Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 00 (2018) 000–000

Transportation Research Procedia

www.elsevier.com/locate/procedia

World Conference on Transport Research - WCTR 2019 Mumbai 26-31 May 2019

Analysis of Pedestrian Movements on Stairs at Metro Stations

Tinku Goyal[a], Dharitri Kahali[b], Rajat Rastogi[c]

[a] *Assistant Engineer, HPGCL, Hisar, India*
[b] *Research Scholar, IIT Roorkee, Roorkee, India*
[c] *Associate Professor, IIT Roorkee, Roorkee, India*

Abstract

Pedestrian flow characteristics while moving on stairs at metro stations in Delhi, India has been studied. Data are collected during morning and evening peak periods or periods having substantial flow, using video graphic method, at three Delhi Metro Rail stations. One of the metro rail stations is near City Inter-State Bus Terminal and other two are line interchanges. Variations in pedestrian speed and flow on stairs, with respect to various factors are analyzed. Mean speed of woman pedestrians' is found relatively lower than speed of male pedestrians. The pedestrians carrying luggage negatively impacted the overall speed of the crowd. Friction caused by the opposing flow on the same stair flight caused a decrease in the speed of the pedestrians moving in normal direction. Segregated or defined bi-directional flows remained efficient. The pedestrian speed beyond 105 m/min is considered as the running speed. Pedestrians preferred to move on their left hand side. The speed and flow analysis presented in this study can contribute information for incorporation in pedestrian facility guidelines like IRC-103-2012 as used in India. The design criteria may be modified as per the needs of the pedestrians and to ensure an efficient management of pedestrian flows at level change facilities.

Keywords: Pedestrian Flow; Stairs; Metro Rail Stations; Variation in Speed; Distribution of Flow

1. Introduction

Population of India is 1.35 billion and increasing unyieldingly. Around one-third population resides in urban areas. The increase is also visible in terms of number of commuters. According to available data the total number of passengers carried by long distance trains in India was 8.116 billion (Statistical summary - Indian Railways 2016-17). In case of urban rail systems, daily ridership of Delhi metro has gone beyond 2.76 million, with the latest ridership record set on 29 March 2017. Government of India is stepping towards metro transit rapidly. There are 11 metro system in service, 5 under construction, 16 under planning and 3 proposed (https://en.wikipedia.org/wiki/Delhi_Metro). The stations of urban rail systems can be defined as commuter station, transfer station and terminal station. Usually, the entry to the station is at ground level but location of a platform is either elevated or underground. Movement of pedestrians between floor levels is facilitated through provision of stairs, escalators or elevators. These level change facilities need to be designed properly so that there is no queuing at approaches to the facilities, the pedestrian movements are safe and efficient and the pedestrian accumulation is released within time before flow again starts accumulating based on metro train schedules. The need of level change facilities is going to be increased in near future. Indian Government is aggressively pushing for smart cities. Smart city concept approaches towards the efficient use of the space and for that construction in vertical direction is a must. The scaling of floor levels will be possible only and only if efficient and pedestrian friendly design of level change facilities are made available. Stairs are conventional facilities which consume time and energy. Escalators are technically faster in catering to high pedestrian flows. Proper guidelines for the provision and safety on stairs are not available in Indian guidelines named as IRC:103-2012. This research work is aimed at studying the pedestrian flows on level change facilities like stairs and to suggest the possible additions to existing pedestrian facility guidelines in terms of design and implementation.

Next section presents an overview of research works that have been carried out on stairs worldwide.

2. Literature Review

Early in 1970s, Fruin (1971) studied pedestrians flow on different facilities. In case of flow on stairs, it is reported that mean speed of the woman pedestrians is lower than that of male pedestrians and mean speed decreases with an increase in the age of the pedestrian. Descending speeds are found higher than the ascending speeds. Lam et *al*. (1995) studied unidirectional pedestrian flow behaviour in Hong Kong. The average ascending speed at metro transit station (35.40 m/min) is found lower when compared with railway station (38.70 m/min). Similar results are found for average descending speed (40.80 m/min and 48.20 m/min at metro transit station and railway station respectively). Later, Cheung and Lam (1997) analyzed the effect of bi-directional movement of pedestrians on speed and capacity of stairway at a mass transit railway station in Hong Kong. Reduction in speed and capacity with increasing unbalanced directional distribution of flow is observed. Cheung and Lam (1998) further analyzed the pedestrians' choices between escalator and stairway in MTR stations in Hong Kong. They found that free flow speed of descending pedestrians is higher than that of ascending pedestrians. Henson (2000) gave attention to the speed of the pedestrians moving on stairways and walkways in Sydney. The comparison of pedestrian speed is done at global level. He commented that ethnic and cultural attitude; type of area and characteristics of pedestrians should be considered while designing a pedestrian facility. Fujiyama and Tyler (2004) studied walking speed under laboratory conditions on stairs in University Campus in London, UK and found that mean speed of the woman pedestrians and ascending pedestrians is less than that of male pedestrians and descending pedestrians respectively. Overall mean speed is found lower than that given by Fruin (1971). Kretz et *al*. (2008) compared the walking speed upstairs on a long stairway with that of short stairway in Germany. They observed that mean ascending speed for the short stairs is approximately double of the ascending speed for the long stairs and people accelerates while ascending on short stairs but not while descending on short stairs. Same happens while ascending and descending movement on long stairs. Liu et *al*. (2008) studied pedestrians' flow on stairways in Shanghai Metro transfer station and fitted Greenshield model between flow characteristics. They observed that the speed of pedestrians at staircase is lower than that of walkway and speed downstairs is more than upstairs. Zhang et *al*. (2009) studied pedestrian traffic characteristics on two staircases having different width in the underground transfer hub in Beijing on both working and non-working days. In general, the speed in ascending direction is found lower than that in descending direction. The descending speed of pedestrians at staircase is found to be more if the width is more. This effect is not found in the case of ascending movement. They also found that woman pedestrians are slower compared to man and the speed decreases in order from young pedestrians (18- 35 years) to middle–aged pedestrians (36-60 years) to old age pedestrians (>60 years). Muller (2010) found that an increase in slope by 10-degree caused only a minor effect on fundamental diagram of flow and this result confirmed the results given by Graat et *al*. (1999), who found a 0.09 p/m/s decrease in the mean capacity on increasing the slope by 10-degree. Fujiyama and Tyler (2011) studied the effect of stair gradient and obesity of pedestrians on free walking speeds at stairs in United Kingdom. A linear relationship with negative slope is observed between average walking speed and stair gradient. No significant effect of obesity (overweight) on speeds of pedestrians is reported. The notion that the speed in ascending direction is less than descending direction is found more dominating in the case of young pedestrians as compared to elder pedestrians. Yang et *al*. (2012) studied the flow characteristics of the pedestrians (students in this case) on stairs of different dimensions for normal conditions (movements of students, after and before classes) and emergency conditions (evacuation drill) at University of Science and Technology, China. Authors found that no overtaking movements are made in the normal conditions and speed is affected by individual characteristics at lower values of density and by level of congestion at higher value of density. They also found that people moves two times faster under emergency conditions than normal one. Shah et *al*. (2013) analyzed the pedestrian's behavioural characteristics at Vadodara railway station in Gujarat. The relationship Flow = Density*Speed is not found valid for the observed data. They observed that pedestrians move faster during day time compared to in evening and luggage carrying persons cause decrease in the average speed of the crowd. They also observed that power relationship exists between flow and area-module. Shah et *al*. (2015a) studied pedestrian flow behaviour on stairs at Dadar metro transit station in Mumbai, India. They observed that beyond density 4-4.5 p/m^2 flow becomes stable which is in contrast to the values given by Yang et *al*. (2012) i.e. 2.5-3.5 p/ m^2. The reason behind this could be the adjusting behaviour of the pedestrians in India in terms of need of space. Average speed of pedestrians is found higher on stairs having more width. Shah et *al*. (2015b) analyzed bidirectional movement of pedestrians on an undivided staircase at Dadar railway station (Suburban) in Mumbai and found that average walking speed in individual direction and capacity of staircase decreases due to unbalanced distribution ratio and this effect is found to be more significant when ascending flow is more dominant as compared to descending. They reported mean ascending speed and mean descending speed of 28.02 m/min and 30.72 m/min. They compared the results with that of study carried by Cheung and Lam (1998) in Hong Kong and reported that speed of pedestrians in India is lower compared to Hong Kong. Sharifi et *al*. (2015) observed that reduction in mean speed due to presence of pedestrians with disability is more pronounced in the case of level change facilities like stairs, ramps and elevators. Yu et *al*. (2015) studied interaction behaviour characteristics (overtaking behaviour and opposite avoidance behaviour) of pedestrians on staircase in a metro station in Shanghai, China. Shah et *al*. (2017) analyzed pedestrians' movements on staircases at Dadar, Mumbai (Suburban Station) and Vadodara (Intercity Station). It is observed that average walking speed of female and elder pedestrians is lower than male and younger pedestrians and that at intercity station is lower compared to suburban station. They reported decrease in the average walking speed due to luggage carrying activities and decrease in stairway width. They also reported that variation in walking speed is higher at lower density value and vice versa.

