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Pedestrian Stream Flow Modeling using Single and Multi Regime Concepts

PritikanaDas[1], M. Parida[2*], and V. K. Katiyar[3]

[1] *Centre for Transportation Systems (CTRANS), Indian Institute of Technology Roorkee, India*
[2*] *Department of Civil Engineering, Indian Institute of Technology Roorkee, India*
[3] *Department of Mathematics Indian Institute of Technology Roorkee, India*

Abstract. Analysis of stream flow parameters describes the relationships among the characteristics of pedestrian traffic stream. The level of functional effectiveness of pedestrian infrastructure can be measured and analyzed considering the relationships between stream flow parameters of pedestrian traffic. In this studysingle regime and multi regime models have been proposed for mixed pedestrian traffic condition on sidewalks and carriageways to develop a suitable traffic stream model for heterogeneous traffic condition. Very limitedstudied have been reported in this respect so far from India.Various types of pedestrian facilitiesand regimes based on density rangehave an impact on pedestrian walking behavior which differentiates the response of pedestrian micro-characteristics to its macro-characteristics. Two regime and three regime models have been explainedin the present study to characterize pedestrian traffic in different regimes such as free flow, transitional flow and congested flow regime. A suitable modelhas beendeveloped minimizing error values such as MAPE, RMSE valueand better fitness of predicted data to real situation. This study will be helpful for analyzing and improving pedestrian facilities in terms of efficiency and shall be used for developing the Highway Capacity Manual for India.

Keywords: Clustering, LRM,MAPE, RMSE, Single and Multi-regime, Traffic Flow and Trust region Method.

1. Introduction

Characterization of pedestrian flowstudies were started in 1960s. In recent practice of transportation design and planning, pedestrianization is an integral module of sustainable development. In this paradigm pollution free, safe, convenient and comfortable pedestrian facilities are basic requirement of transport system. Pedestrian flow is a complex and stochastic phenomena. Pedestrian movement study could be categorized broadly into two groups: microscopic and macroscopic level. (Teknomo et al., 2000)observed the individualinteraction of pedestrians in microscopic study for movements.In case of macroscopic study, group movements of pedestrians i.e. stream characteristics are considered for flow characterization. Macroscopic concept for pedestrian flow was suggested by Fruin in 1971 and it was adopted by TRB in 1985.

Pedestrian traffic flow modelling involves mathematical relationships among fundamental parameters of traffic stream. Stream flow models are useful for planning, design, operation and management of transport facilities. Flow parameters such as Speed, Flow, Density/ Space are basic inputsfor pedestrian stream flow modelingin macroscopic approach. (Drew, 1968), (Fruin, 1970), (May and Harmut, 1967)developed Speed-Density relationshipas fundamental and further Speed-Flow, Flow-Space and Flow-Density relationships were calibrated using the fundamental traffic stream equation(1) considering speed (u), flow (q) and density (k)stream flow parameters.

This fundamental equation describes mean speed of pedestrians increase withthe decreasing trend of density and vice-versa considering fixed flow rate for a pedestrian facility. The present study was done for development of optimal model describing relationship between pedestrian stream flow parameters in single regime and multi regime concept for sidewalk and carriageway.

Corresponding author: mparida@gmail.com

Flow=density × space mean speed

$$q = k \times u \qquad (1)$$

Basic equation of state (Equation 2) was derived from equation of motion using fluid flow analogy (Drew, 1968). Estimation of other salient parameters such as optimum density (k_m), optimum speed (u_m) and capacity (q_m) were calibrated based on this methodology (Equation3, 4, and 5). For linear model n will be 1 and for parabolic model n will be 0. Most of these equations are amenableto pedestrian flow because these models were developed based on fluid flow analogy.

$$q = ku_f\left(1 - \left(k|k_j\right)^{(n+1)/2}\right) \qquad (2)$$

$$k_m = k_j\left((n+3)|2\right)^{-2/(n+1)} \qquad (3)$$

$$u_m = \frac{n+1}{n+3}u_f \qquad (4)$$

$$q_m = \frac{u_f k_j (n+1)}{(1|2)^{2/(n+1)}(n+3)^{1+\left(2/(n+1)\right)}} \qquad (5)$$

Precise measurement of required parameters is a challenge for space mean speed and density.(Bauer et al., 2009) observed that there are no optimal sensors for pedestrian counting and with the present sensors having various problems such as limitations for installation heights, occlusion problems etc. Also in pedestrian counting tracking systems are not developed to a point where real-world scenarios are considered. Manual counting from the videos was adopted to avoid possible errors resulting from automatic image recognition, especially in high density range.

Macroscopic approach for traffic stream modelling develops algorithm which relate the flow to the density and space mean speed (Garber and Hoel, 2014). (Roess et al., 2004) described volume, speed, density are the three principle macroscopic parameters of traffic stream. (Chakroborty and Das, 2003) defined the condition of traffic stream by two stream variables speed and density.It was summarized by(May, 1990) that the multi regime models provide a considerable improvement over single regime models, whereas both models had different strengths and weakness.(Ardekani et al., 2011) observed four conventional traffic stream flow models (Greenshield, Greenberg, Underwood, and Drake) as well as five modifications of these models for free flow speed and density relationship for freeway traffic condition. (May, 1990)described similarities between flow phenomena of vehicles and pedestrians. There are only two differences in terms of numerical values of flow characteristics and units of stream parameters. Various researchers applied vehicular traffic flow models in characterization of pedestrian movements (Fruin, 1970, Virkler and Elayadath, 1994).

