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Behavioral Characteristics of Pedestrian Flow on Stairway at Railway Station

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Abstract

India has witnessed higher level of mobility at urban as well as intercity segments due to improvisation of socio-economic conditions in last two decades. Even though, majority of the intercity travel is made by road based modes, number of passengers traveling by railways is significant on certain highly industrialized corridors. Collection and dispersal of passengers on railway platforms take place through stairways and foot over bridges. Design of these vital elements needs to incorporate the behavior of pedestrian flow to ensure desired level of service as well as safety in case of emergency. As reported in literature, pedestrian flow characteristics are influenced by number of attributes of pedestrian like age, gender, physical dimensions, luggage carried, group size, activity while walking, purpose in addition to the other attributes such as space availability, direction of movement and schedule of train as well. Very limited efforts are made in India to study pedestrian flow behavior in this context.

Fluctuations in pedestrian flow depends on schedule of arrival and departure of the train, particularly during the peak hours as there is large passenger flow in short interval of time. Due to limited capacity of pedestrian facility, especially staircases, desired speed cannot be achieved by the pedestrian while walking in crowd with luggage. Higher walking speed is reported on downstairs than upstairs with reduction in speed with increase in pedestrian density. Most of the pedestrian facilities are designed by rule of thumb, especially stairways, largely governed by ideal pedestrian behavior. However behavior of individual pedestrian and hence flow at rail transit stations are dynamic on stairways depending on the factors mentioned above. Present study attempts to highlight the results of the study carried out on pedestrian flow behavior at Vadodara railway station in the state of Gujarat, India. Total 3411 number of pedestrian data are extracted by employing videographic technique. Flow models of speed- flow, speed-density and flow-density are developed to illustrate behaviour of pedestrian stream on stairways of different dimensions.

Selection and peer-review under responsibility of International Scientific Committee.

Keywords: Pedestrian flow; Stairway; Luggage; Railway station; Arrival of train

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1. Introduction

High level of industrialization in along specific industrial regional corridors generate huge amount of commuter traffic as well as casual travel. The demand for mobility encourages the development of mass rapid transit infrastructure along such corridors (Townsend and Zacharias, 2010). The state of Gujarat in Western India is leading industrial growth of the country through continuous rise in industrial activities along its urban corridor between Ahmedabad and Mumbai. Apart from daily commuters for work and business purpose, better socio-economic conditions in the region generate significant amount of non-work travel along the corridor through railways as well as roadways. Most of the stations on the rail corridor witness intercity commuters as well as casual travelers. In India, railway is the most efficient mode of the transportation carrying nearly 21 million passengers daily through its rail network of more than 60,000 km and has passenger growth rate of 5.3% p.a. Railway stations are important public transport buildings, which besides giving an access to trains, perform a variety of functions. Primary function of passenger transport station is gathering and distributing passengers (Yang, 2010), goods and train operation (including allied services e.g. parcel and post) and enhance operation efficiency. Design of vital elements like stairways and foot over bridges should incorporate the behaviour of flow of various class of pedestrian to ensure desired level of service as well as safety in case of emergency. As reported in literature, pedestrian flow characteristics are influenced by number of attributes of pedestrian like age, gender, physical dimensions, luggage carried, group size, activity while walking, purpose etc. The relationship between fundamental flow attributes like speed, density and flow are expected to be influenced by this factors along with the arrival time of trains at the station.

