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Modelling of Pedestrian Walking Behavior at Foot over bridges

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Abstract
The paper aimed to develop a model of pedestrian speed at foot over bridge considering five site of the New road area of Kathmandu Metropolitan city. A videography survey was done for data collection. Speed variation in each category of pedestrian speed was determined based on gender,age, mobile use, luggage carrying condition and group size. Macroscopic(speed,flow & density)and microscopic parameter(age, gender,mobile use,luggage condition & group size) along with physical dimension of the foot over bridge was taken into consideration for model development. Multiple linear regression analysis was done for model formulation using SPSS. Independent variables gender(female), age(11-20), age(21-40), age(>=60), mobile use(no), luggage(yes), group size(G2 & G>2) and average pedestrian density were found to be significant. MAPE and Pearson correlation coefficient was determined for model validation. Hence, the model was found to predict well for pedestrian speed.

Keywords
Foot over bridge, Pedestrian speed, Multiple linear regression, Correlation analysis, Speed variation

1. Introduction

Kathmandu is the center of urbanization, there is high number of traffic as well as pedestrian flow. For efficient traffic operation and pedestrian safety different pedestrian facilities like sidewalk, crosswalk, traffic signal, pedestrian signal, overpass and underpass are provided. Kathmandu has been facing the problem of congestion since long time. Difficultly in crossing the road is also the another problem. In order to reduce the pedestrian-vehicle interaction overpass and underpass are provided.Foot over bridges are a mostly common in context of Nepal.

Foot over bridge is a type of grade separated pedestrian facility consisting of an enclosed or covered bridge connecting two footpaths[1]. Foot over bridges is a one of the safest form of crossing facilities, however people find it time consuming and tends to cross the road illegally which is the main reason for crashes. Pedestrian speed is the key element in the design of pedestrian facilities. It is the average walking speed of the pedestrian which depends on various attributes related to road, traffic and pedestrians[2]. Pedestrian speed varies on the different type of facilities.

The objective of the study is to develop model of pedestrian speed at foot over bridges and to analyze the walking behavior of pedestrian at foot over bridges. Planning and implementing such facilities requires an understanding of the characteristics of pedestrian movements. Factors affecting pedestrian walking speed is of paramount importance for efficient operation and management of foot over bridges. The scope of study is to ensure pedestrian to use the facilities by designing as per their requirement and developed model can be used by road designers to find the wellness of a particular foot over bridge that accommodates pedestrian travel mode.

2. Literature review

Several studies have conducted on modelling of pedestrian speed of different pedestrian facilities like sidewalk, signalized crosswalk, mid block and so on but there is limited study in case of foot over bridges.

Al-Azzawi & Raeside (2007), developed model to predict the pedestrian walking speed the United Kingdom using regression analysis. It was used to understand the effect of physical nature of sidewalk, surrounding environment, weather and seasonal variable. Pedestrian flow was found to be insignificant variable. Gender was not found to be an important determinant of walking behavior. Pedestrian speed

decline with age. MAPE and Pearson correlation coefficient was used for model validation.[3]

Kotkar et al. (2010), analyzed pedestrian flow characteristics under mixed traffic condition. The pedestrian speed was found to be influenced by age and gender. Male pedestrian speed was higher than female. Pedestrian age group of 10-15 years was highest. The speed of pedestrian carrying luggage was reduced by 85%.[4]

Gupta et al. (2015), reviewd on pedestrian flow characteristics and level of service over different pedestrian facilities(sidewalk, walkway, crosswalk, grade separated, stairways and escalators). The type of facility, width, age, gender and location of the study were found to be influencing factor for pedestrian flow characteristics. Primarily factors such as physique (height), culture (dress), vendors, friction (due to parked vehicles), purpose of walking trip and environmental condition.[5]

Maurya & Panda (2015), studied pedestrian movement at foot over bridge. Relationship among different parameters like speed, density, flow and area module were plotted .The relationship between pedestrian speed and density was found to be moderate negative exponential relation while a polynomial (three degree) relationship was observed between pedestrian speed and area module. Pedestrian speed and flow relationship showed a negative logarithmic relationship and a quadratic correlation was observed between pedestrian flow and density. The study on walking speed showed that young pedestrians walk faster than old pedestrians which was as expected. Speed of male pedestrians was observed higher than speed of female pedestrians on this FOB.[6]

Adhikary & Shrestha (2021), conducted the study to identify the factors that influence the usage of the pedestrian bridge using questionnaire survey at twelve pedestrian bridge locations in Kathmandu Valley.The non use of pedestrian bridge was found tobe more than 50% tham use. Binary model was developed in order to identify the factors influencing use and non-use of pedestrian bridge. The model showed that use of the pedestrian bridge was significantly influenced by crossing time, crossing principles, baggage, previous crash experience, presence of bus stop and driving license.[7]

