needed approximately 20% less average gaps compared to those walking at normal speeds. The mean speed was 2.43 m/s for running pedestrians and 1.51 m/s for normal walking pedestrians.

In a limited number of cases, pedestrians were crossing from both sides at the same time (flow against). When these cases occurred, pedestrians accepted smaller gaps. Opposite results were observed in the case of pedestrians crossing from the same side at the same time (flow with). Only seven drivers (0.7%) reduced their speed, and 28 drivers (2.9%) changed their lane after seeing a pedestrian waiting to cross, which is not a surprising as similar behavior was identified in other studies in the region (Shaaban, Wood, & Gayah, 2017). Due to the limited observations, both characteristics were treated as yield in the analysis.

Regression analysis

A multipel linear regression (MLR) model was developed to estimate the size of the accepted gaps based on pedestrian behavioral and traffic-related characteristics. Since the MLR model was developed with a prediction goal, the number of rejected gaps were excluded from the analysis as these are difficult to determine compared to their correlated variables. Multiple regression analysis was chosen as it is a robust technique which can model the effect of continuous and categorical variables. Due to the presence of several variables in the model, it was important to detect the presence of multicollinearity among variables. The collinearity is present when independent variables are having a strong linear relationship (Field, 2013). The inclusion of the correlated variables produces unreliable and unstable regression coefficients and standard errors. It also poses difficulties in predicting the importance of predictors (Field, 2013; Kleinbaum et al. 2013). This process was achieved using correlation coefficients and collinearity diagnostic's procedure. The correlation coefficients were determined for all independent variables to be included in the model. The correlation coefficient can range from -1 to $+1$, with -1 indicating a perfect negative correlation, $+1$ indicating a perfect positive correlation, and 0 indicating no correlation at all.

Table 3 presents the bi-variate correlations between the variables used in the study. The correlation coefficients indicated an association between waiting time and number of attempts ($r = 0.512$, $p < 0.001$). Additionally, the density is associated with the group size ($r = 0.793$, $p < 0.001$). As expected, a significant negative correlation was also identified between the crossing time and the pedestrian speed ($r = -0.931$, $p < 0.001$). Furthermore, the number of rejected gaps is correlated with the waiting time ($r = 0.850$, $p < 0.001$) and number of attempts ($r = 0.439$, $p < 0.001$).

The stepwise selection procedure was chosen for the model development, and the best model was selected using the adjusted R^2 to determine the predictive ability of the model. All the non-continuous independent

Table 3. Correlation matrix and two-tailed probabilities.

		1	2	3	4	5	6	7	8	9	10
1	Effective gap	1									
2	Group size	0.036	1								
3	Waiting time	0.215**	0.182**	1							
4	No. of attempts	0.118**	0.175**	0.512**	1						
5	Pedestrian speed	−0.283**	−0.214**	−0.112**	−0.100**	1					
6	Density	0.068*	0.793**	0.232**	0.196**	−0.196**	1				
7	Critical distance	0.251**	0.129**	0.026	0.001	−0.228**	0.106**	1			
8	Vehicle speed	−0.260**	−0.003	0.010	0.020	0.244**	−0.052	0.153**	1		
9	Crossing time	0.316**	0.215**	0.107**	0.104**	−0.931**	0.194**	0.243**	−0.256**	1	
10	No. of rejected gaps	0.204**	0.083**	0.850**	0.439**	−0.011	0.128**	−0.021	−0.001	0.004	1

**Correlation is significant at the 0.01 level (2-tailed).

Table 4. Recoding of ordinal and nominal variables.

Variable	Reference category
Gender	Pedestrian is male
Age	Pedestrian is middle-aged
Type of clothing	Pedestrian wears normal clothes
Flow with	No pedestrian crosses in the same direction
Flow against	No pedestrian crosses in the opposite direction
Carrying bags	Pedestrian does not carry any bags/luggage
Mobile phone use	Pedestrian does not use a mobile phone while crossing
Crossing point	Pedestrian crosses from the curb
Near lane	Pedestrian accepts gap in any lane other than near lane
Rolling gap	Pedestrian does not use rolling gap to cross
Gap type	Pedestrian accepts lag gap while crossing the road
Pedestrian path	Pedestrian uses perpendicular path for crossing
Pedestrian speed change	Pedestrian does not reduce speed while crossing
Running	Pedestrian does not run while crossing the road
Vehicle yield	Driver does not change lanes or reduce speed

variables included in the study have two levels except for age. Since there is only one child in the dataset, this record was removed during the statistical modeling resulting in 971 records and two levels for age; middle-age and elderly. Table 4 shows the reference category for each variable.