The comparative speeds of pedestrians as reported by different researchers are given in Table 1.

Table 1: Speeds of pedestrians on stairs

Researcher (year)	Country	Movement	Mean Speed (m/min)	
			Ascending	Descending
Fruin (1971)	USA	Bi-directional		
Staircase with slope of 27°			40.24	30.48
Staircase with slope of 32°			46.34	34.45
Lam et al. (1995)	Hong Kong	Bi-directional		
Staircase at MTR station			35.40	40.80
Staircase at railway station			38.70	48.20
Henson (2000)	Australia	Bi-directional	48.20	56.60
Fujiyama and Tyler (2004)	UK	Bi-directional	32.15	36.70
Zhang et al. (2009)	China	Bi-directional		
Staircase with width of 2.4 m			42.60	42.60
Staircase with width of 1.2 m			54.00	40.8
Shah et *al*. (2015b)	India	Bi-directional	28.02	30.72

The discussion made in preceding paragraph has given sufficient information on the speed of pedestrians on stairs and the effect of various attributes on the same. In its light the next section outlines the objective of this study.

3. Objectives and Scope of the Study

This paper specifically discusses the speed of pedestrians and variation in it with respect to the gender, age and load carrying conditions of the pedestrians, time of the day, direction of movement, position of pedestrian on a staircase and increase in opposing flow. Another aspect discussed is the distribution of pedestrians on the multiple-parallel staircases, which are divided by railings.

The scope of the study is confined up to the staircases at metro stations. The stairs selected are in use for bidirectional flows and are either placed at the side of an escalator or as multiple-parallel segregated stairs. Multiple stairs are segregated by a railing.

Next section provides information of the study location and data collected.

4. Data Collection

4.1 Selection of Sites for Study

The sites are selected such as to get substantial flow for analysis, with difference in the flow characteristics at sites and variation in specifications of staircases. Out of three selected metro stations Kashmiri Gate metro station is near City Inter-State Bus Terminal and Rajiv Chowk and Central Secretariat are line interchanges. The variations in specifications of staircases are shown in Table 2. All three sites are shown in Figure 1.

Table 2. Variations in the data collection sites selected for study

Delhi Metro Rail Station	Stair Width (*m*)	Flow Pattern	Stair path division	Height(m) / Landings (Nos.)	Tread (mm) / Riser (mm) / Slope (°)
Central Secretariat Metro Station (CSMS)	2.45	Bi-directional	Undivided	5.5 / 2	150 / 300 / 26.56
Rajiv Chowk Metro Station (RCMS)	6	Bi-directional	Divided in three parts by railings	7.3 / 3	150 / 300 / 26.56
Kashmiri Gate Metro Station (KGMS)	5.4	Bi-directional	Divided in three parts by railings	5.5 / 2	150 / 300 / 26.56

Figure 1 Photographs of Staircase at (a) Central Secretariat Metro Station (b) Rajiv Chowk Metro Station (c) Kashmiri Gate Metro Station

4.2 Data Collection Methodology

Videography method is adopted for the data collection. Two cameras are used simultaneously. The videos are captured in July, 2016 during the peak time period or periods having substantial flow in morning and evening on a normal working day. The cameras were visible to the pedestrians due to unavailability of appropriate locations like ceiling, which might have influenced the pedestrian behaviour and flow characteristics. Heights of the cameras were set such that substantial stretches needed to extract flow information is covered.

4.3 Data Extraction and Sample

Data extraction is done by setting videos at 25 numbers of frames per second. Flow of pedestrians is calculated by adding the number of pedestrians entering a particular section in one minute. Speed of an individual pedestrian is estimated by dividing the length of the stretch with the time taken by a pedestrian to cover that stretch. It is observed that conventional linear relationship between flow (Q), speed (V) and density (K) i.e Q = KV does not apply therefore pedestrian density was extracted from videos instead of calculating from the values of flow and speed. Pedestrian density for a particular minute is found as an average of the number of pedestrians captured in snapshots taken at the rate of 20 snapshots per minute. Area module is calculated as inverse of pedestrian density. The pedestrians' movements on each portion (left, center and right) and each flight (Near Lap, Middle-Lap and Far-Lap) are observed and extracted separately with an aim to analyze the disparity between flow characteristics with respect to the use of portion and flight of a stair.

Total numbers of pedestrians constituting the flow at RCMS, CSMS and KGMS during the time of data collection and also constituting the sample size are 17647, 2293 and 6155 respectively.

The characteristics of the sample extracted at three metro stations are given in Table 3.

Table 3: Characteristics of pedestrian sample extracted for three metro stations

Description	RCMS	CSMS	KGMS
Categorization by Gender			
- Male	85.44%	81.86%	79.40%
- Woman	14.56%	18.14%	20.30%
Categorization by Age			
- Kids	00.12%	00.26%	00.32%
- Children	00.94%	00.52%	01.14%
- Young	48.63%	61.23%	54.13%
- Middle Age	43.19%	32.27%	37.16%
- Elder	07.12%	05.72%	07.25%

Pedestrians are divided into five groups according to the age (in years) i.e. kids $\leq$ 5, children > 5 and $\leq$ 15, young > 15 and $\leq$ 25, middle age > 25 and $\leq$ 50 and elder > 50. The age is recorded based on facial looks and body structure. The sample population is composed of higher percentage of the young pedestrians as compared to other age groups. Percentage of young pedestrian in the sample population is observed to be 61.23 %, 48.63 % and 54.13 % at CSMS, RCMS and KGMS respectively. The presence of male pedestrians is high i.e. 81.86%, 85.44% and 79.40% at CSMS, RCMS and KGMS respectively. Pedestrians carrying baggage are found to be less i.e. 3.45%, 1.22% and 10.45% at CSMS, RCMS and KGMS respectively.

Next section now presents the analysis of speeds of pedestrians and variation in it with respect to various influencing attributes.

5. Speed Analysis and Variation

Two factors i.e. variation of speed and distribution of flow are considered for analysis. Variation of speed is analyzed with respect to the location (i.e. metro station), gender and age of the pedestrian, load carrying conditions, time of the day, direction of movement, use of different flights (laps) on staircase and percentage of opposite flow. The mean speeds and the variations are now discussed in the following successive sub-sections.

5.1 Pedestrian Speed and its Variations

The statistical variation of mean speed and its variation with respect to different attributes is shown in Table 3. Mean speed, standard deviation, 85th percentile speed, maximum speed and minimum speed are the factors considered under analysis. Comparison is done between mean speeds of different group of pedestrians and verified by performing Z-test with two means and standard deviations of known population at 5% degree of error or 95% level of confidence. The results of the hypothesis testing are given in Table 4. The speeds and its variation are now discussed in successive paragraphs.

