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Analysis of Pedestrian Crossing Speed and Waiting Time at Intersections in Dhaka

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Received: 23 May 2019; Accepted: 30 June 2019; Published: 2 July 2019

Abstract: Pedestrian crossing speed and waiting time are critical parameters for designing traffic signals and ensuring pedestrian safety. This study aimed to carry out microscopic level research on pedestrian crossing speed and waiting time at intersections in Dhaka. To fulfill this aim, crossing-related data of 560 pedestrians were collected from three intersections in Dhaka using a videography survey method. Descriptive and statistical analyses were carried out, and then two multiple linear regression (MLR) models were developed for these two parameters by using the collected data. From the results, 1.15 m/s was found to be the design pedestrian crossing speed. Results also show that the crossing speed of pedestrians was associated with intersection control type, gender, age, crossing type, crossing group size, compliance behavior with control direction, and crossing location. In case of waiting time, findings show that pedestrians did not want to wait more than 20–30 s to cross the road. Furthermore, the waiting time of the pedestrians varied with intersection control type, gender, age, minimum gap, waiting location, and vehicle flow. Findings of this study will help to alleviate traffic safety problems by designing an effective intersection control system.

Keywords: crossing speed; waiting time; pedestrian safety; intersection control type; multiple linear regression; Dhaka

1. Introduction

Most of the daily trips are made on foot in Bangladesh, just like many other low-income and developing countries, and a recent study indicated that 42% of trips were made on foot in Dhaka City, the capital city of Bangladesh [1]. Unfortunately, pedestrians are the most vulnerable user group on the roadways of Dhaka. From the data of Accident Research Institute (ARI), Bangladesh University of Engineering and Technology (BUET), it is found that from 1998–2013, 28,244 pedestrian causalities occurred in Bangladesh (34% of all traffic-related causalities). Among them, 31% of the pedestrian causalities occurred while crossing a road [2]. In addition, the roadway environment of Dhaka is not pedestrian-friendly because of the lack of pedestrian facilities, faulty design, and improper maintenance [3]. Rahman and Khadem conducted a study on the physical and operational deficiency of signal system of Dhaka. They found that among the 70 signalized intersections, 84% were fixed time (FT) signal systems where the prefixed timing plan in those intersections did not match with the demand of actual flow [4]. Hasan also found a similar result in his study. He also added that the timing deficiency of traffic signals made the pedestrians and road users confused and increased difficulties [5]. Both studies concluded that the signal control system of Dhaka was not working properly.

Traffic signals are designed for improving the safety of pedestrians. Enough time should be provided in traffic signal phasing so that pedestrians can cross the road comfortably during the green signal phase [6]. This can be possible if the crossing speed of all pedestrian groups is considered at the time of installing traffic signals at crossing locations. In addition, the vulnerability of the pedestrians increases with the increase of waiting time since most of the pedestrians lose their patience over long waiting times and violate the direction of the traffic control system at the time of crossing the road [7–12]. To minimize the vulnerability, optimum signal timings should be designed by considering a tolerable waiting time for the pedestrians at intersections [13,14].

The Government of Bangladesh has shown interest in wanting to make the traffic signal control system functional recently [15,16]. In the case of installing traffic signals, no manual is available in Bangladesh. Generally, United States, British, and other internationally-recognized standards are followed for installing and operating traffic signals [17]. However, the crossing speed of pedestrians varies for each country. Tanaboriboon and Guyano showed that the speed of pedestrians is lower in Asia compared to Western countries [18]. Therefore, foreign guidelines may not be applicable in the context of Dhaka [19]. Hence, microscopic level research on pedestrian crossing speed and waiting time, and factors affecting these, is required for proper traffic management and pedestrian safety enhancement. For this reason, the objective of this study is to analyze pedestrian crossing speed and waiting time at intersections in Dhaka in detail. This outcome will help the policy-makers, planners, and engineers to provide facilities for intersections in a proper way and help to alleviate traffic crash risk.

2. Literature Review

The crossing speed of pedestrians is not the same all over the world. The 15th percentile crossing speed is suggested as the design speed value. Based on this, several studies found different design speeds and various design manuals set a variety of design speed standards. In the USA, the design speed is considered to be 1.21 m/s [20,21]. This value is 1.4 m/s in the case of Turkey [22]. In Jordan, Tarawneh recommended a design speed of 1.11 m/s [23]. The Institute of Transportation Engineers (ITE) Technical Committee 4A-6 recommended a lower pedestrian crossing speed: 0.75 m/s [24]. Wu et al. recommended a crossing speed of 0.85–0.93 m/s for four-way intersections in China [25]. Jain et al. showed in their study that the 15th percentile speed of pedestrians was approximately 1.56 m/s for India [26]. In addition, Brazil and Malaysia also considered a design speed of 1.21 m/s [27,28]. Goh et al. showed that the 15th percentile speed for Malaysia is 1.09 m/s and they summarized the mean crossing speed of pedestrians in different countries; these findings are shown in Table 1 [19].

Table 1. Mean speed in different countries [19].

Country	Mean Walking Speed (m/s)
Asia	
Riyadh, Saudi Arabia	1.08
Madras, India	1.20
Hong Kong	1.20
Thailand	1.22
Singapore	1.23
Colombo, Sri Lanka	1.25
Israel	1.39
Malaysia	1.31
Jordan	1.34
United States	
Columbia	1.32
New York	1.35
Pittsburgh	1.47
Others	
England	1.32
Calgary, Canada	1.40

A considerable number of studies have been conducted to analyze pedestrian crossing speed and factors that affect it at signalized [13,19,29–31] and unsignalized intersections [19,26,32,33]. Previous studies found that male pedestrians were significantly faster than female pedestrians while crossing the road [13,19,26,29–35]. While observing the impact of age on crossing speed, previous studies suggest that with the increase of the age, pedestrian crossing speed tends to slow down [13,19,26,29,30,32,34,35]. Previous studies also show that the speed of the pedestrians who cross the road alone is higher than the pedestrians who cross in a group [13,31,36,37]. Furthermore, pedestrians who handle baggage cross the road slower than pedestrians who do not handle any baggage [13,26,37]. On the other hand, Peters et al. did not find any impact of baggage handling on crossing speed of the pedestrian [31]. The use of a mobile phone while crossing also leads to a decrease in the crossing speed [38,39]. Studies also show that crossing pattern, road width, and traffic volume also influence the crossing speed of the pedestrian [26,37]. It is also found that the crossing speed of a pedestrian differs with the physical ability of the pedestrian. Crossing speed is significantly lower for physically disabled pedestrians, especially wheelchair users [36,40,41]. Song et al. calibrated a multiple linear regression model for investigating pedestrian crossing speed. Results of this model showed that crossing speed varied with gender, age, crossing by direction, one-time crossing, running across the street, and crossing while talking [42].

