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# Investigation on Behavioral Attributes of Pedestrians at Railway Stairways

**JAGANNATH PATTANAIK[a], UJJAL CHATTARAJ[b], AAROHI KUMAR MUNSHI[c,d], ASHISH KUMAR PATNAIK[e*]**

**a.** *Former M.Tech Student, Department of Civil Engineering, NIT Rourkela, India, Email: jagannathpattanaik1989@gmail.com*
**b.** *Associate Professor, Department of Civil Engineering, NIT Rourkela, India, Email: chattaraju@nitrkl.ac.in*
**c.** *Research Scholar, Birla  Institute of Technology Mesra, Ranchi, India, Email: phdcee10051.20@bitmesra.ac.in*
**d.** *Assistant Professor, Department of Civil Engineering, Usha Martin University, Ranchi, India, Email: aarohikumar.munshi@umu.ac.in*
**e.** *Assistant Professor, Department of Civil & Environmental Engineering, Birla  Institute of Technology Mesra, Ranchi, India, ORCID:0000-0002-8674-9148*

**ABSTRACT:** The objective of the present study is to statistically assess pedestrian activity in various railway transit stairway facilities within a railway station as a contrasting stage. In the four study areas of Bhubaneswar, Bhadrak, Lucknow, and Kazipet, pedestrian attributes are categorised based on age, gender, and physical activities (with or without luggage). This study compa res the flow activities of pedestrians in vertical movements, such as bi-directional routes, between males and females. The analysis evaluated maximum space values of 0.91 and 0.84 m²/ped. in Bhadrak and Bhubaneswar, respectively. The increase in the dimension of the pedestrian facility resulted in an increase in available space for pedestrian movement, but optimum density was confirmed with a reduced maximum flow rate. Bi-directional flow on a stairway facility controls the free flow speed and space available to high-density pedestrian activities, implying that the pedestrian flow in the current analysis is slightly lower than that of earlier studies. The presence of people in multiple lanes forming a queue creates a bottleneck, reduces free flow speed, and maximum flow. The maximum flow rate is confirmed to be 37.82 and 38.22 ped./min/m in both ascending and descending stairways of the selected sites. The regression model analysis for maximum flow offers a reliable estimation by considering a congested pedestrian environment, unlike the standard parameters used in crowd dynamics modelling.

**KEYWORDS:** Railway transit stairways, Pedestrian attributes, Bi-directional flow,  bottleneck, Level of service (LOS)

## 1. INTRODUCTION

Walking is a primitive mode of conveyance. Pedestrian facilities, stairways, corridors, and passages are vital components of any city's transportation system, as most people walk to their destinations. This needs the provision of exclusive walking facilities. In India, numerous studies have been conducted on traffic flow; however, there are few studies on pedestrian facilities. Several research studies have been undertaken on road infrastructure pedestrian flow features, such as shoulders, carriageways, and side buffers. Nevertheless, pedestrian attributes at railway facilities have received less attention. Indian railways are the world's fourth-largest network, covering 67,368 kilometres (Ministry of Railways, 2018). The railway transportation system is utilised by 23 million passengers daily and 8.4 billion passengers annually, respectively (Ministry of Railways, 2018). Due to India's constantly growing population, an immense number of people enter and exit train stations, and as a result, existing facilities fail to meet the needs of pedestrians. A study has been conducted to understand and assess pedestrian behaviour at railway staircases to facilitate pedestrians' seamless movement.

Required data have been collected from two major railway stations (Bhubaneswar and Lucknow) and two mid-sized railway stations (Kazipet and Bhadrak). Therefore, pedestrian movements are captured using high-definition (HD) video cameras at railway staircases. Traffic parameters such as speed, flow, and density are extracted from the office com puter for further analysis. To carry out this analysis, pedestrian attributes such as age, gender, and luggage are considered. The relationships between flow-speed, speed-density, and flow-density are established to understand the traffic parameters in detail. Additionally, pedestrian flow relations are evaluated by considering the pedestrian's gender. Thus, the relationships between male and female pedestrians are obtained in the' upward and downward streams of railway staircases. In addition, a flow-space relationship of pedestrians at the four railway stairways—Bhubaneswar, Lucknow, Kazipet, and Bhadrak—is established. Then, equation-based models are developed to observe the relationships between flow-speed, speed-density, and flow-density. The standard error of the developed models and t-statistic tests are conducted to ascertain the predictive capability of the models. To evaluate the developed model's predictive ability, the pedestrian flow model equations were compared with the existing studies. Different studies have been conducted in various settings, such as walkways, sidewalks, and directional movements in the central business district (CBD) under heterogeneous traffic flow conditions, where pedestrian movement is observed in unidirectional or bidirectional directions. However, very few studies focus on pedestrian flow characteristics at railway stations. Therefore, in-depth research has been conducted on these characteristics at railway staircases.

The stairway is regarded as the most critical part of the railway station due to the uninterrupted flow of pedestrians. Several researchers and academicians (Fujiyama & Tyler, 2004; Lam et al., 1995; Lee et al., 2005; Talamini et al., 2022; Tanaboriboon et al., 1986) have estimated the average walking speed of pedestrians by considering factors such as