Mean speed by location: The mean speed at RCMS is observed to be around 16% lower as compared to other two metro stations i.e. KGMS and CSMS. The reason behind this may be the heavier flow of pedestrians at RCMS (17647 in 2 hours) as compared to CSMS (2293 in 4 Hours) and KGMS (6155 in 4 Hours). Another reason may be relatively lower proportion of young pedestrians at RCMS (48.63%) as compared to CSMS (61.23%) and KGMS (54.13%), wherein young pedestrians may be walking fast as compared to other age categories. The variation in speed is found to be quite high in the case of these two metro stations i.e. CSMS and KGMS. It seems that some pedestrians are almost galloping on the stairs, may be scaling two stairs at a time. Mean speed at stairs is lower than the mean speed at sidewalk or at surface where the speed usually ranges between 65 m/min and 93 m/min (Kotkar et at. 2010). A comparison with pedestrian speeds in different countries reveal that mean speed at selected metro stations in India are higher than the mean speeds of other countries like USA (Fruin, 1971), Hong Kong (Lam et al. 1995), Australia (Henson, 2000), UK (Fujiyama and Tyler, 2004) and China (Zhang et al. 2009).

Mean speed by age: It is observed that the mean speed of the young pedestrians is relatively higher than other age groups and the mean speed of kids is lowest among all the age groups. The speeds of kids are 50 to 55% of the speed of young pedestrians. This may be because of longer strides and agility of young pedestrians as compared to other age groups and small strides of kids. In fact children are second lowest or are at par with elders in their speed. The results are contradictory with the results of Fruin (1971) according to which speed decrease with age. The results are consistent with the results of Zhang et *al*. (2009), according to which speed of youth is more than middle-aged whose speed is more than old age. The results are consistent with the results of Shah et *al*. (2017) according to which average walking speed of elder is lesser than younger.

A look at the comparative speeds across locations for these age groups reveals that the speeds are increasing in the order of RCMS – CSMS – KGMS, in general, leaving higher age groups where the order changes. No proper reasoning is possible for this type of behavior of the pedestrians.

Mean speed by gender: The mean speed of woman pedestrian is found to be relatively lower by around 15% than the male pedestrians at all the locations. This may be due to higher physical dimensions and abilities of males as compared to woman. This observation is consistent with the observations made by Fruin (1971), Zhang et *al*. (2009) and Shah et *al*. (2017). Further it is interesting to note that the maximum speed of woman pedestrians are 15% to 45% lower than the maximum speed of males, whereas, the minimum speed of woman is higher by 4 to 20% than that of males.

From examination of variation with respect to the three stations, it is observed that male speeds are increasing in the order of RCMS-CSMS/KGMS, whereas, in the case of woman it is increasing in the order of RCMS-CSMS-KGMS. Identification of reasons of such behavior need more analysis.

Mean speed while carrying load: The mean speed of the pedestrians carrying the luggage is found relatively less than the speed of pedestrians who moved without luggage. The speed due to handling of luggage is observed to have reduced by 16% in the case of RCMS and KGMS, whereas, this reduction has been found to be 30% at CSMS. Initially, the speed of pedestrians at CSMS and KGMS, when not carrying luggage, are found to be equal, but carrying of luggage has caused heavy reduction at CSMS. Overall, the pedestrians carrying luggage lowers the overall speed of the crowd. The reason behind it is the need of more physical efforts while moving with luggage. This reduction will be substantial if the percentage of pedestrians carrying luggage is high. This observation is consistent with the observation made by Shah et *al*. (2017).

Negligible reduction is observed in the minimum speeds when pedestrians carried luggage with them on stairs. In case of maximum speed the reduction has been observed to be 15% at RCMS, whereas, at CSMS and KGMS it is around 35 to 38%.

Mean speed of ascending and descending movement: The mean speed of pedestrians moving in descending direction is found to be higher than that of ascending direction for all locations and this is consistent to the observation made by Fruin (1971), Cheung and Lam (1998), Henson (2000), Liu et *al*. (2008), Zhang et *al*. (2009), Fujiyama and Tyler (2011), Burghardt et *al*. (2013) and Shah et *al*. (2015). It clearly indicates that the physical effort needed in moving down is lower and that increases the speed of the pedestrians. Higher values of standard deviation for the mean speed in ascending direction than that in descending direction indicates higher variation in speed in ascending direction as compared to descending. The reason behind this is that the speed of pedestrians moving in ascending direction is impacted by physical conditions of pedestrians and surroundings, whereas, the speed in descending direction is mainly limited by structural conditions of the staircase and assisted by gravitation.

Further, it has been observed that the descending speed is 5% to 10% higher than ascending speed in the morning, but the gap increases in the evening by 10% to 18%. It is also interesting to note that at CSMS the maximum ascending speed is higher than the maximum descending speed. This is contrary to normal conditions.

Mean speed during different time periods: The results show that the mean speed during morning time is more than that observed during evening time in the case of CSMS and RCMS, but it is contrary at KGMS. This is true for both ascending and descending movements. The probable reasons behind these are the fatigue and tiredness of pedestrian in evening time or hurry for reaching workplaces in morning. The opposite pattern observed at KGMS may be attributed to the connectivity to Inter-State Bus Terminus and haste shown by commuters.

Lap wise variation of mean speed: The results for KGMS show that for ascending movement in morning as well as evening the mean speed decreases as pedestrians climb up i.e. mean speed at Far-Lap is relatively less than that at Middle-Lap, which is relatively less than that on Near-Lap. The reason behind this may be the physical efforts which pedestrians have to apply while climbing up. In general, mean speed of the pedestrians moving in the descending direction increases as pedestrians move down i.e. mean speed on Far-Lap is relatively more than at Middle-Lap, and which is relatively more than that on Near-Lap. The reason behind this may be the excitement for reaching home in the evening and also effect of gravity, which pulls pedestrians and reduces the physical efforts.

The results for CSMS show that for both ascending as well as descending movement in morning as well as evening the mean speed decreases as pedestrians climb up or move down i.e. mean speed at Far-Lap is less than that of Near-Lap. The probable reason behind this may be the tiredness felt while ascending or descending on the stairs. The decrease in mean speed in ascending direction is more pronounced than decrease in descending direction.

Table 3 Statistical Variation of Mean Speed

Sr. No.	Description and metro Station		Sample Size, N	Mean Speed (m/min)	Std. Deviation (m/min)	85th Percentile Speed (m/min)	Max Speed (m/min)	Min Speed (m/min)
1	Location	CSMS	2293	56.09	25.38	81.33	196.76	25.52
		RCMS	17647	46.68	20.05	67.25	141.85	13.24
		KGMS	6155	56.12	19.68	75.30	196.76	13.46
2	Age-Location							
	Kids	CSMS	6	31.50	8.08	43.81	44.20	25.52
		RCMS	22	31.27	11.18	43.18	53.25	13.24
		KGMS	20	39.36	11.71	54.04	56.48	17.73
	Children	CSMS	12	41.55	15.63	63.61	64.89	26.41
		RCMS	166	38.15	11.94	47.25	57.54	16.22
		KGMS	70	51.49	13.18	65.13	93.84	18.36

