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ANALYSIS OF COMMUTER FLOW BEHAVIOUR ON STAIRWAYS AT METROPOLITAN TRANSIT STATION IN MUMBAI, INDIA

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Abstract: The number of passenger travelling by railway has increased significantly in last two decades due to rapid urbanization. The passengers are in high density within the station premises during the operation time particularly during arrival and departure of trains at urban transit stations. Pedestrian flow reaches to peak level instantaneously causing sudden change in the pedestrian behavior and may lead to unsafe pedestrian movement. The study of pedestrian flow in such situation calls for more attention in view of the likely gravity of the situation turning adverse. Hence, for the efficient design as well as effective operation, modeling of the pedestrian flow for such situation is necessary to gain important insight into the pedestrian behavior. This paper is focused on pedestrian traffic movement on stairways at busy suburban railway station. Video-graphic data is collected at two stairways at Dadar suburban train station in Mumbai. Extracted data of 1-minutes interval is used to develop Speed-Density and Flow-Density relationships for different stairways. Critical aspects of the pedestrian flow behavior observed through the models are compared with pedestrian flow characteristics and walking behavior reported in earlier studies. The analysis presented in this paper can be used as a base to understand the peculiarity of pedestrian characteristics; specifically urban commuters and can become a useful reference for future pedestrian flow study in Indian metropolitan context.

Keywords: stairway, high density, walking speed, pedestrian flow behaviour, transit station.

1. Introduction

Rail based transit system plays important role in ensuring the urban mobility particularly in metro cities. Advantages of such system are; large transportation capacity, high speed, low pollution, low energy consumption, uninterrupted movement, and comfort; which are essential requirements of sustainable transport particularly for mega and metro-sized cities. Heavy pedestrian movement is observed at urban rail transit station, all throughout the daytime in metropolitan cities like Mumbai. Similar to the vehicular traffic, heterogeneity in pedestrian behaviour plays a vital role in characteristics of pedestrian movement and it is more sensitive during the high volume pedestrian traffic. Collection and dispersion of passengers on railway platforms take place through stairways and such vital element needs to be studied appropriately to ensure desired level of service as well as safety in case of emergency (Shah et al., 2013).

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As reported in literature, pedestrian walking speed is often determined by density and is significantly influenced by the arrival of trains. Generally, arrival and departure of train facilitate gathering of pedestrian at common facility from all directions, which restrict individual movement by reduction in space and speed. A number of physiological, psychological, and environmental factors make a significant contribution to the free flow movements of a pedestrian. These factors include age, gender, the baggage-carrying capacity of a pedestrian and the walkability of a facility (Rahman et al., 2013), the gradient or roughness of surface (Older, 1968), time of day (Hoel, 1968), the intention, intelligence, and physical fitness of a pedestrian (Robertson et al., 1994), indoor or outdoor walkway (Lam et al., 1995), and type of walking facility (Tanaboriboon and Guyano, 1991). The most important factor governing pedestrian movement on a public transport facility is the presence or absence of other pedestrian (Older, 1968). However, many researchers made attempt to study the pedestrian flow characteristics and travel pattern within station premises at microscopic as well as macroscopic level to optimize the use of pedestrian facility. Microscopic study considers individual characteristics such as individual speed and individual interaction (Teknomo, 2002). On the other hand, in macroscopic study considers the movements of all pedestrians in a pedestrian facility at an aggregate level to determine their characteristics in traffic flow. Macroscopic studies have identified three important variables as speed, flow, and density that could describe pedestrian flow characteristics on pedestrian facilities. A considerable number of researches on macroscopic pedestrian studies (Khisty, 1985; Lam et al., 1995; Laxman et al., 2010; Liu et al., 2008; Smith, 1995; Tanaboriboon et al., 1986; Sarkar and Janardhan, 1997) have been carried out to evaluate site- and region-specific pedestrian traffic flow characteristics. Among others, Navin and Wheeler (1969) suggest that the average walking speed of pedestrian is affected by many attributes, however for the purpose of a capacity analysis only density need be considered. Thus, the proper estimation of pedestrian speed and density relationship is of vital importance. A variety of models have been developed for different pedestrian facilities to determine the relationship between speed and density. Majority of such studies (Fruin, 1971; Lam et al., 1995; Laxman et al., 2010; Navin and Wheeler, 1969; Older, 1968; Polus et al., 1983; Sarkar and Janardhan, 2001; Tanaboriboon et al., 1986) suggest a linear relationship, while others suggest a nonlinear relationship or both (Chen et al., 2010; Smith, 1995). Parabolic relationships of density-speed and density-flow have been established from the linear relationships of density-speed. The available literature provides good insight into the analytical framework and location specific aspects of pedestrian behaviour, however no study on pedestrian flow behaviour at important locations like stairways at urban transit station has been reported so far particularly in Indian metropolitan context.

