Pedestrian Facilities and Perceived Pedestrian Level of Service (PLOS): A Case Study of Chittagong Metropolitan Area, Bangladesh

Abstract
The promotion of active transport (a type of sustainable transportation) such as walking is a form of response against environmental pollution engendering from transport sector. Pedestrian Level of Service (PLOS) is a measurement tool to evaluate the degree of pedestrian accommodation on roadway to provide a comfortable and safe walking environment. The roadway characteristics-based model to measure PLOS has been widely applied since this approach is conceived as being transferable to different contexts. We present a comprehensive framework to measure the influence of pedestrian facilities on perceived PLOS qualitatively and quantitatively. We modelled triangular relationships among pedestrian facilities, perceived roadway conditions (accessibility, safety, comfort, and attractiveness), and perceived PLOS to identify pedestrian facilities, related to footpath, carriageway, and transit, influencing perceived PLOS. We developed these models for a case study of Chittagong Metropolitan Area in Bangladesh. Poor condition of pedestrian facilities in the region resulted in PLOS B as the highest tier of perceived PLOS. Findings of this study showed that accessibility and attractiveness influenced the perceived PLOS for footpath, carriageway, and transit, whereas safety is an important roadway condition for carriageway and transit facilities. We further measured the influence of 22 selected parameters of pedestrian facilities on roadway conditions and perceived PLOS. We concluded that achieving a better perceived PLOS is dependent on the availability, maintenance, and planning of different pedestrian facilities, as improper placement and poor condition of such facilities increased the probability that a lower level PLOS will be perceived.

Keywords

Active transport; walking; pedestrian facilities; pedestrian level of service; roadway condition; Chittagong

1. Introduction
Pollutants released by motor vehicles cause adverse effects on health and environment [1,2]. The increasing automobile dependency [3,4] exacerbates environmental problems such as air and noise pollution. The preeminent victims of pollutions caused by automobile sector are those who are directly exposed to it, such as road users and people living or working near the busy urban roads [5]. An implementation of sustainable transportation system is one of the responses to alleviate transport related problems [6]. According to Gouda, Masoumi [7], "Sustainable transportation is a main subset of urban sustainability and Urban sustainability certification (USC) supports six components of sustainable transportation: active transportation, public transportation, carpooling, car-sharing, alternative transportation, and sustainable management of freight transportation". Among the six components, active transportation such as walking is a widely recognized type of sustainable transportation [8].

The promotion of active transport has been considered as an important intervention to minimize environmental pollution, improve the health, and quality of life of city dwellers [9-11]. Besides, significant economic benefits are also associated with active travel. For instance, the USA might have been able to save 5.6 billion USD annually from heart diseases treatment cost had 10% adult started to walk [12]. Despite several economic and health benefits of walking, it constitutes a small proportion of the total trips in different countries (e.g. 3% of total trips in the USA) [13,6,14] and is marginalized compared to other modes of transport [7]. A lower percentage active trips is one of the consequences of increasing car use [15-18]. Besides, pedestrians are the most vulnerable road users in traffic crashes, as they are susceptible to sever injuries during vehicle-pedestrian collisions. To increase the number of walk trips, it is imperative to make pedestrian facilities functional, along with ensuring the safety to pedestrians [19]. Pedestrian Level of Service (PLOS) is a recognized measurement tool that evaluates the degree of pedestrian accommodation on roadway to provide comfortable and safe walking environment [20]. PLOS further explicates the current pedestrian facilities, situations, and infrastructures in streets, and evaluates the quality of service [21].

The walking conditions and qualities of a pedestrian space can be measured using PLOS, which indicates the standard of pedestrian facilities [22]. There are two common methods to estimate PLOS: capacity-based model and roadway characteristics-based model. The capacity-based model considers sidewalk capacity, volume, and speed of pedestrian and vehicular traffic to assess PLOS. This approach has been widely criticized, as this model treats pedestrians like cars and was designed solely based on the context of USA [23], which overlooks the potential character of road that connects people and act as a social space. The socio-economic context of developing countries is different from the USA; hence few studies have considered the characteristics of roadway to measure PLOS in context of developing countries [24]. Roadway characteristics-based model focuses on the relationship between pedestrian facilities and environmental factors. Most of the existing studies applied roadway characteristics-based model to evaluate the impacts of pedestrian facilities on PLOS [21,25,26]. This model considers user opinion while designing for pedestrian facilities [21], to cater the needs of pedestrians [27]. Various roadway characteristics, such as, safety, comfort, convenience, and so forth, attract pedestrian traffic [19]. Several authors who considered user opinion to evaluate the influence of pedestrian facilities on PLOS [21,19] overlooked the interaction of existing pedestrian facilities with roadway conditions and PLOS. From current studies, we identified that a triangular relationship exists among pedestrian facilities, perceived roadway condition, and perceived PLOS: 1) influence of roadway conditions on perceived PLOS [23], 2) influence of pedestrian facilities on roadway conditions [28], and 3) influence of pedestrian facilities on perceived PLOS [21,19,29]. In this study, we modelled this triangular relationship for a case study on Chittagong Metropolitan Area of Bangladesh, to identify pedestrian facilities, related to footpath, carriageway, and transit facilities, affecting the perceived PLOS. This study further highlighted the pedestrian facilities required to improve the perceived PLOS.

2. Case study: Chittagong Metropolitan Area (CMA) of Bangladesh

Chittagong Metropolitan Area (CMA) of Bangladesh was selected as a case for this study (Figure 1). It is the second largest metropolis and the commercial capital of Bangladesh [30,31]. Despite a rapid motorization, walking forms a significant share of all urban trips and pedestrians are the largest road user in Bangladesh. For instance, walking constitutes approximately 65% trips in the capital Dhaka city. However, pedestrians are at the highest risk of road traffic fatalities. For instance, about 70% road traffic deaths in Dhaka city in 2013 were among pedestrians [32]. Chittagong is also facing a rapid urbanization, resulting in an augmented demand for transportation. An increase in vehicle ownership, economic activities, and population has created social, economic, and environmental challenges due to an increase in road traffic congestion. Besides, a large number of non-motorized vehicles, lack of roadway facilities and user disciplines, poor pavement condition and so forth characterize the traffic condition of Chittagong city. The existing transport development policies and measures less prioritize the promotion of active modes and encourage the use of motorized vehicles. For example, rehabilitation/construction of footpaths is given the less priority in the Long-Term Development Strategy (LTDS) for Traffic and Transportation in Chittagong compare to measures such as widening the existing roads and construction of new roads [33].

For Bangladesh, Hasan et al. [24] evaluated different techniques and identify the most suitable approach to measure PLOS for the capital Dhaka city. But no further research has been conducted that investigates the significance of different pedestrian facilities and their influence on PLOS for Bangladesh context. This type of relationship helps improving roadway conditions. This study applied the roadway characteristics-based model comprehensively to assess the perceived PLOS of Chittagong to identify inadequacies in existing pedestrian facilities. The assessment has further facilitated us to recommend the future pedestrian facilities to improve the perceived PLOS.