Fruin (1987); Tanaboriboon (1991); Lam et al. (1995); Fujiyama & Tyler (2004); Lee (2005) found average walking speed on staircase for different pedestrian; considering age, gender, direction of flow and physical dimension of stair. Stairway is more critical element in station area than walkway due to generally undivided pedestrian flow and narrower in size reducing half of the capacity which makes more sensitive follow-on effect in average walking speed of pedestrian (Fruin, 1987). Zhang et al. (2009) found that average walking speed of nonworking day is lower than normal working day considering leisure or recreational trip. Yang et al. (2012) reported that in emergency situation, average walking speed as well as density rises significantly compared to the speed and density during normal condition during which speed varies between 24-42 m/min for density less than 1 p/m^2. Lee (2005) observed that the free speed is affected by direction of movement and reported higher free speed on downstair 0.771 m/s compared to 0.68 m/s on upstair. Tang and Liu (2009) have observed free speed of pedestrian as 49.2 m/min for 0.5 p/m^2 density for upstairs and 0.4 p/m^2 on downstairs. The optimum densities of 2.25 p/m^2 and 2.27 p/m^2 are reported corresponding to highest pedestrian flow rate of 69 p/min/m. Hongfei et al. (2009) established the static and dynamic space criteria. Accordingly, dynamic behaviour of pedestrian needs to be taken into account to predict the impact of a station layout design in practice (Daamen et al., 2001). Yao et al. (2012) showed weaving phenomena of crowd to avoid conflict during transfer process with available minimum space at transport terminal. Yang (2010) established the LOS criteria based on speed-flow-space relation and has proposed space as an evaluation index. He showed that lowest service level occurs when flow reaches to its maximum with least dynamic space. However, when space available per pedestrian is beyond 1.73m^2 for upstair movement and 1.95m^2 for down stair movement, pedestrian are able to walk freely and experience highest service level. Similar observations are made by Xianqing et. al (2011) in their study on passenger flow modeling of rail station in China. Wen et al. (2007) developed LOS criteria based on speed-flow-space study at Shanghai Metro station and found that pedestrian need less space on walkway due to smaller physical dimension of Chinese pedestrian and more average space on stairways. Interestingly, average walking speed on up stairways at LOS B is observed more than at LOS A due, probably; to some push force on up-stairways even though space available reduced at LOS B.

Seer et al. (2008) gives information about fundamental diagram of flow variables (Q-K-V) for stairs to estimate maximum and effective capacity of staircase system on controlled experiment at subway station. Wang et al. (2013) developed the stochastic speed-density model and found that stochastic model is more suitable for widely scattered data than the deterministic model.

The influence of pedestrian flow and its behaviour should be categorized in to attributes such as age, gender, purpose of journey, carrying luggage, and physical dimension of pedestrian facilities, arrival time of train and time of day (Networkrail, UK, 2011). In this context, present study has been undertaken for analysis of macroscopic pedestrian flow characteristics like speed, flow and density on staircases of different width during afternoon and evening durations at Vadodara railway station on western rail corridor in Gujarat, India.

2. Data Collection

Vadodara is the third largest city of Gujarat and is cultural capital of the state. It is located on the western rail corridor connecting national capital New Delhi with financial capital Mumbai as well as Ahmedabad. Figure 1 shows layout of station premises with selected location for videography. Pedestrian movement data was collected by videographic survey at Vadodara railway station premises in mid-October, 2012, on four different stairways connecting to station platform and FOB leading to exit of railway station on East and West side. Strip marking with yellow paint were made across the width of stairways to define the trap length and area. Due to restricted permission for survey, the duration was selected to capture pedestrian traffic 15 min before and after the arrival of train during afternoon peak periods (3:40pm-4:10pm and 6:57 pm – 7:55 pm). The stairways selected have variation in their physical dimension. The detailed dimensions of selected stairways are shown in Table 1.