	Young			CSMS	1404	58.81	26.24	87.14	196.76	29.75
				RCMS	8582	50.64	24.79	65.59	141.85	28.53
				KGMS	3332	59.39	21.11	79.21	196.76	27.94
	Middle - Age			CSMS	740	54.26	24.07	79.22	145.23	27.47
				RCMS	7621	46.04	18.17	58.65	138.12	24.22
				KGMS	2287	53.67	17.37	71.76	191.19	24.12
	Elder			CSMS	131	45.71	14.69	63.81	93.84	26.46
				RCMS	1256	41.66	13.79	50.41	120.25	24.14
				KGMS	446	45.39	13.44	60.39	95.30	17.73
3	Gender – Location									
	Male			CSMS	1877	57.95	26.68	87.14	196.76	25.52
				RCMS	15077	48.32	22.48	71.20	141.85	13.24
				KGMS	4887	57.74	20.31	77.21	196.76	17.73
	Woman			CSMS	416	47.84	16.43	65.34	108.92	26.45
				RCMS	2570	41.81	13.68	56.35	124.49	16.13
				KGMS	1268	49.13	14.73	64.21	119.60	18.15
4	Load Carrying Condition - Location									
	With Luggage			CSMS	79	42.58	18.41	61.12	129.78	26.74
				RCMS	215	41.58	11.01	52.15	120.09	14.12
				KGMS	643	48.93	14.76	65.59	121.99	19.18
	Without Luggage			CSMS	2214	56.61	25.52	82.43	196.76	25.52
				RCMS	17432	48.14	21.79	68.92	141.85	13.24
				KGMS	5512	56.84	19.96	76.24	196.76	17.73
5	Time- Direction – Location									
	Morning	Ascending		CSMS	360	55.59	29.54	95.31	179.40	25.52
				RCMS	1917	48.20	35.93	84.17	135.13	18.25
				KGMS	452	52.73	29.02	74.66	174.27	17.73
		Descending		CSMS	402	61.15	22.16	84.72	160.52	26.22
				RCMS	8114	48.32	16.75	66.02	141.85	21.84
				KGMS	2993	55.57	17.69	73.49	190.61	18.84
	Evening	Ascending		CSMS	710	51.94	28.10	83.56	196.76	26.25
				RCMS	1515	40.26	18.35	57.67	122.15	13.24
				KGMS	306	52.11	29.66	81.46	184.83	18.31
		Descending		CSMS	821	58.59	19.89	78.20	156.40	27.37
				RCMS	6101	47.60	21.57	68.32	138.52	19.29
				KGMS	2404	57.73	18.78	76.24	196.76	21.26
6	Location-Time- Direction - Lap									
	Kashmiri Gate	Morning	Ascending	Near Lap	452	57.69	31.22	98.38	217.84	21.48
				Middle-Lap		53.94	28.43	88.79	164.85	22.67
				Far-lap		52.73	29.02	74.66	174.27	17.73
			Descending	Near Lap	2993	55.57	17.69	73.49	190.61	19.26
				Middle-Lap		54.25	17.73	72.61	160.51	18.84
				Far-lap		54.50	18.34	72.61	190.61	18.93
		Evening	Ascending	Near Lap	306	57.93	30.01	86.06	174.27	23.15
				Middle-Lap		54.94	28.74	85.91	190.61	22.83
				Far-lap		52.11	29.66	81.46	184.83	18.31

		Descending	Near Lap	2404	57.73	18.78	76.24	196.76	21.26
			Middle-Lap		58.27	21.00	78.20	190.61	22.43
			Far-lap		59.71	21.83	80.26	203.32	21.33
Central Secretariat	Morning	Ascending	Near Lap	360	61.68	31.20	101.66	174.28	27.64
			Far-lap		55.59	29.54	95.31	179.40	25.52
		Descending	Near Lap	402	61.15	22.16	84.72	160.52	28.25
			Far-lap		56.21	22.76	78.20	156.40	26.22
	Evening	Ascending	Near Lap	710	57.34	29.73	91.28	184.84	27.59
			Far-lap		51.94	28.10	83.56	196.76	26.25
		Descending	Near Lap	821	58.59	19.89	78.20	156.40	28.48
			Far-lap		54.56	20.04	73.94	152.49	27.37

Table 4. Details of Hypothesis Testing of the Mean Speed Variations

Data Head to be Compared		Metro Station	Hypothesis Statement	Statistical Value	Critical Value	P Value	Rejected or not
μ1	μ2						
1. Variation of mean speed by age							
Child	Young	CSMS	$H_o = \mu1 - \mu2 \geq 0$	-3.778	-1.645	0.000	Rejected
		RCMS	$H_o = \mu1 - \mu2 \geq 0$	-11.191	-1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 \geq 0$	-4.889	-1.645	0.000	Rejected
Child	Middle Age	CSMS	$H_o = \mu1 - \mu2 \geq 0$	-2.764	-1.645	0.003	Rejected
		RCMS	$H_o = \mu1 - \mu2 \geq 0$	-7.156	-1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 = 0$	1.354	1.960	0.176	Not Rejected
Child	Elder	CSMS	$H_o = \mu1 - \mu2 = 0$	0.887	1.960	0.375	Not Rejected
		RCMS	$H_o = \mu1 - \mu2 \geq 0$	-2.98	-1.645	0.001	Rejected
		KGMS	$H_o = \mu1 - \mu2 \leq 0$	3.588	1.645	0.000	Rejected
Child	Kids	CSMS	$H_o = \mu1 - \mu2 \leq 0$	2.892	1.645	0.002	Rejected
		RCMS	$H_o = \mu1 - \mu2 \leq 0$	2.684	1.645	0.036	Rejected
		KGMS	$H_o = \mu1 - \mu2 \leq 0$	3.966	1.645	0.000	Rejected
Young	Kids	CSMS	$H_o = \mu1 - \mu2 \leq 0$	8.096	1.645	0.000	Rejected
		RCMS	$H_o = \mu1 - \mu2 \leq 0$	8.074	1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 \leq 0$	7.574	1.645	0.000	Rejected
Young	Middle Age	CSMS	$H_o = \mu1 - \mu2 \leq 0$	4.026	1.645	0.000	Rejected
		RCMS	$H_o = \mu1 - \mu2 \leq 0$	13.108	1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 \leq 0$	11.093	1.645	0.000	Rejected
Young	Elder	CSMS	$H_o = \mu1 - \mu2 \leq 0$	8.956	1.645	0.000	Rejected
		RCMS	$H_o = \mu1 - \mu2 \leq 0$	16.418	1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 \leq 0$	19.073	1.645	0.000	Rejected
Middle Age	Kids	CSMS	$H_o = \mu1 - \mu2 \leq 0$	6.664	1.645	0.000	Rejected
		RCMS	$H_o = \mu1 - \mu2 \leq 0$	6.17	1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 \leq 0$	5.413	1.645	0.000	Rejected
Middle Age	Elder	CSMS	$H_o = \mu1 - \mu2 \leq 0$	5.484	1.645	0.000	Rejected
		RCMS	$H_o = \mu1 - \mu2 \leq 0$	8.445	1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 \leq 0$	11.304	1.645	0.000	Rejected
Kids	Elder	CSMS	$H_o = \mu1 - \mu2 \geq 0$	-4.015	-1.645	0.000	Rejected
		RCMS	$H_o = \mu1 - \mu2 \geq 0$	-4.302	-1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 \geq 0$	-2.236	-1.645	0.013	Rejected
2. Variation of mean speed by gender							
Woman	Male	CSMS	$H_o = \mu1 - \mu2 \geq 0$	-9.973	-1.645	0.000	Rejected
		RCMS	$H_o = \mu1 - \mu2 \geq 0$	-19.962	-1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 \geq 0$	-17.051	-1.645	0.000	Rejected
3. Variation of mean speed by time of data collection							
Evening	Morning	CSMS	$H_o = \mu1 - \mu2 \geq 0$	-2.798	-1.645	0.003	Rejected
		RCMS	$H_o = \mu1 - \mu2 \geq 0$	-6.726	-1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 \leq 0$	3.718	1.645	0.000	Rejected
4. Variation of mean speed by direction of movement							
Ascending Morning	Descending Morning	CSMS	$H_o = \mu1 - \mu2 \geq 0$	-5.267	-1.645	0.000	Rejected
		RCMS	$H_o = \mu1 - \mu2 = 0$	-0.1379	-1.645	0.890	Not Rejected
		KGMS	$H_o = \mu1 - \mu2 \geq 0$	-2.02	-1.645	0.890	Rejected
Ascending Evening	Descending Evening	CSMS	$H_o = \mu1 - \mu2 \geq 0$	-2.91	-1.645	0.002	Rejected
		RCMS	$H_o = \mu1 - \mu2 \geq 0$	-13.51	-1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 \geq 0$	-3.239	-1.645	0.000	Rejected