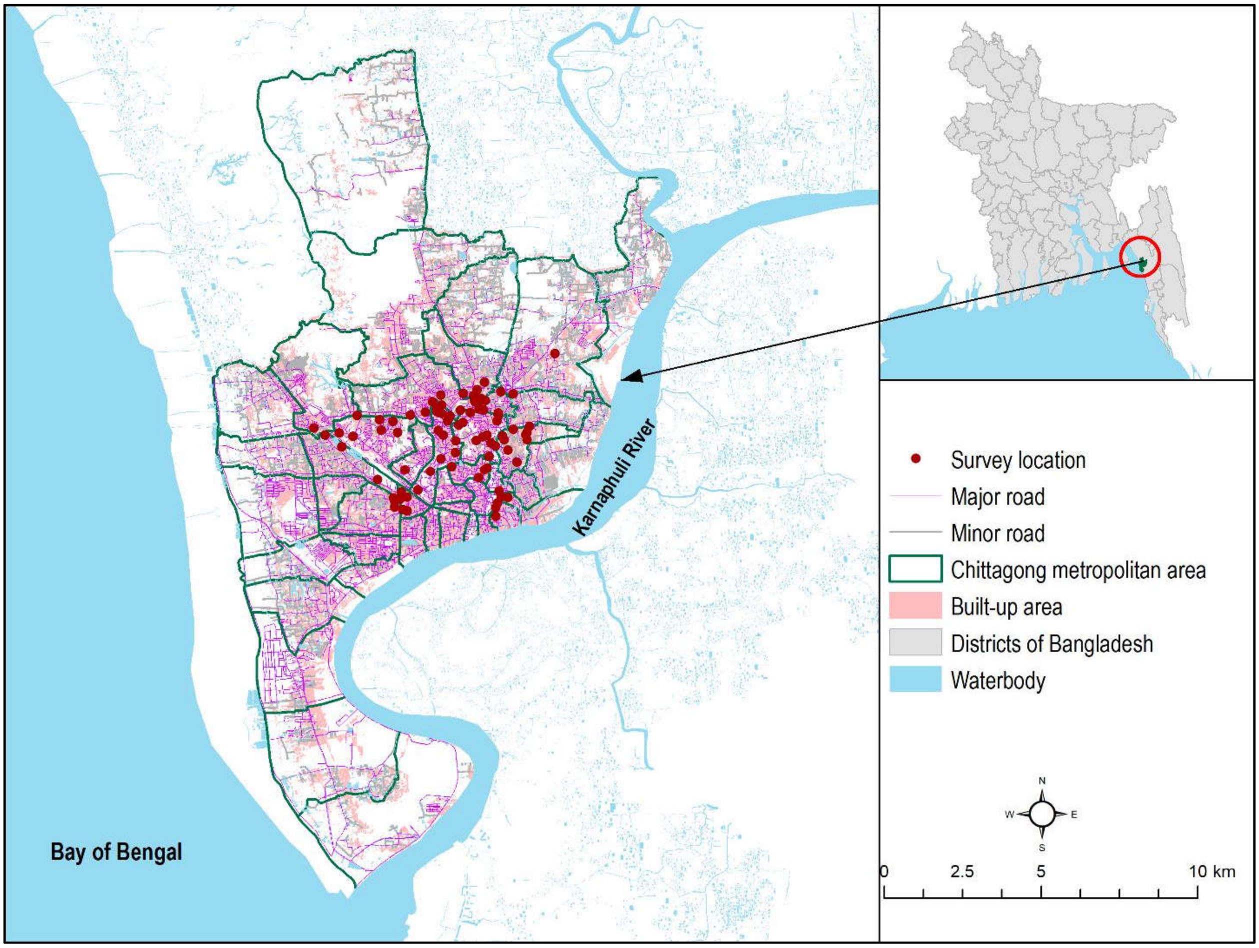

Figure 1: Chittagong Metropolitan Area

3. Methodology

This study was conducted in three stages. First, we identified different indicators of roadway condition that influence the perceived PLOS and collected data on perceived PLOS through conducting a field survey. Second, we collected information on existing pedestrian facilities by a physical feature survey. Third, we evaluated the influence existing pedestrian facilities on perceived PLOS.

