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Research Article

Impact of Train Schedule on Pedestrian Movement on Stairway at Suburban Rail Transit Station in Mumbai, India

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Pedestrian flow takes place in confined environment on stairways under the influence of composition, direction of movement, and schedule of trains. During peak-period, alighting and boarding rate is quite high resulting in very high pedestrian movement from one platform to the other to catch the next train at interchange stations. The transfer of passengers from railway platforms through common undivided stairways becomes difficult, uncomfortable, and unsafe at times when pedestrian flow reaches the capacity level. Understanding of criteria defining quality of flow that affect the effectiveness of facilities like stairways in handling the pedestrian traffic is vital for planning and designing of such facilities to ensure the desired level of service as well as safety in case of emergency. The present paper is based on the study of pedestrian movement on stairways at busy suburban rail transit interchange station at Dadar in Mumbai, India. Pedestrian movements are captured through videography at two stairways and the effect of bidirectional movement on average walking speed is analyzed. The ascending flow in small proportion is found to be more influential in causing speed reduction on undivided stairways. The outcome of the study is useful for capacity and level of service analysis while planning and designing the transit station stairways.

1. Introduction

The past two decades have witnessed rapid pace of growth of Indian economy demanding mass transport infrastructure for its fast growing metropolitan cities. The unidirectional migration towards metropolitan cities due to higher level of employment opportunities and better standard of living has increased tremendous pressure on urban transport infrastructure due to rising demand for mobility. Rail based transit system plays an important role in ensuring the urban mobility particularly in metro cities [1]. While designing and planning urban transit system, transport planners contribute towards designing best alignment with shortest distance between two stations while engineers concentrate on optimization of operational efficiency and technical specification of rolling stock and also maximized use of infrastructure in general. However, the operation of facilities for passenger transfer from one platform to the other through stairways and foot over bridges is not attended to at planning as well as design stage keeping operating schedule of trains and passenger load at transit station in sight. Relatively few efforts have been made to understand the efficiency of existing facility based on pedestrian movement behavior. Passengers' entry and exit at platform and transfer to another platform are executed through critical element like stairways and can have significant effect on overall performance of transit service. In view of the growing concerns for the safety of transit users and its quality of service, it is pertinent to study the effect of characteristics of pedestrian flow generated due to train schedules on the performance of the undivided stairways in terms of walking speed in ascending and descending directions.

As reported in the literature, walking speed as the measure of effectiveness of pedestrian facility has been one of the major issues in pedestrian flow analysis. Pedestrian walking speed is significantly influenced by the arrival of trains. Generally, on schedule arrival of trains is likely to make efficient gathering and dispersion of pedestrian and to provide easy transfer of pedestrian for the next train on the other platform through transfer facilities. A number of factors

make significant contribution to the free flow movements of a pedestrian. These factors include age, gender, the baggage carried by a pedestrian and the walkability of a facility [2], the gradient or roughness of surface [3], time of day [4], and type of walking facility [5]. The most important factor governing pedestrian movement on a public transport facility is the presence or absence of other pedestrians [3]. Burghardt et al. [6] carried out comparative study on fundamental diagrams of pedestrian flow on stairway developed by various researchers and observed larger uncertainty in maximum specific flow in the upward motion than the downward motion. However, in downward motion discrepancies occur in maximum specific flow, when density rises more than 1.5 p/m^2 whereas for density below 1.5 p/m^2, flow-density functions are close to each other. Authors also compared a field study and experimental study carried out by different scholars and their study and found that the flow decreases with increase in slope of stair. Fruin [7], Tanaboriboon and Guyano [5], Lam et al. [8], and Liu et al. [9] observed higher walking speed on downstairs than upstairs with reduction in speed with increase in pedestrian density. Pedestrians obtain higher walking speed on outdoor stair than the indoor [10], and also mean upward walking speed on the short stairway was found to be roughly twice the long stairway. Lee and Lam [11] observed that walking speed variation was the smallest when pedestrian flow approaches towards capacity. Authors also observed that direction of pedestrian movement and arrival time of train also affects the average horizontal speed. However, effect of various activities (baggage and use of cell phone) on ascending and descending speed was not taken into consideration. There are very few studies on schedule of train and its effect on average walking speed on stairways. Hence, it is necessary to study the schedule of train at busy railway station and its effect on average walking speed of pedestrian for smooth and safe pedestrian movement for achieving overall efficiency of transit system.