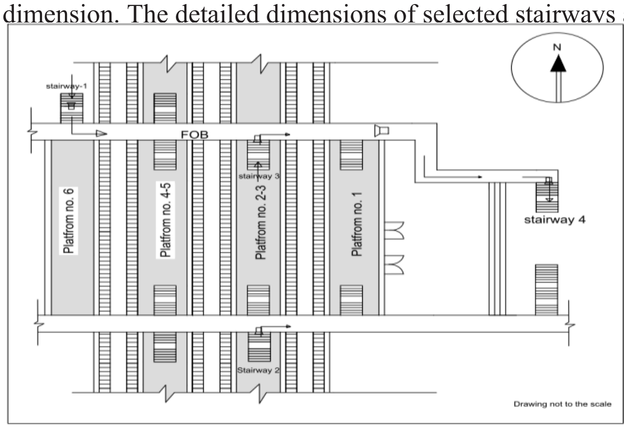


Figure 1. Location of study area

Table 1. Dimensions of the selected stairways

Stair No.	Trap Length (m)	Width (m)	Area (m^2)	Riser (m)	Tread (m)	Slope (°)	Total Length (m)	Height (m)
1	3.55	3.68	13.06	0.15	0.31	23.3	13.50	5.8
2	3.66	2.14	7.79	0.15	0.28	23.8	13.15	5.8
3	5.32	2.26	12.03	0.13	0.28	23.8	13.15	5.8
4	3.5	2.45	8.58	0.15	0.30	23.6	14.06	6.15

Camera setup was positioned at the centre of stair ceiling with approximately 45° inclination with horizontal to cover maximum number of steps and to increase visual perception of age group. The required pedestrian data were extracted from recorded videos on one minute interval basis. The pedestrian volume data is extracted by noting down pedestrian entering in trap area. Five samples from each category (Gender, age, direction of movement and luggage condition) are selected randomly for calculating pedestrian speed by noting entry and exit time in the trap area. The density was determined based on the number of pedestrian per square meter area by taking average of 20 snapshots per minute. The inverse of pedestrian density provides available space for each pedestrian.

3. Analysis of Result

3.1. Pedestrian behaviour on staircase movement during arrival of train

Compared to the horizontal movement on sidewalk, there are several specific characteristics on stairway movement as under. They are analyzed by visual observation at transit station:

At the time of arrival and departure of trains, pedestrian arrive at the platform move with speed higher than the normal speed irrespective of the age.

Commuters are found to alight from moving train as soon as it reaches near the stairways so as to avoid crowd on pedestrian facility and also to reach in time to pick up the next mode of transportation.

At times, passengers sitting on the stairway for waiting for the incoming train cause in reduction of the usable width affecting the pedestrian movement.

Immediately after train comes to halt, the alighting passengers move towards the stair in large number creating jam condition for few moments at the entry of the stairway influencing individual movement.

Pedestrian with luggage or holding a child require more space and affects movement of the pedestrian moving behind them.

Overtaking rarely occurs in normal condition for two reasons. First, fast moving pedestrian follow the slower pedestrian with certain amount of patience by reducing their speed and second they have no extra space for overtaking the front slower pedestrian in narrow staircase (Yang et al, 2012).

Pedestrian moving in group are observed to talk with each other by matching their walking speed. Such group of pedestrian affects the whole pedestrian flow.

3.2. Pedestrian flow with respect to arrival of train

Generally, arriving passengers are in hurry to leave the station premises to reach their destination. However, the amount of luggage and number of children carried affects individual walking speed. In the present study, pedestrian flow was observed during afternoon and late afternoon (evening) when number of long distance and regional trains arrive at the station. Trends of pedestrian flow on stairways 1, 2, 3, 4 and FOB are plotted as a function of time as shown in Figure 2.