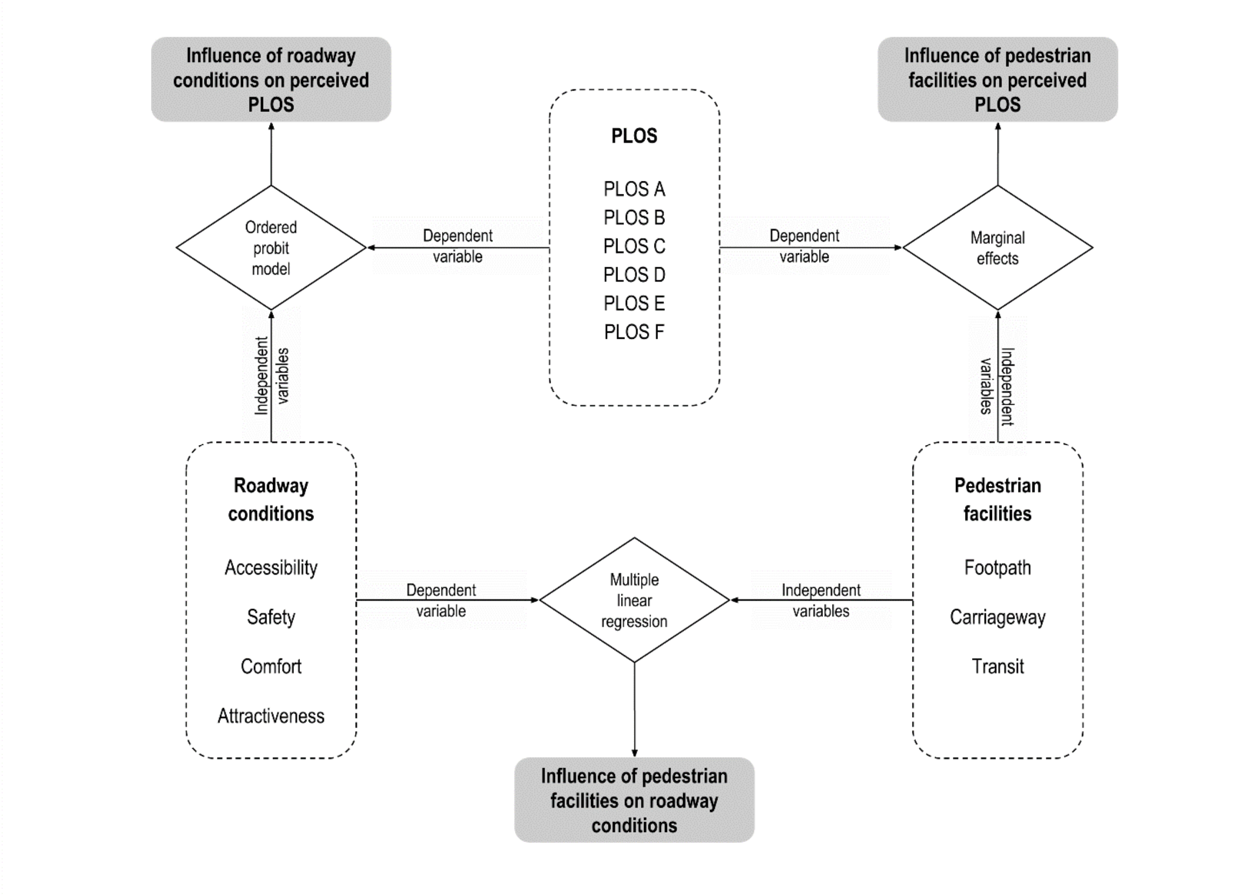

Figure 2: Analytical framework of this study

3.1. Identifying indicators to define roadway condition and measuring PLOS

The roadway characteristic-based model prioritizes pedestrian infrastructure requirements to improve the PLOS [21]. According to this approach, four indicators characterizing roadway condition influence on PLOS, such as safety, security, attractiveness, and comfort. Henson [28] used comfort, convenience, safety, security, and economy as five environmental factors of roadway to determine PLOS. Here, the term 'economy' denotes users' costs associated with travel delays and inconvenience. Similarly, Talavera-Garcia, Soria-Lara [20] identified four 'hierarchies of walking needs' such as accessibility, safety, comfort, and attractiveness to fulfill pedestrian needs. These four roadway conditions explain PLOS comprehensively, hence we considered these factors to explain the perceived PLOS in this study. Among these four indicators, safety and comfort have been highly recommended in the contemporary research [19,34,35], as important indicators to understand mode choice behavior as well as perceived PLOS. Besides, accessibility has also been recognized as an important roadway condition for pedestrians, since a high level of accessibility means a better connectivity of pedestrian facilities with the adjacent land use and other facilities (transit or crosswalk etc.), that reduces travel time and cost [19,27]. Finally, the attractiveness adds a vitality to the surroundings and provides a pleasing walking environment and encourage people to walk [27].

We conducted a questionnaire-based survey in June 2018 at 88 points (road sections) within CMA to collect a wide range of information from randomly selected pedestrians. The sample size for the Chittagong Metropolitan Area (CMA) was calculated using Equation 1. From this equation, a minimum number of respondents required at 95% confidence level with a normal distribution response of a large population size is determined [36].

$$n = z^2 pq/e^2 \quad (1)$$

Here, n is the minimum sample size; z is z-value of a given confidence level (for 95% confidence level it is 1.96); p is estimated proportion of an attribute that is present in the population, and q is (1-p) and e is the tolerance level (assumed as 5%).

The CMA has a total population of 2.5 million [33]. Since, the population is large, and we do not know the variability in the population (proportion of people walk), we assumed p = 0.5 (maximum variability) and thus q was also be 0.5. Hence, the minimum sample size was estimated to be 384. To avoid additional missing value, we collected information from 413 respondents in 88 different locations. The survey locations were selected carefully that included arterial, sub-arterial, collector, and access roadway sections. Each of the respondents was interviewed once only. In each location, respondents were asked to provide a score based on the condition of accessibility, safety, comfort and attractiveness in relation to three types of pedestrian facilities (footpath, carriageway and transit facilities), with the help of a semi-structure questionnaire (attached in Appendix A). They provided scores on a 1-10 scale for each question, where 1 means very poor condition and 10 means excellent condition of corresponding roadway section. To start the interview, respondents were first asked how frequent they walk through the surveyed road section. Respondents who walked at least three times in a week on average in corresponding locations were selected for further interview. The survey was conducted in Bengali and later we translated it in English.

Pedestrians were further asked to mark PLOS for footpath, carriageway, and transit facilities of each location using a 1 to 6 likert scale, where 1 denotes an ideal environment (PLOS A) and 6 means an unsuitable condition for pedestrian (PLOS F). To assist the respondents, we provided six different pictures of footpath conditions, resembling each tier of PLOS. The picture of the ideal footpath environment (PLOS A) was selected carefully in such a way that all the physical facilities (Obstacle free, continuous footpath with curb, gutter, fence, green elements, street furniture and facilities for disable etc.) necessary to be an ideal footpath were available there. Required facilities essential for an ideal footpath were determined from literature review. Then, five other pictures were arranged in a descending order where the last picture (PLOS F) has negligence facilities. Likewise, six different pictures of carriageway and transit facilities were shown to compare them with the respective carriageway and transit facilities of that roadway section and grade them appropriately. Each of the respondents was explained the difference between the cards prior asking them to grade the PLOS of survey locations. The card is attached in the Appendix B. Picture cards were used only to determine perceived PLOS of existing footpath, carriageway and transit facilities. SPSS 24 and R programming language were simultaneously used to develop the data base and carry out data analysis.

3.2. Collecting information on pedestrian facilities

In absence of a street guideline for Chittagong city, we identified pedestrian facilities based on literature review and field observation. A physical feature survey was carried out at 88 points where we conducted the questionnaire survey to collect information on perceived PLOS. Table 1 shows the major information (hereinafter, parameter) collected through physical feature survey for three categories of pedestrian facilities. The influence of each parameter on perceived PLOS is context specific [21]. Therefore, this study sought to identify pedestrian facilities significantly influence the roadway conditions and perceived PLOS in CMA.

Table 1 Physical feature survey checklist

Facilities	Parameters	Data type
Footpath	Footpath width	Value in feet
	Footpath height	Value in feet
	Net footpath width	Value in feet
	Footpath curb	Yes/no
	Gutter	Yes/no
	Fence	Yes/no
	Green elements	Yes/no
	Lighting	Yes/no
	Street furniture (bin, sitting arrangements etc.)	Yes/no
	Disable facilities	Yes/no
	Vertical obstruction	Yes/no
Carriage way facilities	Crosswalk (zebra-crossing/foot over pass)	Yes/no
	Median width	Value in feet
	Median height	Value in feet
	Shoulder width	Value in feet
	Guardrail	Yes/no
	Parking	Yes/no
	Total lane number	Value
	Speed breaker	Yes/no
	Signal	Yes/no
Transit facilities	Bus bay	Yes/no
	Bus stoppage	Yes/no
	Sign &	Yes/no

3.3 Evaluating the relationship of pedestrian facilities with PLOS

To evaluate the interaction between existing pedestrian facilities, perceived roadway condition and perceived PLOS, we developed three types of roadway characteristics-based model using the qualitative data on roadway condition and PLOS, in addition to the quantitative data on pedestrian facilities. Figure 2 shows the analytical framework of this study. First, we estimated the influence of different roadway conditions on perceived PLOS. Second, we estimated the influence of pedestrian facilities on roadway condition, hypothesizing that different parameters of pedestrian facilities influence the perceived pedestrian accessibility, safety, comfort, and attractiveness conditions. Finally, we quantified the influence of the current state of pedestrian facilities on different tiers of PLOS to elicit pedestrian facilities that contribute to a change on perceived PLOS.

3.3.1. Estimating the influence of roadway conditions on PLOS

An ordered probit model [37] was developed incorporating perceived PLOS as dependent variable and the scores for four roadway conditions as independent variables (Figure 2). Three models were developed for each type of pedestrian facility such as footpath, carriageway, and transit. Data incorporated to develop these models are listed in Table 2.