Previous studies have suggested that waiting time is also an important traffic signal design parameter. From a study of Wang et al. it is found that 50% of pedestrians did not wait longer than 40 s [12]. Jain et al. found in their study that waiting time of the pedestrian at unsignalized intersection varies from 1–6 s [26]. They found that female and older pedestrian wait more time than male and younger-aged pedestrians. Mako showed in his study that the average waiting time of pedestrians was about 5.1 s at an unsignalized intersection [43]. Li showed that the average waiting time while crossing at a signalized intersection was 48.2 s [7]. He also showed that the waiting time of males and young pedestrians was less than female and older pedestrians. Hamed found that approaching traffic volume and vehicle speeds were influential in determining the waiting time of the pedestrians [44].

3. Materials and Methods

3.1. Data Collection

Data were collected from three intersections in Dhaka city: Gulshan-2, Bangla Motor, and Shyamoli intersections. The intersection control type for these three intersections was different from each other. The Gulshan-2 intersection was a signalized intersection, whereas Bangla Motor intersection was a traffic-police-controlled intersection. Shyamoli intersection was an unsignalized intersection. Geometric characteristics of these intersections were almost the same. Pedestrian characteristics, behavior, and traffic-related data were collected using a videography survey method from 11:30 am to 12:30 pm on Wednesday, 2 January 2019, in good weather. Screenshots were taken from videos at five-minute intervals and all the required data of all the pedestrians presented in the screenshots were manually extracted from the videos. From the three studied intersections, a total of 560 pedestrians' data were extracted.

3.2. Data Analysis

Extracted data were analyzed in three steps. First, descriptive analyses were carried out. Then, the impact of intersection control type, pedestrian characteristics, crossing type, crossing behavior, and traffic condition on pedestrian crossing speed and waiting time was analyzed by various statistical tests. Parametric statistical tests were carried out to fulfill some assumptions such as normality, homogeneity of variances, and so on. If parametric tests failed to fulfill any assumption, then nonparametric tests were carried out. Finally, two multiple linear regression (MLR) models were developed for examining the crossing speed and waiting time in detail. For developing the model, predictors were identified first from the literature and then finalized by incorporating the results of statistical analyses. After finalizing the predictors, several MLR models were developed and a best fit model was identified based on the highest R^2 value.

MLR is the most common form of regression analysis. An MLR model is a statistical tool for understanding the relationship between a dependent variable and one or more independent variables [45–47]. Generally, the relationship between the predictors is given as in Equation (1):

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

Here, Y is the dependent variable; β_i (i = 0, 1, . . . , n) indicates the regression coefficients, which are generally estimated by ordinary least squares (OLS) method; and X_i (i = 0, 1, . . . , n) indicates the predictors.

Four assumptions need to be fulfilled for developing a good MLR model: a linear relationship between the dependent variable and the predictors, absence of multicollinearity issues within the predictors, a constant variance within the error term (no heteroscedasticity), and the residuals should be normally distributed [47–49].

4. Results and Discussion

4.1. Crosing Speed

4.1.1. Descriptive Analysis

From the results of this study, it is found that the mean crossing speed of pedestrians was 1.265 m/s (Table 2). This mean crossing speed is lower than several previous studies [13,19,23,26,36]. Goh et al., Tarawneh, and Onelcin and Alver showed in their studies that the mean crossing speed was about 1.31 m/s [13,19,23]. Several studies were found where mean crossing speed was lower than 1.265 m/s [6]. Dündar showed the mean crossing speed in Turkey was 1.20 m/s [6]. The mean crossing speed of this present study was compared with the mean crossing speed of Table 1. It shows that the mean crossing speed of this study is consistent with Asian countries. The median and mode crossing speed of the pedestrian was estimated to be 1.259 m/s and 1.000 m/s, respectively. The 15th percentile value was found to be 0.939 m/s. Descriptive statistics about the crossing speed of the pedestrians are given in Table 2.

Table 2. Descriptive statistics of pedestrian crossing speed.

		Speed (m/s)
Mean		1.265
Median		1.259
Mode		1.000
Std. Deviation		0.337
Minimum		0.357
Maximum		2.566
Percentiles	15	0.939
	50	1.259
	85	1.574

For estimating the design pedestrian crossing speed, the 15th, 50th, and 85th percentile crossing speeds were determined for the three types of intersection (Figure 1). The 15th percentile crossing speed of a signalized intersection was found to be 1.15 m/s. This value is recommended as the design speed for a signal timing design in the context of Dhaka. This value is higher than the prescribed designed speed in ITE [24], Tarawneh [23], Wu et al. [25], Goh et al. [19], and Dündar [6], but lower than Transportation Research Board (TRB) [20], Federal Highway Administration (FHWA) [21], Turkish Standards Institute (TSI) [22], and others.

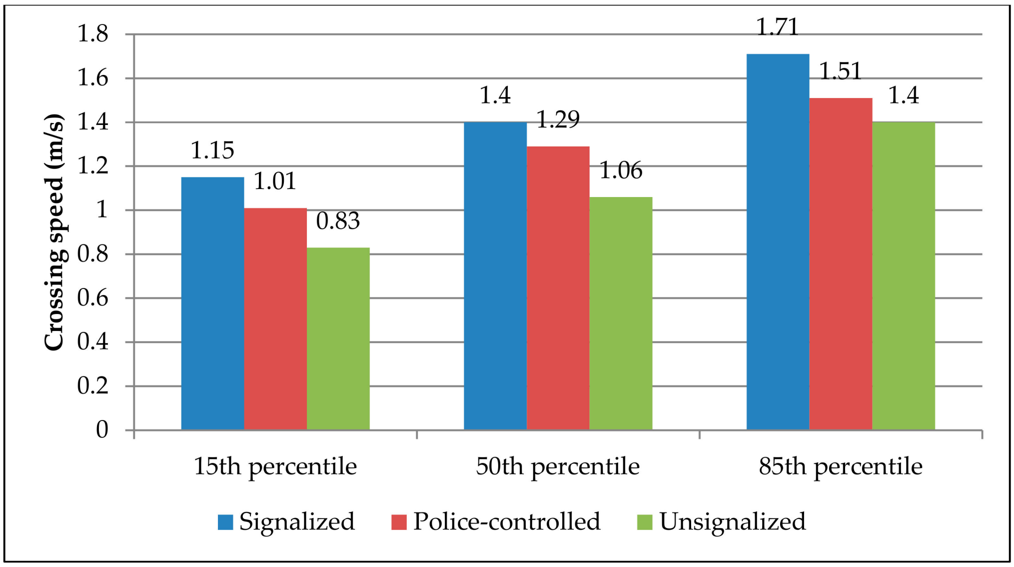

Figure 1. Pedestrian crossing speed by intersection control type.