2. Study Area Profile

The present paper reports the outcome of the study carried out in this regard at suburban rail transit interchange station at Dadar in Mumbai, the financial and commercial capital of India. The average decadal population growth of Mumbai metropolitan region increased after 1951 and has reached to 15.99% in 2001–2011 in outer Mumbai, Thane, and Raigarh as shown in Figure 1. At present, about 22 million people travel regularly and commute by local trains over varying distances ranging from 10 to 60 kilometers a day to reach their destinations for performing different activities like job, business, marketing, shopping, recreation, and education. The rising passenger traffic demands for the transportation infrastructure for high capacity and efficient transit system in different parts of the metropolitan city. However, the planning agency has not been successful in augmenting the suburban rail transit infrastructure to burgeoning travel demand and continues to serve at load factor of more than 3.5 during peak periods. Such super dense crush load condition in trains creates extremely heavy pedestrian flow on suburban railway stations, particularly those located in the CBD area. The subsequent paragraph provides details of suburban rail network of Mumbai.

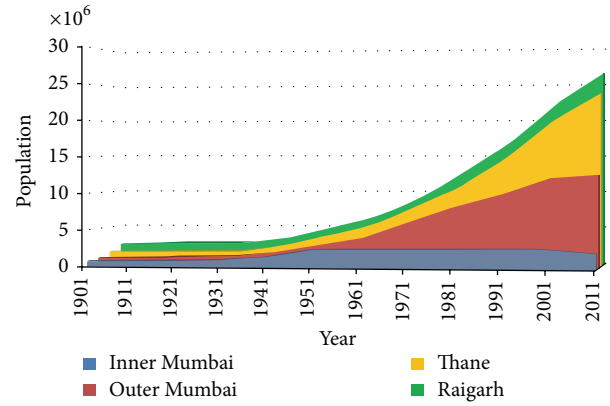


Figure 1: The population growth of Mumbai Metropolitan Region. Source: Urban Age (2007).

The Mumbai local railway network branches out through three main lines: Central (CL), Western (WL), and the Harbour (HL), each connecting a distinct part of the city to another as shown in Figure 2.

Dadar is situated in the CBD of Mumbai, and the transfer station is common to both the Central and Western lines. About 0.5 million passengers visit the station daily, thereby making it one of the most crowded railway stations of the network. The passenger entry and exit movement takes place only through stairways and during peak period; due to high frequency of trains (30 trains/hour) pedestrian movement is also increased significantly. During this period, pedestrian movement on platforms and stairways becomes critical and complex due to extremely high passenger volume and constraints of physical dimensions of pedestrian facilities. As a result, the pedestrian efficiency reduces in terms of walking speed and cannot achieve their desired walking speed. This eventually generates queues at ends of stairway and leads to delay in pedestrian movement.

3. Data Collection and Extraction

The pedestrian movement data were collected through videographic survey method at two different stairways inside Dadar railway station on Western line (WL) in mid-June, 2013, on normal weekday. Figure 3(a) shows the schematic diagram of interchange station and location of the stairways. Fast trains arrive on platforms 2 and 4 and slow trains arrive on platforms 1 and 3. Platform 5 takes care of all long route trains. Figure 3(b) shows 3D view of platform and connected stairway at railway station. The selection of stairway is carried out in such a way that it covers both fast and slow trains and includes variation in the stairway physical dimensions. Thus to accomplish the above criteria, stairways of platforms 2-3 and 4 are selected. The detailed dimensions of selected stairways are shown in Table 1.