Table 2 Variables used to develop ordered probit models

Model	Dependent variable	Independent Variable (method to obtain the variable)
PLOS model of footpath facilities	Perceived PLOS for footpath facilities (in a 1 to 6 scale)	<u>Indicators of roadway conditions for footpath facilities:</u> Perceived accessibility (mean of Q1.1 and Q1.2) Perceived safety (mean of Q2.1 and Q2.2) Perceived comfort (mean of Q3.1 and Q3.2) Perceived attractiveness (mean of Q4.1 and Q4.2)
PLOS model of carriageway facilities	Perceived PLOS for carriageway facilities (in a 1 to 6 scale)	<u>Indicators of roadway conditions for carriageway facilities:</u> Perceived accessibility (mean of Q5.1 and Q5.2) Perceived safety (mean of Q6.1 and Q6.2) Perceived comfort (mean of Q7.1 and Q7.2) Perceived attractiveness (mean of Q8.1 and Q8.2)
PLOS model of transit facilities	Perceived PLOS for transit facilities (in a 1 to 6 scale)	<u>Indicators of roadway conditions for transit facilities:</u> Perceived accessibility (mean of Q9.1 and Q9.2) Perceived safety (mean of Q10.1 and Q10.2) Perceived comfort (mean of Q11.1 and Q11.2) Perceived attractiveness (mean of Q12.1 and Q12.2)

**Q is the question used to collect data during field survey (Appendix A)*

The ordered probit models were derived by defining an unobserved variable z for modeling the ordinal ranking of data. Here, the PLOS of footpath, carriageway, transit facilities were ordinal data and defined as a linear function for each observation of pedestrian perception regarding accessibility, safety, comfort and attractiveness of corresponding footpath, carriageway, and transit facilities.

$$z_n = \beta X_n + \varepsilon_n \tag{1}$$

Where, X = vector variables determine the perceived PLOS, β = vector of estimable parameters, and ε = a random disturbance. Using this equation, observed pedestrian level of services (y) for each observation are defined as

$$\begin{aligned} y &= 1 \quad \text{if} \quad z \leq \mu_0 \\ y &= 2 \quad \text{if} \quad \mu_0 < z \leq \mu_1 \\ y &= 3 \quad \text{if} \quad \mu_1 < z \leq \mu_2 \\ y &= 4 \quad \text{if} \quad \mu_2 < z \leq \mu_3 \\ y &= 5 \quad \text{if} \quad \mu_3 < z \leq \mu_4 \\ y &= 6 \quad \text{if} \quad \mu_4 < z \leq \mu_5 \end{aligned} \tag{2}$$

Where, μ were the estimable parameters (referred to as thresholds) that define *y*, which corresponds to integer ordering. The μ were estimated jointly with the model parameters β. This determination is accomplished by assuming on the distribution of ε. If ε is assumed to be normally distributed across observations with mean = 0 and variance = 1, an ordered probit model results with ordered selection probabilities as follows:

$$\begin{aligned} p(y=1) &= \Phi(-\beta X) \\ p(y=2) &= \Phi(\mu_1-\beta X)-\Phi(\beta X) \\ p(y=2) &= \Phi(\mu_2-\beta X)-\Phi(\mu_1-\beta X) \\ p(y=3) &= \Phi(\mu_3-\beta X)-\Phi(\mu_2-\beta X) \\ p(y=4) &= \Phi(\mu_4-\beta X)-\Phi(\mu_3-\beta X) \\ p(y=5) &= \Phi(\mu_5-\beta X)-\Phi(\mu_4-\beta X) \\ p(y=6) &= 1-\Phi(\mu_5-\beta X) \end{aligned} \tag{3}$$

Where, Φ(.) is the cumulative normal distribution.

In this cross-sectional study, each respondent was surveyed once only, hence, there was a minor chance to share unobserved effects in each observation. Since, the assumption of independent disturbances made in equation 1 remain persistent, therefore, this study does not consider here random effects. summarizes the variables used to develop ordered probit models, along with the methods of processing the independent variables.

3.3.2. Estimating the influence of pedestrian facilities on roadway conditions

We developed four multiple linear regression models, employing indicators of roadway condition as dependent variables and parameters of pedestrian facilities as independent variables (Figure 2). For each roadway condition, the obtained scores were averaged across three types of pedestrian facilities. For instance, the dependent variable in accessibility model was estimated averaging the scores on existing accessibility condition of footpath, carriageway, and transit facilities of the selected roadway sections. Similarly, mean safety, comfort, and attractiveness scores were employed as dependent variables for respective models (Table 3).

Table 3 Variables used to develop multiple linear regression models

Model	**Dependent variable (method to obtain the variable)**	**Independent Variable**
Accessibility	Perceived accessibility (mean score of Q1.1, Q1.2, Q5.1, Q5.2, Q9.1, and Q9.2)	Availability of footpath, carriageway and transit facilities
Safety	Perceived safety (mean score of Q2.1, Q2.2, Q6.1, Q6.2, Q10.1, and Q10.2)	Availability of footpath, carriageway and transit facilities
Comfort	Perceived comfort (mean score of Q3.1, Q3.2, Q7.1, Q7.2, Q11.1, and Q11.2)	Availability of footpath, carriageway and transit facilities
Attractiveness	Perceived attractiveness (mean score of Q4.1, Q4.2, Q8.1, Q8.2,	Availability of footpath, carriageway and transit facilities

Q12.1, and Q12.2)

**Q is the question used to collect data during field survey (Appendix A)*

We applied a split sample method to develop these models, where data collected from field survey were split into two groups — training and test dataset. The four models were developed using 80% samples and remaining 20% samples were used for model validation. Prior to develop regression models, we diagnosed multicollinearity among independent variables estimating variance inflation factor (VIF). Independent variables that resulted VIF greater than or equal to 2.5 was excluded from the model [38]. To assess the normality of the data, we applied a visual method, developing Q-Q plots, since this type of plot is easy to interpret for a larger sample size (sample $\geq$ 50) when quantitative method like Shapiro-Wilk test is not recommended [39]. In Figure 3, most of the data under each indicator fall approximately along the reference line; hence we assumed data were approximately normally distributed.