There are no different stream flow models for different pedestrian facilities considering multi regime concept. Here an attempt is made to develop models for sidewalk and carriageway facilities. Existing definition of sidewalk is suitable for only homogeneous condition but in heterogeneous condition, wherepedestrians comprises both motorised and non-motorised vehicles,sharing the same right-of-way. Under such situation there is need to define a type of facility for pedestrians rather than sidewalk concept. In this study carriageway term is used to define such type of facility along the roadside only.

Furtheran empirical Speed-Density relationship was developed for sidewalk and carriageway for heterogeneous traffic condition in this study. For development of stream flow models using multi regime concept,K means cluster analysis was used to decide boundary values. Based on this fundamental relationship corresponding other stream flow models were developed.

2. Past Studies on Pedestrian Flow Modelling

Various models have been developed to describe Speed-Density relationship for different facilities and most of them suggested for linear relationship (Fruin, 1970, Lam et al., 1995, Navin and Wheeler, 1969, Older, 1968, Tanaboriboon et al., 1986, Polus et al., 1983, Tanaboriboon and Guyano, 1989, Laxman et al., 2010). Three regime model was developed to define Speed-Density relationship by Polus et al. (1983), which is more realistic than one regime model by utilizing a visual and statistical approach (Polus et al., 1983).They observed no significant deterioration up to 0.6 p/m^2 densitywhich is the range for free flow speed estimation.(Ando et al., 1988) observed free flow speed range for level surface up to 0.8 p/m^2 density. The value of jam density 3.89 p/m^{2}on shopping street in Britain(Older, 1968), 3.99 p/m^2 around bus terminal in USA(Fruin, 1970), 3.32 p/m^2 on sidewalk facility in Dhaka (Rahman et al., 2013), 3.6 p/m^2 in mixed traffic condition in metro Manila for walkway (Gerilla et al., 1995),4.17in India mixed traffic condition (Laxman et al., 2010), 4.2 p/m^2 at an intermodal transfer terminal at Howrah station (Sarkar and Janardhan, 2001).

(Al-Masaeid et al., 1993) established a relation between Speed-Flow for CBD areas in developing countries.(Parida et al., 2007) considered different type of models for developing relationships between pedestrian flow parameters for sidewalk in Delhi based on single regime. (Al-Azzawi and Raeside, 2007)observed quadratic relationship between the reciprocal of walking speed and pedestrian density for sidewalks in UK. (Ye et al., 2008)and (Chen et al., 2010)worked on level passageway, stairway and confined passageway to establish relationships and characteristics of pedestrian traffic considering single regime approach.(Jia et al., 2009)worked on pedestrian flow characteristics at Chinese comprehensive passenger transport terminal—Xizhimen underground station and observed a linear relationship between Speed-Density and quadratic equation for flow-density relation model in corridor.Level of Service of Sidewalk facility in current HCM methodology was developed based on one-regime concept (Manual, HCM, 2010).(Rastogi et al., 2013)observed negative exponential relationship which was best fitted to the observed data for Speed-Density relationshipon sidewalks, wide-sidewalks and precincts in five cities in India considering single regime concept.(Rahman et al., 2013)developed Speed-Density relationship for sidewalk using OLS and weighted regression method in Dhaka.(Nazir et al., 2014)developed pedestrian flow characteristics in the walkways of Rajshahi metropolitan city of Bangladesh and Speed-Density relationship for both directions of traffic considering general relationship based on single regime approach.

3. Data Collection and Extraction Methodology

In this section details of study locations, data collection methodology and data extraction procedure have been discussed. Results of Exploratory Data Analysis (EDA) for collected stream flow parameters are described here.

3.1 Data Collection and Basic Statistics

Dehradun Railway Station and Dehradun ISBT area were selected as carriageway and Roorkee Railway Station and Delhi North campus were selected as study area for sidewalks. In first step data was collected manually in Dehradunfor 16 hours from 6 am to 10 pm to identify peak and off-peak demand for pedestrian flow. Then further data were collected using video recording in peak hour and off peak hour in Roorkee, Dehradun and Delhi.For recording purpose camera was fixed at a vantage position so as to obtain an overall view of the selected test location. Trap section considered for the study was marked with self-adhesive yellow road tape to make it visible in the video.

Exploratory Data Analysis (EDA) was done to describe the basic characteristics of stream flow parameters for sidewalk and carriageway and out coms from the analysis are given in Table 1. Correlation between mean values of speed and density -0.89 for sidewalk and -0.86 for carriageway represent strong correlation between speed and density for both the facilities.

Table 1: Results from EDA Analysis on Stream Flow Parameters

Statistic of Data	Speed		Flow		Density	
	Sidewalk	Carriageway	Sidewalk	Carriageway	Sidewalk	Carriageway
Maximum	87.91	98.63	89.85	78.68	1.58	1.62
Minimum	47.01	55.01	0.66	0.91	0.01	0.01
Mean	72.19	74.55	17.24	17.63	0.26	0.26
Variance	64.90	65.79	275.04	221.63	0.09	0.07
Std. Deviation	8.06	8.11	16.58	14.89	0.30	0.27