5. Variation of mean speed by loading							
With Luggage	Without Luggage	CSMS	$H_o = \mu1 - \mu2 \geq 0$	-6.549	-1.645	0.000	Rejected
		RCMS	$H_o = \mu1 - \mu2 \geq 0$	-8.543	-1.645	0.000	Rejected
		KGMS	$H_o = \mu1 - \mu2 \geq 0$	-12.332	-1.645	0.000	Rejected
6. Lap wise variation of mean speed							
MDNL	MDFL	CSMS	$H_o = \mu1 - \mu2 \leq 0$	3.115	1.645	0.001	Rejected
MANL	MAFL	CSMS	$H_o = \mu1 - \mu2 \leq 0$	2.689	1.645	0.004	Rejected
EDNL	EDFL	CSMS	$H_o = \mu1 - \mu2 \leq 0$	4.084	1.645	0.000	Rejected
EANL	EAFL	CSMS	$H_o = \mu1 - \mu2 \leq 0$	3.516	1.645	0.000	Rejected
MDNL	EDNL	CSMS	$H_o = \mu1 - \mu2 \leq 0$	2.426	1.645	0.0076	Rejected
MANL	EANL	CSMS	$H_o = \mu1 - \mu2 \leq 0$	2.186	1.645	0.014	Rejected
MDNL	MDML	KGMS	$H_o = \mu1 - \mu2 \leq 0$	2.884	1.645	0.002	Rejected
MDML	MDFL	KGMS	$H_o = \mu1 - \mu2 = 0$	0.546	1.960	0.585	Not Rejected
MANL	MAML	KGMS	$H_o = \mu1 - \mu2 \leq 0$	1.891	1.645	0.029	Rejected
MAML	MAFL	KGMS	$H_o = \mu1 - \mu2 = 0$	0.629	1.960	0.529	Not Rejected
EDNL	EDML	KGMS	$H_o = \mu1 - \mu2 = 0$	0.933	1.960	0.351	Not Rejected
EDML	EDFL	KGMS	$H_o = \mu1 - \mu2 \geq 0$	-2.33	-1.645	0.010	Rejected
EANL	EAML	KGMS	$H_o = \mu1 - \mu2 = 0$	1.259	1.960	0.208	Not Rejected
EAML	EAFL	KGMS	$H_o = \mu1 - \mu2 = 0$	1.201	1.960	0.230	Not Rejected
MDNL	EDNL	KGMS	$H_o = \mu1 - \mu2 \geq 0$	-4.325	-1.645	0.000	Rejected
MANL	EANL	KGMS	$H_o = \mu1 - \mu2 = 0$	0.106	1.960	0.915	Not Rejected

Note: NL: Near Lap; ML: Middle Lap; FL: Far Lap; MD: Morning Descending; MA: Morning Ascending; ED: Evening Descending; EA: Evening Ascending

Hypothesis testing has provided further inputs regarding the differences between speed values estimated for different pedestrian characteristics at three metro stations. The mean speed of children at CSMS is found significantly different than speed of young, middle age and kids, but not from mean speeds of elders. Mean speed of young is significantly higher than that of kids, middle age and elders. Mean speed of middle age is significantly higher than that of kids and elders. Mean speed of kids is significantly lower than elders. At RCMS, mean speed of children is significantly found lesser than that of young, middle age and elders and more than mean speed of kids. Mean speed of young is significantly more than that of kids, middle age and elders. Mean speed of middle age is significantly more than kids and elders. Mean speed of kids is significantly lower than that of elders. Similar analysis at KGMS indicated that mean speed of children is significantly lower than the mean speed of young and more than mean speed of elders and kids. But no significant difference is found between the mean speed of children and middle age. Mean speed of young is significantly higher than that of kids, middle age and elders. Mean speed of middle age is significantly higher than mean speed of kids and elders. Mean speed of kids is significantly lower than that of elders.

In general, mean speed of young pedestrians is significantly higher than other age groups and that of kids is significantly lower than other age groups.

Mean speed of woman is found to be statistically significantly different than the mean speed of male pedestrians at all the stairs at three metro stations. Similar results are observed for mean speed of pedestrians during evening and morning periods at stairs.

The ascending and descending speeds of pedestrians are also found to be statistically significantly different for both during morning and evening periods at CSMS and KGMS. No significant difference is found in ascending and descending speeds of pedestrians at RCMS during morning period, though they are statistically significantly different during evening period.

Mean speeds of pedestrians who used stairs and carried luggage with them are found to be statistically significantly different than the speeds of pedestrians who have not carried luggage with them. This is found true for all the stairs and three metro stations.

The movement of pedestrians on different laps of the stairs (i.e. flights) are found to be statistically significantly different at CSMS. This is true for both, morning and evening time periods, as well as, for ascending and descending directions. In the case of KGMS, the speed of pedestrians moving in descending direction at Near Lap during morning is found to be statistically significantly different than the mean speed during evening. Significant difference is not found during morning and evening period for pedestrian speeds in ascending direction at Near Lap.

6.2 Speed Variation of Pedestrians Facing Opposing Flow

It has been observed that even though multiple parallel stairs are provided for bidirectional movement but pedestrians are not following the rule of keep left in Indian condition. This has resulted in bidirectional movement on all the stairs which hinders with the flow of pedestrians in a particular direction. To understand the influence of opposing flow on the ascending and descending speeds of pedestrians, an analysis is carried out using the extracted data of pedestrians during morning period on left portion of staircase at RCMS. Figure 2 presents the change in pedestrian speed in ascending or descending direction with respect to the opposing flow from descending or ascending direction respectively. Figure (a) represents the variation of speed of ascending pedestrians with respect to percentage of descending flow and Figure (b) represents the variation of speed of descending pedestrians with respect to percentage of ascending flow.

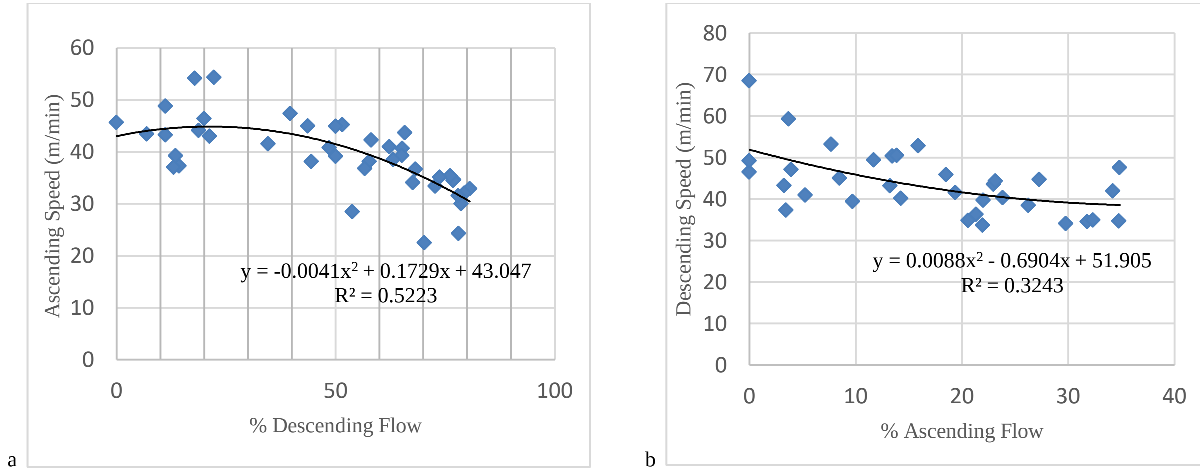

Figure 2 Variation in ascending or descending speed of pedestrians due to increase in opposing flow on staircase at RCMS

From the two plots it is revealed that the speed of pedestrians moving in a particular direction decreases with an increase in percentage of opposing flow. The ascending speeds are not much influenced up till the descending flow (i.e. opposing flow) reaches 30%. After that it starts reducing fast. The relationship is estimated to be quadratic and is convex in nature. In the case of descending speeds it has been observed that, as the ascending flow (i.e. opposing flow) starts building, the descending speeds starts reducing. The relationship again is observed to be quadratic but concave in nature. Here it can be noted that the descending speeds stabilizes at around 40 m/min once the ascending (opposing) flow reaches 30% or more.