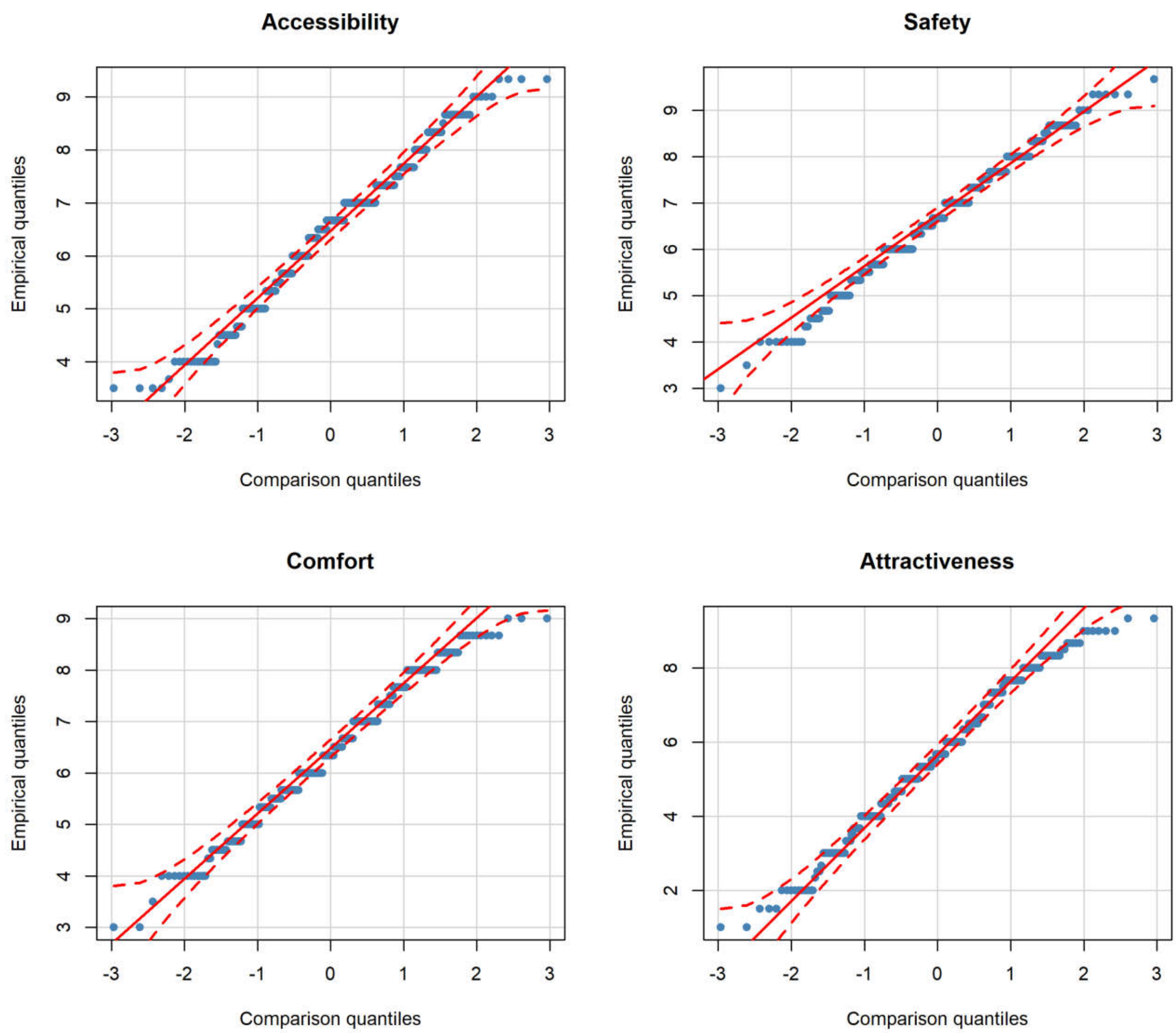

Figure 3 Quantile-Quantile (Q-Q) plot to check normality visually

Finally, 22 independent variables were incorporated in the four models. Multiple linear regression efforts to model a relationship between two or more predictor variables and a dependent variable by fitting a linear equation to observed data [40]. Every value of the independent variable x is associated with a value of the dependent variable y (Equation 4).

$$y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots \beta_n X_n + €\qquad(4)$$

Where, y = averaged score for four indicators of roadway condition; model ID i=accessibility, safety, comfort, and attractiveness; X = the values of different parameters of pedestrian facilities; $n = 22$ (number of parameters of pedestrian facilities); $\beta_1, \beta_2, \ldots\ldots, \beta_n$ = Regression coefficient; β_0 = intercept; $€$= random error in prediction or residuals

The four models were validated applying cross validation techniques. For each model, observed data (test data) was plotted against modelled data and computed corresponding correlation value. Figure 4 illustrates the validation results for four models, where the estimated correlation values are between 0.57 to 0.66, implying that the developed models have moderately strong correlation with the observed data.