3.2 Data Extraction

Optimal time interval was observed in data extraction technique for pedestrian flow modelling for different type of facilities in Shanghai Metro stations (Jianhong and Xiaohong, 2011).Observed optimized measurement interval for development of pedestrian flow model for sidewalk movement in India is 30 seconds (Das et al., 2014). In this study macroscopic parameters were extracted from the recorded videos. The collected videos were played in the laboratory to manually extract the required data on speed, flow and density at 30s intervals. Space mean speed and flow parameters were observed from video but density was estimated considering fundamental Speed-Flow-Density relationship (i.e. density=Flow/Speed). The Pearson Correlation coefficient between the observed and estimated density was 0.959. Speed data were extracted with an accuracy of $1/30^{th}$ of sec. Pedestrian travel time was obtained by subtracting the time of entry into the trap from the time of exit and walking speed was estimated by dividing the known length of the trap by the travel time.In this study space mean speed was considered for speed data collection technique. Randomly maximum 5 pedestrians were observed in 30s interval to observe the average speed. Flow value was measured by the total number of pedestrians passing a line of sight across the width of the pedestrian facility in 30s time interval for bidirectional flow. Flow rate was estimated from dividing the total number of pedestrian by effective width of sidewalk and multipliedwith 2 to get flow rate in terms of P/m/min. Effective width was calculated deducting shy distance considering effective width of fixed objects located on sidewalk as per HCM (2010).

4. Scatter Plots of field data for Sidewalks and Carriageways

Extracted parameters were plotted to observe scatter plot for both pedestrian facilities sidewalk and carriageway. Visible outliers were removed and the scatter plots of speedagainst density are shown in Figures 1. It can be observed from plots, that in each facilitySpeed-Density relationship providing a general trend towards reduction in speed with the increasing density value. But in this stage it is not possible to model a relationship between speed and density because of missing of data for complete range of traffic operation. There is need to accommodate data for higher range of densities. Removal of noise from data is required for development of a model to describe relationship between speed and density. Anoptimum Speed–Density relationship was developed empiricallyusing a trust region-based optimization algorithm using this data set. Based on this basic relationship MFD will be established to represent the pedestrian flow condition in mixed traffic for both facilities.

5. Calibration of Stream Flow Models for Pedestrian Traffic

Nature of Speed-Flow-Density relationships are known as stream models. Modelling aspects includes measurement methods to obtain the data and the type of facility at which the measurements were obtained. Models should represent the behavior of pedestrian traffic variables over the full range of operation. Aggregate analysis was done at each density at each location for bidirectional flow of pedestrian traffic. To obtain data at higher density range video data was extracted for lower trap area considering trap length 5m. In this section proposed pedestrian stream flow models

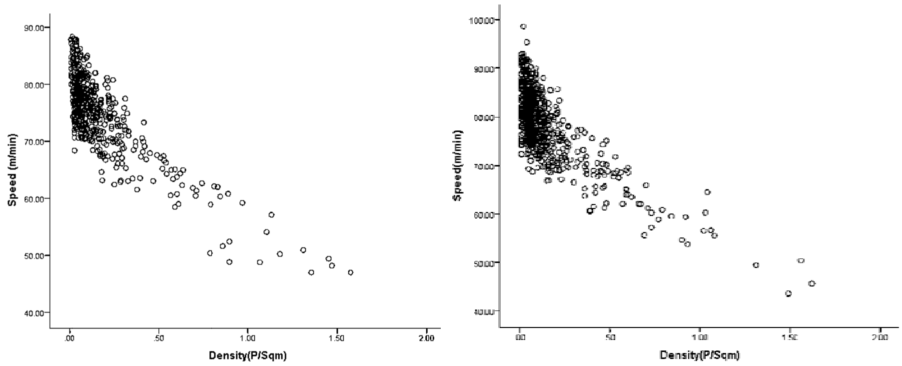


Figure 1: Speed-Density Scatter Plot on Sidewalks and Carriageways

will be discussed for single Regime and multi Regime models for sidewalk and carriageway.

5.1 Proposed Single Regime Stream Flow Models

The relationships for pedestrian traffic flow on sidewalks and carriageway have been established in this section considering single regime concept. In this study collected data have been fitted tofive classical traffic stream model. First, Greenshields' linear model was usedconsidering single regime concept to characterize the Speed-Density relationship (Greenshields, 1935). Secondly, Underwood (exponential) model was fitted to observed data to describe Speed-Density relationship (Underwood, 1961). Other two applied models are Drew (1968) and quadratic model.Drew proposed more generalized model based on Greenshields' model with addition of new parameter n. These single-regime models have certain fitness conditions but each model has some deficiencies over some portion of density range. Disadvantage of Underwood model is that speed never reaches zero and jam density is infinity. Numerousresearches (Daamen and Hoogendoorn, 2006, Fruin, 1970, Duncan, 1976, Duncan, 1979, Older, 1968, Jia et al., 2009, Lam et al., 1995, Tanaboriboon et al., 1986, Rastogi et al., 2013, Laxman et al., 2010, Rahman et al., 2013)have been done on single regime concept for different facilities of different countries.

Statistical as well as logical approaches also have been considered here for selection of best traffic stream model which will represent realistic characteristics of pedestrian flow in mixed traffic condition. In statistical approach, the adequacy of the model has been checked by the "goodness of fit" i.e. R^2 value of model. R^2 is defined as the square of the correlation between the response values and the predicted response values. It is also called the square of the multiple correlation coefficient and the coefficient of multiple determination.

Calibrated models for Speed-Densityrelationship and estimated stream flow parameters for sidewalks and Carriagewaysare given in Table 2. The value of coefficient of determinant $R^2$is 0.836 for Underwood model. This model gives maximum value of R^2 among five models for both the facilities. It represents best fitness of observed data in Underwood model. Graphical representations of single regime models are shown in Figure 2.