The analysis was conducted using a confidence interval of 95%. Different models were obtained through a stepwise selection procedure. The model development was done with prediction aim; hence, pedestrian crossing time and the number of rejected gaps were excluded from the analysis as these are difficult to determine compared to their correlated variables. Remaining correlated variables were added one by one to determine the best suitable model.

The MLR model was created to predict the size of the accepted gaps using stepwise variable selection with multicollinearity diagnostics as indicated in Table 5. Six models were tested with different adjusted R^2 values. The best model was selected based on an adjusted R^2 value of 61.9%, which was the sixth model, having six predictors; the rolling gap, vehicle critical distance, vehicle speed, waiting time, crossing point, and near lane.

The variance inflation factor (VIF) was used to validate the model by checking the presence of collinearity among independent variables (James, Witten, Hastie, & Tibshirani, 2013). A VIF value of more than ten indicates the presence of multicollinearity among variables (Marquaridt, 1970, Neter, Wasserman, & Kutner, 1989, Hair, Black, Babin, Anderson, & Tatham, 2006). Further, the average VIF value should not be substantially greater than one to have an unbiased regression model (Field, 2013). The developed model met both requirements for all independent variables as shown in Table 5.

The model indicated that several pedestrian characteristics, including gender, age, clothing, and group size were not significant. It should be noted that some groups were not well represented in the data, including

Table 5. Model to predict the size of accepted gaps.

	Unstandardized coefficients		Standardized coefficients			Collinearity statistics
	B	Std. error	Beta	t	Sig.	VIF
(Constant)	1.532	0.053		28.932	<0.001	
Rolling gap	0.502	0.019	0.526	25.928	<0.001	1.050
Critical distance	0.012	0.001	0.468	23.068	<0.001	1.048
Vehicle speed	−0.055	0.003	−0.357	−17.589	<0.001	1.052
Waiting time	0.004	0.001	0.121	5.965	<0.001	1.043
Crossing point	−0.111	0.018	−0.124	−6.129	<0.001	1.042
Near lane	0.110	0.025	0.092	4.472	<0.001	1.071

R-Square = 0.622.
Adj. R-Square = 0.619.
F (6, 964) = 263.953, $p < 0.001$.

female, locals, children, and elderly pedestrians. The low number of observations for these variables was expected as indicated in previous observational studies in the city of Doha (Shaaban 2019a; Shaaban, Muley et al. 2017a, 2017b).

On the other hand, the waiting time, crossing point, rolling gap, and position and speed of the critical vehicle were significant in the prediction model. This can be an indication that the traffic conditions have a greater impact than pedestrian characteristics on gap prediction for the conditions investigated.

The model also indicated that the size of the accepted gap increased as the pedestrians' waiting time increased. Further, the pedestrians crossing from the median will require longer gap compared to those crossing from the curb. In addition, pedestrians accepting rolling gaps will select larger gaps. Furthermore, the identified effect for the near lane was positive; that is, the accepted gap was longer for a near-side gap than a far-side gap. Finally, the vehicle speed has indicated a negative sign, as shown in Table 5.

Conclusion

A limited number of studies investigated the pedestrian's gap acceptance behavior at six-lane unmarked crosswalks. Furthermore, this study is one of the first efforts to provide a detailed outlook into pedestrian gap acceptance behavior in a country within the Arabian Gulf region. The study provides comprehensive results highlighting all attributes related to the illegal crossing behavior at unmarked crosswalks, including pedestrians' personal characteristics, pedestrians' behaviors, and drivers' attitudes.

The study revealed that the overall average gap size was 6.52 s and the 85th percentile accepted gap was 9.25 s. The inclusion of multiple variables into the analysis indicated that gap acceptance on multilane roads is a complex phenomenon. The size of the accepted gap largely depends upon the waiting time, crossing point, position of the critical vehicle, rolling gap, and the speed of the critical vehicle. The model for predicting the size of accepted gaps suggested that as the speed of approaching vehicles increase, the accepted gap size decrease. This could be because pedestrians find it hard to find larger gaps in a traffic stream moving at a higher speed.