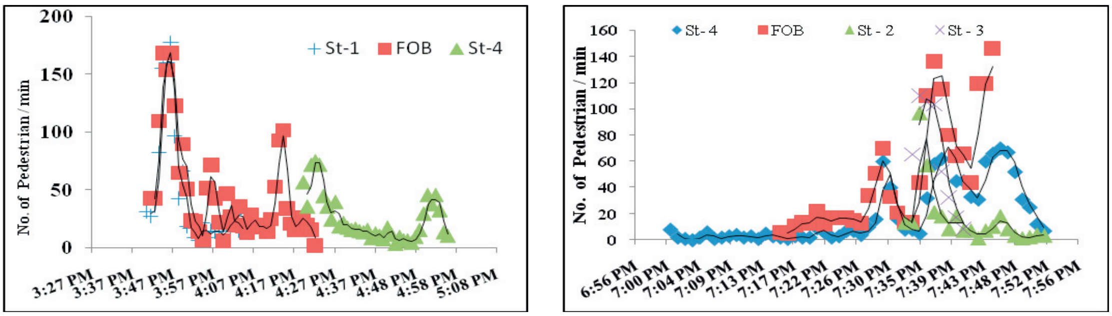


Figure 2 (a) – Afternoon duration Figure 2 (b) - Evening duration

Figure 2. Pedestrian flow variations on stairs and FOB with arrival of train

The peaks in the flow are observed for a limited time period of 3-6 minutes subsequent to the arrival of trains. It is observed that within three minutes of the arrival of the train, pedestrian come to the stair creating maximum pedestrian flow. Similarly, to reach from FOB to exit stair 4, pedestrian take another 2 to 3 minutes. Similar pattern is found during the afternoon period.

The investigation was carried out for 3968 record of pedestrian moving on staircases, out of which 3411 data is used for analysis purpose and building up of relationship between pedestrian flow parameters. Figure 3 shows relationship between speed-flow for stair 2 and 4 considering different time of day.

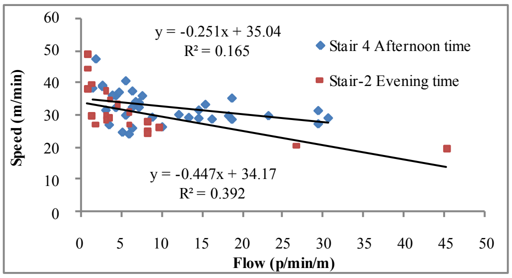


Figure 3. Speed-flow relationship of different stair considering different time of day

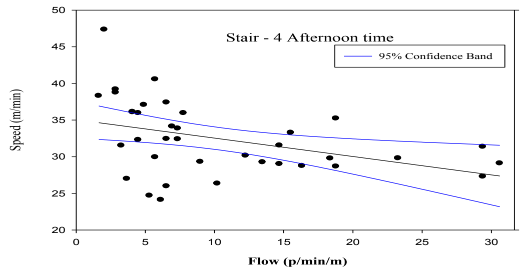


Figure 4. Band of 95 % confidence interval for stair 4 data

From the speed-flow relationship, shown in Figure 3, it is evident that the pedestrian flow below 10 persons/min/m does not affect the individual pedestrian speed which is governed by individual pedestrian's characteristics such as age, loading condition and mainly arrival time of train. In this condition, pedestrian speed is 26.76 m/min when flow is 2 p/m/min. At the flow of 1p/m/min, speed increases to maximum 48.8 m/min. It can be observed that at low flow level, large variation in speed occurs under the influence of individual pedestrian characteristics. Further, the time gap between arrival of train and arrival of departing passenger on stair also affect the speed. At times, pedestrian who is to catch a train; is found running with heavy luggage when train is about to arrive or has already arrived. Whereas, the passengers, with or without any luggage, who have arrived much earlier than the arrival time of train walk slower than the normal speed. Similar results are found for the evening time, however for same flow of pedestrian, average pedestrian speed was lower than the afternoon time possibly due to tiredness of the pedestrian because of return journey with luggage.

The raw data of flow and speed shows large scatter that prevents fitting of acceptable relation. Flow-speed data of all the stairs is filtered by drawing a 95% confidence interval band in SigmaPlot10. Data points, @ 20% of total, lying outside the band are considered as outliers and are removed from the data set used for curve fitting. A specimen data filtering for stair-4 is shown in Figure 4. The basic statistics of filtered data of pedestrian flow characteristics is summarized in Table 2. Co-efficient of determination (R^2) of flow speed model for the filtered data has improved up to 0.80.