4.1.2. Factors Affecting Pedestrian Crossing Speed

To find the impact of the intersection control type, pedestrian characteristics, crossing type, crossing behavior, and traffic condition on the pedestrian crossing speed, various parametric, and nonparametric statistical tests were carried out. For conducting those tests, first, the outlier values of crossing speed were checked using a stem-and-leaf test. A crossing speed less than 0.36 m/s or greater than 2.13 m/s were considered as outliers, and those values were not considered in the analyses. The normality of crossing speed was checked using Kolmogorov–Smirnov test; the *p*-value was found to be 0.089. Therefore, crossing speed was normally distributed for this *p*-value at the 95% confidence level. As the dependent variable (crossing speed) was normally distributed, an ANOVA test was carried out for the categorical predictors having more than two outcomes to identify the influential factors; an independent *t*-test was carried out for the predictors having two outcomes. Levence's test was carried out to examine the equality of variances between two or more groups. If the result of this test was not significant (p-value > 0.05) then the variances were equal. In this case, statistics found for one-way ANOVA test were used to evaluate the relationship between crossing speed and predictors, and the Tukey post hoc test was carried out for further analysis. Otherwise, Welch's ANOVA test statistics were used instead of a one-way ANOVA for evaluating the relation, and Games–Howell post hoc test was used instead of a Tukey post hoc test. Levence's test result was also considered in the case of selecting results from an independent *t*-test. Vehicle flow was the only continuous predictor that was not normally distributed. Therefore, Kendall's tau-b correlation test was carried out between the dependent variable and vehicle flow. Results of the statistical analyses are presented in the following sections.

Intersection control type: Intersection control type, one of the most important predictors, significantly influenced the crossing speed of the pedestrians (Table 3). It was found from the Tukey post hoc test results that crossing speed was significantly lower at unsignalized intersection than signalized and traffic-police-controlled intersections. This is an expected result because the interaction between vehicles and pedestrians is higher at unsignalized intersections than other types; as a result, pedestrian crossing speed reduces. Another important finding of the test was that speed at a signalized intersection was significantly higher than for a traffic-police-controlled intersection (Table 3).

Gender: An independent *t*-test was carried out to examine the effect of gender on crossing speed. This study found that the crossing speed of male pedestrians was significantly higher than female pedestrians (Table 3). This result is consistent with the previous studies' findings [13,19,26,29–34].

Age: To understand the relationship between crossing speed and the age of the pedestrian, a one-way ANOVA test was conducted. This test result showed that the crossing speed of the pedestrian decreased with increasing age. To get a clearer picture of the relationship, Tukey's post hoc test was conducted. Results of this test showed that young pedestrians had the highest mean speed and it decreased significantly with the increase or decrease of pedestrians' age. Speed of the adult pedestrians was found to be significantly higher than the old pedestrians. No significant variation was found between the crossing speed of the adult and child pedestrians, as well as between children and the old pedestrians (Table 3). These findings are also similar with previous studies [13,19,26,29,30,32,34].

Crossing types: Types of crossing are also an important factor that can influence the crossing speed of pedestrians. A Welch's ANOVA test result suggested a close association between the types of crossing (crossing stage, crossing direction, and crossing pattern) and crossing speed of the pedestrians (Table 3). A Games–Howell post hoc test revealed that the crossing speed of pedestrians who crossed the road using a rolling gap was significantly lower than the crossing speed of the pedestrians who crossed the road using a single stage or two stages. This finding is similar to Jain et al. [26]. The crossing speed of the pedestrians was also higher for a single stage than a two-stage crossing type. In the case of crossing pattern, crossing speed was found to be significantly higher for pedestrians who crossed the road by running than those who crossed the road by walking. A similar result was found by Song et al. [42]. A Games–Howell post hoc test also suggested that crossing speed was significantly higher for the pedestrians who crossed the road in a perpendicular direction compared with other directions. This finding differs from the findings of Jain et al. [26]. Pedestrians crossed the road perpendicular when traffic flow is low. Therefore, few interruptions occurred for perpendicular crossings, which increased the speed of the pedestrians. However, there was no significant difference between the oblique and mixed type of crossing (Table 3).

Crossing group size: A significant relationship was found between crossing group size and crossing speed (Table 3). Pedestrians who crossed the road alone had a higher crossing speed than who crossed the road in groups. This finding also matches with previous studies' findings [13,31,36,37].

Baggage handling: A one-way ANOVA test was carried out to find the influence of baggage handling on crossing speed. The result showed a significant relationship between crossing speed and baggage handling (Table 3). A Tukey post hoc test showed that crossing speed was significantly lower for the pedestrians who carried light and medium weight baggage compared to the pedestrians who did not carry any baggage. There was no significant relationship between light and medium weight baggage-carrying pedestrians (Table 3). This result is consistent with previous studies [13,26,37].

Mobile usage: Table 3 shows that the usage of a mobile phone did not have any impact on crossing speed of the pedestrians. However, this finding does not match previous studies' results [38,39].

Compliance with control direction: Compliance with traffic signals or traffic police direction was analyzed to explore the effect of pedestrian compliance behavior on crossing speed. A significant statistical relationship was found from the result of Welch's ANOVA test (Table 3). In the case of compliance with the control direction, a Game–Howell post hoc test suggested that pedestrians who did not comply with signals or traffic police direction had a lower crossing speed as they were interrupted by vehicles in the roadway while crossing when compared with pedestrians who fully or partly complied.

Crossing location: Crossing location had a significant impact on crossing speed (Table 3). Pedestrians who crossed the road in a conflict zone had a lower crossing speed than pedestrians who crossed using a crosswalk or near a crosswalk. It was also found that the speed of the pedestrians was higher for those who crossed the road near a crosswalk location than those who used a crosswalk. Behbahani et al. showed that crossing speed is higher at marked crosswalks than unmarked ones [14]. Therefore, the findings of this study partially match with Behbahani et al. as crossing speed was lower at crosswalks than near crosswalk locations [14]. This may be because a large number of vehicles stopped on the crosswalk at a red signal phase, which interrupted the pedestrians while crossing.

Vehicle flow: A Kendall's tau-b correlation test result showed that the speed of the pedestrians was negatively correlated with vehicle flow (Table 3). This finding matches with the finding of Dündar [6].

Table 3. Results of statistical analyses.