Accuracy of model prediction has been checked by the mean absolute percentage error (MAPE), root mean square error (RMSE). RMSE is a frequently used measure of the differences between value predicted by a model or an estimator and the values actually observed. MAPE basically expresses accuracy as a percentage of the error. For best prediction of model RMSE, MAPE value should be less than others when we consider statistical approach. RMSE and MAPE values were estimated using equation (6) and (7). Considering logical approach in real situation single regime model is not fitted and models should be divided into multi regimes.

$$MAPE\ (\%) = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{O_t - E_t}{O_t}\right| \times 100 \qquad (6)$$

$$RMSE = \sqrt{\left(\frac{\sum_{t=1}^{n}(E_t - O_t)^2}{N}\right)} \qquad (7)$$

After calibration of Speed-Density equation, other stream flow equations have been derived using fundamental classical relationship. Derived models for flow-density, Speed-Flow and flow-space with the MAPE and RMSE values are shown in Table 3 for sidewalks and carriageways. Less MAPE or RMSE value depict less error in predicted value. Minimum MAPE and RMSE value 3.85 and 3.35 Model-III i.e. Drew model for Speed-Density model on sidewalk movement. This represent Model-III will give best fitness of prediction. This model gives best prediction of data for pedestrian movement on carriageway also considering single regime approach.

Table 2: Calibration of Single Regime Speed-Density Models for Sidewalks & Carriageways

Model	Equations	Calibration	R^2	Stream Flow Parameters				
				U_f m/min	U_m m/min	k_j P/m^2	k_m P/m^2	q_m P/min/m
Sidewalks								
Model-I Greenshield	$U = U_f - \left(\frac{U_f}{k_j}\right)k$	U= 78.57 -24.18k	0.799	78.57	39.28	3.25	1.63	63.83
Model-II Underwood	$U = U_f e^{-k/k_m}$	U= 79.06 $e^{-0.37k}$	0.836	79.06	29.08	∞	2.70	78.61
Model-III Drew	$U = U_f\left(1 - \left(\frac{k}{k_j}\right)^{(n+1)/2}\right)$	U= 83.43[1-(k/6.19)$^{0.6}$]	0.832	83.43	60.54	6.19	2.83	88.48
Model-IV Quadratic	$U = U_f\left(1 - \left(\frac{k}{k_j}\right)^2\right)$	U= 74.91(1-k^2/4.35)	0.614	74.91	38.7	2.086	1.45	56.12
Carriageways								
Model-I Greenshield	$U = U_f - \left(\frac{U_f}{k_j}\right)k$	U= 81.39 -26.19k	0.746	81.39	40.53	3.11	1.56	63.23
Model-II Underwood	$U = U_f e^{-k/k_m}$	U= 81.93 $e^{-0.39k}$	0.792	81.93	33.87	∞	2.56	77.28
Model-III Drew	$U = U_f\left(1 - \left(\frac{k}{k_j}\right)^{(n+1)/2}\right)$	U= 87.54[1-(k/6.51)$^{0.6}$]	0.785	87.54	63.58	6.51	2.97	97.64
Model-IV Quadratic	$U = U_f\left(1 - \left(\frac{k}{k_j}\right)^2\right)$	U= 77.08(1-k^2/4.25)	0.529	77.08	51.40	2.06	1.19	61.16

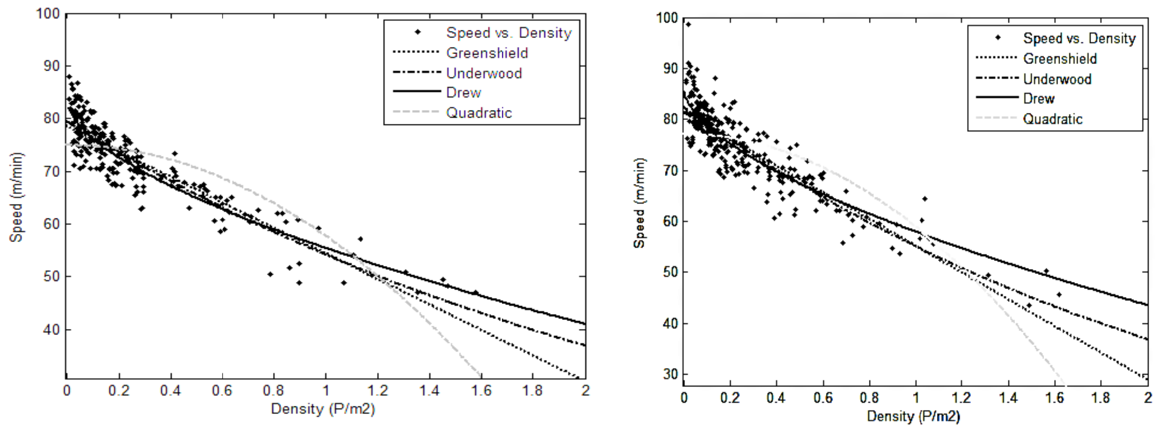


Figure 2: Single regime Models fitted to observed data (Sidewalk & Carriageway)

