PEDESTRIAN BEHAVIOUR MODELLING ON LEVEL CHANGING FACILITIES INSIDE INTERCITY RAILWAY STATIONS

Submitted in partial fulfilment of the requirements
for the award of the degree of
Doctor of Philosophy

by
ESWAR SALA
714115

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, WARANGAL

2020

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CERTIFICATE

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This is to certify that the work presented in the thesis entitled **"PEDESTRIAN BEHAVIOUR MODELLING ON LEVEL CHANGING FACILITIES INSIDE INTERCITY RAILWAY STATIONS"**, is a bonafide work done by me under the supervision of **Dr. K. V. R. Ravishankar**, Assistant Professor, Department of Civil Engineering, NIT, Warangal, Telangana, India and was not submitted elsewhere for the award of any degree. I declare that this written submission represents my ideas in my own words. I have adequately cited and referenced the original sources where others ideas or words have been included. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea /data/ fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Dedicated to

AMMA NANNA GURUVU

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ABSTRACT

The growing demand for public transportation is increasing over the decades. Terminals are infrastructures where pedestrians of various needs and characteristics make use of them. Within the available space, infrastructures are to be managed for efficient functioning of these terminals. Foot over bridges are typical elements where pedestrian movements takes place in both directions. The pedestrian movement on horizontal passageway varies to that of the inclined stairways. Understanding of pedestrian flow on these elements facilitate to arrive at the width of passageway and stairway. To study the pedestrian walking behavior on foot over bridges in intercity railway stations, pedestrian movement of video recording data on seven passageways, six stairway and six escalators were collected from three intercity railway stations namely Secunderabad, Warangal and Vijayawada. The width of passageways observed are 2.1m to 4.5m. The stairway widths observed are 2.0m to 3.6m with inclinations 30^0 to 34^0. The Pedestrian flow characteristics such as maximum flow, optimal density and mean walking speed are determined for each facility from manual extraction from play back videos of collected video recordings. On the passageway, the maximum flow range from 43 to 99ped/m/min with optimal density 0.73 to 3.07ped/m^2. On stairway, the maximum flow range from 26 to 40ped/m/min attained at optimal densities 1.00 to 2.93ped/m^2. The mean walking speed on passageway and stairway are 67.33m/min and 38.49m/min. On escalator, a maximum flow of 51ped/m/min is attained with an optimal density of 3.55ped/m^2.

Pedestrians walking speeds varies with individual’s characteristics such as gender, age and luggage on passageway and stairway. Also the pedestrian walking speed is effected by with infrastructure characteristics such as width as the space available per pedestrian varies. Hence the pedestrian walking speeds variation with individual’s characteristics and infrastructure width are studied.

The comparison of pedestrian walking speeds with different attributes showed that the walking speeds of middle aged female and aged female are similar and there does not exists a significant difference in their walking speeds. The mean walking speeds on passageway widths of 4.5, 3.5-3.6 and 2.1-2.3m are 64.85, 64.48 and 70.88m/min.

Comparison of pedestrian walking speeds on stairways showed that they does not vary significantly on stairways of width 2.0m to 3.6m for pedestrian densities falling less than 1.00ped/m^2. Pedestrian walking speeds are compared to study the width effect on ascending

and descending direction. Statistical results showed insignificant difference in mean walking speeds on stairways with width in ascending direction. The comparison of descending speeds showed significant difference in walking speeds with higher walking speeds on wider stairways. The mean descending walking speeds are 34.33m/min and 37.90m/min on 2.0m and 3.6m stairways with inclination 30^{o}.

Pedestrian level of service on passageway and stairway are determined for the foot over bridges. Comparison of space occupancy with HCM 2010 and TCQSM 2007 showed that the space occupancy thresholds for various LOS are lower for passageways in intercity railway stations than those in HCM with the minimum space required is similar for LOS F and are higher than those of TCQSM. The pedestrian space requirement is higher on passageway in India than in China.