Variable	N	Mean	Std. Dev.	Statistical Test Details
Intersection Control Type				
Signalized	208	1.39	0.27	$F = 40.138$, $p = 0.000$
Police-controlled	142	1.27	0.27	
Unsignalized	198	1.08	0.26	
Tukey Post Hoc Test (Levence Statistic: p-value = 0.731) Signalized vs. Police-controlled: $p = 0.000$, Signalized vs. Unsignalized: $p = 0.000$, and Unsignalized vs. Police-controlled: $p = 0.000$				
Gender				
Male	444	1.28	0.30	$t = -6.363$, $p = 0.000$
Female	104	1.10	0.24	
Age				
Children	14	1.11	0.33	$F = 15.961$, $p = 0.000$
Young	330	1.30	0.29	
Adult	178	1.19	0.29	
Old	26	0.95	0.21	
Tukey post hoc test (Levence statistic: p-value = 0.084) Young vs. children: $p = 0.073$, young vs. adult: $p = 0.000$, young vs. old: $p = 0.000$, adult vs. children: $p = 0.724$, adult vs. old: $p = 0.000$, and children vs. old: $p = 0.359$				
Crossing Stage				
Single stage	198	1.38	0.24	$F = 44.480$, $p = 0.000$
Two stage	86	1.27	0.24	
Rolling gap	264	1.13	0.31	
Games–Howell post hoc test (Levence statistic: p-value = 0.001) Single stage vs. two stage: $p = 0.003$, single stage vs. rolling gap: $p = 0.000$, and two stage vs. rolling gap: $p = 0.000$				
Crossing Pattern				
Walking	422	1.21	0.27	$t = 4.124$, $p = 0.000$
Running	126	1.35	0.35	
Crossing Direction				
Perpendicular	300	1.28	0.27	$F = 4.245$, $p = 0.017$
Oblique	42	1.21	0.37	
Mixed	206	1.20	0.32	
Games–Howell post hoc test (Levence statistic: p-value = 0.000) Perpendicular vs. oblique: $p = 0.496$, perpendicular vs. mixed: $p = 0.013$, and oblique vs. mixed: $p = 0.987$				
Crossing Group Size				
Alone	380	1.29	0.30	$t = 4.928$, $p = 0.000$
Group	168	1.15	0.28	
Baggage Handling				
No	362	1.27	0.29	$F = 5.964$, $p = 0.003$
Light	164	1.20	0.29	
Medium	22	1.10	0.36	
Tukey post hoc test (Levence statistic: p-value = 0.365) No vs. light: $p = 0.034$, no vs. medium: $p = 0.020$, and light vs. medium: $p = 0.261$				

Table 3. *Cont.*

Variable	N	Mean	Std. Dev.	Statistical Test Details
Mobile Usage				
Yes	14	1.34	0.36	$t = -1.210$
No	534	1.24	0.30	$p = 0.227$
Compliance with Control Direction				
Full	136	1.34	0.21	$F = 31.554$
Partial	140	1.35	0.29	$p = 0.000$
No	272	1.15	0.31	
Games–Howell post hoc test (Levence statistic: p-value = 0.000) No vs. partial: $p = 0.000$, No vs. full: $p = 0.000$, and full vs. partial: $p = 0.928$				
Crossing Location				
Crosswalk	124	1.27	0.22	$F = 28.778$
Near crosswalk	104	1.42	0.28	$p = 0.000$
Conflict zone	318	1.18	0.31	
Games–Howell post hoc test (Levence statistic: p-value = 0.000) Crosswalk vs. near crosswalk: $p = 0.000$, crosswalk vs. conflict zone: $p = 0.009$, and near crosswalk vs. conflict zone: $p = 0.000$				
Vehicle Flow				
Vehicle flow	548			$\tau_b = -0.240$ $p = 0.000$

4.1.3. Model Development

An MLR model was developed to show how and to what extent different factors influence the crossing speed of the pedestrians. For developing the model, predictors were identified first from the literature and then finalized using statistical analyses. Then, the assumptions of the MLR were checked. Finally, a best fit model was developed by using Statistical Package for the Social Sciences (SPSS) version 17 software. Detailed description of model development is given in the following section.

Model Variables

Predictors for developing the MLR model were identified and processed from the findings of the previous section (Section 4.1.2), where effects of different factors on the crossing speed of pedestrians were analyzed using different parametric and non-parametric statistical tools. Factors that were found to significantly correlate with crossing speed of the pedestrians were considered for this model. The children pedestrian group and mobile usage were not considered for developing the model. Furthermore, no significant variation was found for light and medium baggage handling on crossing speed; therefore, these two outcomes were merged and considered as a single outcome. Finally, dummy variables were created for the categorical variables having more than two outcomes.

Multiple Linear Regression (MLR) Model Estimation and Discussion

After finalizing the predictors, several MLR models were developed and a best fit model was identified based on the highest R^2 value. There were several assumptions that needed to be fulfilled for multiple linear regression analysis, which were checked for the best-fitting model. First, multicollinearity among predictors was checked using a variance inflation factor (VIF) test. Multicollinearity among the predictors was not found as no value of VIF was greater than 6 (Table A1). Another assumption of MLR is that continuous predictors should be linearly associated with the dependent variable. However, no continuous predictor was present in the developed model. From the probability-probability (P-P) plot graph, it is clear that the residuals of the developed model were normally distributed (Figure A1). A scatter plot between the regression standardized residual and regression standardized predicted value showed that MLR was homoscedastic (Figure A2). Therefore, all the assumptions were fulfilled by the developed model.

Table 4 shows an R^2 value that indicates the percentage of variation in the dependent variable that can be explained by the predictors. The value of R^2 was 0.391 for this study, which means that with the given parameters, 39.1% of changes in the crossing speed could be described by the observed data. The R^2 value of Song et al.'s developed crossing speed model was 45.5%, which is close to the R^2 value of this model [42]. An F-test value determined whether the model was a good fit for the data. Here, the p-value of the F-test was 0.000, which indicates the overall model was significant (Table 5).

Table 4. Model summary of the developed MLR model.

R	*R* Square	Adjusted *R* Square	Std. Error of the Estimate
0.625	0.391	0.376	0.240

Table 5. ANOVA table for the developed MLR model

	Sum of Squares	*df*	Mean Square	*F*	Sig.
Regression	19.757	013	1.520	26.385	0.000
Residual	30.759	534	0.058		
Total	50.516	547			

Table 6 shows the values of the coefficients of the predictors and their significance level. The predictors significance levels show that, except for adult and baggage handling predictors, all the predictors were statistically significant at a 95% confidence level. From this table, it is found that the pedestrian crossing speed at a signalized intersection and traffic-police-controlled intersection was 0.32 and 0.25 times higher than at an uncontrolled intersection, holding other predictors constant. Comparing the coefficient values of all predictors, it was clear that the intersection control type had the highest impact on crossing speed. In the case of gender, it was found that the crossing speed of the male pedestrians was 0.116 times higher than the female ones, holding other predictors constant. It was also found that the speed of the adult and old pedestrians was lower than the young pedestrians. The speed of the pedestrians increased for single stage and two stage crossing types than the rolling gap crossing type. The crossing speed decreased 0.075 times if the pedestrians crossed the road by walking compared to running, holding other predictors constant. Pedestrian speed also increased when showing full compliance and partial compliance behavior compared to noncompliance behavior. The speed of the pedestrians was 0.063 times higher for the pedestrians who crossed the road near a crosswalk location compared to those who used a crosswalk, holding other predictors constant. Crossing speed decreased if the pedestrians carried any baggage while crossing. This model is shown in the following Equation (2):