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*¹ Corresponding author: ashishpatnaik@bitmesra.ac.in*

age, gender, and flow direction, alongside the dimensions of stairways. Zhang et al. (2008) informed that the average walking speed of pedestrians on holidays is generally lower than on regular working days. Yang et al., (2012) noticed that walking speed and pedestrian density significantly increase during emergencies, with speeds and densities varying between 24-42 m/min and 1-11 ped./m², respectively. Lee et al. (2005) testified that the speed of pedestrians is affected by movement direction and found that speeds increase in the downstream direction compared to the upstream direction. The authors examined the static and dynamic characteristics of pedestrians, noting that the design of the station layout needs to account for the dynamic behaviour of pedestrians. Yang et al. (2010) and Ye et al. (2008) characterize the Level of Service (LOS) criteria by accounting for the speed-flow-space fundamental relationships. In this study, space is considered an evaluation index. It is observed that the lowest service level occurs when the flow reaches its maximum with the least available space. Furthermore, it is observed that when the space available for upstream and downstream pedestrians exceeds 1.73 m² and 1.95 m², respectively, pedestrians can walk freely and achieve higher service level criteria. Sahani & Bhuyan, (2019)many intersections are un-signalized as they do not satisfy the warrant for the signal installation. Due to the heterogeneity in traffic, one cannot cross or merge into the traffic easily. In India situation is more complicated as pedestrian and driver do not follow traffic rules strictly. Considering the Indian scenario, pedestrian crossing behavior using gap acceptance parameters is not that prevailed. In this regards the present study attempted to explore various parameters affecting perceived satisfaction level of crossing pedestrians at un-signalized intersections. Observation shows that satisfaction level of pedestrians significantly depends on volume of motorized and non-motorized vehicles, volume of pedestrians and crossing delay at the intersections. Crossing behaviour of pedestrians was analysed to estimate the critical gaps (the actual gap pedestrian need to cross developed a pedestrian LOS model in which the ridge regression technique produced more reliable results than other existing models.

Recent studies on pedestrian movement in rail and metro stations reveal several significant findings. Jiten et al. (2016) observed that the walking speed increases with width on stairs until it reaches approximately 2.68 meters, after which width has minimal impact. Sukor et al. (2018) reported that the walking speed of pedestrians is also faster in descending directions and during peak hours, although it decreases with increasing density. Further, Li et al. (2019) ran simulation models applying random forest algorithms, demonstrating a high accuracy in predicting pedestrian choices and indicating that reminder signs positioned more than 4 meters from vertical facilities enhance flow efficiency. Dubroca-Voisin et al. (2019) suggested commercial pedestrian simulators are typically suitable for real-time management in the same price range; however, additional research is required for operational applications. These conclusions are supported by empirical data from controlled experiments and video-based research, which promote improved pedestrian facility management and design in transit contexts. Goyal et al. (2020) found that the pedestrian speed is affected by gender, the presence of luggage, and direction; specifically, women and individuals with luggage exhibit slower speeds, while descending is quicker than ascending; the walking pace is even reduced as there is an increase in movement in the opposite direction, and pedestrians are inclined to remain to the left. Song et al. (2025) conducted crowd experiments on an elevated platform, used the polarization method for measuring area, and obtained pedestrian density using a Voronoi-based method. The findings demonstrated that pedestrians prefer more space near the edges of the platform, which results in increased speeds and greater headway.

In the present study, the pedestrian attributes such as gender, luggage, and direction of movement are observed to determine the effect of pedestrian characteristics on stairways. By considering genders, including male and female, the walking speeds (m/s) of both male and female pedestrians are measured in ascending and descending directions on four different stairways: Bhubaneswar, Lucknow, Kazipet, and Bhadrak. Additionally, the mean speed of pedestrians, standard deviation, and z-statistic tests are conducted. By analysing pedestrians with and without luggage, speed variations for males and females are evaluated in ascending and descending directions. Moreover, in this analysis, mean speed, standard deviation, z-statistics, and significance tests are performed. Considering the direction of pedestrian movement, the walking speed variation of male and female pedestrians is determined in ascending and descending directions. In addition to the mean speed, standard deviation, and z-statistic tests are carried out. It focuses on the macroscopic flow characteristics of pedestrians, including speed, flow, and density, at four railway stairways in India: Bhubaneswar, Lucknow, Kazipet, and Bhadrak. Furthermore, the study examines the impact of various attributes on pedestrian movements.

## 2. STUDY OBJECTIVES AND ORGANISATION OF THE STUDY

Based on the thorough literature survey regarding pedestrian movements, the following objective is framed for the present study:

– To analyse the pedestrian flow at the stairways of the Indian railway by considering the appropriate methodology and bringing necessary modifications.
– To establish a fundamental relationship of basic flow parameters of pedestrians, such as speed-flow, speed-density, and flow-density, through regression analysis.

With an outline of objectives and scope, the article has five sections. The 'Methodology' is elaborated upon in section 3, which pertains to identifying pedestrian attributes at railway stairways. It also encompasses the selection of study areas and the data acquisition and extraction methods. Section 4 comprises the comprehensive study's "Results and Discussions." The conclusion, limitations of the study, and prospective research avenues are all highlighted in Section 5.

## 3. METHODOLOGY

The methodology section comprises three parts. The details regarding study corridors, data collection, and extraction procedures are explained in sub-sections 3.1, 3.2, and 3.3, respectively. Regression analysis establishes the relationship between speed-density, flow-density, speed-flow, and flow-space.

