A MULTIPLE-LINEAR REGRESSION MODEL FOR PEDESTRIAN GAP ACCEPTANCE AT ROAD SEGMENTS OF UNSIGNALIZED INTERSECTIONS: A CASE STUDY OF KHULNA CITY

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ABSTRACT

In recent years, the construction of the Padma Bridge in Khulna City has increased motor vehicle traffic and congestion on road sections; thus, the analysis and understanding of pedestrian road-crossing behavior has become more vital for improving road safety. Because the highway was poorly designed or lacked pedestrian crossings, most are forced to cross willy-nilly, informally. The result is putting themselves and drivers alike at risk by being confused. This study aims to model pedestrian gap acceptance (PGA) and determine the critical gap at three important unsignalized road sections in Khulna city, i.e., Shibbari Mor, Sonadanga and Gollamari. These intersections, which serve as major links in regional and local traffic, were the locations of extensive field observations and video recordings. A multiple linear regression (MLR) model was established to investigate the determinants of pedestrian uptake of the traffic gap. In addition, Raff's technique was used to determine the critical gap as a critical variable for pedestrian analyses and intersection control design. In regression analysis, PGA is highly affected by various factors (pedestrian age and gender, waiting time, number of crossing attempts, and the presence of children). Further critical factors were identified as vehicle-related, including the velocity of conflicting vehicles and the size of the available gap. The Gollamari intersection had the lowest critical gap (2.87 s), suggesting a site-specific nature of the parameter, as variations in critical gap were observed among the different places under study. The predictive capacity of the MLR model (R-square up to 0.701), coupled with the derived critical gap values (Shibbari: 4.10s, Sonadanga: 3.90s; Gollamari: 2.87s), constitutes an asset for planning and optimizing pedestrian signal timings and refuge islands at these pivotal uncontrolled intersections. Future studies should quantitatively evaluate the effectiveness of the proposed design modifications in reducing pedestrian-vehicle conflicts and enhancing overall traffic flow efficiency by implementing and validating the methods. The models clearly indicate that the optimal gap size correlates positively with wait time and negatively with crossing speed across sites, providing specific quantitative metrics for action. Overall, the findings offer a new local dataset to the global south literature on pedestrian safety, isolating the unique urban context of Khulna from those megacities investigated thus far, such as Dhaka. The results presented provide important implications for traffic engineers, urban planners, and decision-makers, as well as a quantitative basis for enhancing pedestrian model behavior. These findings may be useful for crosswalk facility design and progression control at non-signalized intersections, improving pedestrian safety within the study area, i.e., Khulna City.

Keywords: *Pedestrian, Gap Acceptance Behaviour, Multiple Linear Regression, critical gap, Raff's method*

1. INTRODUCTION

Pedestrians have been identified as one of the most exposed modes of road users throughout the entire world and cause a significant number of death and injury accidents (Kumari et al., 2025). This is an especially significant risk in Low- and Middle-Income Countries (LMICs), where due to a lack of infrastructure and various traffic conditions, there is an increase in the need to improve pedestrian safety (Mukherjee et al., 2024). Human behavior is one which explains the behaviors and reactions of people in their immediate environment. This encompasses the actions of the pedestrians, their understanding of the other non-vehicular factors on the road, their interrelations (Zambare & Liu, 2025).

The study of pedestrian behavior is critical, as it influences the management of highways and traffic and contributes to safety aspects of infrastructure planning (Budzynski et al., 2017).