$$\begin{aligned} \textit{Crossing Speed} &= 0.862 + 0.325\,SI + 0.254\,TI + 0.116\,G - 0.166\,O + 0.186\,SS \\ &+ 0.098\,TS - 0.075\,CP - 0.106\,CG + 0.188\,FC + 0.166\,PC \\ &+ 0.063\,CL \end{aligned} \quad (2)$$

where Crossing Speed = crossing speed of pedestrian, SI = signalized (if signalized = 1, otherwise = 0), TI = traffic-police-controlled (TPC) (if TPC = 1, otherwise = 0), G = gender (if male = 1, otherwise = 0), O = old (if old = 1, otherwise = 0), SS = single-stage (if single-stage = 1, otherwise = 0), TS = two-stage (if two-stage = 1, otherwise = 0), CP = crossing pattern (if walk = 1, otherwise = 0), CG = crossing group (if group = 1, otherwise = 0), FC = full compliance (if full compliance = 1, otherwise = 0), PC = partial compliance (if partial compliance = 1, otherwise = 0), and CL = crossing location (if near crosswalk = 1, otherwise = 0).

Table 6. Estimated parameter values of MLR model.

Variables	Coef.	Std. Error	t	p-Value
Constant	0.862	0.121	7.112	0.000
Intersection Control Type				
Signalized (if signalized = 1, otherwise = 0)	0.325	0.047	6.978	0.000
Traffic-police-controlled (TPC) (if TPC = 1, otherwise = 0)	0.254	0.036	7.068	0.000
Gender				
Gender (if male = 1, otherwise = 0)	0.116	0.028	4.158	0.000
Age				
Adult (if adult = 1, otherwise = 0)	−0.032	0.023	−1.382	0.167
Old (if old = 1, otherwise = 0)	−0.166	0.051	−3.280	0.001
Crossing Type				
Single-stage (if single-stage = 1, otherwise = 0)	0.186	0.048	3.864	0.000
Two-stage (if two-stage = 1, otherwise = 0)	0.098	0.049	1.977	0.049
Crossing pattern (if walk = 1, otherwise = 0)	−0.075	0.014	−5.247	0.000
Crossing Group Size				
Crossing group (if group = 1, otherwise = 0)	−0.106	0.025	−4.216	0.000
Compliance Behavior				
Full compliance (if full compliance = 1, otherwise = 0)	0.188	0.056	3.364	0.001
Partial compliance (if partial compliance = 1, otherwise = 0)	0.166	0.052	3.198	0.001
Others				
Crossing location (if near crosswalk = 1, otherwise = 0)	0.063	0.030	2.080	0.038
Baggage handling (if handle = 1, otherwise = 0)	−0.030	0.022	−1.344	0.180

4.2. Waiting Time of Pedestrians

4.2.1. Descriptive Analysis

Waiting time of the pedestrians is another important design parameter as the exhibition of risky behavior increased for long waiting times at intersections. From Figure 2, it is found that almost one-fourth of the pedestrians did not wait at intersections and 42% of the pedestrians waited less than 10 s. Only 10% of the pedestrians waited more than 40 s. Figure 3 presents the waiting time of pedestrians for the three types of intersection. From this result, it can be concluded that pedestrians of these three intersections did not want to wait more than 20 s, which is significantly lower than the findings of Wang et al. [14]. Therefore, signal phasing should be designed in such a way that pedestrians do not need to wait more than 20–30 s.

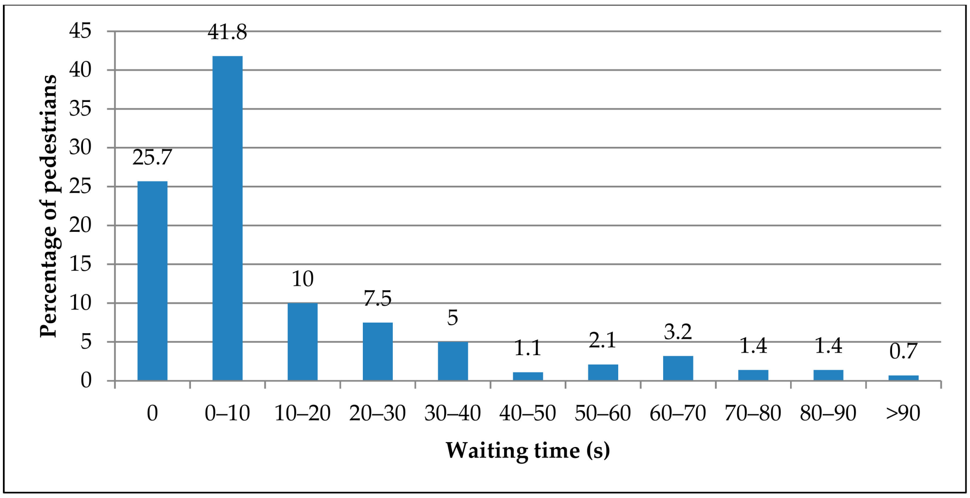

Figure 2. Waiting time of pedestrian at intersections.

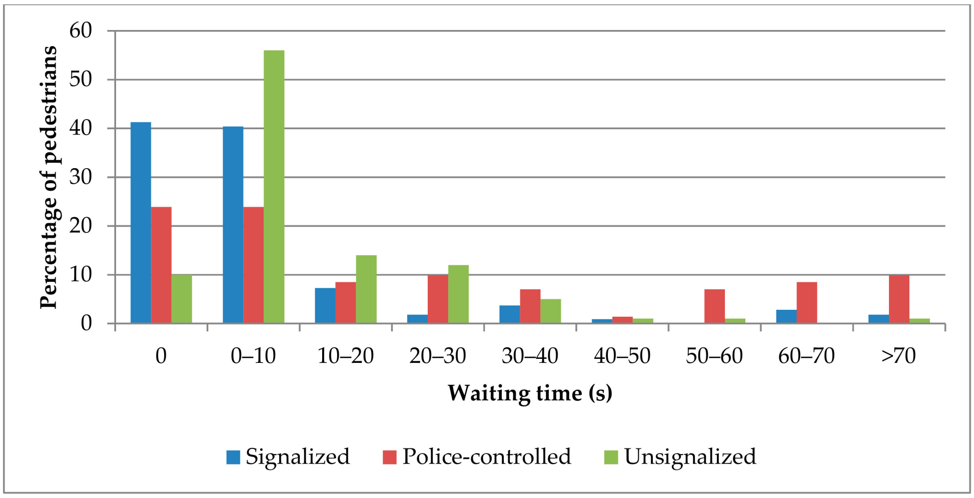

Figure 3. Waiting time of pedestrian by intersection control type.

