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Development of Pedestrian Safety Index Model at Mid-block Crossings for Urban Roads in Developing Countries using Multiple Linear Regression

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ABSTRACT: The present study aims to development of the pedestrian safety index model at mid-block crossings using variables like pedestrian volumes, crosswalk markings, crosswalk length (m), and pedestrian safety ratings etc. The data was collected at different locations in the CBD area of the city where the high pedestrian flow was observed. At these selected locations some of the variables identified like vehicle volume, pedestrian volume, age of pedestrian, peak pedestrian volume, width of road lane (m), width of mid-block crossing (m), Surface condition of the mid-block crossings, mid-block road markings, traffic signs boards, traffic signals and lightning facilities for pedestrians were observed during peak hours. Pedestrians were categorized based on different age groups and gender. The pedestrian safety index models are calibrated and validated from the usage of multiple linear regression technique and based on pedestrian data was collected at various locations. The PSI model results confirm the estimation of correct pedestrian safety levels at mid-block crossings. The study will also be helpful to improve the existing pedestrian facilities, pedestrian flows (ped/hour) and also, to provide pedestrian safety measures on urban roads under mixed traffic conditions.

Keywords: Pedestrians variables, Pedestrians, Pedestrian safety index model, Pedestrian volume.
Abbreviations: PSI: Pedestrian Safety Index; PMM: Pedestrian Mid-block crosswalk Markings; PV: Pedestrian volume; SC: Surface condition of the mid-block crossings; MLR: Multiple linear regressions.

I. INTRODUCTION

Hammed (2000) created models for holding up time at the curbside and number of intersection endeavors utilizing corresponding danger and Poisson and numerous relapse models for both partitioned and unified mid-square streets. It was discovered that sexual orientation, age, number of youngsters in the family, crossing recurrence, number of individuals in the gathering endeavoring to cross were of the most critical indicators from the model [25]. The vast majority of the examinations tended to walker security by building up the degree of administration models; Pedestrians' crossing behaviors [29]. Past analysts have created safety models dependent on ordinary direct relapse techniques, for example, straight or different direct or stepwise or summed up models; Pedestrian safety at intersections under control of permissive Left–Turn signal [24]. Linear regression is easy to create and is the most generally utilized. Previous researchers have developed pedestrian safety models based on conventional linear regression methods such as linear or multiple linear or stepwise or generalized models; Pedestrian risk decreases with pedestrian flow [30]. The Linear regression model commonly dependent on the accompanying two suspicions: (i) the perceptions pursue the typical conveyance, and (ii) implies are fluctuating as for autonomous factors. It has been discovered that the information is requested (or positioned) in nature and can't be characterized by likelihood dispersions [23]. Multiple Linear Regressions: Statistics Solutions gives an information examination plan format for different direct relapse investigation. We can utilize this layout to build up the information examination segment of this investigation. As a prescient investigation, the numerous direct relapses are utilized to clarify the connection between one consistent ward variable and at least two free factors.

$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 + a_6x_6 + a_7x_7 + a_8x_8 + a_9x_9 + a_{10}x_{10} + \ldots + a_nx_n \quad (1)$$

Uyanık and Güler (2013) Y is dependent variable, a_0, a_1, $a_2 \ldots a_n$ are constants, X is independent variable [22].

II. OBJECTIVES OF STUDY

The primary objectives that this study targets are as follows:
(i) Identification of influencing variables for the development pedestrian safety index model at mid-block crossings on urban roads under mixed traffic conditions.
(ii) Development of pedestrian safety index (PSI) model for the safety of pedestrian flows at mid-block crossings on urban roads under mixed traffic conditions and the usage of multiple linear regression technique.

III. LITERATURE REVIEW

The present review of literature was studied about multiple linear regression, data collection methods, selected list of variable extracted from video graphic survey, field observation, questionnaire survey and on-site measurements with pedestrians safety index model variables are discussed in Table 1.

Table 1: The details of previous literature survey.