Banerjee et al. (2021), studied on factors affecting the pedestrian walking speed at elevated facilities was determined by using Tree-Based Ensembles and Shapley Additive Explanations which revealed that walking speed was dependent on the average flow, average density, and length of the facility. Moreover, other features such as gender, age, height, and width of the facility also play a significant role in determining the pedestrian walking speeds.[8]

Banerjee & Maurya (2020), analyzed the pedestrian walking behavior at foot over bridges in four different cities of India under same land use area type. Radar charts and box plots were used to predict the mean and median speed of pedestrians based on gender, age and luggage. Probability density functions were also used to understand the speed variation among the different categories of pedestrians. macroscopic relationships were plotted between the speed-flow rate-density. Mean walking speed of each category of pedestrian at each site was compared.[9]

3. Methodology

3.1 Study area

The five foot over bridges of New road area of Kathmandu metropolitan was taken for the study which is also the Central business district of the city where the pedestrian flow is continuous. Figure 1 shows the site location of Foot over bridges.

- Site 1: New road gate
- Site 2: Near civil mall
- Site 3: Near Kathmandu mall
- Site 4: Near Bir hospital
- Site 5: Asan

3.2 Data collection

Data collection was done using videography survey of foot over bridges.Figure 2 shows data collection (Videography) at FOB. Total 5hrs of data was collected, 1hr on each site. As the variation of flow(high as well as low) can be seen in 1hr, time period of 1hr was considered for each site location. Mobile phone was used for videography survey in data collection process. Trap length of 3 to 4 meters was fixed using binding tape of blue color for FOBs. The physical dimension of foot over bridges were measured using tape. The video tapes were played to extract both macroscopic (flow, speed, density) and microscopic (gender, age, mobile use, luggage

Figure 1: Study area

Figure 2: Videography at FOB

condition, group size) factors. Flow, density and speed, were extracted from videos. A reference point was fixed and the number of pedestrians crossing the point for each minute are been counted and converted to flow in ped/m/min. Three snapshots were taken for each minute and number of pedestrians in each snapshot are counted in each direction, converted to density in ped/m^2. Two reference points were fixed and time taken for crossing the two points were noted and speed of pedestrian was calculated in m/sec and converted to m/min. Pedestrian's gender, age, mobile phone use/non use, with/without luggage are extracted based on visual observation.

The categorical variables were analyzed by creating the dummy variables so that their effect can be properly analyzed.

3.3 Sample size determination

The required sample size is calculated by Krejeie and Morgan's (1970) sample estimation technique at 95 % confidence level and 5% marginal error.Total pedestrian observed in all sites was 6981,then the minimum sample size obtained is 318,hence 500 sample of data is adequate for model formulation. Total sample collected was 620 in which 500 was used for modal formulation and 120 for validation.

3.4 Correlation analysis

Correlation analysis is used to show association between the two variable. It measures the strength of the linear relationship between two variable. Correlation analysis calculates the level of change in one variable due to change in other. A high correlation points to a strong relationship between two variables, while low correlation means variable are weakly related.The high correlation between

Table 1: Description of variables

S.N.	Variable	Variable type	Description
1	Speed	Continous	m/min
2	Gender	Categorical	0:Male, 1:Female
3	Age	Categorical	0:<=10, 1:11-20, 2:21-40, 3:41-60, 4:>=60
4	Mobile use	Categorical	0:No, 1:Yes
5	Luggage	Categorical	0:No, 1:Yes
6	Group size	Categorical	0:G1, 1:G2, 2:>G2
7	FOB length	Continous	Metre
8	FOB width	Continous	Metre
9	Average ped. flow	Continous	Ped/min/m
10	Average ped. density	Continous	Ped/mˆ2

independent variables causes multi-collinearity which is not used for model development. Association between categorical variable can be check through Chi-square test. Similarly, pearson correlation for continuous variable.

3.5 Model development

Multiple linear regression is one of the primary forms of regression modelling. It attempts to model a relationship between two or more independent variables . The method used for computation of multiple linear regression model in SPSS (Statistical Packages for Social Sciences) is based on residual variance and R-Square. R-Square is also known as the coefficient of determination which is a commonly used statistic to evaluate model fitness. The R-square value is an indicator of how well the model fits the sample data i.e., an R-square close to 1.0 indicates that we have accounted for almost all of the variability with the variables specified in the model. Another parameter is the p-value or significance of the variables in the model. The p-value <0.05 are considered as significant. It accounts for the significance of the particular variable to the model.