4.2.2. Factors Affecting Pedestrian Waiting Time

To examine waiting time of the pedestrians, several factors were considered such as intersection control type, gender, age, crossing group size, minimum gap, waiting location, compliance with control direction, and vehicle flow. Here, an ANOVA test cannot be performed as the dependent variable (pedestrian waiting time) was not normally distributed. Instead of an ANOVA test, a Kruskal–Wallis H test was conducted for the predictors containing more than two categories of outcomes, whereas a Mann–Whitney U test was used for predictors with two outcomes. A post hoc test could not be performed as the data was not normally distributed; therefore, a Mann–Whitney U was carried instead of post hoc test. Kendall's Tau-b test was performed for continuous variables in this study. Findings of these analyses are presented below.

Intersection control type: Intersection control type had a significant influence on the pedestrians' waiting time as per the *p*-value (Table 7). According to the result of the Kruskal–Wallis H test, the mean pedestrian waiting time was much higher at the traffic-police-controlled intersection than the both signalized and unsignalized intersections. Again, pedestrians had to wait for less time at a signalized intersection than an unsignalized intersection. However, the standard deviation of the unsignalized intersection was much lower than the signalized intersection, which indicates that variation in waiting time at the signalized intersection was much higher. A Mann–Whitney U test was also conducted to see the pairwise relationship. A significant relationship was found for all pairs (Table 7).

Table 7. Results of statistical analysis between waiting time and factors influencing it.

Variable	N	Mean	Std. Dev.	Statistical Test Details
Intersection Control Type				
Signalized	218	8.33	16.43	$\chi^2 = 57.504$
Police controlled	142	25.32	28.31	$p = 0.000$
Unsignalized	200	11.30	12.62	
Signalized vs. police-controlled: $p = 0.000$, signalized vs. unsignalized: $p = 0.000$, and unsignalized vs. police-controlled: $p = 0.011$				
Gender				
Male	456	13.21	20.82	$U = 19{,}764$
Female	104	15.83	17.65	$p = 0.007$
Age				
Children	014	16.14	10.56	
Young	342	10.15	16.69	$\chi^2 = 43.847$
Adult	178	18.00	23.65	$p = 0.000$
Old	026	29.53	28.46	
Young vs. children: $p = 0.005$, young vs. adult: $p = 0.000$, young vs. old: $p = 0.000$, adult vs. children: $p = 0.254$, adult vs. old: $p = 0.014$, and children vs. old: $p = 0.460$				
Crossing Group Size				
Alone	392	10.17	16.03	$U = 24814$,
Group	168	21.92	26.03	$p = 0.000$
Minimum Gap				
Small (0- 3 s)	276	11.48	16.20	$\chi^2 = 92.720$
Medium (3-6 s)	148	22.82	25.34	$p = 0.000$
Large (>6 s)	136	8.27	18.41	
Small vs. medium: $p = 0.000$, medium vs. large: $p = 0.000$, and small vs. large: $p = 0.000$				
Waiting Location				
Sidewalk	90	32.81	27.01	$U = 3266.00$
On road	94	21.81	23.09	$p = 0.014$
Compliance with Control Direction				
Full	138	7.69	17.91	$\chi^2 = 100.280$
Partial	148	13.20	21.51	$p = 0.000$
No	274	16.99	20.07	
No vs. partial: $p = 0.000$, no vs. full: $p = 0.000$, and full vs. partial: $p = 0.000$				
Vehicle Flow				
Vehicle flow	560			$\tau_b = 0.408$ $p = 0.000$

Gender: A Mann–Whitney U test was carried out to examine the effect of a pedestrian's gender on their waiting time. The result of this test showed that female pedestrians waited for more time than male pedestrians. This result was also statistically significant (Table 7). A similar finding was found in the studies of Jain et al. and Li [7,26].

Age: A Kruskal–Wallis H test was conducted to explore the relationship between different age groups and waiting time. Results of the test showed that old pedestrians waited more time than other age groups. On the contrary, it was found that young pedestrians waited less time at intersections. No variation was found between the waiting time of the children with adults and old pedestrians (Table 7). This finding is consistent with the findings of previous studies [7,26].

Crossing group size: For this predictor, a Mann–Whitney U test was performed as it had two outcomes. Pedestrians tended to wait more time when they crossed in groups than being alone (Table 7).

Minimum gap: The minimum gap accepted by pedestrians was categorized in terms of three outcomes, as per Table 7. Pedestrians who accepted a large gap tended to wait less time than pedestrians accepting small or medium gaps. Usually, pedestrians accepted large gap means there was sufficient space on the roadway available for safe crossing. As a result, pedestrians crossed the road easily without waiting for a long time.

Waiting location: The results from the Mann–Whitney U test showed that pedestrians who waited at a sidewalk waited a longer time than pedestrians who waited on the road (Table 7).

Compliance with control direction: A Kruskal–Wallis H test result indicated that pedestrians showing noncompliance behavior waited a longer time than full and partial compliance (Table 7). This was because, for increasing waiting time, pedestrians lost their patience and violated the direction of the control mechanism.

Vehicle flow: The result of Kendall's Tau-b test showed significant positive association between vehicle flow and pedestrian waiting time (Table 7). This result is consistent with the result of Hamed [44].

4.2.3. Model Development

Model Variables

Predictors for developing the MLR model were identified and processed using the findings of the previous section (Section 4.2.2), where effects of different factors on the waiting time of pedestrians were analyzed by different non-parametric statistical tools. Factors that were found to be significantly correlated with waiting time of the pedestrians were considered for this model. Finally, dummy variables were created for the categorical variables having more than two outcomes while developing the MLR model.

Multiple Linear Regression (MLR) Model Estimation and Discussion

After analyzing several MLR models, the following model was found as the best fit model with the highest R^2 value (0.508) (Table 8). The F-test result showed that the p-value was 0.000, which indicates that the overall model was significant (Table 9). The required assumptions were checked for the best fit model. A linear relationship between the dependent variable (ln(pedestrian waiting time)) and continuous predictors (vehicle flow) was found, as presented in Figure A3. The values of VIF were not found to be greater than four, which indicates the absence of multicollinearity among the predictors (Table A2). From the P-P plot graph, it is clear that the residuals of the developed model were normally distributed (Figure A4). The scatter plot between the regression-standardized residual and the regression-standardized predicted value shows that MLR was homoscedastic (Figure A5). Therefore, all the assumptions were fulfilled for this model.

Table 8. Model summary of the developed MLR model.

R	***R* Square**	**Adjusted *R* Square**	**Std. Error of the Estimate**
0.713	0.508	0.500	0.986

Table 9. ANOVA table for the developed MLR model.