Pedestrian behavior is an essential study that has an impact on highways and traffic management and helps to address safety elements of infrastructure planning (Budzynski et al., 2017). One of its components is Pedestrian Gap Acceptance (PGA), which, in its turn, is conditional on the interval or distance to the following conflict vehicle (Theobald et al., 2022). Variables that can be effective in influencing this behavior are pedestrian rolling gaps, frequency of attempts by the pedestrians, size of the vehicular gap, and fluctuation in the pedestrian and vehicle walking speed. Unless these features are represented adequately, they may lead to the construction of suboptimal crossing infrastructure, contributing to the exposure to non-mobility and crashes (Albert & Marisamynathan, 2022). Also, the Critical Gap assessment can be applied to improve the advantages of PGA application in the safety assessment of unsignalized intersections (Sahani et al., 2018). Critical gap refers to the time separation between two vehicles that a pedestrian considers required to start and perform a manoeuvre that will not cause them to be in danger (Al Bargi et al., 2023). The specific calculation of this parameter is necessary to come up with effective operational controls, review the efficiency of the current crosswalks, and formulate the proper signal timings (Zhang et al., 2022).). The change in behaviour based on risk factors was observed in (Ahmed et al., 2024) that reviewed pedestrian gap acceptance behaviour in the Asia region in 2024. Nonetheless, the characteristics of the behaviour of PGAs are site-specific, and it was limited to a complicated interaction between individual factors (e.g., type of age, gender, size of a group) and environmental factors of the traffic (e.g., speed of vehicles, or presence of a gap, and levels of traffic congestion) (Vasudevan et al., 2020).

Bangladesh, like other countries in the Global South, has cities with large numbers of pedestrians (DTCA, 2015). The major and secondary cities are equally composed of low- and middle-income populations, with a tendency to live within walking distance of their workplaces, schools, and daily necessities. Therefore, the proper design of pedestrian ways and the incorporation of pedestrian facilities within roadways can be considered a primary task for transport planners and engineers. Despite the significant need, studies of pedestrian behaviour in Bangladesh largely focus on Dhaka city, which has a very different physical environment from Khulna city. As the third-largest city by population, Khulna has a large number of pedestrians, requiring data-based interventions to provide appropriate pedestrian services (Fattah et al., 2021). Recent large-scale infrastructure projects, particularly the construction of the Padma Bridge, have led to a significant increase in vehicular traffic and congestion on major arterial road segments in Khulna (Sourav et al., 2023). This rise in traffic, particularly in urban locations, often causes the available road network to be insufficient, with pedestrians having to cross at non-designated and life-threatening locations. This problem becomes more complicated in the case of junctions, where, with increased traffic flow, the space for easy pedestrian walking from one corner to another reduces, and consequently, pedestrian-vehicle conflicts increase (Mukherjee et al., 2024).

Pedestrian behaviour research is a recent development in Bangladesh; thus, only a few studies have so far focused on specific behaviours and safety-related issues at different uncontrolled road sections and urban intersections. Zafri (2023) identified key factors affecting pedestrian crossing behaviours in Dhaka, emphasising that walking almost always occurred at controlled intersections and in groups. However, running was common at uncontrolled intersections and involves shorter gap acceptance, thereby influencing overall pedestrian safety. In another study, Zafri et al. (2019) highlighted factors such as intersection control type, gender, age, crossing type, group size, compliance behaviour, and vehicle flow affecting crossing speed and waiting time. However, these studies have concentrated only on Dhaka city, while pedestrian behaviour and safety in other cities, suburban, and rural areas remain unexplored.

In the context of Khulna, Fattah et al. (2025) applied multi-criteria decision-making models to investigate pedestrian road-crossing behavior and its risk in Khulna City group crossing, mobile phone use, and young pedestrians were identified as having a marked impact on pedestrian road crossing; therefore, it proved to be an evidence-based method for guidance that can make a safer urban environment. While comprehensive, existing studies still have a large literature gap; intersection-level and quantitative analyses of PGA at unsignalized intersections have not yet been considered in the literature. To address the identified research gap, the primary objective of this study is to conduct a quantitative analysis and determine the impact of various socio-economic, traffic, and environmental parameters on gap acceptance behaviour among pedestrians in Khulna. Therefore, this study should provide insights to guide future pedestrian simulation research and to contribute to the development of safer, more efficient pedestrian policies and facilities for Khulna city. Objectives of the study includes:

i) To understand the general and critical pedestrian gap acceptance behavior of pedestrians in Khulna
ii) To determine the relevant factors affecting the variation in pedestrian gap acceptance

2. METHODOLOGY

Data collection took place at the key Khulna CBD junctions of Shibbari Mor, Sonadanga, and Gollamari. The selection was motivated by the heavy pedestrian activity at these sites. The traffic features for each intersection are summarized in the table provided.