### 3.1. Study Corridors

The study corridors include four railway stations, with Bhubaneswar and Lucknow categorised as busy stations; the other two, Kazipet and Bhadrak, are classified as moderate stations, as illustrated in Figure 1. The Bhubaneswar railway station is one of the busiest and most significant railway stations in the eastern region of India. It serves as the headquarters for the East Coast Railway zone, accommodating over 1.5 lakhs passengers daily. Bhadrak station is part of the East Coast Railway zone and is smaller than Bhubaneswar city. Meanwhile, the Lucknow railway station is the busiest and most prominent rail route under the North Eastern Railway,

serving over 1.8 lakh passengers daily. Kazipet railway station is a well-known station in Warangal, Telangana, and is part of the South-Central Railway zone. The four study corridors, Lucknow, Bhubaneswar, Bhadrak, and Kazipet, are located across the country, covering India's Northern, East Coast, and South-Central railway zones.
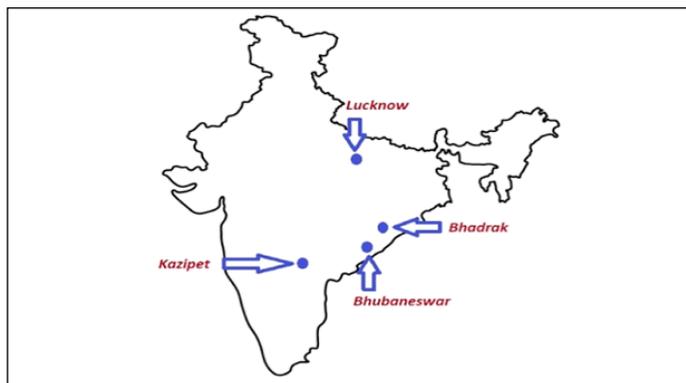


**Figure 1. Map View of Study Corridors**

### 3.2. Data Collection

Video graphic footage data was collected using a high-definition camera to analyse pedestrian activities on the railway stairways of four study areas: Bhubaneswar, Bhadrak, Lucknow, and Kazipet. Data collection occurred on regular weekdays in March and April 2022. The stairways of these study areas connect the consecutive platforms. Additionally, the exit of the stations is linked by foot over bridges to ensure pedestrian accessibility. Data were obtained by creating a trap length, with strip markings made using white paint across the width of the stairways, as shown in Figure 2 (a). The survey aimed to capture pedestrian flow traffic 10 minutes before and after the arrival of a train during peak rush hours (9:00 am-10:00 am). The goal was to analyse pedestrian walking speed behaviour during the arrival and departure of trains. To capture video footage of the entire stairway, the camera was positioned at the midpoint of the stairway, which was deemed suitable for data coding. The camera was set at a 45-degree angle to the horizontal to cover the maximum possible extent and facilitate easy data coding. The physical dimensions of the existing pedestrian facilities in the four study areas are presented in Table 1.

### 3.3. Data Extraction

Pedestrian movement was observed for 240 minutes in the four selected study areas. Data were obtained by marking the entry-exit strap at stairways, as depicted in Fig. 2(a). The data were processed using an office computer with a large screen monitor to facilitate a precise observation. A total of 4505 bi-directional data points were extracted on a consecutive one-minute basis from the video graphics footage of 240 minutes duration. Of these, 1489 and 1537 bi-directional data were observed at the busiest railway stations, such as Bhubaneswar and Lucknow. In addition, Bhadrak and Kazipet are marked as moderately busy railway stations where bi-directional data are observed to be 682 and 797, respectively. The video graphics footage was manually analysed to determine the pedestrian attributes, including density, flow rate, and walking pace. Gender, cargo condition, and direction of movement are the determinants of pedestrian flow. The pedestrian volume was analysed when it entered the specified dimension trap length, as illustrated in Figure 2(a); gender-based activities, such as male and female activities, characterised it. The recorded videos were displayed in the office system to estimate accurate pedestrian flow. The pedestrian flow is measured as the number of pedestrians passing through the first trap length for one minute. Hence, the flow value of pedestrians is measured as ped./m/min. The pedestrian walking speeds are evaluated at four selected study areas. The time of entry and exit across the trap dimensions in ascending and descending directions is observed in a 15-second time interval, and specimens from each category (Gender, movement direction, and luggage condition) are selected arbitrarily by category. Video graphics footage was utilised to identify pedestrians' attributes, including gender and activity level. Through the acquisition of video footage, the density was determined by the number of pedestrians per square metre (ped/m$^2$). The whole video was paused to calculate the density. To measure the density of pedestrians, video files of respected sites are converted into 30 frames per minute, in which several pedestrians are available in the trap area of each frame, and further, the average number of pedestrian occupancies in each frame gives the density as per Shah et al. (2013). Figure 2(b) shows the pedestrian occupancy (11 in count) in one frame. Furthermore, the occupancy of pedestrians in the remaining frames is also noted similarly. The space available is determined by the inverse of the density provided by each pedestrian. The pedestrian speed was recorded in m/s for the time elapsed at

| Stairways | Trap length (m) | Width (m) | Area (m²) | Riser (m) | Tread (m) | Slope (⁰) | Total length (m) | Height (m) |
|---|---|---|---|---|---|---|---|---|
| Bhubaneswar | 3.68 | 3.95 | 12.25 | 0.18 | 0.38 | 26.80 | 18.55 | 5.9 |
| Bhadrak | 2.88 | 2.76 | 8.250 | 0.14 | 0.29 | 23.50 | 14 | 5.4 |
| Lucknow | 3.6 | 3.5 | 12.60 | 0.16 | 0.34 | 26.90 | 19.78 | 6.1 |
| Kazipet | 2.72 | 3.2 | 8.70 | 0.15 | 0.31 | 24.43 | 18.09 | 5.5 |

**Table 1. Dimensions of the Selected Four Study Area Stairways**



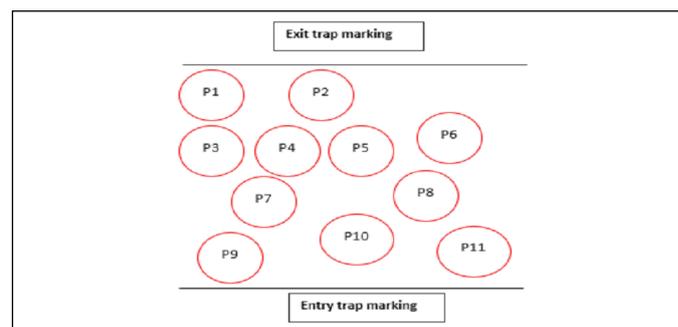**Figure 2(a). Entry-exit strap marking of stairway**