5.2 Proposed Two Regime Stream Flow Models

A unique model to represent the entire regime of traffic including the free-flow and congested regimes is not true in real condition, so it is required to include multi-regime model concept to represent different flow conditions. In multi-regime models two regime model was first proposed by Edie (Edie, 1961) which includes free-flow regime and congested-flow regime and for three regime models were proposed by Drake and May (Drake and May, 1967; May, 1990) considering free-flow, transitional-flow and congested-flow regimes in motorized traffic flow models. (May and Keller, 1900) determined traffic flow model on tunnel data considering single and two regime modeling approach. The basic requirement of multi-regime models is to determine breakpoints in a scientific way. (Polus et al., 1983)

Table 3: Calibration of Relationships between Stream Flow Parameters for Sidewalk

Model	Stream Flow Relationships	Calibration	MAPE (%)	RMSE
Sidewalks				
Model I	Speed-Density	$U = 78.57 - 24.18k$	4.03	3.60
	Flow-Density	$Q = k(78.57 - 24.18k)$	4.95	2.90
	Flow-Space	$Q = \left(78.57/M - 24.18/M^2\right)$	4.75	2.34
	Speed-Flow	$Q = \frac{U}{24.18}(78.57 - U)$	73.56	9.09
Model II	Speed-Density	$U = 79.06e^{-.37k}$	3.86	3.45
	Flow-Density	$Q = 79.06ke^{-.37k}$	4.85	2.45
	Flow-Space	$Q = \frac{79.06}{M}e^{-0.37/M}$	4.85	2.45
	Speed-Flow	$Q = 2.7Uln(79.06/U)$	67.48	8.40
Model III	Speed-Density	$U = 83.43\left(1 - \left(k/6.19\right)^{0.6}\right)$	3.85	3.35
	Flow-Density	$Q = 83.43k\left(1 - \left(k/6.19\right)^{0.6}\right)$	4.88	2.30
	Flow-Space	Q= $\frac{83.43}{M}$[1-(1/(6.19×M))$^{0.6}$]	4.88	2.30
	Speed-Flow	Q= $6.19U\left(1 - \frac{U}{83.43}\right)^{1/0.6}$	60.84	7.52
Model IV	Speed-Density	U= 74.91(1-k^2/4.35)	5.69	4.99
	Flow-Density	$Q = 74.91k\left(1 - k^2/4.35\right)$	6.33	4.08
	Flow-Space	Q= $\frac{74.91}{M}\left(1 - \left(1/(M^2 \times 4.35)\right)\right)$	6.33	4.08
	Speed-Flow	Q=U〚4.35*(1-U/74.91)〛^0.5	129.29	17.54
Carriageways				
Model I	Speed-Density	$U = 81.39 - 26.19k$	4.28	4.09
	Flow-Density	$Q = k(81.39 - 26.19k)$	4.29	1.77
	Flow-Space	$Q = \left(81.39/M - 26.19/M^2\right)$	4.29	1.77
	Speed-Flow	$Q = \frac{U}{26.19}(81.39 - U)$	66.66	9.12
Model II	Speed-Density	$U = 81.93e^{-.39k}$	4.08	3.93
	Flow-Density	$Q = 81.93ke^{-.39k}$	4.10	1.42
	Flow-Space	$Q = \frac{81.93}{M}e^{-0.39/M}$	4.10	1.42
	Speed-Flow	$Q = 2.6Uln(81.93/U)$	60.76	8.38
Model III	Speed-Density	$U = 87.54\left(1 - \left(k/6.51\right)^{0.6}\right)$	4.05	3.85
	Flow-Density	$Q = 87.54k\left(1 - \left(k/6.51\right)^{0.6}\right)$	4.47	1.56
	Flow-Space	Q= $\frac{87.54}{M}$[1-$(1/(6.51 \times M))^{0.6}$]	4.47	1.56
	Speed-Flow	Q= $6.51U\left(1 - \frac{U}{87.54}\right)^{1/0.6}$	74.43	9.82

Model IV	Speed-Density	U= 77.08(1-k²/4.25)	6.03	5.56
	Flow-Density	$Q = 77.08k\left(1 - k^2/_{4.25}\right)$	5.99	2.99
	Flow-Space	$Q = \frac{77.08}{M}\left(1 - \left(1/_{(M^2 \times 4.25)}\right)\right)$	5.99	2.99
	Speed-Flow	Q=U 〚4.25*(1-U/77.08)〛^0.5	123.51	18.08

developed three regime Speed-Density model for pedestrian traffic in subways. (Virkler and Elayadath, 1994) applied seven different stream flow models with two regime and three regime models for paved walkway in Columbia.

Northwestern researchers used work of Quandton likehood functions to determine breakpoints between regimes multi regime modeling (May, 1990). (Polus et al., 1983) observed visually most reasonable limits to differentiate between the various groups of data and best possible model was calibrated in terms of correlation coefficient and other statistical parameters to obtain breakpoints for multi regime modelling. (Virkler and Elayadath, 1994) also used Quandt's technique to find out breakpoints for multi regime modelling.

In this study breakpoints have been identified using K-mean clustering in SPSS in first stage.Then final selections of breakpoints were determined by utilizing a visual and statistical approach considering limitations of macroscopic parameters. Goodness of fit measures for each of the regime component models are strongly accepted to underscore the validity of this formulation as a basis for developing an improved understanding of behavior.Calibrated Speed-Densitymodels for two-regime concept are presented in Table 4for sidewalk and carriageway.Figure 3 shows best fitted Speed-Density models for sidewalk and carriageway in two regimemodeling. Other stream flow models were calibrated and MAPE and RMSE values were observed similarly as single regime models to measure accuracy for data prediction.