	Sum of Squares	***df***	**Mean Square**	***F***	**Sig.**
Regression	553.32	9	61.48	63.13	0.000
Residual	535.56	550	0.97		
Total	1088.88	559			

Table 10 shows the coefficients, t-value, and p-value for each predictor. The predictor's p-value shows that, except for pedestrians with a small minimum gap, all the predictors were statistically significant at a 95% confidence level. In this model, the dependent variable was transformed by converting to a natural logarithm (ln(waiting time)) to get the best fitting model. From this table, it is found that the pedestrian waiting time at the signalized intersection and traffic-police-controlled intersections was higher than for the uncontrolled intersection. This result seems valid given the findings of previous studies [7,26]. From the coefficient values of all predictors, it is clear that the intersection control type had the highest impact on pedestrian waiting time. It is also found that male pedestrians waited less time than female pedestrians. In addition, adult and old pedestrians waited more time than young pedestrians. Pedestrian who accepted large gap waited less time than who accepted small or medium gap while crossing. Furthermore, pedestrians who waited at the sidewalk waited a longer time than pedestrians who waited on the road. The waiting time increased by 2.1% with the increase of one unit of vehicle flow, holding other predictors constant. This model is presented in the following Equation (3):

$$\begin{aligned} \ln(wait\ time) = \; & -3.000 + 0.958\, SI + 0.682\, TI - 0.408\, G + 0.208\, A - 0.715\, O \\ & + 0.410\, MG + 0.812\, WL + 0.021\, VF \end{aligned} \quad (3)$$

where, wait time = waiting time of pedestrian, SI = signalized (if signalized = 1, otherwise = 0), TI = traffic-police-controlled (TPC) (if TPC = 1, otherwise = 0), G = gender (if male = 1, otherwise = 0), A = adult (if adult = 1, otherwise = 0), O = old (if old = 1, otherwise = 0), MG = minimum gap (if medium = 1, otherwise = 0), and VF = vehicle flow (veh/min).

Table 10. Estimated parameter values of MLR model.

Variables	Coef.	Std. Error	t	p-Value
Constant	−3.000	0.510	−5.87	0.000
Intersection Control Type				
Signalized (if signalized = 1, otherwise = 0)	0.958	0.153	6.24	0.000
Traffic-police-controlled (TPC) (if TPC = 1, otherwise = 0)	0.682	0.139	4.89	0.000
Gender				
Gender (if male = 1, otherwise = 0)	−0.408	0.110	−3.71	0.000
Age				
Adult (if adult = 1, otherwise = 0)	0.208	0.093	2.23	0.026
Old (if old = 1, otherwise = 0)	0.715	0.208	3.44	0.001
Minimum Gap				
Small (if small = 1, otherwise = 0)	0.126	0.142	0.88	0.376
Medium (if medium = 1, otherwise = 0)	0.410	0.137	3.00	0.003
Others				
Waiting location (if sidewalk = 1, otherwise = 0)	0.812	0.122	6.64	0.000
Vehicle flow	0.021	0.001	13.9	0.000

* Dependent variable: ln(waiting time).

5. Conclusions

This study examined the pedestrian crossing speed and waiting time of pedestrians at intersections in Dhaka city. Finding of the crossing speed analysis showed that the mean pedestrian crossing speed was 1.26 m/s for the three studied intersections. The recommended design speed was found to be 1.15 m/s. Results of the statistical analyses showed that crossing speed was significantly lower at the unsignalized intersection than the signalized and traffic-police-controlled intersections. Females, children, and old pedestrians had a lower crossing speed than male, young, and adult pedestrians, respectively. In the case of crossing types, a higher speed was found for single-stage, two-stage, perpendicular, and running crossing types. Pedestrians who crossed the road alone and who did not carry any baggage had higher speeds. In the case of compliance behavior, pedestrians who did not comply with signals or traffic police directions had lower crossing speeds, as well as pedestrians that crossed the road using a conflict zone. Finally, it was found that the speed of the pedestrians negatively correlated with vehicle flow. For a better understanding, an MLR model was prepared for the crossing speed analysis, which showed that intersection control type, gender, age, crossing type, crossing group size, compliance behavior of pedestrians, and crossing location had a significant impact on crossing speed. In the case of waiting time, it was found that pedestrians did not want to wait more than 20 s. From the statistical analyses, it was found that the intersection control type played the most significant role in terms of the estimated waiting time. Pedestrians tended to wait more at the traffic-controlled intersection compared to the signalized and unsignalized intersections. Again, male pedestrians waited less time than female pedestrians. Pedestrians who waited at the sidewalk waited a longer time than pedestrians who waited on the road. In addition, the MLR model results showed that pedestrian waiting time depended on the intersection control type, gender, age, minimum gap, waiting location, and vehicle flow. In planning signal phase timing, the pedestrians' crossing speed should be considered to be 1.15 m/s and the waiting time of pedestrians should be minimized and not more than 20–30 s. These findings will help further in policy formulation and plan preparation; eventually, this will aid to address traffic safety problems through addressing them in engineering, enforcement, and education interventions. Furthermore, research should be conducted in future that considers the crossing speed and waiting time of disabled people and wheelchair users to design a more inclusive roadway.

Author Contributions: Conceptualization, N.M.Z. and A.I.R.; methodology, N.M.Z.; software, N.M.Z. and A.I.R.; formal analysis, N.M.Z.; investigation, N.M.Z. and A.I.R.; data curation, N.M.Z. and A.I.R.; writing—original draft preparation, N.M.Z.; writing—review and editing, N.M.Z. and A.I.R.; supervision, N.A.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Multicollinearity (VIF) test result.

Variable	VIF
Signalized	4.857
Traffic-police-controlled	2.356
Gender	1.130
Adult	1.151
Old	1.102
Single-stage	5.097
Two-stage	3.074
Crossing pattern	1.386
Crossing group	1.282
Full compliance	5.525
Partial compliance	4.889
Crossing location	1.348
Baggage handling	1.075