Table 01: Traffic Elements of the Intersection

Intersection Name	Lane Number	Carriage Way (m)	Footpath (m)	Traffic Control
Shib bari	2	6.25	1.67	Traffic Police
Sonadanga	2	10.4	2.44	Traffic Police
Gollamari	2	8.5	0	Traffic Police

Videographic traffic data was captured at selected intersections in June 2025 for this purpose. To do so, the study recorded pedestrian characteristics including behavior and traffic in two peaks, one off-peak hour on weekdays, and a peak-off-peak hour during weekends under fine weather. Most of the data was extracted through repeated screenshots from the videos every 5 min. From these snapshots, all necessary data were manually selected for each visible pedestrian on the corresponding video segments. This resulted in an aggregated dataset of 462 pedestrians over the three intersections.

Data analysis occurred in three stages: descriptive statistics, statistical tests, and modelling. Preliminary descriptive results and pedestrians´ behavior assessments are presented on the adjacent table. Statistical testing, including parametric tests to confirm assumptions (such as normality and homogeneity of variances), followed. The final stage involved developing and comparing three Multiple Linear Regression (MLR) models—one for each intersection—to investigate gap acceptance. MLR, a standard regression technique, is used to define the relationship between a dependent and several independent variables. Given equation develops a relationship between these variables.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \dots \dots + \beta_n X_n \quad (1)$$

Here, Y is the dependent variable; β_i indicates the regression co-efficient, which are generally estimated by ordinary least squares (OLS) method; and X_i (i = 0, 1, ……, n) indicates the predictors (Zafri et al., 2019). Statistical Package for the Social Sciences (SPSS 20.0) software package at a 95%

confidence interval was used to develop the MLR model. In this model, gap acceptance (second) is taken as dependent variable and age, gender, waiting time, crossing groups, crossing attempts, baggage handling and crossing speed are taken as independent variables.

The critical gap is the difference between the threshold gap and the difference to which the pedestrians are likely to cross. To approximate this value, the graphical method known as Raff's method, described as a macroscopic model by (Brilon et al., 1999; Kadali et al., 2015) was used in which the percentage cumulative frequency of accepted gaps and the percentage cumulative frequency of rejected gaps were plotted against the gap size on the x-axis. The point of intersection of these two cumulative curves was defined as the critical gap, which is the probability of accepting or rejecting a gap at the same time. The calculation involves utilizing the empirical distribution functions of accepted gaps ($F_a(t)$) and rejected gaps ($F_r(t)$), a relationship defined by Equation 3.

$$F_a(t) = 1 - F_r(t) \tag{2}$$

Table 02: Details of the Risk Factors

Name of variables	Type	Unit/code	Description
Gender	Discrete	Male:1 Female:2	The gender of the pedestrian was categorised as Male *(M)* and Female *(F)*.
Age	Discrete	Child:1 Young:2 Adult:3 Old:4	Age: Pedestrian age is divided into four groups based on visual appearance. They are I. *Child:* Age between 0-15 II. *Young:* Age between 15-30 III. *Adult:* Age between 30-60 IV. *Old:* Age >60
Crossing Group	Discrete	Alone: 1 With Group: 2	This criterion is further divided into two groups, which are: I. *Alone:* The pedestrian crosses the road without any group. II. *With a group:* The pedestrian crosses the road with a group consisting of more than 1 person
Baggage Handling	Discrete	No: 1 Light: 2 Medium: 3	If the pedestrian carries any bag, then it would be described as carrying a light or medium-sized bag, identified by visual. Otherwise, there would be no bag.
Crossing Attempts	Continuous	Number of attempts	The pedestrian can take 1 or more attempts to cross the road.
Waiting Time	Continuous	Second(s)	The time a pedestrian takes to cross the road
Crossing Speed	Continuous	Meter/second (m/s)	The average walking speed of a pedestrian while crossing the road

3. FINDINGS AND RESULTS

3.1 Descriptive Statistics

Findings showed that there was an apparent spatial difference throughout the pedestrian behaviour: the mean accepted interval was best at Shibbari (4.34 s) then Sonadanga (4.09 s) and Gollamari (3.57 s). The trend was also observed in the central tendency measures with the value of median and mode decreasing in the same direction among the sites (median: 4.48, 4.00, 3.50 s; mode: 4.50, 4.00, 3.00 s, respectively). More so, the minimum and maximum values follow the same pattern of gap acceptance with the exception of Shibbari that records lower minimum gap in comparison to Sonadanga. These findings indicate that pedestrians at Gollamari are generally more inclined to accept shorter gaps. The descriptive statistics are presented in Table 03.