6.3 Comfortable Limits of Pedestrian Locomotion Speed on Stairs

According to Fruin (1971), the comfortable limits of pedestrian locomotion speed falls in a range from minimum to the maximum speed of the pedestrians. In the present study the maximum speed is found to be as high as 196.76 m/min (3.28 m/s). This cannot be considered as comfortable climbing speed. Similarly, minimum speed has been observed as 13.24 m/min (0.22 m/s), which is quite low and will cause congestion on the facility. Hence considering minimum and maximum speeds being observed will not serve the purpose. It was felt that the comfortable speeds shall be such that they remain acceptable to the users as well as do not cause performance problem on a facility. Keeping these in mind it is decided that the statistical range (15th percentile speed to 85th percentile speed) be considered as the comfortable speed limits on stairs. These limits are estimated for all the stairs at three metro stations. The comfortable speed limit on the staircase at CSMS can be considered ranging between 35.67 m/min to 84.42 m/min, at KGMS between 38.12 m/min to 75.30 m/min and at RCMS varying between 33.51 m/min and 60.54 m/min.

With a vision of segregating normal speeds from running speeds, overall speed data are plotted as a scattered plot as shown in Figure 3. It can be seen from the plot that the speeds starts rising abruptly after a speed of 105 m/min. A look at the recorded video tells that all such pedestrians who are moving with speed more than the above mentioned are basically running. Therefore, it can be commented that speed beyond 105 m/min can be considered as a running speed.

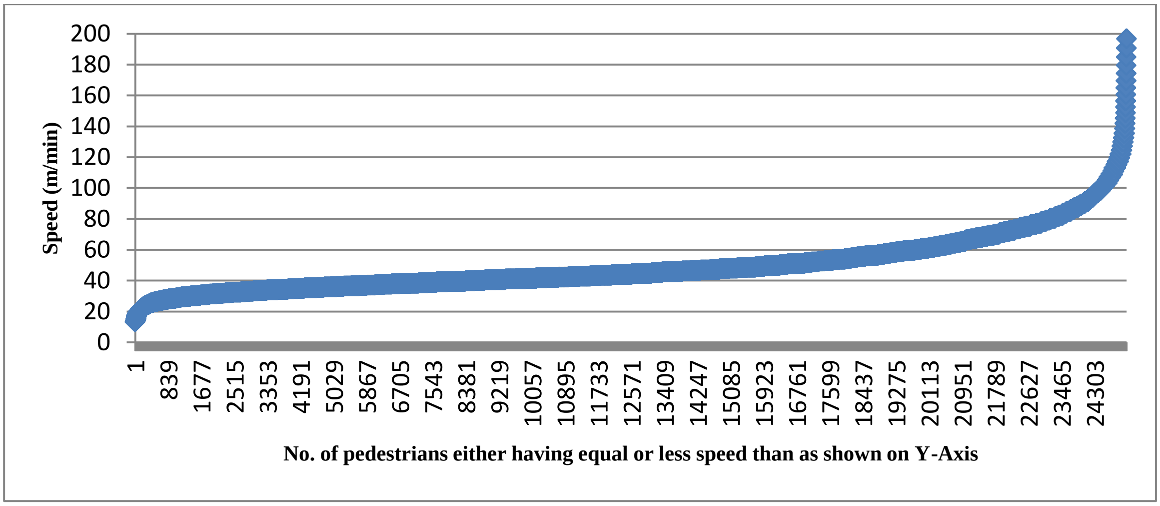

Figure 3 Segregating Speed Data for Identifying Running Speed

Further, it is found that pedestrian speed of 105 m/min corresponds to 98th percentile speed for a combined data, which is usually considered as a design speed. Percentile values corresponding to the speed of 105 m/min at each study location is found separately and it is found that this speed corresponds to either 95th or 96th percentile value at different locations. Therefore, it is decided that 95th percentile value, instead of 98th percentile value, can be considered as design speed value for stairs.

6.4 Distribution of Flow

Segregated pedestrian flow values are examined for analyzing the distribution of pedestrian flow among left, center and right-side of staircase, which are segregated by handrails for ascending and descending movement. Table 5 shows the distribution of pedestrian flow for RCMS and KGMS. A clear vision that we get from these results is that the pedestrians prefer to move on their left hand side but whole population do not follow this trend and this may happen due to reason like avoiding the rush due to heavy flow on their left hand side portion or position of staircase with respect to the platform. Ideally, the flow on right side stair should be zero and highest on left side stair for a pedestrian. Though the percent flow on left side stair is found to be highest but not up to highest possible. Substantial flow has been observed on right side stair. Here, it can be observed that the variation between the distribution of ascending flow at Kashmiri Gate in morning and evening is high. The reason behind it is that the escalator adjacent to stairs on right side was stopped due to a technical problem which caused people to climb through right portion of stairs because of inconvenience in climbing through the escalator. This observation reveals that pedestrians choose their way or the facility according to their convenience.

Table 5 Distribution of Pedestrian Flow on Left, Centre and Right parallel flight of stairway

		Morning			Evening		
		Left	Centre	Right	Left	Centre	Right
RCMS	Ascending	52.07%	26.44%	21.49%	59.27%	27.26%	13.47%

	Descending	40.65%	28.58%	30.77%	46.58%	28.91%	24.51%
KGMS	Ascending	64.16%	17.7%	18.14%	80.07%	18.3%	1.63%
	Descending	57.33%	33.38%	9.29%	59.32%	34.94%	5.74%

6.5 Flow Building Time Lag with Arrival of Train

Flow variation of arriving pedestrians with respect to the arrival of train at platform is observed at the entry point of the staircase at platform level of CSMS during morning time and the same is presented in Figure 4. The peaks in the plot represent the arrival of pedestrians in the approach area of the stair after the arrival of train as per schedule e.g. train arrived in 22nd, 31st, 73rd, 77th, 88th and 90th minutes, which gives peaks in 23rd, 32nd, 74th, 78th, 89th and 91st minutes. The average time lag between arrival time of train and peak building at approaches of stairs is calculated to be 9.16 seconds.