Year	Author	Country	Method of data collection	Focused area	Method of analysis	Type of data
2013	Ling *et al.*, [1]	China	Contingent field survey and extensive video	Signalized intersection	Stepwise regression	Mixed
2013	Kang *et al.*, [2]	China	Video clips and field measurement	Foot path	Ordered probit	Mixed
2013	Jensen [3]	Denmark	Video clips and questionnaire and field measurement	Signalized and unsignalized intersection and round abounts	CLM stepwise regression	Mixed
2013	Kim *et al.*, [4]	Korea	A pedestrian intercept survey, a field	Footpath	Stepwise regression	Quantitative
2013	Bian *et al.*, [5]	China	Questionnaire survey and field survey	Un-signalized intersection	Stepwise regression	Quantitative
2013	Asadi-shekari *et al.*, [6]	Singapore	Result of guidelines	Mixed area	Point system	Mixed
2014	Zhao *et al.*, [7]	China	Questionnaire survey and field survey	Un-signalized mid-block crossings	Stepwise regression	Quantitative
2014	Meng *et al.*, [8]	China	Questionnaire survey	Mixed area	Stepwise regression	Mixed
2014	Kim *et al.*, [9]	Korea	Pedestrian questionnaire survey and video Recording	Footpath	Multiple linear regressions	Mixed
2014	Kadali and Vedagiri [11]	India	Pedestrian questionnaire survey and video	Mid-block crossing	Ordered probit	Mixed
2014	Asadi-shekari *et al.*, [10]	Malaysia	Results of guidelines	Mixed area	Point	Mixed
2015	Zhao *et al.*, [12]	China	Observation and questionnaire survey	Footpath	Fuzzy mathematics method	Quantitative
2015	Ye *et al.*, [13]	China	Video technique and questionnaire survey	Signalized intersection	Linear regression technique	Quantitative
2015	Kadali *et al.*, [14]	India	Questionnaire survey and video graphic survey	Un-signalized mid-block crossing	Ordered probit	Mixed
2015	Hasan *et al.*, [15]	Bangladesh	Questionnaire survey	Footpath	-	Mixed
2015	Archana [16]	India	Visual survey and field surveys	Intersection	Multple linear regressions	Quantitative
2015	Lazou *et al.*, [17]	Greece	Questionnaire survey	Mixed Area	Ordinal regression model (ordered logit)	Qualitative
2016	Zhao *et al.*, [18]	China	Questionnaire survey	Footpath	Fuzzy neural network method	Qualitative
2016	Raghuwanshi., *et al.*, [19]	India	Video graphic survey and field survey	Footpath	Multiple linear regression	Quantitative
2016	Daniel *et al.*, [20]	Malaysia	On-site measurement, video, and visual walk through surveys	Footpath	Multiple linear regression	Quantitative
2016	Chandana *et al.*, [21]	India	Questionnaire survey	Mixed area	Inverse variance method	Qualitative
2017	M. A. M. Bilema *et al.*, [26]	Malaysia	Questionnaire survey	Mid-block crossings	Multiple linear regression	Mixed
2018	Adinarayana and M.S. Mir [27]	India	Video graphic and Questionnaire survey	Mixed area and un-signalized intersection	Multiple linear regression	Mixed
2019	Adinarayana and M.S. Mir [28]	India	Video graphic and Questionnaire survey	Mid-block crossings	Multiple linear regression	Mixed

IV. STUDY METHODOLOGY

The present methodology aims at developing pedestrian safety index models using variables like pedestrian volume, cross walk speed (m/sec), crosswalk marking, crosswalk length (m), and pedestrian safety rating. The data was collected at different locations in the CBD area of the city where high pedestrian flow was observed. At these selected locations, pedestrian volume count and pedestrian average speeds (m/sec) were observed during peak hours. Pedestrians were categorized based on different age groups and gender. Flows were categorized based on crossing speed and direction. The study flow chart as shown in Fig. 1.

V. SELECTION OF STUDY LOCATIONS

Some of the study locations were selected in Srinagar city of J & K and selected locations are shown in Fig. 2-6.

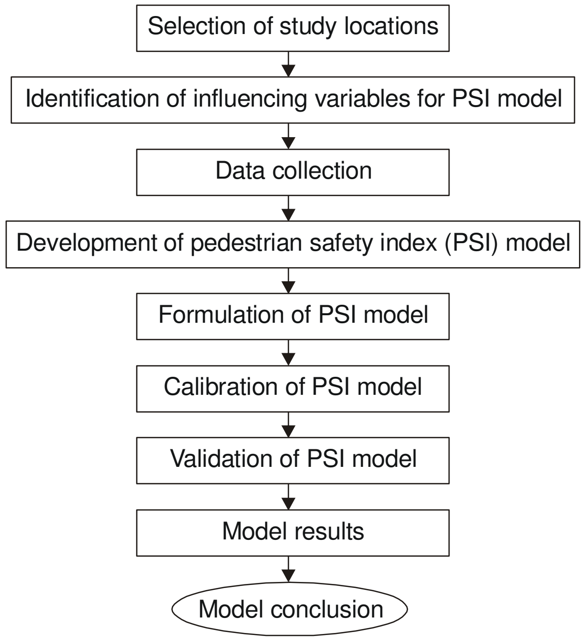


Fig. 1. Study methodology.