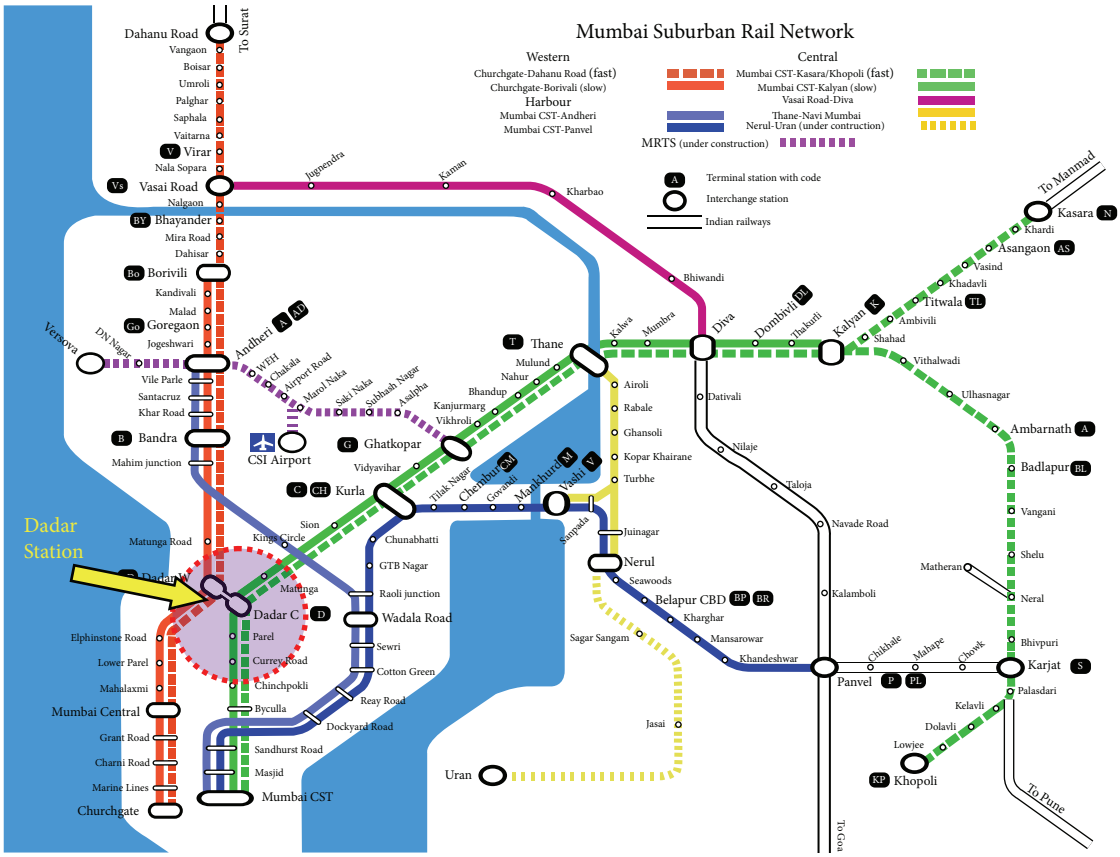


Figure 2: Dadar suburban railway station and network of main lines.

Table 1: Dimension of selected stairways.

Stair number	Horizontal trap length (m)	Inclined trap length (m)	Width (m)	Area (m^2)	Riser (m)	Tread (m)	Slope (°)	Total length (m)	Height (m)
1	3.52	3.8	2.67	8.589	0.13	0.29	22.10	20.6	5.85
2	2.03	2.22	2.15	4.202	0.13	0.3	24.14	20.8	5.98

The videographic survey was carried out to capture pedestrian movement on stairways for 390 minutes including 90 minutes in morning peak and 150 minutes each in evening peak and off-peak hours. Data is obtained by marking the entry-exit trap section on the step depending on the number of steps covered in the camera set up fixed at the ceiling with inclination so as to cover maximum number of steps as shown in Figure 3(c).

The pedestrian flow data like pedestrian volume, speed, and density, with respect to schedule of train, is extracted in the laboratory by repeated play of video files. The pedestrians in the flow are also categorized on the basis of various attributes like age, gender, directional movement, and performance of activity like carrying baggage and/or children. The age group is identified on the basis of visual perception. The age band is classified in three groups of children (age < 15), younger pedestrians (age between 15 and 60), and the elder (age > 60). Pedestrian flow data are extracted from video for every one minute interval for the entire survey duration. Pedestrian volume is collected by noting down the total number of pedestrians in each category at the exit of the marked trap area. Arrival and departure time of each train on selected platform have also been noted during extraction process. Pedestrian walking speeds are calculated for randomly selected minimum five samples in each category by noting down entry and exit time of pedestrian while crossing the trap length. For measuring density of pedestrian, video files are converted into 30 frames per minute and pedestrians occupying the trap area are counted for each frame. Based on these values, the average number of pedestrians occupying the trap area is calculated for every minute.

4. Pedestrian Flow Profile

In total 32,627 bidirectional pedestrian data are extracted manually from the video file on one minute basis for the entire duration of 390 minutes. 20,579 and 12,048 pedestrian data are from stairway 1 and stairway 2, respectively. Figure 4