Table 2. Maximum and average value of pedestrian flow characteristics

Time of Day	Stair No.	Maximum Flow (p/min/m)	Maximum Density (p/m^2)	Maximum Speed (m/min)		Average Flow (p/min/m)	Average Density (p/m^2)	Average Speed (m/min)	
				Upstream Flow	Downstream Flow			Upstream Flow	Downstream Flow
Afternoon	1	50	2.20	58.90	42.29	15	0.87	27.98	30.03
	4	31	1.19	66.04	56.56	13	0.59	28.52	32.28
Evening	2	45	2.60	45.16	48.80	7	0.72	23.09	29.35
	3	49	3.20	22.32	24.33	27	1.45	17.49	19.67
	4	33	1.55	85.71	55.70	10	0.53	25.38	27.43

Comparing the pedestrian flow among four different staircases, it is observed that density increases with the flow rate. Average speed in upstream direction is found to be higher than the downstream direction during afternoon and evening periods for all the stairs. Also, the speed during afternoon period is observed higher than that during evening period for all the stairs. This can be attributed to the relatively lower level of lighting as well as physical state of pedestrian due to luggage and long journey hours. It may be highlighted that the pedestrian walking speed according to this study is lower than the recommended speed range of 30.6-34.2 m/min for upstair and 40.2 - 46.2 m/min for downstair movements by Fruin (1987) and others. Such deviation is expected due to different physique of Indian pedestrian and also due to presence of pedestrian with luggage. The impact of width of the stair, luggage carrying pedestrian, density and available space for walking maneuvering needs more study considering wide range of stairway dimension and pedestrian activity. Figure 5 shows scattered plot of average walking speed and average pedestrian flow rate for various staircases at different time duration of day.

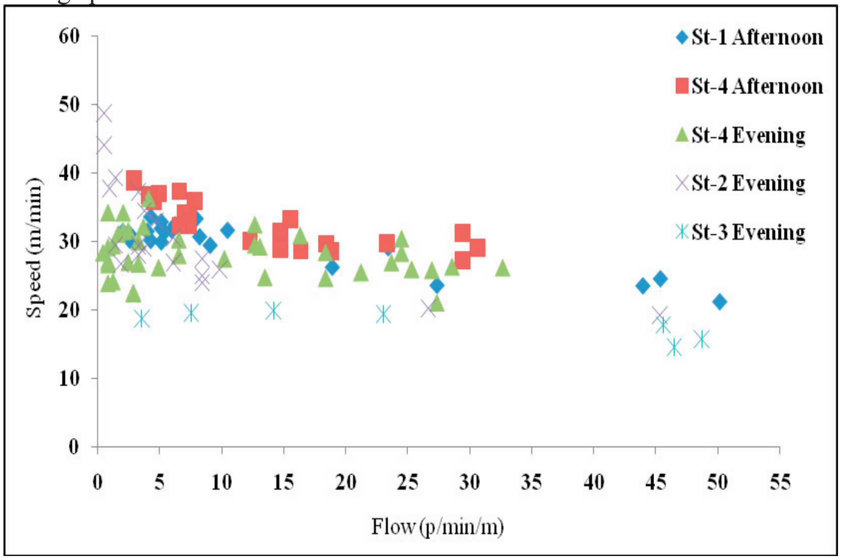
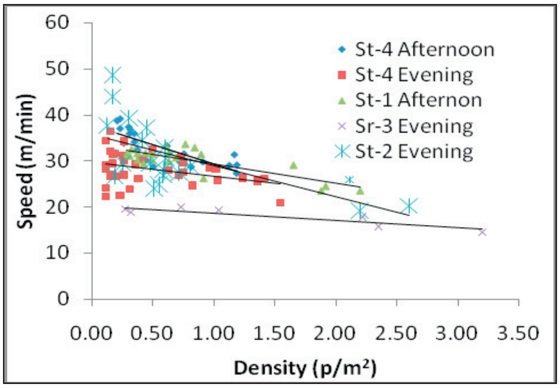


Figure 5. Plot of average speed and average flow rate of different staircases at different time duration of day