**Figure 2(b). Pedestrian occupancy in one frame**

two selected crossing locations, and two points of reference were finalised. Mean speed is calculated by considering the average speed of the pedestrian. The overall flowchart of the data extraction process is depicted in Figure 3. The attributes, like gender and the luggage of pedestrians at the four study areas, are presented in Table 2. The subsequent section elaborates on the results and their discussions based on the methodology adopted in the present study.
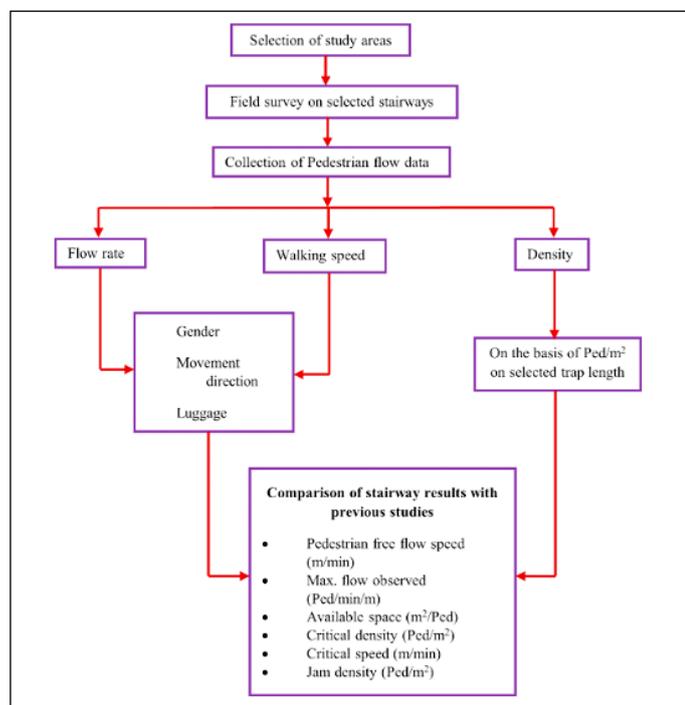


**Figure 3. Flow chart of the data extraction process**

| Attribute | Classification |
|---|---|
| Gender | Male and Female |
| Luggage | • With Luggage/Without Luggage<br>• Holding a child/cell phone |

**Table 2. Pedestrian Attributes Classification in Four Study Areas**

## 4. RESULTS AND DISCUSSION

The pedestrian flow characteristics under congested and non-congested conditions were assessed using microscopic flow parameters, such as speed, flow, and density, which play a vital role. This study examines both crowded and non-congested scenarios to assess current infrastructural facilities and estimate the capacity of the stairway system. The conditions are well explained by the fundamental diagrams, which are widely accepted to depict the basic relationship between these parameters, as suggested by Vanumu et al. (2017). This study explains the fundamental diagrams through pedestrian flow models. Furthermore, to determine the predictive ability of flow parameters, the basic relationships between parameters such as speed-density, speed-flow, and flow-density are obtained through regression models (equation-based models) at four study areas: Bhubaneswar, Bhadrak, Lucknow, and Kazipet. Regression models reflect the findings of fundamental diagrams, constituting the flow parameters. These models are developed to assess the current pedestrian flow strategies without relying on observations of fundamental diagrams. According to the videographic observations, pedestrian identifiers are classified based on gender, such as male and female, and are further characterised by luggage and directional movement. In some cases,

pedestrians are seen with small bags without luggage, while others are observed with luggage and small children. The walking behaviour of pedestrians on stairways at different selected railway stations is discussed in the initial subsections of the results section. Pedestrian flow activities are analysed macroscopically by considering male and female pedestrians. This fundamental approach establishes specific correlations in the present study areas, including Bhubaneswar, Bhadrak, Lucknow, and Kazipet. The analysis of the Bhubaneswar stairs is discussed in the following subsection, and the earlier studies are compared.

### 4.1. Pedestrian Walking Behaviour Particularity at Stairways

The statistical analysis of walking speed variation of males and females in both ascending and descending directions is represented in Table 3, respectively. For the selected stations in the study, it is observed that the walking speed of males eloquently differs from that of females in ascending and descending directions. The prominent stations like Bhubaneswar have the average walking speed of males and females of about 0.743 m/s and 0.584 m/s, respectively, which implies that the walking speed of males is 28% and 26% faster than that of females in both ascending and descending directions. For Lucknow, these values somehow reduce to 0.695 m/s and 0.562 m/s and identify that males are about 28% and 20 % faster than females in both directions of stairways. Similarly, for the Bhadrak and Kazipet stations, the walking speed for males is 0.756 m/s and 0.692 m/s; for females, these values are 0.595 m/s and 0.563 m/s, respectively. The provided Table 3 infers that the Bhubaneswar and Bhadrak stations are confined with good, satisfactory walking speeds, and both stations have good space for comfortable walking in both jam and normal conditions. In contrast, pedestrians in Lucknow and Kazipet stairways walk slightly slower than those in Bhubaneswar and Bhadrak. The standard deviation and Z-statistic values are confined to satisfactory results for all four study areas. The walking speed of pedestrians is assumed to be a prime variable in the design of exclusive walking facilities, as it determines the capacity of facilities. Hence, the walking speeds of pedestrians of all stairways are clubbed together to observe the variation in pedestrian walking behaviour. It is inferred from the analysis that the pedestrian walking speed in the ascending direction is less than in the descending direction in both male and female cases. In addition, it is also reported that when all the stations are clubbed together, the walking speeds of pedestrians in both ascending and descending directions of stairways are slightly lower than the walking speeds of pedestrians in individual stairways. This difference is due to differences in the walking behaviour of individuals from different regions and the pedestrian infrastructural characteristics.