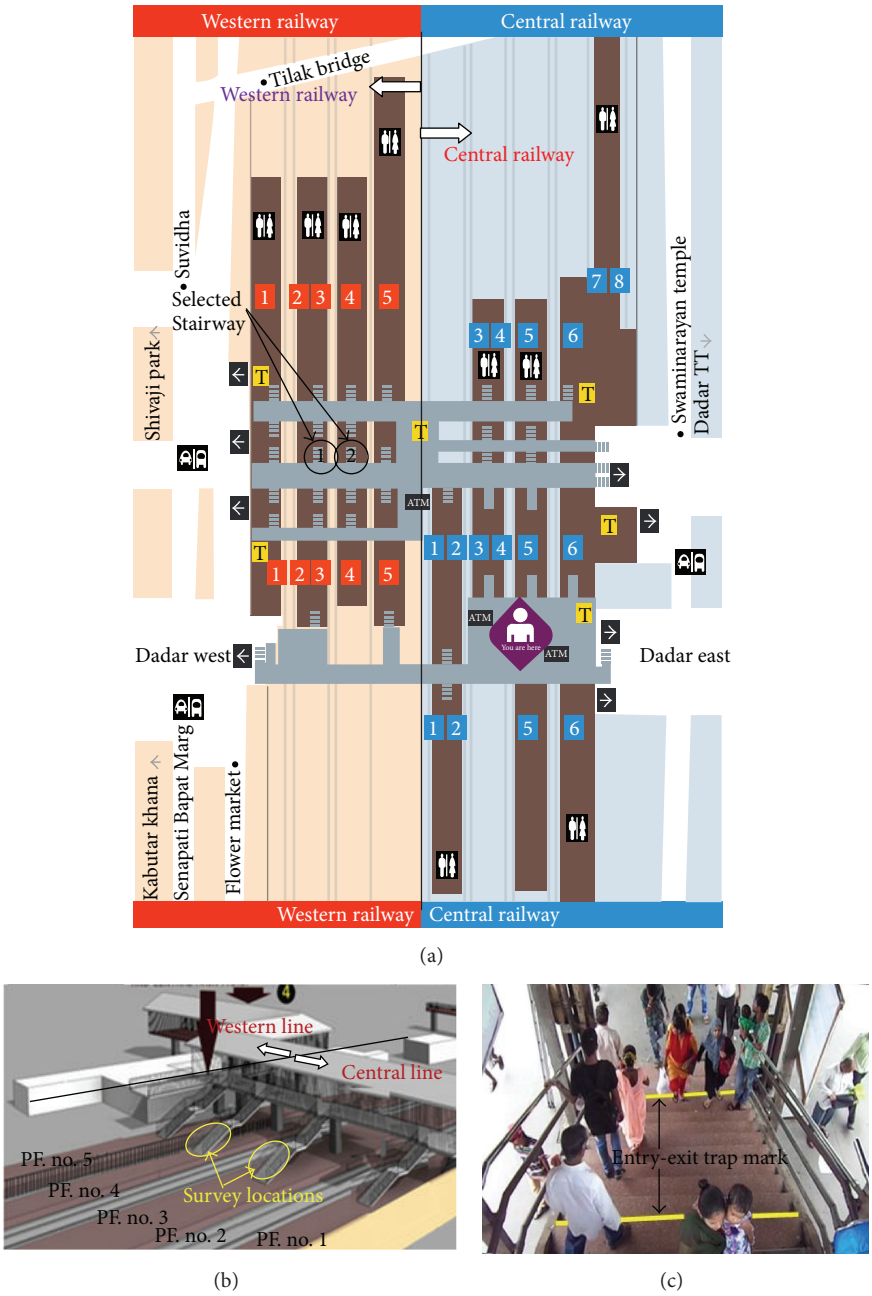


Figure 3: (a) Western and central line of Dadar suburban interchange station connected with horizontal walkway and stairways; (b) 3D view of stairway locations; (c) pictorial view of stairway having entry-exit marking.

shows age-group-wise pedestrian movement in ascending and descending directions for both the stairways.

Figure 4 shows that, in both the stairways, younger pedestrians (age 15–60 years) are the dominant group whereas children and the elder constitute negligibly small proportion (2%) of the pedestrian flow for the ascending and descending movements.

The percentage composition of females is also affecting the overall efficiency of system. It is reported that females have lower walking speed than the males [5, 12–17]. In the present study, males constitute the majority of pedestrian flow on both the stairways with 86% (stairway 1) and 91% (stairway 2) proportion. Figure 5 graphically shows proportion of male and female pedestrian in ascending and descending directions at the study stairways.