Table 4: Calibration of Stream Flow Parameters for Two regime models (Sidewalks& Carriageways)

Relationships	Model Name	Estimated Models	Stream Flow Parameters					R^2
			U_f m/min	U_m m/min	k_j P/m²	k_m P/m²	q_m P/min/m	
Sidewalks								
Linear Linear	Model I	U= 80.11-34.86k (k<0.5) U=74.16 -18.69k (k>0.5)	80.11	37.15	3.96	1.98	52.67	0.50 0.74
Linear Exponential	Model II	U= 80.11-34.86k (k<0.5) $U=76.60e^{-0.33k}$ (k>0.5)	80.11	28.18	∞	3.03	88.14	0.50 0.75
Exponential Linear	Model III	$U=80.13e^{-0.46k}$ (k<0.5) U=74.16 -18.69k (k>0.5)	80.13	37.15	3.96	1.98	52.67	0.51 0.74
Exponential Exponential	Model IV	$U=80.13e^{-0.46k}$ (k<0.5) $U=76.60e^{-0.33k}$ (k>0.5)	80.13	28.18	∞	3.03	88.14	0.51 0.75
Carriageways								
Linear Linear	Model I	U= 82.96-35.76k (k<0.5)	82.96	38.53	3.85	1.93	74.37	0.57

		U= 77.21-20.04k (k>0.5)						0.77
Linear Exponential	Model II	U= 82.96-35.76k (k<0.5)	82.96	29.68	∞	2.85	84.58	0.57
		$U=80.47e^{-0.35k}$ (k>0.5)						0.79
Exponential Linear	Model III	$U=83.12e^{-0.48k}$ (k<0.5)	83.12	38.53	3.85	1.93	74.37	0.58
		U= 77.21-20.04k(k>0.5)						0.77
Exponential Exponential	Model IV	$U=83.12e^{-0.48k}$ (k<0.5)	83.12	29.68	∞	2.85	84.58	0. 57
		$U=80.47e^{-0.35k}$ (k>0.5)						0.79

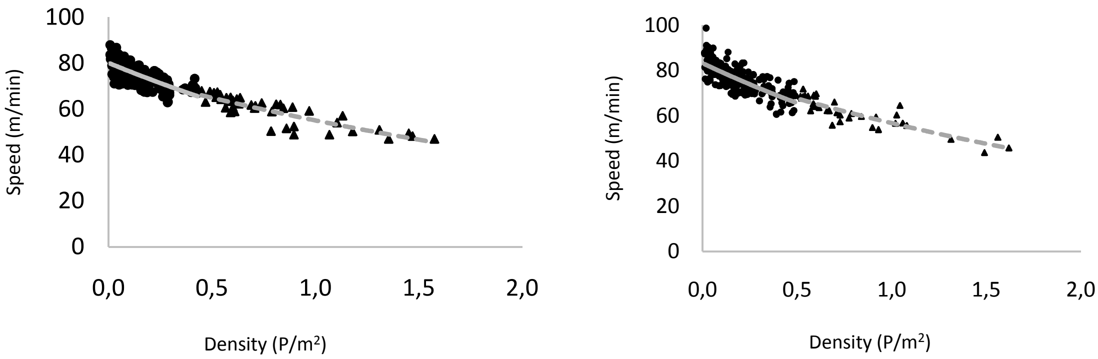


Figure 3: Best fitted Two Regime model for Sidewalks and Carriageways

5.3 Proposed Three Regime Stream Flow Models

Edie first proposed two regime concept for model development in 1961 using Underwood model for free flow condition and Greenberg model for congested flow condition. Then Northwestern University research team proposed two regime model using Greenshield model for free flow and congested flow separately. Lastly three regime model was proposed using Greenshield model separately for Free flow regime, transitional flow regime and congested flow regime. (Polus et al., 1983) proposed three regime model for pedestrian movement on sidewalk in CBD areas of Israel. (Virkler and Elayadath, 1994) applied seven models including two regime and three regimemodels of Drake et al. for highway flow (Drake et al., 1967) in a pedestrian tunnel, Columbia.

Developed Speed-Density models for sidewalk and carriageway with the estimated stream flow parameters using three regime concept are shown in Table 5. Other stream flow models with the accuracy value for prediction i.e. MAPE and RMSE values are given in Table 6 for both facilities. It was observed from the results of sidewalk models that Model IV gives better prediction to characterize pedestrian movement considering lesser value of MAPE and RMSE among four models. Model-II i.e three regime exponentialwas best fitted for carriageway movement after observing prediction error corresponding Speed-Flow relationship. Graphical representation of best fitted model in three regime are shown in Figure 4.

6. Comparison between Single regime and Multi regime models

Firstly, comparing four single regime models' parameters for sidewalk, free flow speed $U_f$varies between 75 m/min to 84 m/min and optimum speed varies from 29 m/min to 61 m/min but optimum speed should not be higher than 49 m/min as per (Ye et al., 2008), (Laxman et al., 2010). Available space for pedestrian at capacity level varies from 0.35m^2/P to 0.69m^2/P. As per (Fruin, 1970), (Manual, HCM, 2010), (Jia et al., 2009) minimum area required for a pedestrian is 0.3 m^2.