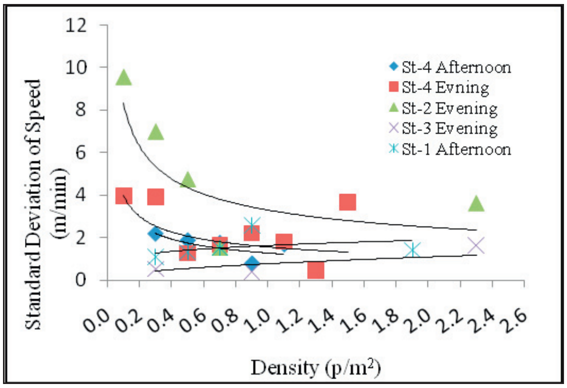
The scattered plot in Figure 5 shows the walking speed and flow as function of time of day and arrival time of train. The speed, in general, decreases with increase in flow; however for flow below 10 p/m/min, speed varies in wide range from 18.78 m/min to 48.80 m/min. This indicates that the speed is not function of flow when flow is less than 10 p/m/min and is largely governed by the attributes of the individual pedestrian and their arrival time at the station with respect to the arrival time of the train. For pedestrian flow higher than 10 p/min/m, the speed decreases with increase in flow with very insignificant variation. The average walking speed of pedestrian during afternoon is found to be 29.70 m/min, while lower average speed 23.73 m/min is observed during evening due to tired state of the pedestrian and insufficient light on stairways. It is also found that 23% of the pedestrian are carrying luggage and 11% were walking in a group of 2 - 3 reducing the average speed of pedestrian flow and same reveal in pictorial view of various stairways cover pedestrian movement in Figure 6.

Figure 6. Pictorial views of pedestrian movement on different stairways

Yang et al.(2012) have observed walking speed in the range of 24 m/min to 42 m/min for density lower than 1 p/m^2; considered as a low density. Observed walking speed and corresponding densities are shown in Figure 7(a) for all the stairs. It is observed that for the density less than 1 p/m^2 , speed varies from 18.78 m/min to 48.80 m/min, showing higher variation than that reported by Yang et. al. In order to probe further about variation in speed with increase in density, standard deviation in walking speeds for every 0.2 p/ m^2 density change is plotted as shown in Figure 7(b). It is observed that when density reaches 1p/m^2 , the standard deviation curves tend to become flatter with lower value indicating less speed variation at higher pedestrian density. But beyond that density, pedestrian speed trend decreases with gradual increase in density and flow. However, during evening period; in case of stair 3 and 4; almost flatter and parallel trend is observed with less difference in speed against large variation in density as compared to other stairways.



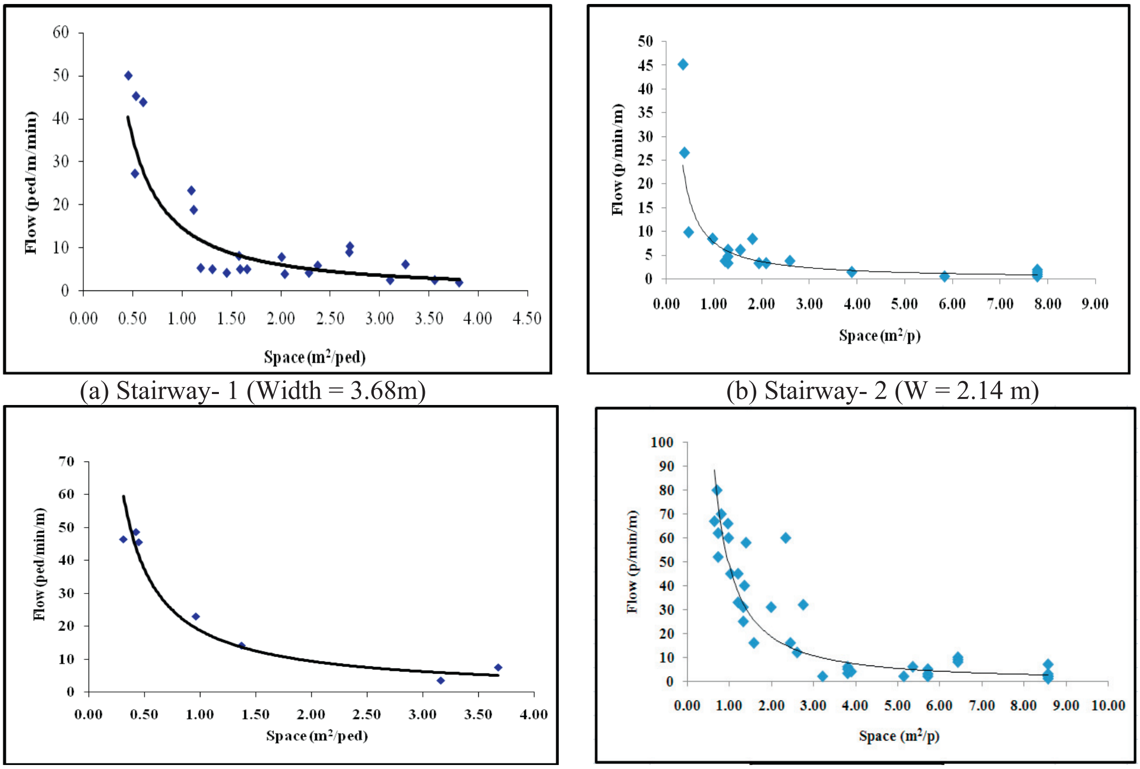
(a)