The average walking speed of pedestrian also depends on the proportion of persons with luggage. Obviously, pedestrians with luggage walk at slower speed [17]. In this study, number of pedestrian without luggage is very high than the number of pedestrian with luggage on both the stairways. The majority of the pedestrians are found walking without luggage or small luggage like brief case or handbag. Direction

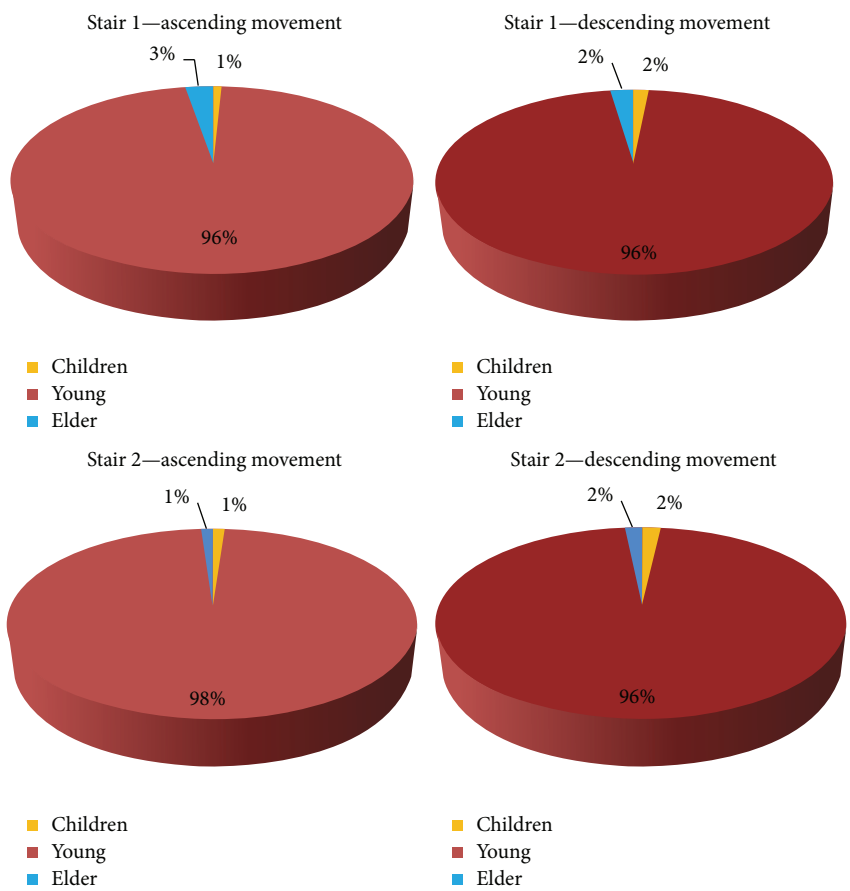


Figure 4: Age-group-wise directional pedestrian movements.

of movement on stairways has a significant effect on the speed of pedestrian at a given flow level [9]. Figure 6 shows distribution of observed pedestrian volume with respect to direction of movement, gender, and luggage carrying status. Pedestrian flow in descending direction is higher in stairway 1 whereas in stairway 2, ascending flow is higher than the descending flow.

5. Effect of Schedule of Train on Pedestrian Walking Speed

The walking speed depends on the various attributes described above. Pedestrian volume on station platform increases at the time of arrival and departure of the train resulting into variation in walking speed. At the selected study location, the headway of trains during morning and evening peak period is 2 min, and it is 4 minutes during off-peak period. In Figures 7(a), 7(b), 8(a), and 8(b) the line plots show time of day versus number of pedestrian movements and average pedestrian walking speed on both the stairs. It is evident from these plots that, at lower pedestrian volume, pedestrians walk with higher speed (seen by numbered circles in Figures 7 and 8). As pedestrian volume increases, pedestrian walking speed decreases. It is observed during the field survey that the capacity of existing stairways is much less than the passengers transfer demand and hence there is uncleared pedestrian volume at the time of arrival of the next train resulting into formation of queues at the entrance of the stairways. However, spikes in the instantaneous pedestrian volume and speed are observed due to 1 minute duration of data extraction and random variation in rate of arriving passengers. At a given instance of time, pedestrian volume is found to be at the highest level followed by a sudden decline and rise due to arrival of another train on the same platform. Due to higher frequency of trains in each direction, a small amount of delay in arrival of a train generates huge crowd on the platform and stairways due to the presence of waiting passengers as well as simultaneous arrival of passengers from two trains coming from different directions. Under the circumstances, the situation on stairway becomes heavily congested with pedestrians jostling to move in the desired direction with extreme level of discomfort due to unavoidable body contacts and pedestrian flow in opposite direction. This phenomenon reduces individual walking speed and also affects average walking speed of pedestrian flow as seen in Figures 7 and 8 by highlighted circles ($V_{2\&3}$ and $S_{2\&3}$ for stairway 1 and $V_{2\&9}$ and $S_{2\&9}$ for stairway 2).