The difference in speed variation of male and female pedestrians is distinguished in two ways: first, when an individual carries luggage or a small child, and in the other case, with no luggage or with a small handbag, in both ascending and descending directions of stairways is provided in Table 4. It is inferred that any individual without any luggage or a small bag walks faster than when carrying heavy luggage, holding a child, or even using a cell phone. It has been analysed that males carrying luggage or without luggage walk at a faster pace than females. At the Bhubaneswar stairway, it is observed that the variation of walking speed of males is 20% in the ascending direction and 24% in the descending direction. In contrast, in females, it is about 19% in the ascending and 14% in the descending direction. At Bhadrak, the speed variation considering males is about 22% and 24% in both ascending and descending directions, respectively; while in

the Lucknow stairway, the speed variation among males is 29% and 22% in both ascending and descending directions. By observing the female pedestrians, the values are around 16% and 10% in both ascending and descending directions, respectively, at both stations. In Kazipet Stairway, the variation in walking speed is around 19% in ascending males and 15% in descending males. Further, among female pedestrians, it was about 16% and 11% in both ascending and descending directions of stairways, respectively. Moreover, the Z-statistics and the standard deviations indicate satisfactory values for the selected railway stations.

## 4.2 Analysis of Bhubaneswar Stairway

Concerning fundamental relations, the pedestrian activities of males and females are analysed individually using regression analysis and presented in Table 5 below. Here, Table 5 presents the relationship between the speed-flow-density of males and females separately in ascending and descending directions. Similarly, speed-flow-density relationships were observed for the Bhadrak, Lucknow, and Kazipet stairways separately. It is concluded that speed and density are fitted negatively exponentially with each other at four railway

stations, such as Bhubaneswar, Bhadrak, Lucknow, and Kazipet, respectively. Similarly, the relationship between speed is established, in which speed is fitted negatively logarithmically with flow, gender-wise, in both ascending and descending directions. Like flow exponentially varies with density in both directions of the selected four railway stairways, the relationship between flow and space is a negative exponential. As per the space concern, the available space for pedestrians at Bhubaneswar and Bhadrak stations is 0.84 and 0.91 m²/ped. In addition, at Lucknow and Kazipet railway stations, the available spaces are found to be 0.62 and 0.58, respectively. These indicate that the space available at Bhubaneswar and Bhadrak stations is comfortable for walking, while moderate space is available for walking at Lucknow and Kazipet railway stations (stairways). In Bhubaneswar, the average pace of males and females while walking is 0.743 m/s and 0.584 m/s, respectively. The average free flow speed is 49.15 m/min, considering the upstream and downstream of four selected study areas. Generally, the relationship is defined by several statistical methods like the model equations, coefficient of determination, standard error, and t-statistic values. The

| Stations | Ascending | | | | | | | Descending | | | | | | |
|----------|-----------|----|----|----|----|----|----|-----------|----|----|----|----|----|----|
| | Male | | | Female | | | Z | Male | | | Female | | | Z |
| | Ns | $\mu$ | $\sigma$ | Ns | $\mu$ | $\sigma$ | | Ns | $\mu$ | $\sigma$ | Ns | $\mu$ | $\sigma$ | |
| Bhubaneswar | 171 | 0.713 | 0.181 | 151 | 0.556 | 0.143 | 6.384 | 164 | 0.774 | 0.213 | 157 | 0.613 | 0.128 | 8.354 |
| Bhadrak | 91 | 0.732 | 0.126 | 69 | 0.563 | 0.112 | 4.521 | 86 | 0.781 | 0.124 | 75 | 0.627 | 0.126 | 4.513 |
| Lucknow | 121 | 0.683 | 0.274 | 107 | 0.532 | 0.139 | 7.752 | 129 | 0.707 | 0.291 | 110 | 0.592 | 0.153 | 7.892 |
| Kazipet | 83 | 0.673 | 0.191 | 75 | 0.554 | 0.103 | 4.783 | 70 | 0.712 | 0.231 | 75 | 0.573 | 0.116 | 5.763 |
| Clubbed Stations | 466 | 0.700 | 0.367 | 402 | 0.551 | 0.189 | 9.787 | 449 | 0.743 | 0.389 | 417 | 0.601 | 0.213 | 11.787 |

*Note*: Ns = Number of samples for observation; $\mu$ = Mean speed; $\sigma$ = Standard deviation; Z = Z-statistic