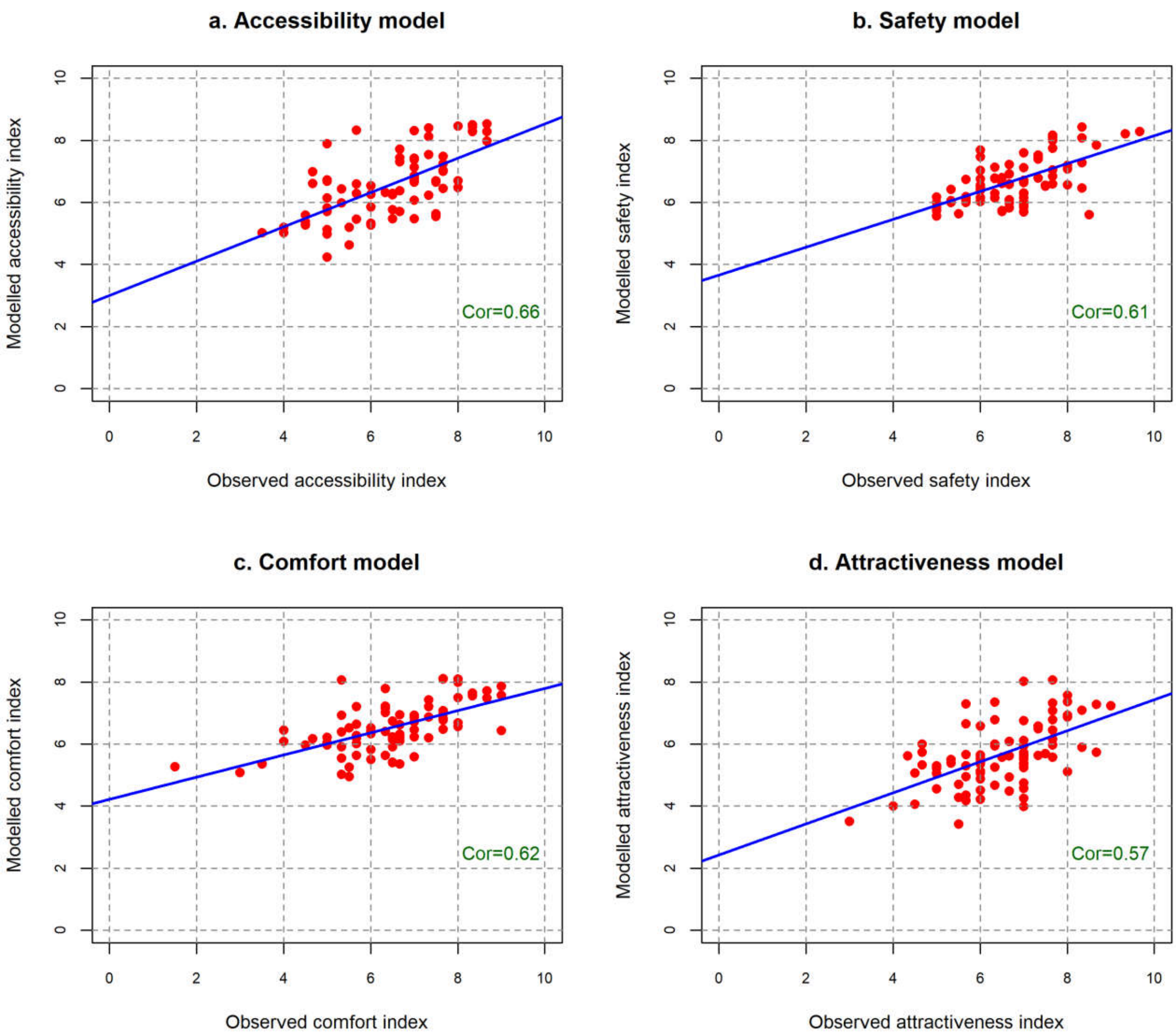

Figure 4: Validation of four multiple linear regression models

3.3.3. Estimating the influence of pedestrian facilities on PLOS

We determined the relative influence of each of the pedestrian facilities on different levels of PLOS through estimating marginal effects. The marginal effects explained the effect of one-unit change in independent variables on each of the six PLOS categories (A, B, C, D, E, and F). In R programming language, we applied a fitting linear model under 'stats' package [41] and then differentiate the model object in respect to all variables using 'margins' package [42]. When estimating marginal effects, we recoded the dependent variable as binary variable. For instance, to estimate marginal effect of PLOS A under footpath model, the dependent variable was recoded into 1 (for PLOS=1) and 0 (for PLOS $\neq$ 1). Then a linear fitting model incorporated the recoded dependent variable and corresponding physical features under footpath facilities (Table 1) as independent variable. The resultant model was used to estimate marginal effect of each footpath facility on PLOS A. This method was repeated for all six tiers of PLOS under three broad types of pedestrian facilities (footpath, carriageway, and transit).

4. Results and Discussion

4.1. Influence of roadway conditions on PLOS

The coefficients obtained from ordered probit model explained the relationship of different indicators of roadway condition with the different tiers of perceived PLOS. The scores received for roadway conditions are negatively correlated with the levels of PLOS. For an indicator of roadway condition, negative coefficient denotes an increase in score of that indicator will increase in probability that PLOS A will be perceived. Table 4 summarizes the ordered probit model coefficients for three types of pedestrian facilities. While we found negative coefficients for all four indicators of roadway conditions, but the level of significance in relation to their influence on perceived PLOS varied, which can be observed from the estimated p-values. Accessibility, comfort, and attractiveness are the significant indicators impacting the perceived PLOS related to footpath facilities. Here, the perception of safety is not a significant indicator, as pedestrians experienced less crime and traffic collision while using footpaths. But safety is an important indicator that influence the perceived PLOS for carriageway, along with other three indicators. One unit increase in the score for safety resulted in 26.2% greater probability that a higher level of PLOS will be perceived. Pedestrians were under a higher risk of traffic collision and crime while using carriageway, hence, an increase in perceived safety score will increase the likelihood to perceive a higher level of PLOS for carriageway. Finally, in terms of transit facilities, accessibility, safety, and attractiveness were the most influential roadway conditions. One unit increase in the perception of being accessible and safe transit facilities will increase the probability by 23.3% and 26% respectively that a higher PLOS will be perceived. The 'comfort' indicator of roadway condition is related to physical facilities such as bus bay, comfortable waiting place, and so forth, which were unavailable in most of the surveyed locations, hence the relationship of this indicator with perceived PLOS was found insignificant for Chittagong city.

Table 4: Results of ordered probit model

	PLOS model regarding footpath facilities		**PLOS model regarding carriageway facilities**		**PLOS model regarding transit facilities**	
	Estimate	p-value	Estimate	p-value	Estimate	p-value
Accessibility	-.328	.000***	-.206	.000***	-.233	.000***
Safety	-.012	.840	-.262	.000***	-.260	.000***
Comfort	-.217	.000***	-.158	.003**	-.068	.191
Attractiveness	-.217	.000***	-.125	.000***	-.214	.000***
Threshold (LOS-2)	-7.628	.000	-7.028	.000	-7.570	.000

Threshold (LOS-3)	-5.572	.000	-5.582	.000	-5.808	.000
Threshold (LOS-4)	-4.343	.000	-4.241	.000	-4.482	.000
Threshold (LOS-5)	-3.259	.000	-3.178	.000	-3.393	.000
Number of Observation	283		413		389	
Cox and Snell	.537		.444		.402	
Nagelkerke	.567		.469		.428	
McFadden	.262		.200		.183	

*Significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1*

4.2. Influence of Pedestrian facilities on indicators of roadway condition

The outcomes of multiple linear regression models explained the influence of pedestrian facilities on four indicators of roadway condition. Since independent variables were either binary variables (0 means no facility and 1 means the presence of facility) or scale data, a positive coefficient indicates either the presence of a pedestrian facility or an increase in dimension of that facility will increase the probability that a higher quality of roadway condition will be perceived. Table 5 presents the outcomes of three models developed for three categories of pedestrian facilities.

4.2.1. Footpath facilities

Seven types of footpath facilities significantly (p-value ≤ 0.05) influenced the perception of accessibility condition of roadway. Availability of footpath curb, gutter, and green elements were the most significant footpath facilities. The presence of footpath curb creates an impression on pedestrians that they use a designated footpath which is in good condition for walking. Gutter helps to channelize storm water during heavy rainfall event that minimizes the chance of water stagnation, making footpaths accessible to pedestrians. Green elements separate footpaths from motorways, creating a sense of accessibility among pedestrians. However, a negative regression coefficient (β=-0.53) for the 'availability of street furniture' indicates that the presence of street furniture decreases pedestrian accessibility. The street furniture includes bin, siting arrangement, flower vase, and so forth. Poor maintenance of such facilities and incompatible placements impeded pedestrian movement. Notably, the installation of fence also positively influenced the perception of pedestrian accessibility. In absence of fence, motorcyclists often use footpaths to avoid congested road, creating an inconvenience to pedestrians while using footpaths. Therefore, despite observing fence in 14.8% of total surveyed locations, a p-value 0.001 was found for this variable.

Five footpath facilities such as availability of curb, light, green element, street furniture, and facilities for disable people influenced the perception of pedestrian safety. The highest positive regression coefficient of 0.96 was found for the presence of green elements, which indicates that one unit change in this variable will increase the probability that safety score will be changed by 0.96. Respondents perceived that green elements segregate the footpath from vehicular ways, ensuring safety to pedestrians. On the other hand, a negative regression coefficient of -0.42 for street furniture means per unit increase in this variable will increase the probability that perceived safety score will be reduced by 0.42. Despite disable facilities were present in only 6.8% surveyed footpaths, but this facility had a positive influence on the perception of pedestrian safety. Likewise, the presence of lights and curbs are footpath facilities significantly influenced the perception of safety among pedestrians in Chittagong.

In relation to comfort, the presence of curb, light, and green elements in footpaths positively influenced the perception of pedestrians towards more comfortable walking condition. The highest estimated coefficient for green elements suggests that one unit increase in green elements will increase the probability that the perceived comfort score will be increased by 0.77. Respondents perceived green elements as an important parameter to ensure comfort, as Bangladesh is characterized by tropical climate condition and green elements like trees provide shade to pedestrian, creating comfortable environment for walking. Pedestrians also comprehended curbs as a major element to ensure comfort. Curb is an indicator of footpath condition that properly maintained footpaths, comprise of curbs, ensure pedestrian comfort. Besides, curbs provide a lateral separation between pedestrian and motorized vehicles and protect footpaths against waterlogging in rainy season. Although the presence of lighting positively influenced the perception of comfort, but lighting facilities were found in about 57% surveyed footpaths. A presence of such facility makes walking comfortable, especially during the night.