Figure 9 shows three scenarios representing different condition of the pedestrian movement. In scenario I, at

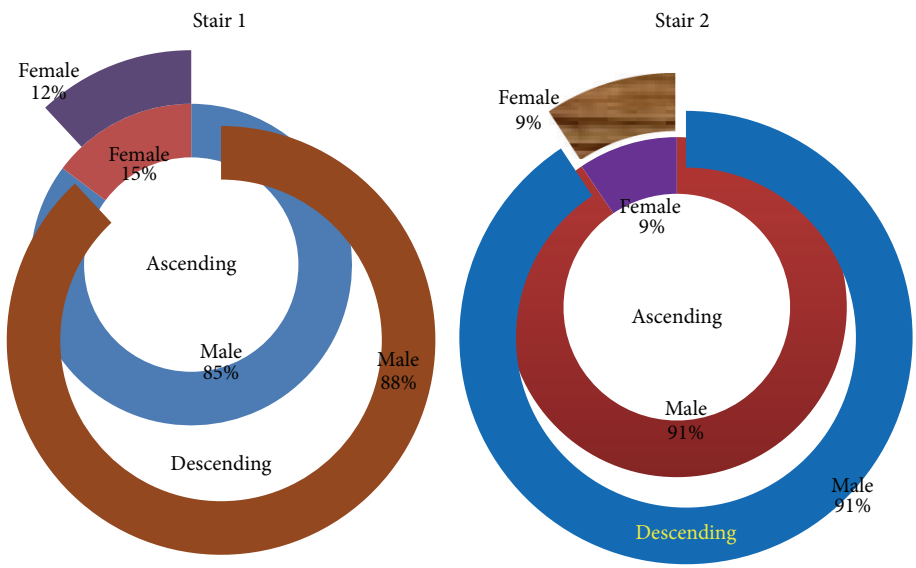


Figure 5: Genderwise distribution of pedestrian movement on both stairways.

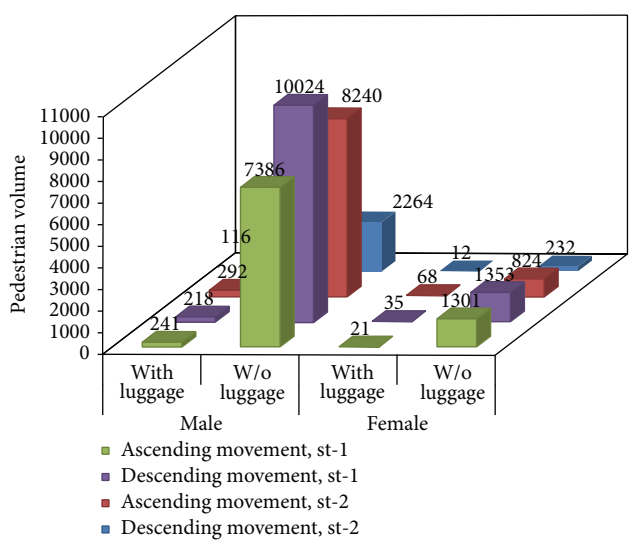
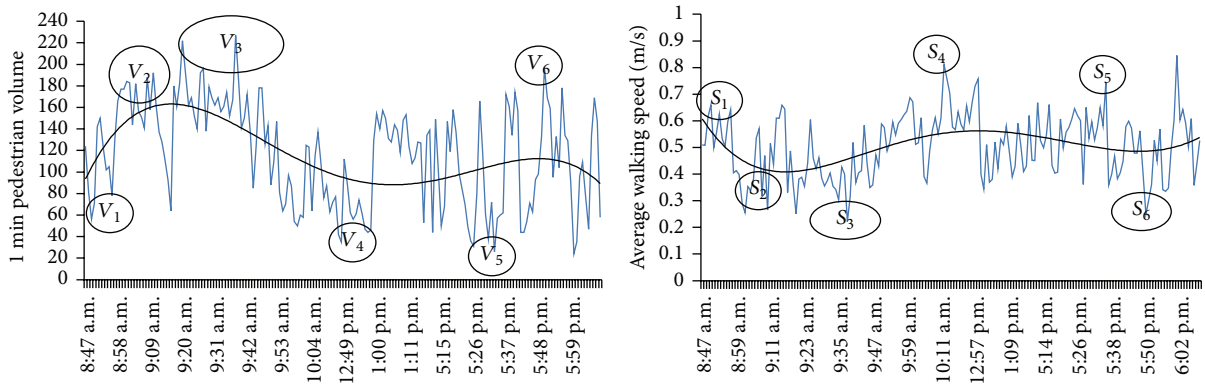