Therefore, present study has been carried out at macroscopic level to study pedestrian flow behaviour in terms of variation in speed and flow with density on stairways at busy suburban rail transit station; Dadar in Mumbai. Results through insight into the behaviour of pedestrian comprising largely of daily commuters; in the planning and design of efficient and safe pedestrian stairways at urban transit stations. The results can be applied to other Asian cities with similar pedestrian characteristics.

2. Data Collection and Extraction

The pedestrian data were collected through videography method at two different (in physical dimension) stairways inside railway station in mid- June, 2013 at Dadar, a very busy suburban railway station in Mumbai, Maharashtra shown in Fig. 1. Due to restricted permission for survey, one hour duration was selected in morning and evening peak and one hour in off peak, to capture pedestrian traffic. Data is obtained by marking the entry-exit trap section on the step depending on number of steps covered in the camera set up at the bottom of ceiling with inclination so as to cover maximum number of steps. The detailed dimensions of selected stairways are shown in Table 1.

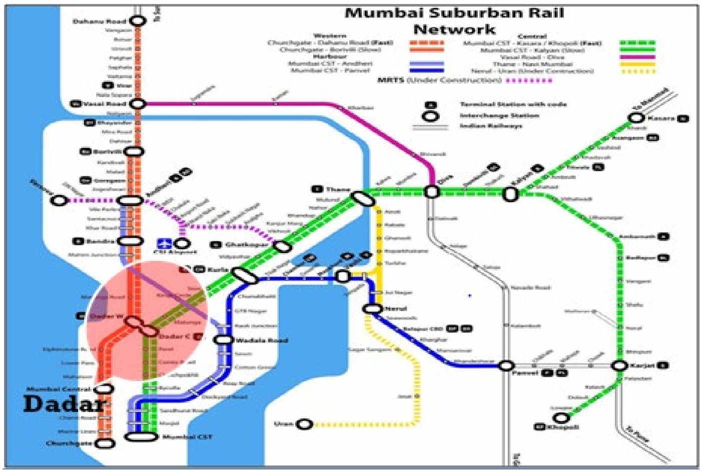

Fig. 1.
Pictorial View of Dadar Suburban Railway Station

Table 1
Dimension of Selected Stair at Dadar Station

Stair No.	Horizontal Strip Length (m)	Inclined Strip Length (m)	Width (m)	Area (m^2)	Riser (m)	Tread (m)	Slope (o)	Total Length (m)	Height (m)
1	3.52	3.8	2.65	8.589	0.13	0.29	22.1	20.6	5.85
2	2.03	2.22	2.15	4.202	0.13	0.3	24.14	20.8	5.98

Data extraction is carried out in a systematic manner in the laboratory by repeated play of video files. Pedestrian volume count, walking speed (v) and density (ρ) are extracted from video for every one minute interval. Pedestrian walking speed were calculated for randomly selected minimum five samples in each category by noting down entry and exit time to cross the trap length. The pedestrians in the flow (Q) are also identified on the basis of age, gender, directional movement and performance of activity like carrying baggage and/or children.

3. Results and Discussion

This section presents pedestrian flow characteristics at different flow conditions with respect to the density. The peculiar effect of density on walking speed and pedestrian flow at both the stairways is discussed below.

The scatter plot and best fit models of density and speed is presented in Fig. 2. Fig. 3 shows scatter plot and best fit models of density and flow.