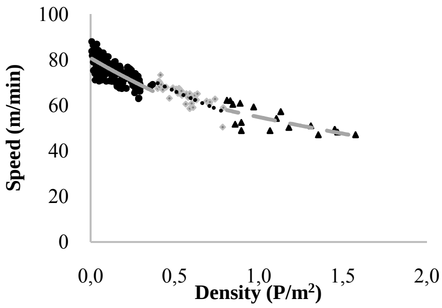
Estimated free flow value for carriageway varies from 77 m/min to 88 m/min, optimum speed varies from 34 to 64 m/min and estimated space at capacity varies from 0.34m^2/P to 0.83m^2/P. Using MAPE and RMSE values Drew model has been selected as better model and considering R^2 value Underwood model has been best fitted model among four models for Sidewalk and carriageway. Secondly for two regime models estimated free flow speed 80.1 m/min, optimum speed varies from 28 m/min to 37 m/min and required space at capacity 0.33 to 0.5 m^2/P for sidewalk movement. For carriageway movement estimated free flow speed 80.1 m/min, optimum speed varies from 30 to 39 m/min and required space at capacity varies from 0.35m^2/P to 0.52 m^2/P.

Thirdly for three regime models free flow speed 81 m/min, optimum speed varies from 26 m/min to 36 m/min and required space at capacity varies from 0.28m^2/P to 0.44m^2/P on sidewalk. Estimated free flow value for carriageway in three regime models varies from 83.4 m/min, optimum speed varies from 30 to 38 m/min and estimated space at capacity varies from 0.34 to 0.48 m^2/P. It can be observed from estimated parameters estimation of optimum speed and minimum required space for pedestrian values are more accurate and realistic for multi regime concept. Also free flow speed prediction by multi regime model concept appeared reasonable with the field data.

Table 5: Calibration of Stream Flow Parameters for Three regime models (Sidewalks & Carriageways)

Relationships	Model Name	Estimated Models	Stream Flow Parameters					R^2
			U_f m/min	U_m m/min	k_j P/m^2	k_m P/m^2	q_m P/min/m	
Linear Linear Linear	Model I	$U= 80.69-40.25k$ $(k<0.4)$ $U=82.13-31.71k$ $(0.4<k<0.8)$ $U= 70.47-15.43k$ $(k>0.8)$	80.69	35.29	4.57	2.28	80.46	0.51 0.67 0.50
Exponential Exponential Exponential	Model II	$U=80.74e^{-0.54k}$ $(k<0.4)$ $U=85.15e^{-0.50k}$ $(0.4<k<0.8)$ $U=72.92e^{-0.29k}$ $(k>0.8)$	80.74	25.9	∞	3.45	92.50	0.51 0.65 0.51
Exponential Exponential Linear	Model III	$U=80.74e^{-0.54k}$ $(k<0.4)$ $U=85.15e^{-0.50k}$ $(0.4<k<0.8)$ $U= 70.47-15.43k$ $(k>0.8)$	80.74	35.29	4.57	2.28	80.46	0.51 0.65 0.50
Exponential Linear Exponential	Model IV	$U=80.74e^{-0.54k}$ $(k<0.4)$ $U=82.13-31.71k$ $(0.4<k<0.8)$ $U=72.92e^{-0.29k}$ $(k>0.8)$	80.74	25.9	∞	3.45	92.50	0.51 0.67 0.51
Linear	Model	$U= 83.34-38.91k$ $(k<0.4)$	83.34	37.56	4.19	2.09	78.49	0.54

Linear Linear	I	$U=84.09-31.94k$ (0.4<k<0.8) $U=75.01-17.92k$ (k>0.8)						0.48 0.63
Exponential Exponential Exponential	Model II	$U=83.494e^{-0.51k}$ (k<0.4) $U=87.07e^{-0.49k}$ (0.4<k<0.8) $U=80.34e^{-0.34k}$ (k>0.8)	83.49	29.57	∞	2.94	86.93	0.55 0.48 0.65
Exponential Exponential Linear	Model III	$U=83.494e^{-0.51k}$ (k<0.4) $U=87.07e^{-0.49k}$ (0.4<k<0.8) $U=75.01-17.92k$ (k>0.8)	83.34	37.56	4.19	2.09	78.49	0.55 0.48 0.63
Exponential Linear Exponential	Model IV	$U=83.494e^{-0.51k}$ (k<0.4) $U=84.09-31.94k$ (0.4<k<0.8) $U=80.34e^{-0.34k}$ (k>0.8)	83.49	29.57	∞	2.94	86.93	0.55 0.48 0.65



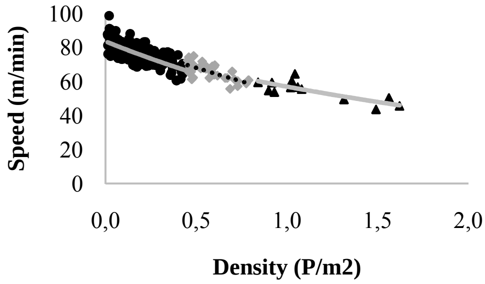


Figure 4: Three Regime Linear model for Sidewalk and Carriageway

Table 6 showsbetter fitness of three regime model considering MAPE and RMSE values as comparable to single regime and two regime model. Another statistical approach for comparing all the calibrated models, LRM was used for comparison of observed and predicted data. Linear Regression Model (LRM) was used for observing the fitness of observed and estimated data using developed fundamental stream flow models and results in terms of R^2 are given in Table 7. Using this analysis it can be concluded that three regime stream flow modeling better fits to the observed data.