A high percentage of the pedestrians (32.1%) crossed the road using a rolling gap. This type of behavior is associated with high-risk vehicle–pedestrian interaction, especially in the case of crossing a multi-lane road section with high travel speeds. Under these conditions, there is a high chance that pedestrians get killed or seriously injured if a vehicle-pedestrian crash occurs. However, these conditions still exist in many developing countries. To improve these conditions, the speed limit should be reduced in urban areas especially in the case of multi-lane roads. Moreover, more marked mid-block crosswalks and pedestrian footbridges should be provided. Furthermore, there is a need to enhance the walking environment in this region to improve pedestrian safety and allow proper access to proper crossing locations (Shaaban, 2019b).

In summary, a high number of pedestrians were found crossing illegally in this study. This type of behavior is not strictly enforced in this region due to a lack of resources (Shaaban, 2017). The outcomes of the study give an indication that more efforts are needed in the area of education and enforcement. The results can also be used in simulation models in order to develop more precise and reliable models.

A number of limitations with the current study should be noted. The variables included in the study were selected based on previous research. Some variables were not well characterized, including locals, children, and elderly pedestrians. This was expected in this region as documented by previous studies. Some variables, such as vehicle type and weather conditions, were not considered in the study. These factors were not included since the data collection took place in good weather condition, and on a road segment where heavy trucks are not allowed. In addition, the pedestrian data at the signalized intersection were not collected due to the limited number of video cameras available. Therefore, it was not possible to compare legal and illegal crossings in order to know if they differ. Finally, the prediction model was developed using the data obtained from one site only. The model may need to be validated by considering additional observations from other sites.

Acknowledgment

The publication of this article was funded by the Qatar National Library.

Funding

This publication was made possible by an NPRP award [NPRP 4-1170-2-456] from the Qatar Research Fund (a member of Qatar Foundation). The statements made herein are solely the responsibility of the author.

References

Avinash, C., Jiten, S., Shriniwas, A., Gaurang, J., & Manoranjan, P. (2018). Evaluation of pedestrian safety margin at mid-block crosswalks in India. *Safety Science*, *119*, 188–198. doi:10.1016/j.ssci.2018.12.009

Cherry, C., Donlon, B., Yan, X., Moore, S. E., & Xiong, J. (2012). Illegal mid-block pedestrian crossings in China: Gap acceptance, conflict and crossing path analysis. *International Journal of Injury Control and Safety Promotion*, *19*(4), 320–330. doi:10.1080/17457300.2011.628751

Das, S., Manski, C. F., & Manuszak, M. D. (2005). Walk or wait? An empirical analysis of street crossing decisions. *Journal of Applied Econometrics*, *20*(4), 529–548. doi:10.1002/jae.791

Demiroz, Y., Onelcin, P., & Alver, Y. (2015). Illegal road crossing behavior of pedestrians at overpass locations: Factors affecting gap acceptance, crossing times and overpass use. *Accident Analysis & Prevention*, *80*, 220–228. doi:10.1016/j.aap.2015.04.018

Dommes, A., & Cavallo, V. (2011). The role of perceptual, cognitive, and motor abilities in street-crossing decisions of young and older pedestrians. *Ophthalmic and Physiological Optics*, *31*(3), 292–301. doi:10.1111/j.1475-1313.2011.00835.x

Dommes, A., Cavallo, V., & Oxley, J. (2013). Functional declines as predictors of risky street-crossing decisions in older pedestrians. *Accident Analysis & Prevention*, *59*, 135–143. doi:10.1016/j.aap.2013.05.017

Dommes, A., Cavallo, V., Dubuisson, J.-B., Tournier, I., & Vienne, F. (2014). Crossing a two-way street: Comparison of young and old pedestrians. *Journal of Safety Research*, *50*, 27–34. doi:10.1016/j.jsr.2014.03.008

Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. London: Sage.

Granié, M.-A., Pannetier, M., & Gueho, L. (2013). Developing a self-reporting method to measure pedestrian behaviors at all ages. *Accident Analysis & Prevention*, *50*, 830–839. doi:10.1016/j.aap.2012.07.009

Guo, H., Gao, Z., Yang, X., & Jiang, X. (2011). Modeling pedestrian violation behavior at signalized crosswalks in China: A hazards-based duration approach. *Traffic Injury Prevention*, *12*(1), 96–103. doi:10.1080/15389588.2010.518652

Hair, J. F., Black, W. C., Babin, B. J., Anderson, R. E., & Tatham, R. L. (2006). *Multivariate data analysis* (Vol. 6), Upper Saddle River, NJ: Pearson Prentice Hall.