The graph in Figure 01 displays the gap acceptance at the 15th, 50th, and 85th percentiles for pedestrians at three locations to avoid extreme values. It confirms the earlier findings that pedestrians of Shibbari have a larger acceptable gap than at the other two intersections. This indicates that pedestrians are more likely to encounter risks in Gollamari than in Sonadanga and Shibbari.

Table 03: Descriptive statistics of pedestrian gap acceptance behavior in three selected intersections

	Gap Acceptance in seconds		
	Shibbari	Sonadanga	Gollamari
Mean	4.34	4.09	3.57
Median	4.48	4.00	3.50
Mode	4.50	4.00	3.00
Std. Deviation	1.09	0.73	0.75
Minimum	2.25	3.00	1.90
Maximum	9.80	6.50	5.80

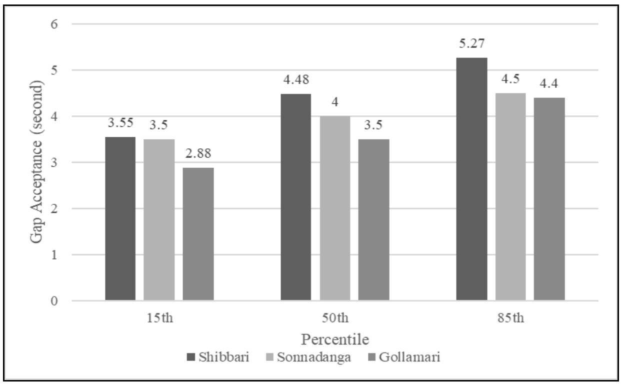


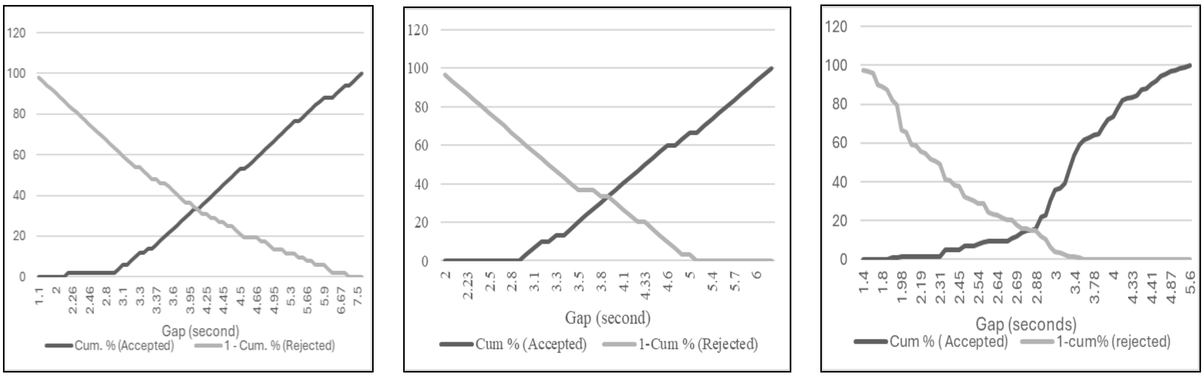
Figure 01: Descriptive analysis of accepted gap (seconds) at three intersections

3.2 Identifying Critical Gap by Raff's Method

After conducting the descriptive analysis, Raff's method was conducted as first the descriptive statistics give an overall gap acceptance distribution which is necessary to properly obtain the critical gap, which is used as a statistically defensible reference value. Subsequently a Multiple Linear Regression model was developed to measure the marginal effects of the explanatory variables on gap acceptance and hence systematic modelling and forecasting of the decision-making behavior of pedestrians. The results of the analysis indicated that the critical gap values of all three study crossings were significantly different in location (Fig 03). The critical gap at Shibbari was found to be 4.10 seconds compared to Sonadanga (3.90 seconds) and Gollamari (2.87 seconds). This difference is an indicator of the change in the pedestrian crossing environment and the local traffic flow variables. To avoid waiting, the pedestrians in Gollamari were more likely to tolerate a smaller gaps between vehicles because the traffic volume is relatively high. Subsequently, the behaviour increases their susceptibility to danger and risks risky crossings.