Four parameters of footpath facilities such as ‘net footpath width’, ‘fence’, ‘light’, and ‘green elements’ significantly influenced the perception of ‘attractiveness’. The highest coefficient was estimated for the presence of lighting facilities (β=1.02). The presence of green elements also positively influenced the perception of attractiveness. Pedestrians also expressed that an implementation of fence makes footpaths more attractive to them, in addition to ensure safety.

4.2.2. Carriageway facilities

Six parameters of carriageway facilities significantly influenced the perception of pedestrian accessibility (Table 5). The highest negative regression coefficient was estimated for the parameter guardrail. Guardrails were installed in some places along the median to prevent pedestrian crossing in undesignated locations. However, respondents perceived that the presence of guardrails makes carriageway less accessible to them. The parameter median height also negatively influenced the perception of pedestrian accessibility in carriageway. Pedestrians require a greater kinetic energy to cross a street with an elevated median. However, wider median, availability of zebra crossing, speed breaker, and traffic signal improved the perception of pedestrian accessibility while using the carriageway.

In relation to perceived pedestrian safety in carriageway, only zebra crossing had a significant positive influence. Respondents perceived the places as being safe where they found functioning zebra crossing. But the zebra crossing was observed only in 8.5% of surveyed carriageways. Zebra crossing also positively influenced the perception of pedestrian comfort in carriageways, along with shoulder width. However, a little use of zebra crossing was observed, since pedestrian cross busy roads quite randomly. Finally, in respect to carriageway attractiveness, only the number of lanes had a significant positive influence.

Table 5: Outcomes from four multiple linear regression models

Predictor variables	Accessibility		Safety		Comfort		Attractiveness	
	B	p-value	B	p-value	B	p-value	B	p-value
Intercept	5.63	.000***	6.12	.000***	5.62	.000***	4.37	.000***
Footpath facilities								
Net Footpath Width							0.066	.000***
Footpath Curb	0.66	.000***	0.48	.000***	0.60	.000***		
Gutter	0.66	.000***						
Fence	0.44	.001*					0.37	.023*
Light	0.28	.002*	0.63	.000***	0.67	.000***	1.02	.000***
Green elements	0.78	.000***	0.96	.000***	0.77	.000***	0.95	.000***
Street furniture	-0.53	.058˙	-0.42	.040*				

Vertical clearance	0.47	.002**						
Disable facilities			0.77	.005**				
Carriageway facilities								
Median width	0.02	.004**						
Median height	-0.13	.014*						
Shoulder width					0.05	.037*		
Guardrail	-1.11	.002**						
Number of lanes							0.14	.010*
Zebra crossing	0.48	.017*	1	.000***	0.68	.002**		
Speed breaker	0.72	.000***						
Signal	0.84	.000*						
Transit facilities								
Availability of transit stoppage	-0.84	.000*	-0.44	.036*	-0.56	.022*	-0.75	.014*
Number of Observation	336		325		332		328	
McFadden	0.49		0.38		0.35		0.40	

*Significance codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1*

4.2.3. Transit facilities

Transit stoppage is the single parameter of transit facilities that negatively influenced all the four indicators of roadway condition (Table 5). The transit stoppages were not properly marked, and designated transit stoppages were found only in 9.4% of total surveyed locations. Besides, a lack of regulatory measures allows public bus services to use any location along the road as a pickup point. Therefore, pedestrians sometimes become reluctant to go to designated transit stoppages, hence respondents felt that the availability of transit stoppages impeded their accessibility.

4.3. Influence of pedestrian facilities on perceived PLOS

We determined the influence of pedestrian facilities on perceived PLOS by estimating marginal effects. Marginal effects explain how one unit change in each pedestrian facility will change the probability that each discrete category of PLOS will be changed. Table 6 summarizes the estimated marginal effects of different parameters of footpath, carriageway, and transit facilities. Our survey result showed PLOS B as the highest tier of PLOS in Chittagong. We found both linear and non-linear relationship between pedestrian facilities and perceived PLOS. For instance, in the footpath model, linear relationship was found for the presence of curb and perceived PLOS, implying that the presence of curb in footpath will increase the probability that higher level of PLOS will be perceived. Curb in footpaths will lower the probability by 16.6% that PLOS F will be perceived and increase the probability by 8.7% that PLOS B will be perceived, and vice versa. However, the relationship of rest of the parameters of footpath facilities with perceived PLOS is non-linear. Different respondents considered different set of parameters of pedestrian facilities while selecting a tier of PLOS, which resulted in a non-linear relationship between pedestrian facilities and PLOS. For instance, the presence of gutter has a positive relationship with PLOS C and PLOS D. About 64% of total gutters were found in road sections for which PLOS C and PLOS D were perceived. Poor maintenance and garbage disposal cause blocking in gutters, hence respondents who perceived PLOS of a road section as B ruled out the presence of gutter while making their decision. Likewise, a negative relation was found for the presence of fence and PLOS B. The presence of light, green area, furniture, and disable facilities in footpath increase the probability that PLOS B will be perceived. In relation to furniture, poor condition and placement created a negative impression to some respondents (section 4.2.1). Thus, despite the presence of furniture in some areas, the perceived PLOS was F, resulting in a positive marginal effect of furniture for PLOS F. In case of vertical clearance of footpath, effects were quite random. This could be due to the type of vertical clearance available on the footpath. Some vertical obstructions provide shade to the pedestrian and protect them from sun and rain, whereas some obstructs pedestrian movement. Though the net footpath width is an important feature to improve PLOS, however, here its effect on PLOS of footpath is negligible. This is because, one unit increase in the net footpath width does not indicate that they are well maintained and useable. In the selected survey locations, wide footpaths were observed, however, some of those were damaged and unattractive to use. Therefore, this result suggests that only the presence of wide footpath does not ensure an improved perceived PLOS for footpath — well maintained footpaths are equally important.

In relation to carriageway facilities, a greater median height, presence of designated parking space, number of lanes, and presence of speed breaker increase the probability that PLOS B will be perceived. The presence of guardrail on carriageway was perceived as an impedance to pedestrian movement, which lowers the probability by 31.51% that PLOS B will be perceived. Notably, the presence of guardrail could also lower the likelihood to perceived PLOS F for carriageway. This is because, guardrails were also found in areas which are better maintained. Respondents primarily characterized those areas as PLOS D and PLOS E. The probability of perceived PLOS B level would be 15.57% higher if speed breakers are present in carriageway. But, the opposite effect was observed in case of zebra-crossing. The probability of PLOS B would be 6.47% lower in the presence of zebra crossing on carriageway. Although zebra-crossings were observed in carriageway, but pedestrians were not prioritized to cross the carriageway on zebra crossing. The presence of signals would also lower the probability for PLOS B, as, traffic police imposes manual traffic control instead of automated signal system. carriageways with one or two lanes in the study area are predominantly the access roads where the presence of footpath was rarely observed. All the carriageways with more than two lanes are comprised of footpaths. Thus, an increase in the number of lanes resulted in a higher probability towards a better PLOS.