Hamed, M. M. (2001). Analysis of pedestrians' behavior at pedestrian crossings. *Safety Science*, *38*(1), 63–82. doi:10.1016/S0925-7535(00)00058-8

Holland, C., & Hill, R. (2010). Gender differences in factors predicting unsafe crossing decisions in adult pedestrians across the lifespan: A simulation study. *Accident Analysis & Prevention*, *42*(4), 1097–1106. doi:10.1016/j.aap.2009.12.023

James, G., Witten, D., Hastie, T., & Tibshirani, R. (2013). *An introduction to statistical learning*. New York: Springer.

Kadali, B. R., & Vedagiri, P. (2013a). Effect of vehicular lanes on pedestrian gap acceptance behaviour. *Procedia – Social and Behavioral Sciences*, *104*, 678–687. doi:10.1016/j.sbspro.2013.11.162

Kadali, B. R., & Vedagiri, P. (2013b). Marked versus unmarked pedestrian road crossing behaviour at uncontrolled midblock crosswalk in mixed traffic condition. Transportation Research Board 92nd Annual Meeting. Washington, D.C. (2013).

Kadali, B. R., & Vedagiri, P. (2013c). Modelling pedestrian road crossing behaviour under mixed traffic condition. *European Transport*, *55*(3), 1–17.

Kadali, B. R., & Vedagiri, P. (2016). Proactive pedestrian safety evaluation at unprotected mid-block crosswalk locations under mixed traffic conditions. *Safety Science*, *89*, 94–105. doi:10.1016/j.ssci.2016.05.014

Kim, J.-K., Ulfarsson, G. F., Shankar, V. N., & Kim, S. (2008). Age and pedestrian injury severity in motor-vehicle crashes: A heteroskedastic logit analysis. *Accident Analysis & Prevention*, *40*(5), 1695–1702. doi:10.1016/j.aap.2008.06.005

King, M. J., Soole, D., & Ghafourian, A. (2009). Illegal pedestrian crossing at signalised intersections: Incidence and relative risk. *Accident Analysis & Prevention*, *41*(3), 485–490. doi:10.1016/j.aap.2009.01.008

Kleinbaum, D., Kupper, A. Nizam, L., & Rosenberg, E. (2013). *Applied regression analysis and other multivariable methods*. Boston, MA, United States: Nelson Education.

Lobjois, R., & Cavallo, V. (2007). Age-related differences in street-crossing decisions: The effects of vehicle speed and time constraints on gap selection in an estimation task. *Accident Analysis & Prevention*, *39*(5), 934–943. doi:10.1016/j.aap.2006.12.013

Lobjois, R., & Cavallo, V. (2009). The effects of aging on street-crossing behavior: From estimation to actual crossing. *Accident Analysis & Prevention*, *41*(2), 259–267. doi:10.1016/j.aap.2008.12.001

Marquaridt, D. W. (1970). Generalized inverses, ridge regression, biased linear estimation, and nonlinear estimation. *Technometrics*, *12*(3), 591–612. doi:10.1080/00401706.1970.10488699

Neter, J., Wasserman, W., & Kutner, M. H. (1989). Applied linear regression models. Homewood, IL: Irwin.

Oxley, J., Fildes, B., Ihsen, E., Charlton, J., & Day, R. (1997). Differences in traffic judgements between young and old adult pedestrians. *Accident Analysis & Prevention*, *29*(6), 839–847. doi:10.1016/S0001-4575(97)00053-5

Oxley, J. A., Ihsen, E., Fildes, B. N., Charlton, J. L., & Day, R. H. (2005). Crossing roads safely: An experimental study of age differences in gap selection by pedestrians. *Accident Analysis & Prevention*, *37*(5), 962–971. doi:10.1016/j.aap.2005.04.017

Ren, G., Zhou, Z., Wang, W., Zhang, Y., & Wang, W. (2011). Crossing behaviors of pedestrians at signalized intersections: Observational study and survey in China. *Transportation Research Record: Journal of the Transportation Research Board*, *2264*(1), 65–73. doi:10.3141/2264-08

Rosenbloom, T. (2009). Crossing at a red light: Behaviour of individuals and groups. *Transportation Research Part F: Traffic Psychology and Behaviour*, *12*(5), 389–394. doi:10.1016/j.trf.2009.05.002

Rosenbloom, T., Nemrodov, D., & Barkan, H. (2004). For heaven's sake follow the rules: Pedestrians' behavior in an ultra-orthodox and a non-orthodox city. *Transportation Research Part F: Traffic Psychology and Behaviour*, *7*(6), 395–404. doi:10.1016/j.trf.2004.10.004

Serag, M. (2014). Modelling pedestrian road crossing at uncontrolled mid-block locations in developing countries. *International Journal of Civil & Structural Engineering*, *4*(3), 274–285.