On the other hand, pedestrians at Shibbari used a more careful crossing strategy, waiting for larger distances to ensure safety due to reduced traffic congestion and comparatively higher vehicle speeds. The critical gap value increased because of this behaviour, suggesting a decreased gap acceptance. The Sonadanga intersection had intermediate characteristics, with traffic flow and vehicle speed falling between the other two locations. Because of this, the critical gap value also decreased between

Shibbari and Gollamari, indicating an adequate interaction between traffic volume and pedestrian safety.



(a) Shibbari (b) Sonadanga (c) Gollamari

Figure 02: Critical gap at three intersections

3.3 Statiscal Analysis and Estimation and Validation from Multiple Linear Regression (MLR) Model

Several socio-economic factors usually dominate pedestrian gap acceptance behaviour. Additionally, it also shows variation based on geographical, contextual and regulatory variables. To do statistical analysis, an independent t test was performed on discrete data group to identify whether there is statistically significant difference between the means of two independent or unrelated groups and an tukey post hoc test was performed following an one way ANOVA to do a pair-wise comparison to identify the specific two groups that are different as opposed to each other when there are three or more independent groups of data. Lastly under continuous type of data, A non-parametric Kendall's Tau b test was applied to determine the strength and direction of the relationship between two variables of specific ranks.

Gender: The findings from the independent t-test showed that male pedestrians crossed the street considerably faster than female pedestrians (Table 4). Among the three study locations, male pedestrians at Gollamari had the smallest mean gap (3.55 s), whereas female pedestrians at Shibbari had the largest (4.52 s).

Age: The one-way ANOVA revealed that the accepted gap decreased with increasing age. A subsequent Tukey's post-hoc test confirmed that young pedestrians exhibited the highest mean crossing speeds, which declined significantly with both increasing and decreasing age. Adult pedestrians accepted significantly larger gaps than older pedestrians, but no significant differences were found between adults and children or between children and older pedestrians (Table 4). Notably, the largest accepted gaps were observed in Shibbari, while even children in Gollamari accepted smaller gaps than adults in Shibbari.

Crossing group size: Across the three sites, only Sonadanga showed a significant relationship between crossing group size and the accepted gap (Table 4). At Gollamari and Sonadanga, pedestrians who crossed alone tended to accept wider gaps than those who crossed in groups. Contrarily, at Shibbari, the opposite pattern was observed. Contextual factors may be causing this variation across groups.

Baggage handling: The types of baggage and the accepted gap showed a significant correlation (Table 4). Tukey's post-hoc test results showed that pedestrians with lightweight bags tended to accept greater gaps than pedestrians without any baggage. However, pedestrians with medium-weight bags in Shibbari also showed larger tolerated gaps. Light- and medium-weight baggage carriers did not have a statistically significant difference (Table 4).

Table 04: Results from comparison and correlation tests against the 'pedestrian gap acceptance' variable