3.6 Model validation

Model validation is a verification process to check the accuracy of developed model. 80% of data are used for model formulation and 20% for model validation.Validation is done by comparing observed value with predicted value by using MAPE (Mean Absolute Percentage Error). MAPE is the measure of prediction accuracy of forecasting method. The lewis scale is used for interpretation of MAPE values.The Pearson correlation coefficient is also the way to measure the similarity of the data. Lewis scale interpretation based on MAPE is shown in Table 2

Table 2: Lewis scale of interpretation based on MAPE

MAPE(%)	Forecasting
Less than 10	Highly accurate
10-20	Good
20-50	Reasonable
Greater than 50	Inaccurate

4. Results and Discussions

4.1 Descriptive statistics of Speed

The maximum and minimum pedestrian speed at foot over bridges are 88.235m/min and 20.57m/min respectively.The mean pedestrian speed is 57.07m/min with standard deviation of 10.28 m/min. Frequency of each category of pedestrian is listed in Table 5. Out of 500 sample, 274 were male and 226 were female. Likewise, pedestrian with age less than 10,11-20 and greater that 60 were less that is 15,35 and 35 respectively. Majority of pedestrian were from age group 21-40 which is 257 and then 41-60 with pedestrian number 158. Pedestrian not using mobile is higher as, 47 pedestrian uses mobile, rest 453 does not during movement. 80 pedestrian were seen carrying luggage while 420 doesnot.331 were seen moving single, 148 two in group and 21 more than two in a group. The number of disabled approximately 1-2 in all sites.

4.2 Speed variation

Figures 3-7 indicates the speed variation in the form of probability density function (i.e. a function whose