**Table 3. Walking Speed of Males and Females in a Stairway**

| Stations | Significance parameter | Ascending | | | | Descending | | | |
|----------|-----------------------|-----------|------|--------|------|-----------|------|--------|------|
| | | Male | | Female | | Male | | Female | |
| | | WL | WOL | WL | WOL | WL | WOL | WL | WOL |
| Bhubaneswar | Ns | 120 | 146 | 106 | 89 | 135 | 90 | 65 | 90 |
| | $\mu$ | 0.671 | 0.811 | 0.547 | 0.659 | 0.712 | 0.886 | 0.592 | 0.674 |
| | $\sigma$ | 0.247 | 0.218 | 0.143 | 0.129 | 0.339 | 0.289 | 0.127 | 0.103 |
| | Z | 7.543 | | 3.289 | | 6.581 | | 2.943 | |
| | Sig | S | S | S | S | S | S | S | S |
| Bhadrak | Ns | 51 | 67 | 28 | 48 | 61 | 49 | 23 | 34 |
| | $\mu$ | 0.652 | 0.798 | 0.561 | 0.648 | 0.702 | 0.868 | 0.595 | 0.652 |
| | $\sigma$ | 0.312 | 0.298 | 0.187 | 0.165 | 0.337 | 0.308 | 0.133 | 0.154 |
| | Z | 4.587 | | 3.876 | | 5.621 | | 3.432 | |
| | Sig | S | S | S | S | S | S | S | S |
| Lucknow | Ns | 110 | 135 | 86 | 104 | 112 | 147 | 78 | 98 |
| | $\mu$ | 0.683 | 0.884 | 0.575 | 0.665 | 0.732 | 0.892 | 0.603 | 0.666 |
| | $\sigma$ | 0.287 | 0.210 | 0.178 | 0.194 | 0.453 | 0.376 | 0.209 | 0.176 |
| | Z | 9.878 | | 5.654 | | 9.998 | | 6.201 | |
| | Sig | S | S | S | S | S | S | S | S |
| Kazipet | Ns | 63 | 79 | 39 | 55 | 82 | 96 | 31 | 49 |
| | $\mu$ | 0.648 | 0.776 | 0.578 | 0.671 | 0.728 | 0.832 | 0.587 | 0.645 |
| | $\sigma$ | 0.242 | 0.278 | 0.118 | 0.125 | 0.225 | 0.255 | 0.165 | 0.141 |
| | Z | 3.878 | | 3.510 | | 4.334 | | 4.767 | |
| | Sig | S | S | S | S | S | S | S | S |

*Note*: WL = With luggage, WOL= Without luggage, Sig = Significance level, S = Significant

**Table 4. Pedestrians Walking Speed with and Without Luggage**

highest R² value is 0.90 for the speed-density relationship of ascending females. In addition, the R² value is the lowest, 0.65, in the speed-flow relationship of descending females at the Bhubaneswar stairway. The standard error is close to zero, and the t-statistic value is greater than 1.960 at the four selected railway stations, indicating that the model statistically fits at a 95% confidence level.

## 4.3. Comparison of Stairway Results with Previous Case Studies

The present study compares pedestrian characteristics conducted at railway stairways in previous studies. Table 6 presents the comparison of present study findings with existing studies considering the pedestrian characteristics by taking account of pedestrian free flow speed (m/min), max flow observed (ped/min/m), available space (m²/ped), critical density (ped/m²), critical speed (m/min) and jam density (ped/m²) respectively. The study conducted by Shah et al. (2013) observed the highest pedestrian free flow speed of 85.71 m/min in the ascending direction of stairways; while in the present study conducted in Bhubaneswar stairways, it is observed that pedestrian free-flow speed in the descending direction is found to be 66.24 m/min; and is the highest value as compared to the rest of the present study areas (Bhadrak, Lucknow, and Kazipet).

The research presented by Weidmann, (1993) reported that the free flow speed was found to be 22.32 m/min and 24.33 m/min in ascending and descending stairways, respectively. In this study (Bhubaneswar), the maximum free flow speed is found to be 61.52 m/min and 66.24 m/min in both ascending and descending directions, respectively. It is examined in stations like Bhadrak and Kazipet, where the free flow speed values are found to be lower, which are 22.42 m/min and 39.07 m/min in ascending and descending directions of stairways, respectively. In focus on the present case study, it is ascertained that the flow values are relatively low as compared to previous studies. Xianqiang et al. (2011) observed the maximum flow rate having 89 ped/m/min, while the lowest flow rate of 22.42 ped/m/min is observed at the Bhadrak stairway. Bhubaneswar stairway reported a higher flow rate of 37.82 ped/m/min as compared to the rest of the present case studies. The least value of space is observed in Fruins'(1971) study, which is 0.26 m²/ped. In the present study (Bhadrak), it is evaluated that the highest pedestrian flow space is 0.91 m²/ped and inferred that

enough space is available for comfortable walking. Bhubaneswar stairway has a satisfactory available space of 0.84 m²/ped, which is good for walking purposes for the passengers. Lucknow and Kazipet are observed as having a little lower value of available space, having 0.62 and 0.58 m²/ped, as compared to Bhubaneswar and Bhadrak stairways. As available space is a bit lower in Lucknow and Kazipet stairways, it was examined that there is a little predicament for comfortable walking. In addition, the Bhadrak stairway has the lowest value of critical density among all the selected stairways.

The modification in LOS categorisation has been considered to accurately measure the LOS of pedestrian infrastructure in public spaces by Shan et al. (2016). The modified LOS values were comparable to the pedestrian conditions of India, as the values derived are representative of an equivalent populous nation. The current study has selected the stairways of stations in different zones of Indian Railways, and their critical density values (> 1.07 ped/m²) fall in the LOS 'F'. As per space concerns, Indian railway stairways need pedestrian traffic management during the rush hours of pedestrian flow. During the period of arrival and departure of trains at stations, blockage and sometimes stampede-type situations are created at the entry and exit points of stairways. These situations could be avoided by deploying police personnel so as to maintain clear routes for pedestrian movements. In another way, barrier setup and installation of signals near the entry and exit points of stairways would give better performance in terms of crowd management for emergencies.

## 4.4. Crowd Dynamics of Selected Stairway Sites

Crowd Dynamics can be stated as a macroscopic model and is assessed by capacity flow ($Q_{max}$) and the number of lanes ($N_{lanes}$) in a stairway as provided by equations 1(a) and (b) as per Fruin, (1971) and Weidmann, (1993). It aligns with the behaviour and interactions among groups of people in shared spaces. It affirms the planning and design of infrastructure for pedestrian movements such as stairways, corridors, and transport terminals.