Location	Shibbari				Sonadanga				Gollamari			
Variable	N	Mean	Std. Dev.	Test details	N	Mean	Std Dev.	Test details	N	Mean	Std Dev.	Test details
Gender												
Male	71	4.15	.93	τ=-2.14	115	4.098	.77	τ=.158	75	3.55	.732	τ=-.392
Female	71	4.52	1.21	ρ= 0.39	71	4.08	.67	ρ= 0.453	53	3.6	.778	ρ= 0.31
Age												
Child	8	5.52	.22	F=94.77	10	5.75	.35	F=237.77	9	4.28	.27	F=140.93
Young	58	3.44	.63	ρ=.000	58	3.5	.36	ρ=0.000	42	2.78	.29	ρ=.000
Adult	64	4.52	.35		107	4.08	.32		47	3.57	.297	
Old	18	6.13	1.30		11	5.78	.73		30	4.47	.52	
Tukey post hoc test result	Young vs. child: ρ = 0.000, young vs. adult: ρ = 0.000, young vs. old: ρ = 0.000, adult vs. child: ρ = 0.000, adult vs. old: ρ = 0.000, and child vs. old: ρ = 0.126				Young vs. child: ρ = 0.000, young vs. adult: ρ = 0.000, young vs. old: ρ = 0.000, adult vs. child: ρ = 0.000, adult vs. old: ρ = 0.000, and child vs. old: ρ = 0.996				Young vs. child: ρ = 0.000, young vs. adult: ρ = 0.000, young vs. old: ρ = 0.000, adult vs. child: ρ = 0.000, adult vs. old: ρ = 0.000, and child vs. old: ρ = 0.558			
Crossing Groups												
Alone	69	4.45	.857	τ =1.12	147	4.04	.67	τ =-1.97	90	3.57	.74	τ =-.115
Group	79	4.25	1.27	ρ =0.24	39	4.29	.91	ρ =.001	38	3.59	.78	ρ =0.637
Baggage Handling												
No	70	4.36	1.15	F=.752	114	4.08	.72	F=.501	88	3.59	.788	F=4.063
Light	54	4.23	1.01	ρ =.473	50	4.17	.83	ρ =.607	27	3.78	.64	ρ =.02
Medium	24	4.55	1.11		22	4	.59		13	3.08	.43	
Tukey post hoc test result	No vs. light: ρ = 0.798, no vs. medium: ρ = 0.721, and light vs. medium: ρ = 0.445				No vs. light: ρ = 0.730, no vs. medium: ρ = 0.886, and light vs. medium: ρ = 0.622				No vs. light: ρ = 0.411, no vs. medium: ρ = 0.061, and light vs. medium: ρ = 0.014			
Pedestrian crossing speed												
Speed	148			τ_b=-.49 ρ =.000	186			τ_b=-.37 ρ =.000	128			τ_b=-.596 ρ =.000
Crossing attempts												
Attempt	148			τ_b=.019 ρ =.348	186			τ_b=.065 ρ =.147	128			τ_b=.299 ρ =.000
Waiting Time												
Waiting time	148			τ_b=.604 ρ =.000	186			τ_b=-.298 ρ =.000	128			τ_b=-.277 ρ =.000

Pedestrian crossing speed: Pedestrian speed and accepted gap showed an inverse relationship, according to the results of the Kendall's tau-b test (**Table 3**). Speedy pedestrians tended to accept shorter gaps, according to this connection, which was statistically significant across all locations. This finding is consistent with conventional theories of pedestrian crossing behaviors.

Crossing Attempt: There were no significant difference in crossing attempt at Shibbari and Shonanga but significant differences were observed at Gollamari. It is likely that increased caution led to the tendency of pedestrians to wait longer before success on a withdrawal attempt had been achieved and then wait longer.

Waiting time: Waiting time was identified to be an important parameter that affects the behavior at the pedestrian crossing. It was acquired through the Kendall's tau-b correlation test. The findings indicated that those pedestrians who waited more time to cross tended to admit larger distances between the subsequent vehicles. This relationship was observed in all study sites indicating that longer waiting times can lead to higher risk aversion among pedestrian during crossing decision.

In order to establish the minimum size of the vehicle-vehicle gap at different crossings to allow pedestrians cross the road safely, a lognormal regression model was developed. Table 5 demonstrates the moderate strength of the included variables explaining the gap acceptance as model performances. A residual analysis was to be done to test the correlation between the observed and predicted sizes in the pedestrian gap and hence test the adequacy of the model.

Finally, the F-test was employed to evaluate the overall model significance. The results showed that when the p-value of the F-test equaled 0.000, the regression model provided a statistically significant fit to the data.