Comparison of pedestrian LOS on stairways showed that the minimum space requirement per pedestrian is observed to be higher than those of Chinese and Americans. This is because the LOS standards defined for the in the earlier studies are for unidirectional stairway (ascending direction) and for the metro stations where the daily commuters with no/less luggage are more in proportions. The LOS thresholds are in higher range to those of sub-urban railway station. Whereas pedestrian in intercity railway stations are mostly luggage carrying making long hauling trips with various trip purposes and are not frequent visitors or users of railway stations. Hence the higher space are required to cater for the luggage and individuals require more room for free movement.

To understand the perception of pedestrians in making a choice between stairway and escalator to ascend a passageway, six videos each of a minute are cropped form the video recording data of pedestrian flows collected on the six stairways in the three intercity railway stations. A questionnaire survey form is prepared to collect respondent’s stated preference in choosing between stairway and escalator for the excerpts. Questionnaire includes respondent’s characteristics such as age, gender, educational qualification, employment status, marital status, and frequency of visiting railway station. A binary logit model is developed and the model included the variables like pedestrian age, gender, qualification, employment, marital status, frequency, inclination, and time of day.

Keywords - Pedestrian, Intercity Railway Stations, Passageway, Stairway, Escalator, Level of Service (LOS), Choice behavior.

CHAPTER 1

INTRODUCTION

1.1 General

Opportunities and needs drive people to travel various places. Passengers make long hauling trips for various reasons via public transportation. Railways being economical and fast means of access, majority of passengers rely on rail transportation in comparison to road transportation in developing countries like India. As per Indian Railway Year Book (IRY 2017-18), there are 7,318 railway stations and passenger traffic of 22.70 million per day. Indian railways have a total investment of ₹ 5,17,324.19 crore by the financial year 2017- 18. These figures reveal the importance of rail transportation in India. Figure 1.1 shows the passengers originating (in Millions) over the decades. About 3,621 million passengers used the non-suburban railway services in 2017-18. Figure 1.2 shows the average distance travelled per passenger using suburban and non-suburban rail transportation over the decades in India. The average distance travelled per passenger is 297.01 kilometers using non-suburban railway stations where as it is 32.03 kilometers for suburban travel as observed in figure 1.2. This shows the growing demand for rail transportation mode.

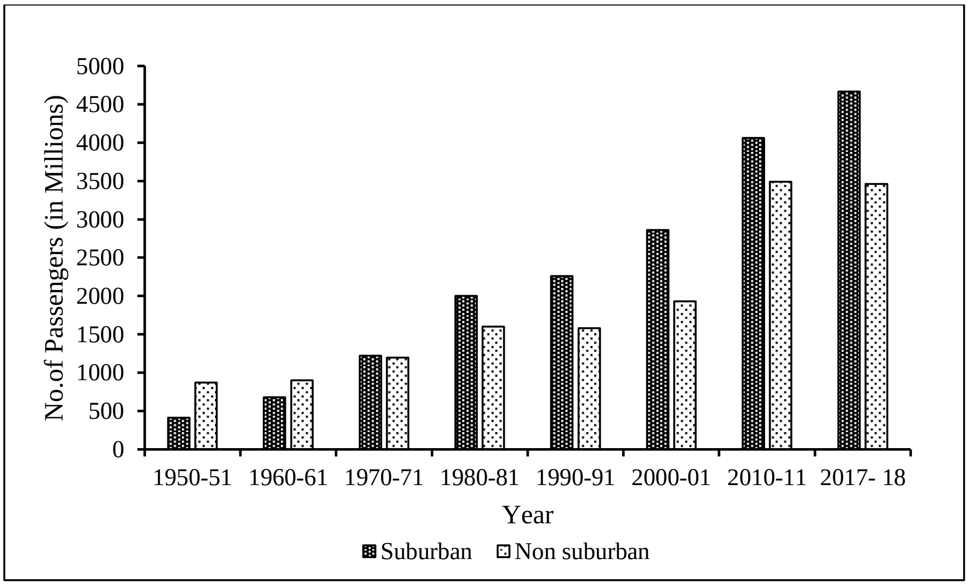


Figure 1.1 Passengers Originating over the Decades in Indian Railways.