1(a) $\quad Q_{max} = \rho_c \cdot v_c$

Where, $Q_{max}$ is Capacity Flow per minute per metre width, $\rho_c$ and $v_c$ are the average critical density and critical speed of pedestrians at any respective stairway.

| Pedestrian flow characteristics | Relation | Model equation | R² | N | Standard Error | t-statistic |
|---|---|---|---|---|---|---|
| Speed-density | USF (Male) | $y = 0.642 \, x \, e^{-3.281 \, x}$ | 0.65 | 142 | 0.064 | -15.03 |
| | USF (Female) | $y = 1.1063 \, x \, e^{-12.26 \, x}$ | 0.90 | 97 | 0.283 | -18.94 |
| | DSF (Male) | $y = 1.4564 \, x \, e^{-6.747 \, x}$ | 0.84 | 173 | 0.190 | -21.04 |
| | DSF (Female) | $y = 1.5159 \, x \, e^{-9.244 \, x}$ | 0.83 | 84 | 0.275 | -11.46 |
| Speed-flow | USF (Male) | $y = 1.651 \ln x + 1.238$ | 0.81 | 166 | 0.190 | -29.72 |
| | USF (Female) | $y = -0.493 \ln x + 0.238$ | 0.82 | 78 | 0.046 | -26.55 |
| | DSF (Male) | $y = -0.363 \ln x + 0.563$ | 0.71 | 167 | 0.112 | -16.06 |
| | DSF (Female) | $y = -0.293 \ln x + 0.878$ | 0.65 | 74 | 0.031 | -12.59 |
| Flow-density | USF (Male) | $y = 0.0598 \, x \, e^{-8.136 \, x}$ | 0.87 | 178 | 0.019 | 37.23 |
| | USF (Female) | $y = 0.052 \, x \, e^{9.055 \, x}$ | 0.78 | 97 | 0.012 | 20.25 |
| | DSF (Male) | $y = 0.123 \, x \, e^{-1.781 \, x}$ | 0.78 | 145 | 0.008 | 20.39 |
| | DSF (Female) | $y = 0.1016 \, x \, e^{-3.925 \, x}$ | 0.78 | 87 | 0.007 | 20.81 |
| Flow-Space | Male and Female | $y = 3.286 \, x \, e^{-0.222 \, x}$ | 0.80 | 497 | 0.021 | -13.61 |

*Note*: USF (Male) = Upstream flow of male, USF (Female) = Upstream flow of female, DSF (Male) = Downstream flow of male, DSF (Female) = Downstream flow of female, N = Number of samples, R² = Co-efficient of determination

**Table 5. Summary of the Fundamental Relationship in the Bhubaneswar Stairways**

| Study | Pedestrian free flow speed (m/min) | | Max flow observed (ped/min/m) | | Available space (m²/ped) | Critical density (ped/m²) | | Critical speed (m/min) | | Jam density (ped/m²) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Upstream flow | Downstream flow | Upstream flow | Downstream flow | | Upstream flow | Downstream flow | Upstream flow | Downstream flow | Upstream flow | Downstream flow |
| Fruin, (1971) | 33.6 | 39.00 | 61.80 | 66.60 | 0.26 | 3.68 | 3.35 | 16.8 | 19.8 | 7.37 | 6.7 |
| Daly et al. (1991) | | | 62.00 | 68.00 | | | | 21.6 | 33.6 | | |
| Weidmann, (1993) | 36.6 | 41.4 | 51 | 58.8 | | 2.23 | 2.23 | 22.8 | 26.4 | 5.4 | 5.4 |
| Cheung & Lam, (1997) | 51.62 | 58.25 | 70 | 80 | | | | 25.59 | 36.07 | | |
| Lam et al. (1995) | 46.08 | 52.36 | 70 | 73 | | | | 24.99 | 34.15 | | |
| Lee et al. (2005) | 55.20 | 45 | 74.4 | 60.6 | 0.59 | 1.7 | | 34.80 | 21 | | |
| | | | | | 0.59 | 2.7 | | | | | |
| Jia et al. (2009) | | | 67 | | 0.41 | 2.44 | | | | | |
| Yang et al. (2010) | | | 67 | | 0.41 | 2.44 | | | | | |
| Xianqiang et al. (2011) | 58.90 | 42.29 | 89 | | 0.28 | 3.57 | | | | 2.22 | |
| | | | 50 | | 0.45 | 2.22 | | | | | |
| Shah et al. (2013) | 45.16 | 48.80 | 45 | | 0.35 | 2.86 | | | | 3.22 | |
| | 22.32 | 24.33 | 49 | | 0.43 | 2.33 | | | | 1.55 | |
| | 85.71 | 55.70 | 33 | | 0.71 | 1.41 | | | | | |
| Patra et al. (2017) | 49.56 | 51.36 | | 32 | 0.83 | | 1.2 | | 24.6 | | 3.1 |
| Present study (Bhubaneswar) | 61.52 | 66.24 | 37.82 | 38.22 | 0.84 | | 1.18 | 34.58 | 37.56 | | 2.85 |
| Present study (Bhadrak) | 39.07 | 39.97 | 22.42 | 20.98 | 0.91 | | 1.09 | 43.2 | 45.60 | | 1.85 |
| Present study (Lucknow) | 51.43 | 55.67 | 32.07 | 34.12 | 0.62 | | 1.76 | 24.73 | 26.54 | | 3.27 |
| Present study (Kazipet) | 41.30 | 38.00 | 37.17 | 32.89 | 0.58 | | 1.708 | 37.8 | 41.7 | | 1.48 |

**Table 6. Comparison of Stairway Results with Previous Studies**

1(b)   $N_{lanes} = \frac{W}{w}$

Where, $N_{lanes}$ is the total effective number of lanes at a particular stairway. $W$ and $w$, were the lane width of a stairway and the average lateral space between pedestrians are usually considered as 0.6 m.