Shaaban, K. (2017). Assessment of Drivers' Perceptions of Various Police Enforcement Strategies and Associated Penalties and Rewards. *Journal of Advanced Transportation*, *2017*, 1. doi:10.1155/2017/5169176

Shaaban, K. (2019a). Analysis of pedestrian crossing speeds at signalized intersections in Qatar. *Arabian Journal for Science and Engineering*, *44*(5), 4467–4476. doi:10.1007/s13369-018-3460-3

Shaaban, K. (2019b). Assessing sidewalk and corridor walkability in developing countries. *Sustainability*, *11*(14), 3865.

Shaaban, K., Muley, D., & Elnashar, D. (2017a). Evaluating the effect of seasonal variations on walking behaviour in a hot weather country using logistic regression. *International Journal of Urban Sciences*, 22(3), 382-391. doi:10.1080/12265934.2017.1403363

Shaaban, K., Muley, D., & Elnashar, D. (2017b). Temporal variation in walking behavior: An empirical study. *Case Studies on Transport Policy*, *5*(4), 671–680. doi:10.1016/j.cstp.2017.07.001

Shaaban, K., Muley, D., & Mohammed, A. (2018). Analysis of illegal pedestrian crossing behavior on a major divided arterial road. *Transportation Research Part F: Traffic Psychology and Behaviour*, *54*, 124–137. doi:10.1016/j.trf.2018.01.012

Shaaban, K., Wood, J. S., & Gayah, V. V. (2017). Investigating driver behavior at minor-street stop-controlled intersections in Qatar. *Transportation Research Record: Journal of the Transportation Research Board*, *2663*(1), 109–116. doi:10.3141/2663-14

Sun, D., Ukkusuri, S., Benekohal, R. F., & Waller, S. T. (2002). Travis Waller Modeling of motorist–pedestrian interaction at uncontrolled mid-block crosswalk. Presented at the 82nd Transportation Research Board TRB Annual Meeting, Washington, D.C.

Tiwari, G., Bangdiwala, S., Saraswat, A., & Gaurav, S. (2007). Survival analysis: Pedestrian risk exposure at signalized intersections. *Transportation Research Part F: Traffic Psychology and Behaviour*, *10*(2), 77–89. doi:10.1016/j.trf.2006.06.002

Tom, A., & Granié, M.-A. (2011). Gender differences in pedestrian rule compliance and visual search at signalized and unsignalized crossroads. *Accident Analysis & Prevention*, *43*(5), 1794–1801. doi:10.1016/j.aap.2011.04.012

Wang, T., Wu, J., Zheng, P., & McDonald, M. (2010). Study of pedestrians' gap acceptance behavior when they jaywalk outside crossing facilities. *13th International IEEE Conference on Intelligent Transportation Systems, September 19–22.* Madeira Island, Portugal: IEEE.

Yannis, G., Papadimitriou, E., & Theofilatos, A. (2013). Pedestrian gap acceptance for mid-block street crossing. *Transportation Planning and Technology*, *36*(5), 450–462. doi:10.1080/03081060.2013.818274

Zhang, C., Chen, F., & Wei, Y. (2019). Evaluation of pedestrian crossing behavior and safety at uncontrolled mid-block crosswalks with different numbers of lanes in China. *Accident Analysis & Prevention*, *123*, 263–273. doi:10.1016/j.aap.2018.12.002

Zhang, C., Zhou, B., Qiu, T. Z., & Liu, S. (2018). Pedestrian crossing behaviors at uncontrolled multi-lane mid-block crosswalks in developing world. *Journal of Safety Research*, *64*, 145–154. doi:10.1016/j.jsr.2017.12.018

Zhao, J., Malenje, J. O., Tang, Y., & Han, Y. (2019). Gap acceptance probability model for pedestrians at unsignalized mid-block crosswalks based on logistic regression. *Accident Analysis & Prevention*, *129*, 76–83. doi:10.1016/j.aap.2019.05.012