Table 05: MLR model performance for individual locations

Shibbari		R	R Square	Adjusted R Square	Std Error of the Estimation	
		.796	.634	.624	.67238	
	Model	Sum of Squares	***df***	Mean Square	*F*	Sig.
	Regression	112.028	4	28.007	61.950	.000
	Residual	64.649	143	.452		
	Total	176.678	147			
Sonadanga		R	R Square	Adjusted R Square	Std Error of the Estimation	
		.748	.559	.550	.49136	
	Model	Sum of squares	***df***	Mean Square	*F*	Sig.
	Regression	55.461	4	13.865	57.429	0.000
	Residual	43.699	181	.241		
	Total	99.160	185			
Gollamari		R	R Square	Adjusted R Square	Std Error of the Estimation	
		.837	.701	.689	.41774	
	Model	Sum of squares	***df***	Mean Square	*F*	Sig.
	Regression	49.958	49.958	9.992	57.257	0.000
	Residual	21.289	21.289	.175		
	Total	71.248	71.248			

Table 06 shows the results for the selected intersections involving four criteria for Shibbari and Sonadanga and five for Gollamari (pedestrian age, gender, CS, WT, and BH). The coefficient will demonstrate how the change in the input variable affects the resulting variable's standard deviation. The positive or negative sign of coefficient B will indicate whether the output value increased or decreased because of a change in the input variable. The pedestrian accepted gap size will increase due to the increase in pedestrian age and waiting time and decrease with the crossing speed and baggage handling.

Table 06: MLR model results for individual locations

	Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
		B	Std. Error	Beta		
Shibbari	(Constant)	2.747	.558		4.922	.000
	Gender	.171	.112	.078	1.534	.127
	Age	.147	.092	.103	1.602	.111
	CS	-.164	.298	-.039	-.552	.582
	WT	.138	.014	.692	9.751	.000
	Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
Sonadanga	(Constant)	5.118	.335		15.257	.000
	Gender	.076	.074	.051	1.020	.309
	Age	.094	.056	.087	1.682	.094
	CS	-1.113	.141	-.447	-7.909	.000
	WT	.213	.027	.424	7.798	.000
	Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
Gollamari	(Constant)	5.475	.371		14.768	.000
	Gender	-.016	.076	-.011	-.214	.831
	Age	.189	.048	.225	3.975	.000
	CS	-1.821	.169	-.611	-10.790	.000
	WT	.150	.034	.228	4.409	.000
	BH	-.088	.056	-.079	-1.567	.120

Note: Where, gap= accepted gap by pedestrian, Gen= Gender (if male=1, female=2), Age= age of the pedestrian (if child=1, young=2, adult=3, old=4), CS= Crossing speed (speed in meter/second), WT= waiting time (time in second) and BH= baggage handling (no=1, light=2, medium=3)

For Shibbari

$$\ln(gap) = 2.747 + .171Gen + .147Age - .164CS + .138WT \tag{3}$$

For Sonadanga,

$$\ln(gap) = 5.118 + .076Gen + .094Age - 1.113CS + .213WT \tag{4}$$

For Gollamari

$$\ln(gap) = 5.475 - .016Gen + .189Age - 1.821CS + .150WT - .088BH \tag{5}$$

The model uncovers similarities and differences in factors that exert influence in the gap that is accepted by pedestrians in the locations. Waiting time (WT) in all locations has a positive effect that is always positive and therefore the longer the waiting time the larger the gap accepted by the pedestrians. Crossing speed (CS) presents a significant negative correlation with accepted gap in Sonadanga and Gollamari with higher speeds of crossing being correlated with less accepted gap and in Shibbari the same is not of a significance. The age of the people does not vary with the tolerable effect on the acceptable spacing in Shibbari and Sonadanga, but it has significant effect in Gollamari since older individuals conform to the broad intervals. In all models, gender is insignificant and does not have a noticeable impact on the acceptability of disparity. Moreover, baggage handling (BH) with an appearance of negative but insignificant impact on the accepted gap is not present in any other study. Overall, the waiting period is a good predictor in all the three places with age and crossing speed showing different results, which throws light on the pedestrian behavior of each location