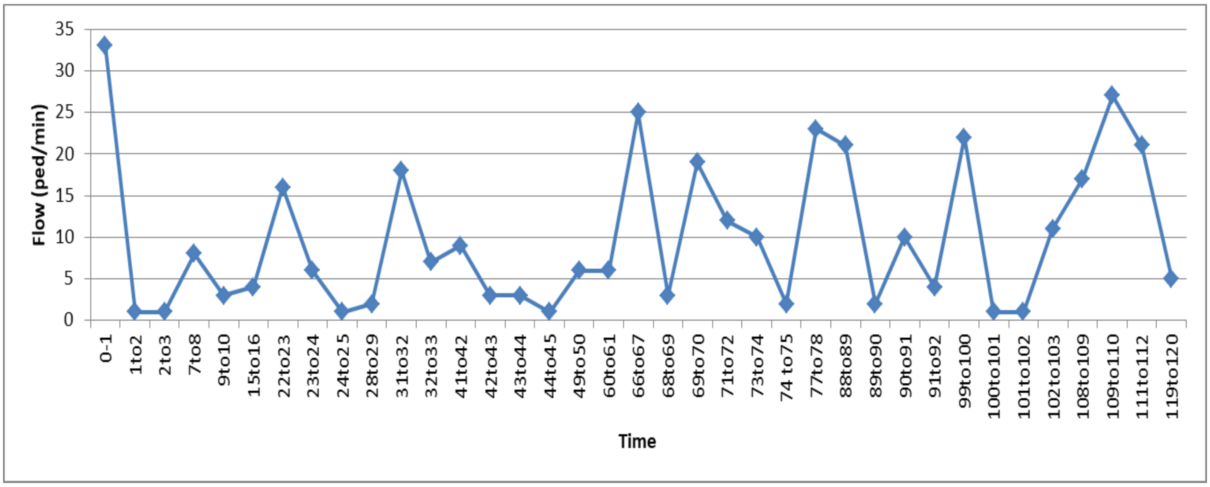

Figure 4 Variation of Flow with Arrival of Train at Central Secretariat Metro Station in Morning

6. Conclusions

The availability of space for construction, under population pressure, is drastically decreasing at every place. Construction in vertical direction is one solution, but this generates need for the level change facilities, which should be efficient, safe, and pedestrian friendly. These are going to be important in the light of Government of India policy to push for metro transit and aggressively plan for smart cities. Understanding of pedestrian flow characteristics is vital for this purpose. Pedestrians walking speed is usually considered as an important factor for evaluation of performance level of the associated facilities, especially stairways and ramps. Pedestrian speed is dependent on pedestrians' personal characteristics (gender, age, body dimensions, physical ability, etc.), direction of movement (ascending or descending), flow volume, purpose, activities involved (e.g. catching commuter train), time period of movement (morning/evening, peak/off-peak), land use around, cultural attitude of the pedestrians, etc.

This study has examined the pedestrians' speed at metro stations where most of the users are commuters. The findings fall in both domain, supported by literature and contrary to it. Observations like mean speed of the woman pedestrian is statistically significantly different (lower) than the speed of male pedestrians, heavy flow reduces crowd mean speed, young pedestrians' mean speed is statistically significantly different than other age groups, mean speed of pedestrians carrying luggage during use of stairs is statistically significantly different than those not carrying luggage and descending speeds are higher than ascending speeds have found support in the literature (Fruin 1971, Lam et al. 1995, Cheung and Lam 1998, Fujiyama and Tyler 2004, Liu et al. 2008, Zhang et al. 2009, Shah et al. 2013, Shah et al. 2015a, Shah et al. 2015b and Shah et al. 2017). Reasons attributable are differences in physical dimensions and abilities of pedestrian groups, heavy pedestrian flow due to surrounding land use (at RCMS), difference in agility and stride length of pedestrians in different age groups, and negative or positive gravitational pull effect during scaling stairs in up or down direction respectively. Mean speed of kids is found to be lowest and that of children is found to be comparable to elders. This is contrary to the finding of Fruin (1971).

Certain observations are made which needs mention. Mean speeds of pedestrians on stairs at metro stations are higher than the speeds at long distance train railway station. The genesis of such behavior lies in difference in functional characteristics of the two types of stations and inherent or psychological haste associated with commuting. Ascending speeds vary more compared to descending speeds. It is inferred that the ascending speeds are impacted by the physical condition of pedestrians and surrounding land use, whereas, the descending speed is influenced by the structural condition of the staircase. Morning time speeds are found higher than evening time speeds. Associated reasons are fatigue and tiredness while returning from office in the evening or hurry for reaching workplaces in the morning. The connectivity of metro station to Inter-State Bus Terminus reversed the trend. Minimum speeds of woman are higher than males'. Examination of speed on multiple flights of a stair indicates that ascending speeds reduces as a pedestrian moves from near to far flight. This seems obvious. The opposing flow of 30% and above from descending direction impacts ascending speeds adversely and the ascending flow 30% and above stabilizes the decrease in the descending speed. The pedestrian speed above 105 m/min can be considered as running speed, which corresponds to 95th percentile of speed distribution and can be used as a design speed.

Next section now provides inputs on how efficiency of the stairs can be improved on metro stations, which is affected by varied frictions.

7. Application

Pedestrians carrying luggage lowers the overall speed of the crowd, and in turn the efficiency of the staircase. It is suggested to provide proper automotive arrangements like rollers, conveyor belts etc. at the side of stairway for carriage of luggage. The pedestrians use all the portions of staircase (left, center and right) for both side movements i.e. ascending and descending, which decrease the efficiency of staircase and safety of pedestrians. The ascending and descending pedestrian flow can be routed in different lanes segregated by railings, by using any regulatory or mandatory signs or signals indicating use of staircase for ascending or descending only. Restricting arrangements like gates can be used at both side approaches to restrict the directional movement of pedestrians. These signals and gates arrangements will work on the instruction given by sensors according to live pedestrians flow. A tentative arrangement for management of bidirectional movement of pedestrians moving on a staircase is shown in Figure 5. This arrangement consists of 4 no. of gates with two leaves each (G_{11}, G_{12}, G_{21}, G_{22}, G_{31}, G_{32}, G_{41}, G_{42}) and 6 no. of pedestrian's signals (S_1, S_2, S_3, S_4, S_5 and S_6). A tentative plan of working of these signals and gates is presented in Table 6.

Table 6: Tentative Plan for managing bidirectional movement of pedestrians on multiple-parallel staircase

Ascending LOS	Descending LOS	Gates								Signals					
		G_{11}	G_{12}	G_{21}	G_{22}	G_{31}	G_{32}	G_{41}	G_{42}	S_1	S_2	S_3	S_4	S_5	S_6
A,B,C,D	A,B,C,D	O	C	O	O	O	O	C	O	R	G	G	G	G	R
A,B,C,D	E,F	O	C	O	O	C	O	O	O	R	G	G	G	R	R
E,F	A,B,C,D	O	O	O	C	O	O	C	O	R	R	G	G	G	R
E,F	E,F	O	O	O	O	O	O	O	O	A	A	A	A	A	A