Location (S1): M.A. Road Kothi Bagh

(**Source:** Google Satellite Map Srinagar City accessed on 04/03/2018)

Fig. 2. Shows the mid-block crossing for M.A. road Kothi Bagh.

Location (S2): Hazratbal Road, near KU

(**Source:** Google Satellite Map Srinagar City accessed on 04/03/2018)

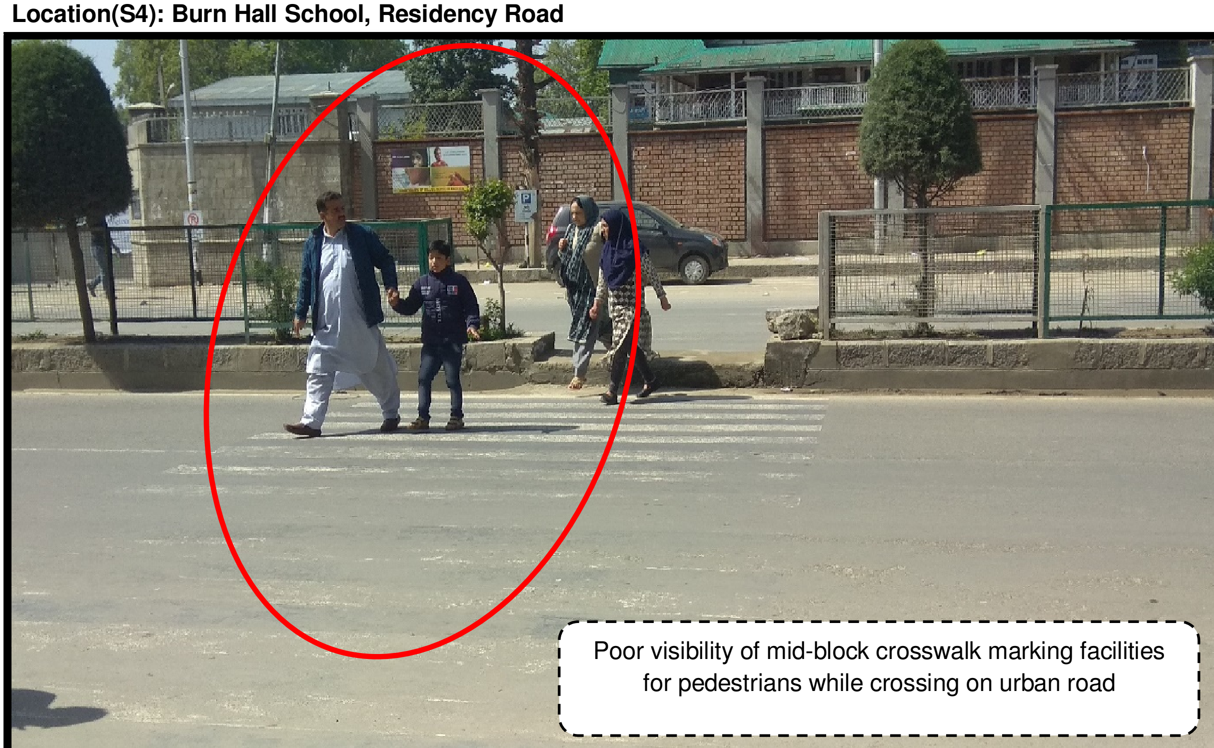
Fig. 3. Shows the mid-block crossing for hazratbal road.

Location (S3): Burn Hall School, Residency Road

(**Source:** Captured by camera on 24/04/2018)

Fig. 4. Shows the burn Hall School, Residency Road.