Table 6: Model Fitting Results for Two & Three Regime model on Sidewalksand Carriageways

Model	Relationships	Sidewalk		Carriageway	
		MAPE (%)	RMSE	MAPE (%)	RMSE
Two Regime Model-I	Speed-Density	4.03	3.87	4.07	3.86
	Flow-Density	5.03	2.50	4.07	1.34
	Flow-Space	4.89	2.39	4.07	1.34
	Speed-Flow	61.44	7.59	59.48	7.52
Two Regime Model-II	Speed-Density	3.84	3.39	4.05	3.85
	Flow-Density	4.88	2.31	4.06	1.34
	Flow-Space	4.88	2.31	4.06	1.34
	Speed-Flow	61.27	7.53	59.37	7.46
Two Regime Model-III	Speed-Density	3.84	3.38	4.04	3.84
	Flow-Density	4.88	2.38	4.05	1.34
	Flow-Space	5.4	3.44	4.05	1.34
	Speed-Flow	64.05	11.26	57.42	7.50
Two Regime	Speed-Density	3.83	3.37	4.02	3.83

Model-IV	Flow-Density	4.87	2.30	4.03	1.33
	Flow-Space	4.86	2.30	4.03	1.33
	Speed-Flow	53.49	53.49	57.13	7.36
Three Regime Model-I	Speed-Density	3.75	3.29	3.98	3.79
	Flow-Density	4.85	2.20	4.02	1.32
	Flow-Space	57.10	6.79	57.13	7.07
	Speed-Flow	4.85	2.20	4.02	1.32
Three Regime Model-II	Speed-Density	3.75	3.28	3.96	3.78
	Flow-Density	4.84	2.18	3.99	1.32
	Flow-Space	55.75	6.78	56.23	7.03
	Speed-Flow	4.85	2.22	4.00	1.32
Three Regime Model-III	Speed-Density	3.76	3.28	3.96	3.78
	Flow-Density	4.85	2.20	3.99	1.32
	Flow-Space	57.15	6.88	56.55	7.09
	Speed-Flow	4.84	2.20	3.99	1.32
Three Regime Model-IV	Speed-Density	3.76	3.28	3.96	3.78
	Flow-Density	4.85	2.22	4.00	1.32
	Flow-Space	55.77	6.77	56.28	7.05
	Speed-Flow	4.85	2.22	4.00	1.32

Table 7: Model Comparison using LRM for Observed and Estimated Data for Sidewalk & Carriageway (R^2 Value)

	Single Regime				Two Regime				Three Regime			
	Model I	Model II	Model III	Model IV	Model I	Model II	Model III	Model IV	Model I	Model II	Model III	Model IV
SW	0.780	0.817	0.820	0.610	0.770	0.823	0.824	0.824	0.833	0.833	0.834	0.834
CW	0.745	0.765	0.770	0.530	0.530	0.774	0.776	0.777	0.780	0.782	0.783	0.782

***** SW: Sidewalk CW: Carriageway

7. Conclusions

Stream flow characteristics have been analyzed for two different pedestrian facilities in three locations in India. Noise from the collected data was removed using trust region method. Speed-Density model was estimated using four models and other stream flow models were calibrated using classic model (Equation 1). Stream flow parameters were estimated from the models based on basic equations as per fluid flow analogy (Drew, 1968). Relationship between stream flow parameters were estimated using single regime and multi regime concept. For multi regime modelling breaking points were identified using K-mean clustering using SPSS. In single regime concept Greenshield (linear), Underwood (exponential), Drew and Quadratic models were applied to the collected data.

It was observed from the statistical analysis in single regime Speed-Density model for sidewalk error in prediction varies from 3.85 to 5.69 MAPE value whereas in Two regime model error in terms of MAPE varies from 3.83 to 4.03 and in Three regime model MAPE value varies from 3.75 to 3.76 . Also considering LRM fitness of data for single regime model on sidewalk varies from 0.53 to 0.745 in terms of R^2, for two regime model this value varies from 0.773 to 0.777 and for three regime model this value varies from 0.780 to 0.783. It represent three regime model gives better fitness and prediction of data. For carriageway model analysis MAPE value for single regime model varies from 4.05 to 6.03, for two regime model this value varies from 4.02 to 4.07, and for three regime model it varies from 3.96 to 3.98. Here also it can be conclude that three regime model has better prediction efficiency. Similarly for data fitness efficiency three regime model gives better performance for carriageway considering LRM analysis.

From statistical and logical approach Drew and Underwood model was best fitted model for sidewalk and carriageway. In single regime concept estimation of free flow speed and capacity is not able to represent real scenario, free flow and congested regime should be modeled separately. In literature two regime linear and three regime linear models were applied mostly, but in this study four different models were used for two regime and three regime modelling. Estimated stream flow parameters from multi regime models are more accurate and realistic. In two regime model Model-IV i.e. two regime exponential model for carriageway and sidewalk movement which gives less error in prediction. Three regime exponential model i.e. Model-II was best fitted for sidewalk and carriageway movement comparing MAPE and RMSE values for Speed-Flow-Density relationships. Comparing MAPE and RMSE values of all the models, single regime models have more error than multi regime modelsand also more error in prediction from single regime model as comparable to multi regime concept. LRM was used to compare relationship between observed and estimated data in Speed-Density model i.e. fundamental stream flow model. It can be concluded from the R^2 values of the LRM fittings that three regime model gives best and optimized among other models for both the facilities.

From this present study it can be concluded that stream flow modelingconcept can be approved for sidewalk and carriageway using multi regime modelling which will have better ability to represent real life scenario.

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