Whereas O = Open, C = Closed, R = Red, G = Green, A = Amber

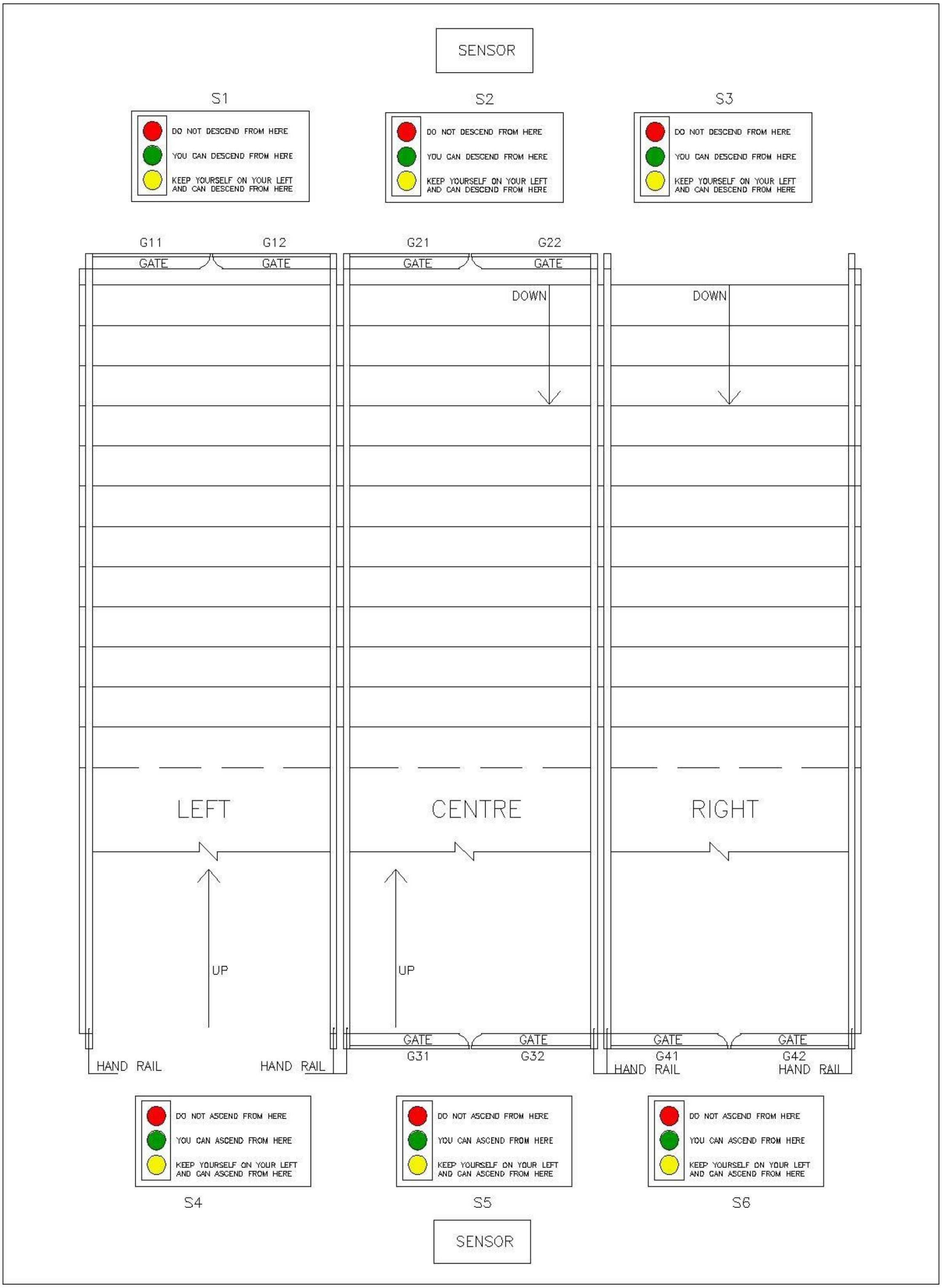

Figure 5 Tentative Arrangement for Management of Bidirectional Movement of Pedestrians on Multiple-Parallel Staircase

This study provides the technical information that can be incorporated in the Indian guidelines of Indian Roads Congress on pedestrian facilities i.e. IRC-103 (2012) so that the design criteria may be modified as per the needs of pedestrians and efficient management of pedestrian flows at level change facilities like stairs can be done.

Acknowledgements

Authors are thankful to Delhi Metro Rail Corporation (DMRC) for giving permission to conduct study in and outside the premises of selected metro rail stations and their constant support during data collection.

References

Cheung, C.Y. and Lam, W.H.K., 1997. A study of the bi-directional pedestrian flow characteristics in the Hong Kong mass transit railway stations. Journal of Transportation Engineering, 2(5), pp.1607-1619.

Cheung, C.Y. and Lam, W.H., 1998. Pedestrian route choices between escalator and stairway in MTR stations. Journal of Transportation Engineering, 124(3), pp.277-285.

Fruin, J., 1971. Designing for Pedestrians: A Level-of-Service Concept. New York Metropolitan Association of Urban Designers and Environmental Planners. Highway Research Record, (355), HRB, National Research Council, Washington, D.C., 1971 (reprinted 1987), pp. 1–15.

Fujiyama, T. and Tyler, N., 2004. Pedestrian speeds on stairs: an initial step for a simulation model. Annual Conference Universities Transport Study Group, Newcastle upon Tyne, 2004.

Fujiyama, T. and Tyler, N., 2011. Free walking speeds on stairs: effects of stair gradients and obesity of pedestrians. Pedestrian and Evacuation Dynamics, Springer, Boston, MA, pp. 95-106.

Graat, E., Midden, C., and Bockholts, P. Complex evacuation; effects of motivation level and slope of stairs on emergency egress time in a sports stadium. Safety Science, Pergamon, 1999, pp. 127-141.

Henson, C., 2000. Levels of service for pedestrians. Institute of Transportation Engineers. ITE Journal, 70(9), p.26.

https://en.wikipedia.org/wiki/Delhi_Metro (Accessed on 24.03.2018).

IRC: 103-2012. Guidelines for pedestrian facilities, Indian Road Congress, New Delhi, India

Indian Railways Statistical Publications: Statistical summary - Indian Railways 2016-17. Ministry of Railway Retrieved 22 February 2018. Accessed through http://www.indianrailways.gov.in/railwayboard/uploads/directorate/stat_econ/IRSP_2016-17/Annual_Report_Accounts_ Eng/Statistical_Summary.pdf.

Kotkar, K. L., Rastogi, R. and Chandra, S., 2010. Pedestrian flow characteristics in mixed traffic conditions. J. of Urban Planning and Development, 136 (1), pp. 23-33.

Kretz, T., Grünebohm, A., Kessel, A., Klüpfel, H., Meyer-König, T. and Schreckenberg, M., 2008. Upstairs walking speed distributions on a long stairway. Safety Science, 46(1), pp.72-78.

Lam, W. H. K., J. F. Morrall, and H. Ho. , 1995. Pedestrian Flow Characteristics in Hong Kong.Transportation Research Record: Journal of the Transportation Research Board, No.1487, pp. 56-62.

Liu, W., Zhou, H. and He, Q., 2008, October. Modeling pedestrians flow on stairways in Shanghai metro transfer station. In International Conference on Intelligent Computation Technology and Automation (ICICTA), IEEE 2008, Vol. 2, pp. 263-267.

Muller, M., 2010. Fundamental diagram of stairs in grandstands - comparison of different slopes using the ESPRIT arena as example. Bachelor Thesis, University of Wuppertal, Department of Civil Engineering, Wuppertal.

Shah, J., Joshi, G.J. and Parida, P., 2013. Behavioral characteristics of pedestrian flow on stairway at railway station. Procedia-Social and Behavioral Sciences, 104, pp.688-697.

Shah, J., Joshi, G.J. and Parida, P., and Arkatkar, S., 2015. Analysis of commuter flow behaviour on stairways at metropolitan transit station in Mumbai, India. International Journal For Traffic And Transport Engineering, 1(5), pp.451-457.

Shah, J., Joshi, G., Parida, P. and Arkatkar, S., 2015. Empirical study of bidirectional movement on stairway at a suburban railway station in India. In Transportation Research Board 94rd Annual Meeting (No. 15-3892) , January 11-15, 2015, Washington D.C.

Shah, J., Joshi, G., Arkatkar, S. and Parida, M., 2017. Impact of human factors and functional characteristics of location on walking speed at stairway facility. In Transportation Research Board 96th Annual Meeting (No. 17-06476), January 8-12, 2017, Washington D.C.

Sharifi, M.S., Stuart, D., Christensen, K., Chen, A., Kim, Y.S. and Chen, Y., 2014. Analysis of walking speeds involving individuals with disabilities in different walking environments. In Transportation Research Board 93rd Annual Meeting (No. 14-2134), January 12-16, 2014.

Yang, L., Rao, P., Zhu, K., Liu, S. and Zhan, X., 2012. Observation study of pedestrian flow on staircases with different dimensions under normal and emergency conditions. Safety science, 50(5), pp.1173-1179.

Zhang, R., Li, Z., Hong, J., Han, D. and Zhao, L., 2009, November. Research on characteristics of pedestrian traffic and simulation in the underground transfer hub in Beijing. In Fourth International Conference of IEEE on Computer Sciences and Convergence Information Technology, ICCIT'09, pp. 1352-1357.