The prominent modelling behaviour to analyse and simulate the pedestrian behaviour is the Social Force Model (SFM). It is represented as in equations 2(a) and (b) and is a widely accepted microscopic model utilised for assessing pedestrian movements. It considers the pedestrian as particles and is influenced by forces such as the driving force (towards destination), the repulsive force (between individuals and with obstacles), as stated by Chraibi et al. (2011) and Helbing et al. (2000).

2(a)   $F_i = m_i \frac{dv_i}{dt} = F_i^{desire} + F_{ij}^{social} + F_{ij}^{obstacle}$

Where, $F_i$: total force acting on pedestrian $i$

$m_i$: mass of the individual pedestrian $i$

$\frac{dv_i}{dt}$: rate of change of velocity with respect to time

$F_i^{desire}$: desired force causes the pedestrian to move towards the destination

$F_{ij}^{social}$: repulsive force from pedestrians $j$ on $i$

$F_{ij}^{obstacle}$: repulsive force from obstacles

2(b)   $F_{ij}^{social} = A \cdot e^{\frac{(r_{ij} - d_{ij})}{B}}$

Here, $A$: social strength interaction constant (taken as 2000 N)
$r_{ij}$: combined radius of two pedestrians (usually 0.6 m)
$d_{ij}$: distance between the centres of two individuals (opted as 0.7 m for controllable but uncomfortable crowd conditions)
$B$: interaction range (generally 0.08 m)

Table 7 presents the crowd dynamics of the selected stairways used in the present study. The repulsive force of about 573 N implies moderate to high-density crowd conditions in confined facilities like stairways. These forces vary exponentially, and their values increase as the interpersonal distance decreases, creating unfavourable crowding conditions. Kazipet stairway has the highest capacity flow, implying optimal utilisation and denser but effective movement. In contrast, Bhubaneswar, despite having a wider stairway, indicates that width alone doesn't ensure maximum total capacity of a stairway and highlights the potential issues of congestion points and non-uniform movements.

| Specifics | Repulsive Force (N) | Capacity Flow (ped/min/m) | Total Capacity (ped/min) | Number of Lanes |
|---|---|---|---|---|
| Bhubaneswar | 573 | 42.56 | 168.1 | 6 |
| Bhadrak | 573 | 48.4 | 133.58 | 4 |
| Lucknow | 573 | 45.16 | 158.06 | 5 |
| Kazipet | 573 | 67.89 | 217.25 | 5 |

**Table 7. Crowd Dynamics of the Stairways of Selected Sites in the Study**

The maximum flow, indicated in Table 6, and the capacity flow, as presented in Table 7, are comparative and obtained using distinct methodologies, namely regression analysis and crowd dynamics. The former values represent the realistic field conditions, reflecting the pedestrian behaviour under varying densities and walking speeds, whereas the latter may not adapt to the field complexities and overestimate the values. The crowd dynamics model uses the same mechanics across all sites, whereas the regression approach adapts to behavioural slowdown in congested environments.

## 5. CONCLUSION

The present study emphasises pedestrian flow activity at stairways. Pedestrian flow attributes such as speed density, speed-flow, flow density, and flow space are analysed in four major railway stations: Bhubaneswar, Bhadrak, Kazipet, and Lucknow. The attributes are analysed by considering males and females individually in both stairways' upward and downward directions. Their model equations are built up in which the coefficient of determination ($R^2$) is found to be more than 0.7. These models are statistically fit with minimum standard error. The results are compared with previous studies carried out by other researchers. In addition, this study considers the effect of pedestrian attributes such as gender, luggage, and direction of movement on stairways. Based on this study, the following conclusions are made to identify the research gaps and direction for further research.

– The present study reflects the pedestrian movements on the stairways, in which four railway stairways are analysed statistically to observe the pedestrian flow activities and attention paid to available space and walking speed.
– Pedestrian movement characteristics are examined during peak rush hours before and after the arrival of a train by considering age, gender (male, female), and whether the pedestrian is carrying luggage.
– It is concluded that pedestrians are more sensitive towards comfortable walking and space concerns; a pedestrian is attracted towards the descending direction rather than the ascending direction of stairways.
– As per comparative analysis from the earlier studies, it was observed that the speed varies for pedestrian consciousness, sensitivity, or attraction under available good walking conditions.
– It is observed from this study that pedestrians are more comfortable walking in the descending direction of stairways as speed is reduced while walking in the ascending direction.
– It is inferred that a male walks faster than a female in ascending and descending directions of stairways, and even the speed is reduced while walking with luggage/a cell phone/holding a child/walking in a group.
– The critical density at selected railway stations in different zones exceeds 1.07 ped/m$^2$, indicating LOS 'F'.
– The crowd dynamics analysis underlines that determining total crowd capacity and safety in railway stairways depends critically on physical design (stairway width) and behavioural flow characteristics such as speed, density, and number of lanes used.
– The regression model analysis for maximum flow provides a reliable estimation rather than the generic values used in crowd dynamics modelling.

The endeavour of this study is useful for researchers and planners in the design of existing railway facilities to reduce congestion and improve pedestrian comfort. Evacuation planning for high-density environments at stations can be formulated using a regression-based flow-density model. Other implications could include pedestrian-friendly policy decisions that prioritise space for smoother stairway movements. The present study limits the use of trajectory analysis, effect of escalators on pedestrians and presence of crowd on the platforms. Cultural differences affect the pedestrian flow characteristics as well as the capacity of pedestrian infrastructural systems, as the different selected sites suggest. A universal adjustment factor for optimising crowd capacity

at stairways and on platforms, along with the simulation of crowd dynamics modelling, could be a potential research avenue that would enhance the pedestrian transit infrastructures in railway stations.

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