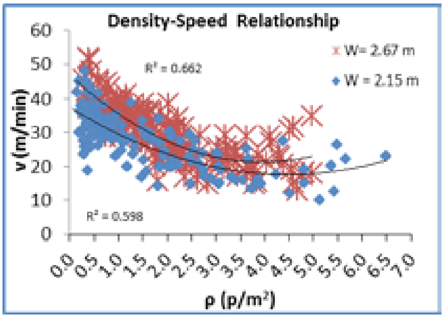

Fig. 2.
Density-Speed Relationship for Stairways with Different Width

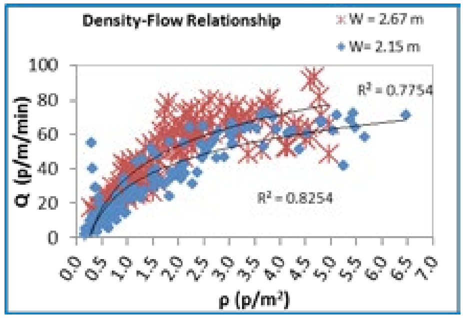

Fig. 3.
Density-Flow Relationship for Stairways with Different Width

Fig. 2 illustrates increase in density resulting into reduction in walking speed due to arrival of trains at gap of 2-3 minutes. The speed-density relationship is explained by polynomial second degree function with reasonably good explanatory power. The trend line describes that till a density of 0.45 p/m^2 is reached, variation of speed is high in both the stairs. It reflects that below density of 0.45 p/m^2, individual walking speed is not affected by the density and pedestrian are able to move at their desired walking speed. However with further increase in density, speed reduces up to density of about 4.0 to 4.5 p/m^2, with significant reduction in the variation in speed of individual pedestrian. Beyond density of 4.0-4.5 p/m^2, the speed becomes almost constant and flow becomes stable. Pattern of density – flow relationship shown in Fig. 3 is complementary to the density-speed pattern. The flow increases with higher rate at lower density levels and at lower rate at higher levels of density till it reaches 4.0 to 4.5 p/m^2 of magnitude. Contrary to reported results in literature, where flow drops beyond density of 2.5-3.5 p/m^2, the present study shows rise in flow till density of 4.0 p/m^2. This might have happened as at lower density, pedestrian can walk freely without any influence. When the density remains 0.45 to 4.0 p/m^2, plot shows that, with increase in density, pedestrian lose their freedom to acquire desired speed and simply follows the crowd speed. This can be attributed to increased friction between pedestrians, pedestrian and handrail, pedestrian and floor, with increase in density. And also, when density increases, pedestrian cannot get space for their movement, so at the same time, height of riser demands for more (Fujiyama and Tyler, 2004) Leg Extensor Power (effort) for climbing stair.

Beyond density of 4.0-4.5 p/m^2, for most of the cases; walking speed of pedestrian decreases but at that point, some observation points are above the line and few are below the line showing interesting behaviour of pedestrian for small interval of time when arrival and departure of trains coincide at both the platforms served by the stairways. In case of Dadar station being a transfer station, arriving passengers of one train, try to catch the next train from another platform because most of them are daily commuter travelling with light baggage. At that time pedestrian at extreme (lower/upper step) end of stair, attempt to come from convergent area (platform) to the throat (stair), that is bottleneck portion which gives thrust to the leading pedestrian forcing him to speed up. As a result, whole flow comes under the influence of driving force resulting in relatively higher walking speed.

Table 2

Comparison of Basic Parameters of Pedestrian Flow Obtained in Various Studies

Stairway/ Study		Effective width	Maximum Flow (p/m/min)	Average Free flow Speed at low density (m/min)	Average Speed at Low-High Density (m/min)	Average Speed at High Density (m/min)	Average Flow (p/m/min)	Average Density (p/m^2)	Average Speed (m/min)
St-1	Present Study	2.65	93	38.26	29.41	22.1	48	1.99	29.41
St-2		2.15	73	34.07	27.03	17.86	29	1.57	28.26
Yang et al. (2012)		2.9	140	91.02	--	45.6	89.4	2.21	54.24
Liu et al. (2008)		--	--	48	--	--	--	--	49.2
Hongfei et al. (2009)		--	67	--	--	--	--	--	--
Xianqiang et al. (2011)		--	89	55	--	22.8	--	--	--

Table 2 shows comparison of findings of various past studies on pedestrian flow on stairways with that of the present study. Yang's study has reported flow rate of 140 p/m/min and also highest average walking speed as the study was carried out simulating emergency condition in college campus, having almost same age group of young students. Compared with other studies, average walking speed observed during the present study is lower, due to resistance offered by opposite direction flow resulting into restricted pedestrian movements. However, average walking speed, specific flow and average density obtained are higher in wider stairway St-1 compared to narrower stairway 2. In comparison with the results of Yang's study on stair width of 2.9 m; specific flow, average speed and density is higher than the present study showing influence of width of facility as one of the determinant for basic flow parameter.

4. Conclusions

In this paper, observations on pedestrian movement characteristics studied at busy suburban railway station for two different stairways are reported. The behaviour of pedestrian flow on stairway is demonstrated through fundamental relationships of density-speed and density-flow. It is found that, at lower density of 0.45 p/m^2, pedestrian are able to move at free walking speed. Between density of pedestrian from 0.45 to 4.0 p/m^2, speed decreases with increase in density in non-linear fashion. Beyond density of 4.0-4.5 p/m^2, speed becomes almost constant and flow becomes stable. The observations of the present study are significantly different from other similar studies in other countries having different stair width, where flow is reported to drop beyond density of 2.5-3.5 p/m^2. The present study shows stability of flow till density of 4.0 p/m^2. This can be attributed to the peculiarity of pedestrian characteristics at busy transit station in Indian Context. The analysis for two stairways show that increase in width of stairway results into increase in the macroscopic characteristics describing the flow. The results of the study may be highly useful for the design of pedestrian facilities for high density pedestrian flow areas to achieve desired level of service.

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