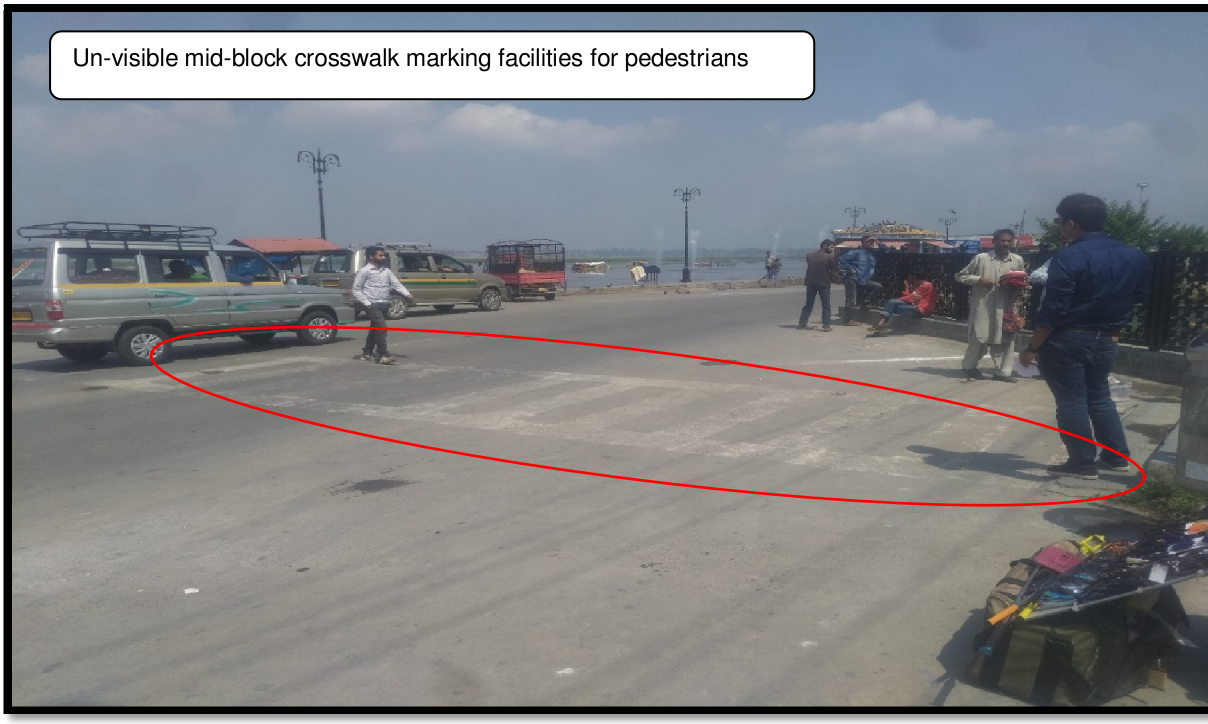
Location(S4): Burn Hall School, Residency Road



(**Source:** Captured by camera on 24/04/2018)

Fig. 5. Shows the mid-block crossing for M.A. road Kothi Bagh.

Location(S5): Nishat Garden



(**Source:** Captured by Camera on 22/04/2018)

Fig. 6. Shows the mid-block crossing near Nishat garden.

VI. DEVELOPMENT OF PEDESTRIAN SAFETY INDEX (PSI) MODEL

The process of development of PSI model was undertaken in three steps (i) Formulation of PSI model (ii) Calibration of PSI model (iii) Validation of PSI model.

A. Identification of influencing variables for PSI model

After collection of different types of variables related to vehicles, pedestrians and roads, we were developed safety index model for the pedestrians. All the variables which we collected are divided into three groups:

1. Motor vehicle volume and pedestrian volume data:
(i) Vehicle volume (VV)
(ii) Pedestrian volume (PV)
(iii) Age of pedestrian (AP)
(iv) Peak pedestrian volume (PPV)
2. Based on the geometric condition of the road
(i) Width of road lane (WRL)
(ii) Width of mid-block crossing (WMC)
(iii) Surface condition of the mid-block crossings (SC)
3. Based on the safety facilities for pedestrian
(i) Pedestrian mid-block markings (PMM)
(ii) Traffic signs and signals (TSS)
(iii) Lightning Facilities (LF).

B. Formulation of PSI model

The formulated variables, description of variables (rating variables) and type of category are given in Table 2.

Table 2: The details of selected variables, Description of variables (rating variables) and type of category.