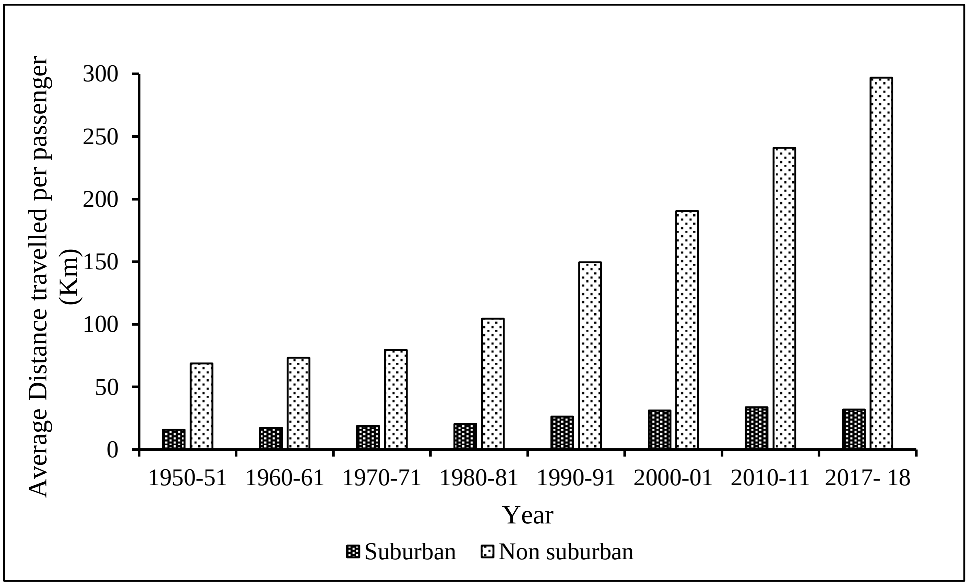


Figure 1.2 Passenger Kilometers over the decades in Indian Railways

Intercity railway stations are nodal points in railway network facilitating pedestrians to alight and board trains arriving and departing from various platforms. These stations are to be well managed to accommodate the growing demand. These are well embedded in urban geography such that development rose around it. Land and resources constraint further expansion of the station infrastructure. Within limited area, designing and planning of various railway station infrastructures is of great challenge.

Unlike a metro and suburban transit user, pedestrians in intercity railway station are rare visitors and are long hauling trip makers. There exists a considerable heterogeneity in pedestrian traffic composition with respect to age, gender, trip purpose, luggage/child carrying, etc. Pedestrians alighting from a train are in a condition of more strain due to the journey related stress. While pedestrians yet to make the journey are more active in comparison to alighting pedestrians. Level changing facilities, in particular foot over bridges (FOB's) provide pedestrians to access among platforms for alighting and boarding trains. These are confined walking environments, unlike sidewalks and walkways. It provides a common access for leisure and hurrying people traveling for various needs and trip purposes.

A greater heterogeneity in pedestrian traffic, environmental characteristics and infrastructure characteristics lead to conflicts for smooth pedestrian flow on these facilities. These facilities often cause interweaving of pedestrian and create bottlenecks. Typical FOB consists of an elevated passageway with stairway and escalator. For all the pedestrians, FOB's are bidirectional pedestrain flow infrastructure. Stairways connecting these FOB's are vital elements. These stairways offer pedestrians common access to ascend and descend a FOB that connects various platforms. It creates a situation where ascending and descending pedestrians obstruct each other's flow, restricting overtaking manoeuvres, etc.

To accommodate the increasing passenger demand, they are to be well planned, designed and managed. These are to be designed for pedestrians ease to ascend and descend with limited effort and fast evacuation considering various personal attributes like age, gender, luggage, trip purpose, etc.