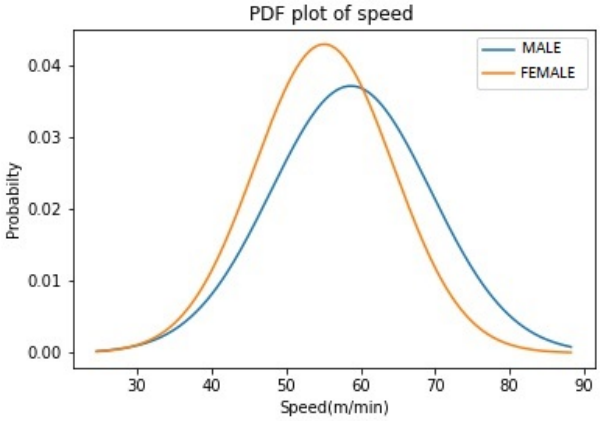

Figure 3: Speed distribution based on gender

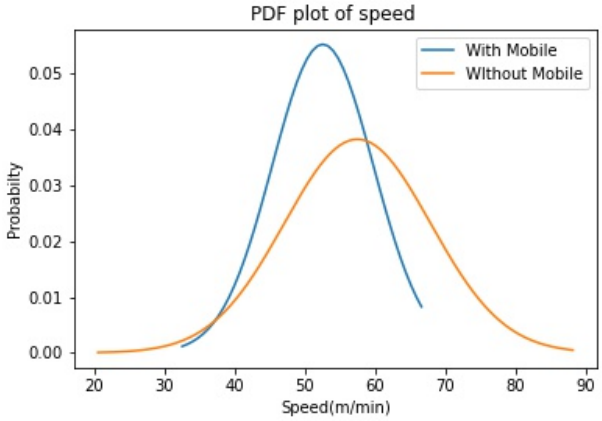

Figure 5: Speed distribution based on mobile use

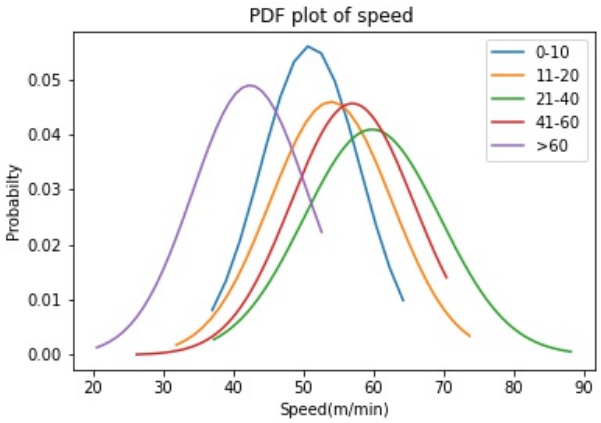

Figure 4: Speed distribution based on age

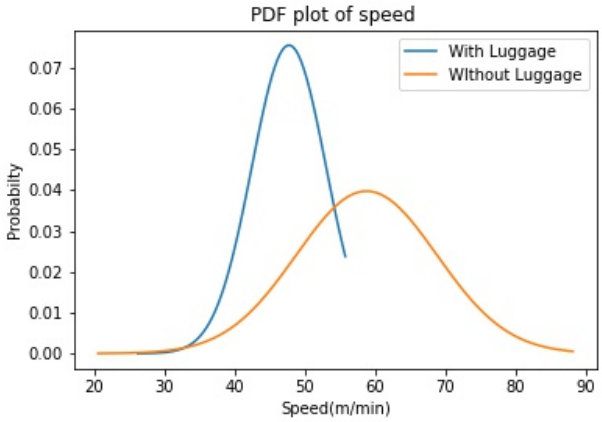

Figure 6: Speed distribution based on luggage condition

value at any given sample in the sample space can be inferred as to offer a relative likelihood that the value of random variable would equal that sample) among pedestrians based on gender, age , luggage and group sizes .Pedestrian speed is plotted at x-axis and relative frequency at Y-axis. Figure 3 ,shows the graph speed variation based on gender ,the mean walking speed of male is higher than female by 3.6m/min and the walking behavior of both male and female is almost similar.Figure 4,speed distribution based on age, the mean speed of age group less than 10, 11-20, 21-40,varies by approximately 2.7m/min while the speed of age group greater than 60 have slower speed among all i.e. 42.426m/min and speed of age group 21-40 has highest mean walking speed. Figure 5 shows the speed distribution based on mobile use/non use,pedestrian speed during mobile usage is slower by 4.933m/min than pedestrian without mobile phone. Figure 6 shows the speed distribution based on luggage condition as the luggage of heavy category was taken into consideration luggage carrying

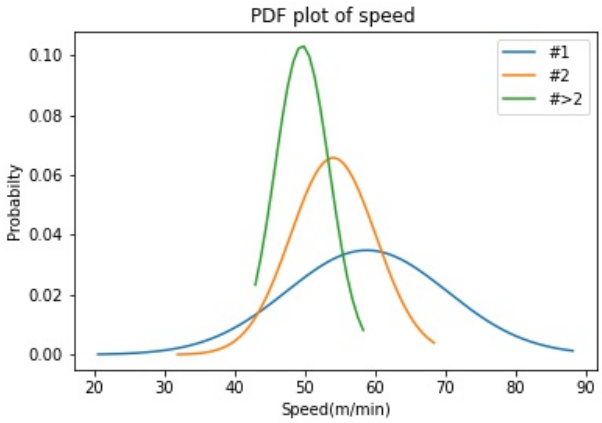

Figure 7: Speed distribution based on group size

condition have significant effect on pedestrian speed that is pedestrian without luggage have 9.75m/min more speed than pedestrian without luggage. Figure 7, shows the speed distribution based on group size, pedestrian walking in group more than two have

slowest speed in and pedestrian walking single has highest mean walking speed 58.880m/min, pedestrian walking two in a group tends to walking approximately 4m/min slower than single.

4.3 Correaltion analysis

Correlation analysis was performed by entering both dependent and independent variables in SPSS. The Chi-square test was used to check the association of the categorical variables. Hence the correlation between all the independent variables were less than 0.5 so, all categorical independent variables gender, age, mobile use, luggage and group size were considered for model development.The correlation between continuous variable was analyzed through pearson correlation test. The correlation between FOB length & FOB width, FOB length & Avg.ped. flow, FOB width & Avg.ped. flow, Avg.ped. flow & Avg.ped.density were found high. When correlation between two independent variables is high one can be omitted. Likewise, FOB length, FOB width, Avg.ped. flow were correlated with more than one variables so, Avg.ped.density was only considered for analysis.

4.4 Model development and interpretation

Model is developed by multiple linear regression analysis using SPSS. Age less than 10, Age 41-60, pedestrian walking single (G1) were found insignificant as p value was greater than 0.05. So, final model was developed considering significant variables.The R-square/Adjusted R-square of final model 0.721/0.716 was obtained. The R-square value 0.721 indicates that 72.1% variation in speed is explained by independent variables.

The coefficient of the final model is shown in Figure 9. The p-value of each independent variable is less than 0.05, each independent variables have significant relation with pedestrian speed. The equation for the final model of pedestrian speed at FOB can be seen in Table 4 with significant independent variables gender(female), age(11-20), age(>=60), mobile use, luggage, group size and average pedestrian density.