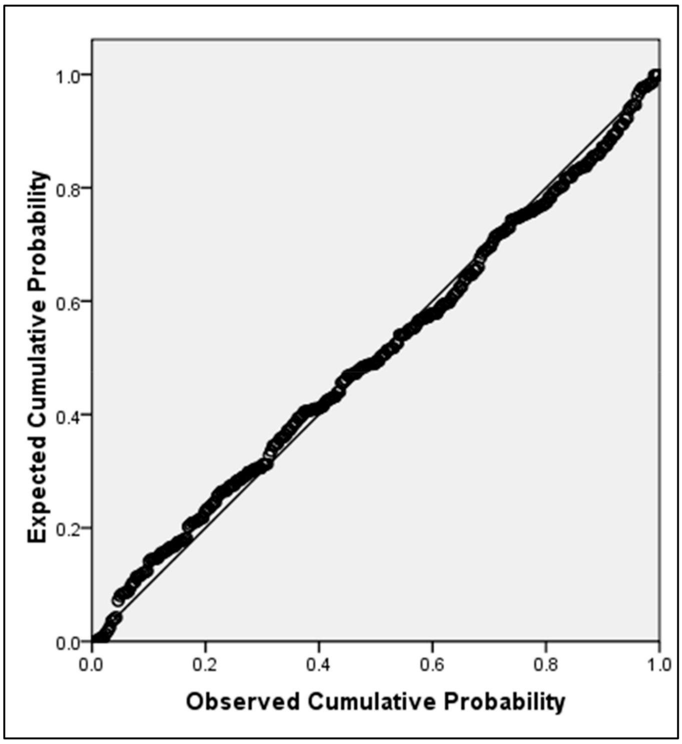

Figure A1. Normal P-P plot of regression standardized residual

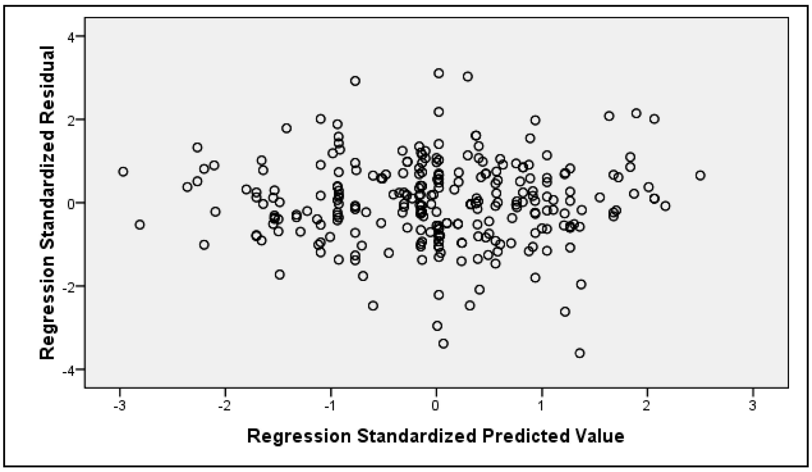

Figure A2. Scatter plot between the regression-standardized residual and the regression-standardized predicted value.

Table A2. Multicollinearity (VIF) test result.

Variable	VIF
Signalized	3.219
Traffic-police-controlled	2.117
Gender	1.053
Adult	1.083
Old	1.101
Small	2.905
Medium	2.086
Waiting location	1.157
Vehicle flow	2.756

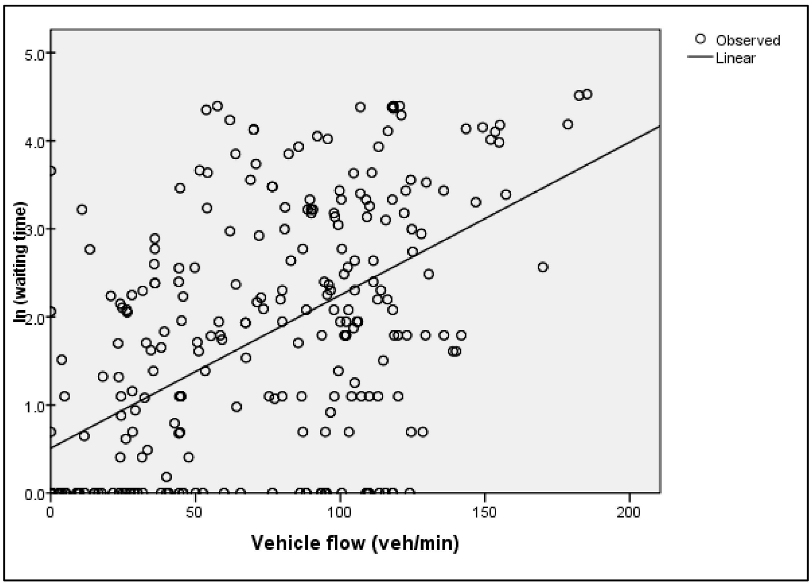

Figure A3. Linear relationship between ln(waiting time) and vehicle flow.

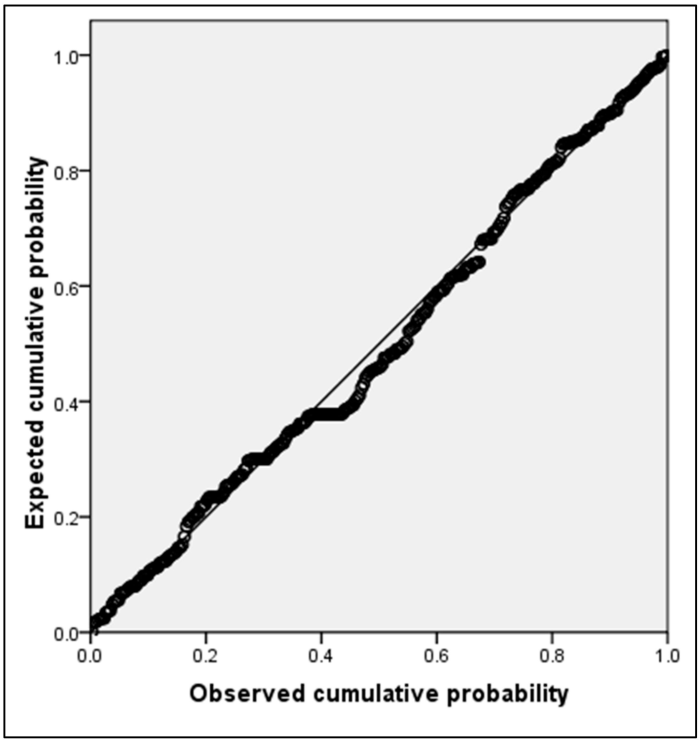

Figure A4. Normal P-P plot of regression standardized residual.

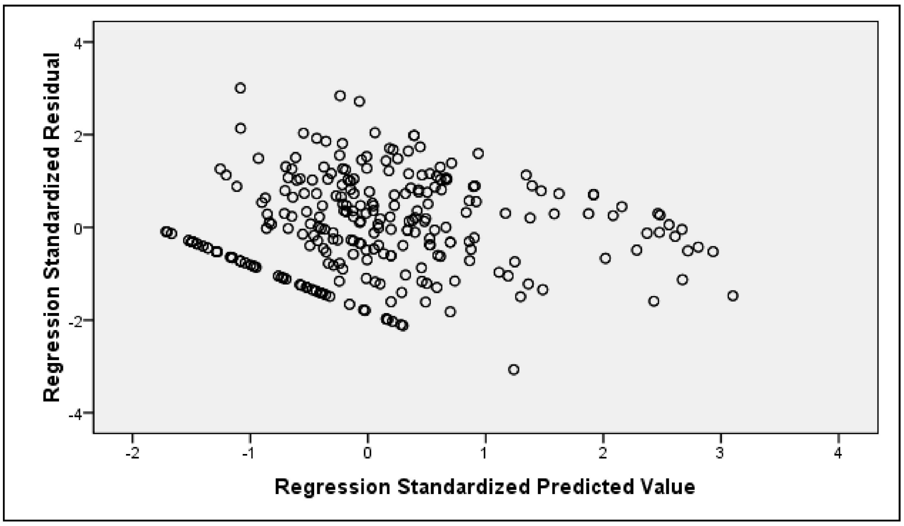

Figure A5. Scatter plot between the regression-standardized residual and the regression-standardized predicted value.

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