Figure 6: Genderwise distribution of pedestrian movement considering luggage status.

lower volume in both the directions, pedestrians achieve their walking speed despite moving with heavy luggage. Scenario II shows that as the volume of pedestrian increases in both the directions, the individual walking speed reduces due to aberration between pedestrian moving in different directions. This restricts the pedestrian movements and creates jam along with queue near the ends of stairway creating stampede like situation. However, in scenario III, showing dominance of flow in one direction, walking speed of pedestrian is higher for the same volume of pedestrian compared with the previous scenario having even directional split of pedestrian volume. Variation in average walking speed of pedestrian on stairways with change in the proportion of pedestrian volumes in ascending and descending directions is shown in Figure 10.

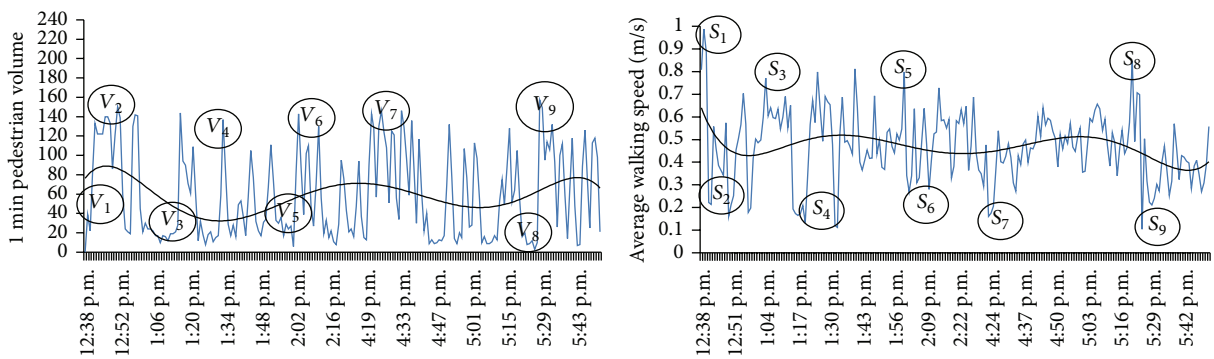
The trend lines in Figures 10(a) and 10(b) illustrate that average walking speed is higher, when pedestrian flow is tidal in one direction, that is, major flow. When the proportion of flow decreases, that is, from 100% to 70%, average walking speed decreases and it continues till major flow becomes minor, meaning that increase in proportion of flow in other directions causes reduction in the walking speed. From Figure 10(a) it can be noted that when total flow in ascending direction is 100 ped/min (>90%), average walking speed obtained is 0.52 m/s. However, at the same flow level, when descending flow increases to 30% average speed in ascending direction drops by 26% to 0.38 m/s. Further increase in descending flow up to an equal proportion of 50% results in the reduction in average walking speed by 30% (0.36 m/s). Decrease in walking speed of 48% (0.27 m/s) is observed when ascending major flow becomes minor (30%). The same observation is obtained in Figure 10(b), with increase in opposite direction of flow; average pedestrian walking speed gets reduced showing influence of opposing flow on average walking speed in the major direction. Table 2 summarizes the average walking speed and percentage reduction in major directional speed with respect to directional distribution in each direction.

Table 2 shows that average walking speed is higher in descending direction when it becomes a major flow. However, in both major directions, the average speed gets reduced with increase in flow in opposite direction. Significantly, once the flow in both the directions becomes equal, reduction in descending direction walking speed is higher than the ascending direction. From the results, it is evident that the influence of ascending directional flow on speed is higher than the descending direction. Although, during arrival of train, both the ascending and descending direction movements increase, it is desirable to know at what proportion



(a) Pedestrian volume on stair (b) Average walking speed of pedestrian

Figure 7: 1-minute pedestrian volume and average walking speed on Stair 1.



(a) Pedestrian volume on stair (b) Average walking speed of pedestrian

Figure 8: 1-minute pedestrian volume and average walking speed on Stair 2.