Selected variables	Description of variable	Type of category
PSI	PSI= Pedestrian safety index rating; Worst – 1; Poor – 2; Fair – 3; Good– 4; Excellent – 5.	
VV PV AP	Vehicle volume (Vel/hr); Pedestrian volume (ped/hr); Age of pedestrian.	Based on Motor vehicle volume and pedestrian volume data
WRL WMC SC	Width of road lane (m); Width of mid-block crossing (m); Surface condition of the mid-block crossings (rating scale: Worst – 1;Poor – 2; Fair – 3 Good– 4; Excellent – 5.)	Based on the geometric condition of the road
PMM TSS LF	Pedestrian mid-block road markings (Pavement markings): Unavailable (No) – 0; Available (yes) – 1 Traffic signs and signals: Unavailable (No) – 0; Available (yes) – 1 Lightning Facilities for pedestrians: Following are considered under the lightning facilities (LF): Unavailable(No) – 0; Available (yes) – 1	Based on the safety facilities for pedestrian

Sigma plot was used for developing the mathematical relationship. We were developed the relationship between PSI (Pedestrian Safety Index) and all the above selected variables.
Following rating are considered under the PSI and OSI:
Worst – 1; Poor – 2; Fair – 3; Good– 4; Excellent – 5.
— *Pedestrian Safety index Model on the basis of motor vehicle volume and pedestrian volume data*

Table 3: The details of data for vehicular volume and pedestrian volume.

SITE	PSI_1	PVV	PV	AP	PPV
S1	3	2594	317	4	804
S2	4	0	262	4	830
S3	2	2462	79	1	290
S4	3	1888	104	2	164
S5	3	1358	370	2	662
Average	3	1661	227	2.6	550

Note: S1, S2, S3, S4 and S5 are the different sites in Srinagar city.

Dependent variable = PSI_1
Independent variable = VV, PV, AP, PPV
Dependent variable = f (Independent variable)

$$PSI_1 = f(VV, PV, AP, PPV) \quad (2)$$

Following rating are considered under the Age of Pedestrians
Children – 1; Young Male – 2; Aged Male – 3; Young Female – 4; Aged Female – 5
We insert the data in the given tabular form:
After the analysis of the data in multiple linear regressions, we have been obtained the following result:
Using Multiple Linear Regression:

$$PSI1 = 2.966 - (0.000452 * PVV) + (0.00234 * PV) + (0.464 * AP) - (0.00173 * PPV) \quad (3)$$

Sample size (N) = 6
R = 0.780 R_{sqr} = 0.890 Adj R_{sqr} = 0.60
Standard Error of Estimate = 0.001

VII. CALIBRATION OF PSI_1 MODEL

The calibrated results for PSI model as given in Table 4 -12.

Table 4: The details of multiple linear regression analysis.

	Coefficient	Std. Error	t	P	VIF
Constant	2.966	0.00180	1652.191	<0.001	0.000
PVV	-0.000452	0.000000552	-819.921	<0.001	1.263
PV	0.00234	0.00000837	279.113	0.002	4.397
AP	0.464	0.000712	651.766	<0.001	3.434
PPV	-0.00173	0.00000504	-342.832	0.002	8.895

Table 5: Analysis of Variance.

	DF	SS	MS	F	P
Regression	4	2.000	0.50	470178.828	0.001
Residual	1	0.00000106	0.00000106		
Total	5	2.000	0.400		

Table 6: Analysis of Variance.

Column	SS_{Incr}	SS_{Marg}
PVV	1.373	0.715
PV	0.138	0.0828
AP	0.364	0.452
PPV	0.125	0.125

Table 7: Value of P.

	P
PVV	<0.001
PV	0.002
AP	<0.001
PPV	0.002

The dependent variable PSI_1 can be predicted from a linear combination of the independent variables.
All independent variables appear to contribute to predicting PSI_1 ($P < 0.05$).
Validation of model:
PSI_1 = 2.966 – (0.000452* PVV) + (0.00234* PV) + (0.464* AP) – (0.00173* PPV)
Taking data of S_3 and after putting in PSI_1
PSI_1 = 2.966 - (0.000452*2462) + (0.00234* 79) + (0.464* 1) – (0.00173* 290)
PSI_1 = 2.0043
— *Pedestrian safety index model on the basis of the geometric conditions:*
Dependent variable – PSI_2
Independent variable – WRL, WMC, SC
Dependent variable = f (Independent variable)

$$PSI2 = f(WRL, PV, WMC, SC) \quad (4)$$

Following are considered under the Surface condition:
Worst – 1; Poor – 2 Fair – 3; Good– 4; Excellent – 5
We insert the data in the given tabular form