Female pedestrian have slower speed than male by 3.5 m/min. Pedestrian of Age group 11-20 and 21-40 were found to have positive increasing impact on walking speed but pedestrian of age(>=60) had slower walking speed which was found to be most significant variable affecting pedestrian walking speed. Pedestrian using mobile reduced the speed by 13.063 m/min. Pedestrian without luggage increased the speed by 15.3 m/min. Pedestrian walking in a group of two and FOB with average pedestrian density reduced speed by 16.3 m/min and 14.9 m/min. Suppose we can predict that, female pedestrian of age group 21-40 walking without using mobile, no luggage in a group of at FOB of average pedestrian density 0.51 ped/mˆ2 have walking speed of 58.8m/min.

4.5 Model validation

Out of 620 data, 500 sample data were used for modal formulation and 120 data was used in validation. Validation is done by comparing observed value with predicted value by calculating MAPE value i.e.16.1%. According to lewis scale of interpretation value within 10-20% denotes model forecasting predicts well. The Pearson correlation coefficient between predicted and observed value was 0.6. Hence model is fit to predict the pedestrian speed. The graph between predicted and observed value is shown in Figure 8.

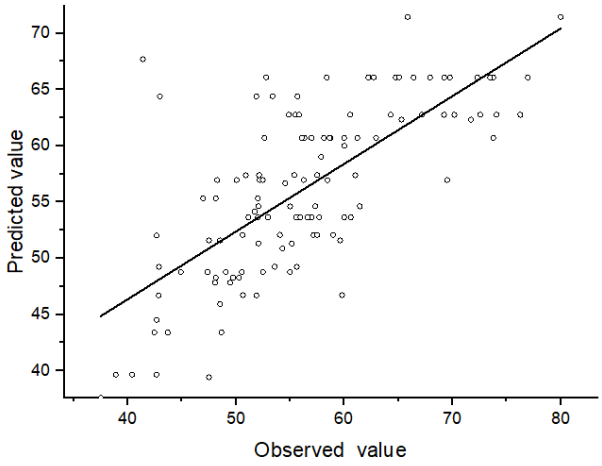

Figure 8: Plot between observed and predicted value of pedestrian speed

5. Conclusion and Recommendation

5.1 Conclusion

The maximum and minimum pedestrian speed at foot over bridges were found to be 88.235m/min and 20.57m/min respectively. The mean pedestrian speed is 57.07m/min with standard deviation of 10.28 m/min. Speed variation was analyzed by probability density function, Graph between each category of pedestrian and probability of occurrence was plotted.

Table 3: Equation of Final model

Pedestrian speed (m/min) = 55.576 - 3.484*Gender (female) +4.446*Age(11-20)+6.1*Age(21-40) – 19.101*Age(>=60) – 13.063*Mobile use(YES) + 15.299*Luggage(NO) – 10.471*Group size(G2) -16.301*Group size(G>2) – 14.989*Avg. ped. density

Table 4: Coefficient of final model

Coefficients[a]						
		Unstandardized Coefficients		Standardized Coefficients		
Model		B	Std. Error	Beta	t	Sig.
1	(Constant)	55.576	1.351		41.123	0.000
	Gender=female	-3.484	0.508	-0.169	-6.862	0.000
	Age=11-20	4.446	1.066	0.110	4.172	0.000
	Age=21-40	6.100	0.554	0.297	11.011	0.000
	Age>=60	-19.101	1.031	-0.475	-18.528	0.000
	Mobile_use=YES	-13.063	0.878	-0.371	-14.871	0.000
	Luggage=NO	15.299	0.701	0.546	21.832	0.000
	Group_size=G2	-10.471	0.582	-0.466	-18.004	0.000
	Group_size=G>2	-16.301	1.291	-0.318	-12.626	0.000
	Avg.ped density	-14.989	2.460	-0.149	-6.093	0.000

Multiple regression analysis was used for modelling pedestrian speed, where geometric parameter was found to be insignificant. Pedestrian behavior and average pedestrian density were significant. Among all independent variables Age(>=60) was found to be most significant. Likewise, walking speed prediction model was developed.

5.2 Recommendation

As pedestrian speed is one of the important parameter to be considered in design and planning of pedestrian facilities.Proper planning helps to increase the usage of foot over bridge. Model can be beneficial in understanding pedestrian movement at foot over bridge which can be supplement in detailed study of the facility. As, Age(>=60) was one of the significant factor affecting pedestrian speed. The number of disabled pedestrian using foot over bridge was also less. Proper provision for these two category of pedestrian should be provided to increase the usage.

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