(b)

Figure 7. Average pedestrian speed variation with average density

Reciprocal of density, space gives visual perception of the congestion level at various flow rates. Space forms very primary basis to evaluate level of service of any pedestrian facility. Figure 8 shows the relation between pedestrian flow and space for various stairways



(a) Stairway- 1 (Width = 3.68m) (b) Stairway- 2 (W = 2.14 m)

(c) Stairway- 3 (W = 2.26 m) (d) Stairway- 4 (W = 2.45 m)

Figure 8. Flow - space relationship for different stairways

These curves illustrate that increase in flow significantly decreases the available space per pedestrian and highest point in the trend gives maximum flow (Q_{max}) having minimum space where congestion occurs. Table 3 shows coordinates of maximum flow and related space for different stairways. The relationships between space and flow are also shown in the last column.

Table 3. Coordinate value of maximum flow and available space

Resource	Stair No.	Observed maximum flow (Q_{max}) p/ min/ m	Available space (S_{min}) m^2/p	Equation
This Study	1	50	0.45	$Q = 14.71\ s^{-1.27}$ ($R^2 = 0.723$)
	2	45	0.35	$Q = 7.739\ s^{-1.09}$ ($R^2 = 0.84$)
	3	49	0.43	$Q = 18.79\ s^{-0.99}$ ($R^2 = 0.915$)
	4	33	0.71	$Q = 48.30\ s^{-1.38}$ ($R^2 = 0.785$)
Fruin		60	0.26	---
Yang		67	0.41	---
Xianquing		89	0.28	---
Hongfei		67	0.41	$Q = -2621.1s^2 + 1886.7\ S - 271.9$

The data in Table 3 also shows comparative values of maximum flow and corresponding available space found by various researchers. The value of Q_{max} in the present study is lower and corresponding space is larger than the other earlier studies due to difference in composition of pedestrian with presence of luggage carrying passengers at the selected intercity rail station.

4. Conclusion

The present study reports characteristics of pedestrian movement found during period of 15 min before and after arrival of train considering age, gender, loading condition and time of the day. Result shows that pedestrian walk faster during the afternoon or day time compared to evening. Also presence of the pedestrian with luggage has potential effect on reduction in the average walking speed of pedestrian. For different sizes of staircase, flow-speed-space and density plots show different trends, of course with general similar pattern. In case of speed flow relationship, influence of flow is more significant on speed when pedestrian flow is more than 10 p/min/m. For lower flow, large variation in speed; in the range of 18-48 m/min is observed. For all the cases, value of observed maximum flow; Q_{max} is found lower and corresponding required space larger than the earlier studies. The findings provide better insight in to the pedestrian flow characteristics by considering small duration covering arrival time of train when movement of large number of passengers take place in Indian context. The study can be further expanded by covering more number of stations with variation in geometrics of stairways and composition of pedestrian carrying luggage.

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