After the analysis of the data in multiple linear regression, we have obtained the following result:

Multiple Linear Regressions**:**

$$PSI2 = 0.0686 + (0.543 * WRL) - (1.165 * WMC) - (1.838 * SC) \quad (5)$$

Sample size (N) = 6

R = 0.95 R_{sqr} = 0.903 Adj R_{sqr} = 0.756

Calibration of PSI_2 model: The calibrated results of PSI_2 model are given in Table 9 -12.

Table 8: Data for Geometric Conditions.

SITE	PSI_2	WRL	WMC	SC
S1	3	21.1	2.46	3
S2	4	26.18	2.39	4
S3	2	7.2	0	1
S4	3	21.1	2.46	3
S5	3	18.4	2.78	2
Avg.	3	18.796	2.018	2.6

Table 9: The details of multiple linear regression analysis.

	Coefficient	Std. Error	t	P	VIF
Constant	-0.0686	0.000000167	-411171.579	<0.001	
WRL	0.543	0.0000000547	9927002.078	<0.001	247.108
WMC	-1.165	0.000000132	-8833578.433	<0.001	37.329
SC	-1.838	0.000000237	-7738733.073	<0.001	121.434

Table 10: Analysis of Variance.

	DF	SS	MS	F	P
Regression	3	2.000	0.667	2.761E+014	<0.001
Residual	2	4.829E-015	2.415E-015		
Total	5	2.000	0.400		

Table 11: Analysis of Variance.

Column	SS_{Incr}	SS_{Marg}
WRL	1.803	0.238
WMC	0.0521	0.188
SC	0.145	0.145

Table 12: Value of P.

	P
WRL	<0.001
WMC	<0.001
SC	<0.001

The dependent variable PSI_2 can be predicted from a linear combination of the independent variables:

All independent variables appear to contribute to predicting PSI_2 ($P < 0.05$).

Validation of model:

PSI_2 = 0.0686 + (0.543* WRL) – (1.165* WMC) – (1.838* SC)

Taking data of S_3 and after putting in PSI_2

PSI_2 = 0.0686 + (0.543* 7.2) –(1.165* 0) – (1.838* 1)

PSI_2 = 2.0689

— *Pedestrian Safety index Model on the basis of the safety facilities for pedestrians:*

Dependent variable – PSI_3

Independent variable –PMM, TSS, LF

Dependent variable = f (Independent variable)

$$PSI3 = f(PMM, TSS, LF) \quad (6)$$

Following are considered under the pedestrian mid-block crossings (PMM) and traffic signs and signals (TSS):

Unavailable – 0; Available – 1; Following are considered under the lightning facilities (LF); Unavailable – 0; Available – 1

We insert the data in the given tabular form:

Table 13: Data for pedestrian safety facilities

SITE	PSI_3	PMM	TSS	LF
S1	3	1	1	0
S2	4	1	1	1
S3	2	0	1	0
S4	3	1	1	0
S5	3	1	0	1
Avg.	3	1	1	0.4

After the analysis of the data in multiple linear regression we have obtained the following result:

Multiple Linear Regressions:

$$PSI3 = 1.119 + (0.910 * PMM) + (0.881 * TSS) + (0.970 * LF) \quad (7)$$

Sample size (N) = 6

R = 0.970 R_{sqr} = 0.940 Adj R_{sqr} = 0.851

Standard Error of Estimate = 0.244.

Calibration of PSI_3 model: The calibrated results for PSI model as given in Table 14 to 17.

Table 14: The details of multiple linear regression analysis.

	Coefficient	Std. Error	T	P	VIF
Constant	1.119	0.415	2.699	0.0014	0.000
PMM	0.910	0.292	3.113	0.0090	1.194
TSS	0.881	0.335	2.628	0.0011	1.567
LF	0.970	0.299	3.250	0.0083	1.791

Table 15: Analysis of Variance.

	DF	SS	MS	F	P
Regression	3	1.881	0.627	10.500	0.088
Residual	2	0.119	0.0597		
Total	5	2.000	0.400		

Table 16: Analysis of Variance.