Pedestrian walking behavior varies with the type of land use: mid-block sections, intersections, sidewalks, recreational areas, terminals, etc. For proper provisions, design and guidelines, understanding pedestrian movement on an infrastructure is of primary importance. Passageway is a horizontal level surface while stairways provide vertical movement. These often create bottlenecks at the interface of passageway with stairways and escalators due to the bidirectional flow with varied pedestrian flow behavior on horizontal and vertical movement.

Infrastructure characteristics widely affect the pedestrian movement. Pedestrian degree of freedom is restricted under lower widths and effort involved varies with inclination of stairway, step rise and step foot. The effort further influenced by the individual's characteristics such as age, gender, luggage and direction of movement. The level of service (LOS) is determined subjectively based on the mean flow characteristic values quantitatively. Transit Capacity and Quality of Service Manual (TCQSM 2007) determined the pedestrian LOS standards for the walkways and stairways for the transits irrespective of the transit functionality. LOS thresholds are based on pedestrian freedom to walk with desired walking speed and ability to bypass slower moving pedestrian. It considered the pedestrian space available to take into account the comfort pedestrian experiences under a flow rate. The capacity of stairways and walkways are determined as 56ped/m/min and 82ped/m/min respectively. Free flow speeds on walkways range from 45m/min to 145m/min which can be observed for space available up to 2.3m^2/ped. It considers the lower up flow rates for designing and analysis as the pedestrian flow rate is lower in ascending direction s and requires more energy to ascend. The ascending speeds range from 12-21m/min and 17-31m/min in ascending direction and descending direction respectively measured in vertical direction. The normal speeds are observed to be attained at 0.9m^2/ped and the maximum flow rate is observed to attain at 0.3m^2/ped. Thus determining the pedestrian speed, density, space and flow in general sense of transit station where the functionality and pedestrian composition are not considered. Highway capacity manual (HCM

2010) determined pedestrian LOS standards for off-Street walkways and stairways. Capacity of walkway and stairways are given as 75ped/m/min and 50ped/m/min respectively. Hence LOS thresholds of HCM 2010 gives the range of pedestrian flow rate and corresponding space availability per pedestrian for off-street stairway and walkways. Both the TCQSM and HCM does not consider the functionality, pedestrian traffic composition, location and region where pedestrian physic, trip purpose and personal characteristics vary. It also obscure the pedestrian perception in using a stairway. This complex behaviour of pedestrians' across various facilities are to be analyzed to arrive at standards for designing a particular facility. Theses prevailing factors particularly on confined foot over bridge elements in intercity railway stations in developing countries like India, poses a challenge to planners and engineers for facility planning, design and management.

1.2 Need for the Study

Pedestrian movements on foot over bridges are impulsive that depends on the train arrival and departure times. Individual's attributes associated with the physical and psychological strain due to the long hauling trips influences the individual's speed, flow and personal space requirement. The pedestrian flow parameters vary with horizontal movement on passageway and vertical movement on stairway/escalator. Degree of freedom in maneuvering and overtaking on these facilities are greatly influenced by pedestrians attributes. This effects the handling capacity and service level a facility offers due to reduction in flow and speed causing the bottle neck at their connecting point. These bottlenecks and accumulation of pedestrian traffic ceases the flow attaining near jam conditions. It in turn may lead to panic situations, unexpected disaster and stampedes due to pedestrian sense of unsecure, unsafe and desire to escape the crowd. Hence the study of pedestrian flow behaviour on the passageway, stairway and escalator is the primary importance to understand the flow variations and design for an anticipated demand with user acceptable dimensions for a continuous and uninterrupted flow along the FOB. Thus an equivalent width of stairway to that of passageway can be arrived. To estimate the capacity of stairway, passageway and escalator for the functionality of intercity railway station, study of pedestrian speed-flow-density variations is the initial step.

Average size of space occupied by a pedestrian is an important index, for evaluating the LOS. The LOS thresholds varied with type of facility, region and location. A gap has been identified in determining the LOS thresholds of passageway and stairway of a FOB in intercity railway station and this research work is directed in that direction.