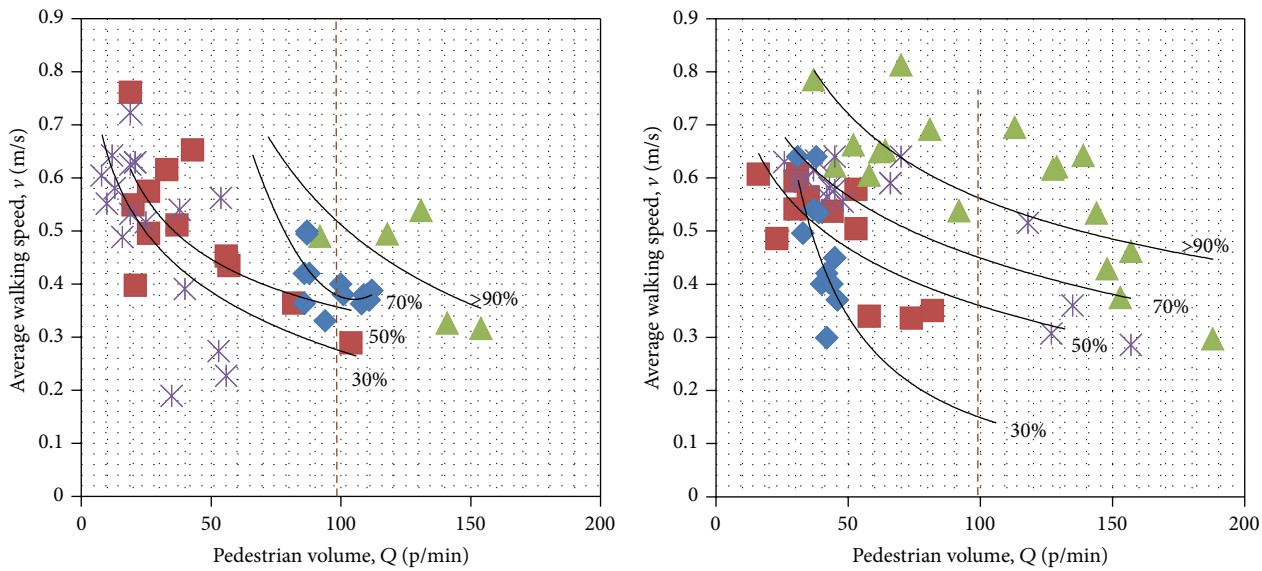
Scenario I Scenario II Scenario III

Figure 9: Image of pedestrian movement for various scenarios.

of directional flows the reduction in walking speed is higher. Hence it is important to understand the bidirectional pedestrian flow phenomenon and at which directional split the effect on speed is significant. The study observations can also be applied to calibrate simulation models for passenger flow on stairways at the transit stations for generating scenario of facility performance in terms of level of service, safety, and efficiency analysis with respect to the scheduling of trains.

6. Conclusions

In this paper, different scenarios of the pedestrian movement on stairways with respect to the arrival of trains during peak and off-peak durations in a normal weekday at busy suburban rail transfer station in Mumbai, India, are analyzed. Due to small headways of trains and space constraints on platforms and stairways, complex pedestrian movement situation arises



(a) Ascending directional distribution

(b) Descending directional distribution

Figure 10: Percentage distributions in ascending and descending Direction.

Table 2: Average walking speed and percentage reduction in major direction.

Pedestrian flow (percentage directional distribution for each direction)	Average walking speed and % reduction with respect to directional speed	
	Ascending (m/s)	Descending (m/s)
>90	0.52 (—)	0.58 (—)
70	0.38 (26%)	0.45 (22%)
50	0.36 (30%)	0.34 (41%)
30	0.27 (48%)	0.15 (74%)

causing high level of congestion on bidirectional undivided stairways. Effect of directional split of pedestrian volumes on average walking speed in ascending and descending directions is reported based on videographic survey data for 390 minutes on two selected stairways. The study is based on three levels of directional splits of 90-10, 70-30, and 50-50 for pedestrian flow in each direction. Reduction in walking speed is observed when the proportion of pedestrian volume in one direction reduces from major (>50%) to minor (<50%). The study shows that the walking speed in descending direction is higher than the ascending movement when the flow is high in descending direction. It can be observed that percentage reduction in walking speed is higher when ascending (minor) directional flow increases. It shows that ascending flow is more influential in causing speed reduction in descending direction when it is minor flow. Therefore, it can be inferred that the directional distribution is an important parameter for planning of pedestrian facility like stairways at transit stations serving high frequency train operations. The study outcomes are also highlighting the impact of train schedules on the quality of pedestrian flow on critical element like stairways. Assessment of performance of the stairways at such transit stations in terms of safety of transit users and efficiency of transfer facilities should be carried out in this context.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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