Column	SS_{Incr}	SS_{Marg}
PMM	1.200	0.579
TSS	0.0500	0.412
LF	0.631	0.631

The dependent variable PSI_3 can be predicted from a linear combination of the independent variables:

Table 17: Value of P.

Variable	P
PMM	0.090
TSS	0.119
LF	0.083

VIII. VALIDATION OF PSI MODEL

The validated PSI model results are based on motor vehicle volume, pedestrian volume data, road geometric conditions and pedestrian safety facilities for pedestrians of model outcomes are discussed given underneath.

— *Based on motor vehicle volume and pedestrian volume data*

PSI_1 = 2.966 – (0.000452* PVV) + (0.00234*PV) + (0.464* AP) – (0.00173* PPV)

Taking data of S_3 and after putting in PSI_1

PSI_1 = 2.966 – (0.000452* 2462) + (0.00234* 79) + (0.464* 1) – (0.00173* 290)

PSI_1 = 2.0043

— *Based on the road geometric conditions*

PSI_2 = 0.0686 + (0.543* WRL) – (1.165* WMC) – (1.838* SC)

Taking data of S_3 and after putting in PSI_2

PSI_2 = 0.0686 + (0.543* 7.2) – (1.165* 0) – (1.838* 1)

PSI_2 = 2.0689

– *Based on the pedestrian safety facilities for pedestrians*

PSI_3 = 1.119 + (0.910* PMM) + (0.881* TSS) + (0.970* LF)

Taking data of S_3 and after putting in PSI_3

PSI_3 = 1.119 + (0.910* 0) + (0.881* 1) + (0.970* 0)

PSI_3 = 2.00.

IX. PSI MODEL RESULTS

– The overall PSI model results are based on motor vehicle volume, pedestrian volume data, pedestrian safety facilities, road geometric conditions and we obtained different PSI scores for various locations in Srinagar city and then we determined overall safety index (Eqn. 8, 9) for all these selected locations in the city.

– The PSI model ratings are (Table 18) based on the availability of pedestrian safety facilities for pedestrians on urban roads under mixed traffic conditions.

A. Validation of Overall Safety Index (OSI) model

The Overall pedestrian safety index (OSI) was calculated using the equation below by taking average of the all calculated PSI scores of different locations falling in our study area.

$$\text{OSI} = \frac{(\text{PSIM}_1 + \text{PSIM}_2 + \text{PSIM}_3 + \ldots \quad \ldots\ldots\ldots.\text{PSI Mn})}{N} \quad (8)$$

$$\text{OSI} = \frac{\sum_1^3 \text{PSI}}{3} \quad (9)$$

$$\text{OSI} = \frac{2.0043 + 2.0689 + 2.00}{3}$$

OSI = 2.0244

OSI obtain for all the locations is 2.0244 (Table 18) hence the overall condition is poor.

Overall safety index (OSI) obtain for all the selected locations in the Srinagar city is 2.4609 (Table 18). Hence the overall condition is 2 = poor to 3= average and N = number of observations.

X. MODEL CONCLUSION

In Srinagar city, the availability of pedestrian facilities as per Srinagar Development Authority is 25 %, so there is a lack of pedestrian safety facilities on urban roads under mixed traffic conditions. The present study brings forth the following conclusions:

– At Mid-block crossings the overall safety index (OSI) obtained for all the selected locations in the Srinagar city is 2.4609 indicating a poor PSI rating. (Table 18)

–This calls for improving the pedestrian facilities at Mid-block crossings of the Srinagar city.

– This developed PSI model can be applied to any urban area of developing countries under mixed traffic conditions for checking their PSI ratings.

– The study will also be helpful to improve the existing pedestrian facilities, pedestrian flows (ped/hour) and also, to provide pedestrian safety measures on urban roads under mixed traffic conditions.

Table 18: The details of pedestrian safety rating level

PSI Rating	Description (at mid-block crossings facilities for pedestrians)
1	Worst
2	Poor
3	Fair
4	Good
5	Excellent

XI. FUTURE SCOPE

There is a scope to identify the new variables for extreme weather conditions at Mid-block crossings for the development of pedestrian safety index model on urban roads under mixed traffic conditions.

Conflict of Interest: The authors proclaimed that no potential conflicting situations regarding the examination, origin, as well as the production of this article.

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