4. DISCUSSION AND CONCLUSION

The study demonstrates pedestrian gap acceptance characteristics in three key intersections of Khulna city. . Besides the locational difference, several other factors were taken into consideration (e.g. age, gender, baggage carrying and crossing mode, waiting duration and cross trial). The intersections are very striking regarding the fact that there is a spatial structure. The biggest gap that was excepted by pedestrians in Shibbari was, 4.34 s, then Sonadanga (4.09 s), and Gollamari (3.57 s). Such spatial gradient can be equivalent to traffic flow in the immediate locality because at Gollamari there are higher volumes and congestion and it would be anticipated that there will be people seeking to cross at shorter crossing gaps. Likewise, fields of space have also been identified in India and Sri Lanka where the width of road, the type of intersection and level of traffic can greatly influence the acceptance of the pedestrian gap (Chandra et al., 2014; Wickramasinghe et al., 2021). Older and child pedestrians took larger gaps, while males adopted smaller gaps and thus crossed faster, in contrast to females. This effect of gender and age is consistent with the previous findings (Kadali et al., 2015; Zhang et al., 2018), which addresses sociodemographic aspects of the acceptance of the road crossing gap. It is worth noting that from the earlier discussion, it appears that children at Gollamari pass children and adults at Shibbari only with smaller OSIs. Of course, these opposing results within a common local context could be due to non-identical traffic conditions, infrastructure, or cultural factors that are not thoroughly analyzed due to insufficient data. Group size effect was found to be inconsistent, with solo pedestrians accepting either higher (Gollamari and Sonadanga) or lower (Shibbari) gaps, due to highly complex relationships with traffic flow and pedestrian behaviour.

There was a negative association between the crossing speed and accepted gap, which made sense because all pedestrians choose smaller gaps when standing with faster rushing and agreed with classical explanations of pedestrian and previous literature (Nor et al., 2017). In Gollamari, there were more attempts to cross, and this made participants cautious, resulting in acceptance of longer time gaps, as reported also for pedestrians from Iran (Arman et al., 2015). In all locations, longer waiting times consistently increased the accepted gaps, indicating observed risk-avoidant behavior among some pedestrian groups. The same was also found in the core intersections of Dhaka (Zafri et al., 2020).

In all the locations, several multiple linear regression models included age, gender, crossing speed and waiting time as predictors in accepted gap size but baggage handling was only at Gollamari. These models are rather moderate and high in explanatory power (0.55 to 0.70). The results align with the work which is carried out in other fields and highlight the ability of these variables to predict (Kadali et al., 2015; Rezwana & Lownes, 2025; Zhang et al., 2018). In addition, the test of this model also gives an insight into the predictors of pedestrians in mixed traffic environments.

The critical gaps calculated by the Raff's method were dissimilar (Shibbari: 4.10 s, Sonadanga: 3.90 s, Gollamari: 2.87 s) depending on the differences in the local traffic conditions and the attention of people. This range is consistent with findings from other research indicating that critical gaps differed based on the complexity of the intersections and vehicle speed (Alhajyaseen et al., 2013; Shaaban & Hamad, 2020). The lower critical gap at Gollamari indicates pedestrian vulnerability amongst high traffic loads, a novel finding for the urban area of Khulna. Many of the gap acceptance factors identified in this study are like those reported in previous studies. Spatial variance across crossings within Khulna city is also covered in this research study. This change in the number of groups and interesting age-related behavior (gap acceptance of children vs adults) offers added information, which needs more socio-traffic research.

The general findings of the descriptive analysis, hypothesis test, critical gap estimation and regression modeling take a detailed and consistent meaning of pedestrian gap acceptance behavior in unsignalized intersection. To test the statistically significant correlations between the risk factors and the gap decision-making are conducted using hypothesis testing and to give a general account of the trends of pedestrian crossing, descriptive statistics are used. The critical gap estimation is the lowest time margin that pedestrians consider safe to permit them to cross over the road. The behavioral threshold so calculated is then used in the regression model with the size of the gap relative to the critical gap serving an influential predictor of pedestrian choice making. These similarities of the analytical methods render the results more rigid and the conclusions of the research more convincing in the frames of the study results on the pedestrian behavior and safety at the uncontrolled intersections. The new validated prediction models can be used to conduct evidence-based decision making to guide at designing pedestrian crossings to increase safety and the critical gap estimates will be used as benchmarks to other similar secondary cities in designing and regulating intersections.

AI DECLARATION STATEMENT

The authors of this study had not used any type of Artificial Intelligence (AI) in methodology of this study, for doing any research, creating any model or writing this manuscript.

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