From the transit model, the availability of proper information and signage resulted in 10.95% lower probability for PLOS F and 7.36% higher probability for PLOS B. But the availability of transit stoppage caused random effects on PLOS of transit facilities. Since, the availability of transit stoppage and use of those stoppages are not properly maintained. More often, their impact on pedestrian is negative. Therefore, a proper care should be given on the maintenance and development of transit stoppage.

Table 6: Average marginal effects of the PLOS models

Model	Pedestrian facilities	PLOS B	PLOS C	PLOS D	PLOS E	PLOS F
Footpath model	Footpath curb	0.0879	0.0189	0.0722	-0.0129	-0.1662
	Gutter	-0.0172	0.0217	0.1574	-0.0656	-0.0962
	Fence	-0.0091	0.0416	0.1457	-0.0477	-0.1305
	Light	0.0275	0.1438	-0.1384	0.0177	-0.0505
	Green elements	0.0120	0.1554	-0.0612	-0.1563	0.050
	Street furniture	0.1101	0.1171	-0.1509	-0.09516	0.0189
	Vertical clearance	-0.0131	-0.0793	0.1931	-0.1029	0.0020
	Disable facilities	0.1145	-0.1321	0.2399	-0.0069	-0.2154
	Net footpath width	-0.0045	0.0031	-0.0107	0.0091	0.0031
Carriageway model	Median width	-0.005	-0.0006	0.0012	0.0041	0.0003
	Median height	0.0028	0.0094	-0.0116	0.0068	-0.0074
	Shoulder	-0.0061	0.0179	0.0132	-0.0133	-0.0117

	Guardrail	-0.3151	-0.1828	0.2556	0.4011	-0.1588
	Car parking	0.4654	0.0613	-0.2863	-0.1864	-0.0540
	Number of lanes	0.0258	0.0112	-0.0329	0.0096	-0.0137
	Zebra crossing	-0.0647	0.0019	0.0072	0.1138	-0.0582
	Speed breaker	0.1557	-0.0507	-0.0777	-0.0921	0.0649
	Signal	-0.1135	-0.0209	0.2314	-0.1065	0.0096
Transit model	Signage and information	0.0736	0.0283	0.0231	-0.0155	-0.1095
	Transit stoppage	-0.0394	0.0105	0.0990	-0.0133	-0.0569

5. Conclusion

In this study, we evaluated the perceived PLOS in CMA of Bangladesh quantifying a triangular relationship among pedestrian facilities, roadway condition, and perceived PLOS using both qualitative and quantitative measurements of pedestrian facilities. The qualitative measurement of pedestrian facilities included four roadway conditions such as accessibility, safety, comfort, and attractiveness. We conducted a physical feature survey to measure pedestrian facilities quantitatively. Both qualitative and quantitative measurements complemented to each other in evaluating the perceived PLOS. For instance, we found that accessibility, comfort, and attractiveness conditions of roadway that influenced the perceived PLOS of footpath. The quantitative measurements helped to identify parameters of pedestrian facilities that influenced those three roadway conditions. In this case, net footpath width, curb, gutter, fence, light, green elements, street furniture, and vertical clearance influenced at least one of the three indicators of roadway condition (Table 5). Besides, we estimated the influence pedestrian facilities (quantitative measurement) on the perceived PLOS. We found that the relationship between the presence of a facility with perceived PLOS is non-linear in most of the cases. This study highlighted that inappropriate planning and poor maintenance of some existing facilities increased the probability that a lower level PLOS will be perceived. For instance, unplanned placement of street furniture and poor condition of gutters along footpaths created a negative impression to pedestrians about the PLOS. In general, poor condition of pedestrian facilities in Chittagong resulted in the PLOS B as the highest tier of perceived PLOS.

Few studies have been conducted that investigated the interaction among different pedestrian facilities, roadway condition and perceived PLOS [24]. Quantitative information on pedestrian facilities helps to identify facilities that are required to improve the overall PLOS, which could enable in optimizing resources while planning to provide new pedestrian facilities, especially in countries with financial constraints [43]. Although developing countries constitute reportedly a higher share of walk trips, so far, researchers have given a little attention to analyze PLOS for the context of developing countries. The traffic characteristics [35] and cultural norms [21] in developed and developing countries are heterogeneous, hence it should be of importance to analyze the influence of pedestrian facilities on PLOS contextually. The findings from this study can be used as a guideline to identify and prioritize cross-sectional design elements of roadway, with an aim to ensure accessibility, safety, comfort, and attractiveness to pedestrian in Chittagong city. This study provides a comprehensive framework to understand perceived PLOS that can be transferable to similar contexts. However, this study is not free from limitation. Large number of samples which is distributed across a greater region could help to improve the results. In absence of walking design standards for Chittagong city, we identified pedestrian facilities based on literature review and personal observation, which is to some extent subjective. Despite all these limitations, this study is an attempt to understand perceive PLOS comprehensively and explore the condition of pedestrian facilities for the context of a developing country.

Appendix A

All the following information was collected on a 1 to 10 scale where 1 denotes inferior condition and 10 denotes superior condition.

1. *Perceived accessibility of footpath*
    1.1. Mark the existing connectivity of the footpath with the adjacent land use
    1.2. Mark the continuity of the footpath throughout your journey
2. *Perceived safety of footpath*
    2.1. Mark the safety from crime on footpath
    2.2. Mark the safety from traffic on footpath

3. Perceived comfort of footpath
    3.1 Mark the usability of the available facilities on footpath
    3.2. Mark your convenience level on using this footpath in different weather condition

4. Perceived attractiveness of footpath
    4.1. Mark the attractiveness of the footpath
    4.2. Mark the attractiveness adjacent to the footpath

5. Perceived accessibility of carriageway
    5.1. Mark the crosswalk facilities available on the carriageway
    5.2. Mark the adequacy of traffic control measures to prioritize the pedestrian on roadway

6. Perceived safety of carriageway
    5.1. Mark the safety from crime on carriageway
    5.2. Mark the safety from traffic on carriageway

7. Perceived comfort of carriageway
    3.1 Mark the usability of the available facilities on carriageway
    3.2. Mark your convenience level on using the carriageway in different weather condition

8. Perceived attractiveness of carriageway
    4.1. Mark the attractiveness of the carriageway for you as pedestrian
    4.2. Mark the attractiveness adjacent to the carriageway for you as pedestrian

9. Perceived accessibility of transit
    9.1. Mark the sidewalk connection with the transit stoppage
    9.2. Mark the adjacent facilities available around the transit stoppage

10. Perceived safety of transit
    10.1. Mark the safety from crime on access/egress point of transit
    10.2. Mark the safety from traffic on access/egress point of transit

11. Perceived comfort of transit
    3.1 Mark the usability of the available facilities on transit
    3.2. Mark your convenience level of using the access/egress point of transit in different weather condition

12. Perceived attractiveness of carriageway
    12.1. Mark the attractiveness of the access/egress point of transit
    12.2. Mark the attractiveness of the adjacent area of access/egress point of transit

Appendix B

Card used to collect information on perceived PLOS of footpath, carriageway, and transit

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