Pedestrian choice between stairway and escalator, route choice from entrance to exit are studied to understand the factors influencing them in metro stations and shopping malls. The pedestrians in metro stations are daily commuters with greater familiarity in using the station infrastructure and layout. While the pedestrians in intercity exhibit different behaviour as they are less familiar in infrastructure usage and the station layout. In this research work, pedestrian perception in making choice between stairway and escalator is studied to understand the pedestrian characteristics, stairway characteristics and flow characteristics.

1.3 Objectives of the Study

The objectives of the study are:

1. To study the pedestrian flow characteristics on a foot over bridge passageway, stairway and escalator in intercity railway stations.
2. To develop pedestrian Level of Service (LOS) thresholds for passageway and stairway of an elevated foot over bridge in intercity railway stations.
3. To develop a model for pedestrian choice between stairway and escalator to ascend an elevated passageway of a foot over bridge in intercity railway stations.

1.4 Organization of the Thesis

The thesis work is presented in eight chapters and the chapters are organized as follows.

Chapter 1 gives the brief background of the topic of this study, the need for the study and the specific objectives of the research work.

Chapter 2 gives an overview of the earlier studies related to the subject matter of this research work i.e., pedestrian flow characteristics, level of service for pedestrian facilities and pedestrian route choice behaviour.

Chapter 3 presents a detailed methodology adopted for the present study with the help of a flow chart. It also presents the selection of study area and its description, pedestrian flow data collection, dimensions of facility in field and extraction of pedestrian flow parameters.

Chapter 4 presents the analysis of observed pedestrian flow characteristics, comparison with earlier studies and their variation on passageway to stairway to understand the pedestrian behaviour.

Chapter 5 presents the study of pedestrian walking speed variations with width of passageway and stairway of the FOB in intercity railway stations.

Chapter 6 presents the pedestrian level of service thresholds development for the passageway and stairway of the FOB in intercity railway stations.

Chapter 7 deals with the study and modelling of pedestrian perception in making choice between stairway and escalator to ascend an elevated passageway of a FOB in intercity railway stations.

The summary and conclusions of the study, major research contribution, limitations of the study and the scope for further research are presented in **Chapter 8.**

CHAPTER 2

LITERATURE REVIEW

2.1 General

This chapter presents the review of literature on pedestrian flow characteristics to understand the flow behaviour on various pedestrian facilities and factors influencing them. A review of studies on pedestrian route choice and choice between stairway/escalator is conducted to identify the influencing factors significant in pedestrian decision making and route choice. The study of literature on pedestrian level of services is presented to understand the pedestrian level of service thresholds for various facilities. This section is divided in to three segments. They are studies related to pedestrian flow characteristics, studies related to pedestrian choice behaviour and studies related to pedestrian level of service for various facilities.

2.2 Studies on Pedestrian Flow Characteristics on Various Facilities

This section deals with the literature review and findings of pedestrian flow characteristics on various facilities passageway, stairway, escalator, sidewalks, crosswalks, walkways at various locations and serving different building types.

2.2.1 Studies on Passageways

Hankin (1958) studied pedestrian flows on subways in experimental and field studies. Experimental set up of two concentric rings of paling and field studies in London are studied for pedestrian flow characteristics. Authors observed that, with increase in crowd, the speed gradually decreases and flow past a point not necessarily increases on subways. For a width of about four feet, pedestrian maximum flow is directly proportional to width on subways and stairs, while multiples of shoulder width becomes important under four feet width. Passageway capacity reduces with center hand rail. Pedestrian movement of stairs is slower than on passageways and hence stairs are likely to become bottlenecks. With the more crowdedness, pedestrian unconsciously slow down to avoid treading on the heels of person in front of them.

Cheung and Lam (1997) studied pedestrian speed-flow relationships on passageway and stairways in Mass Transit Railway (MTR) station and also studied the effect of bi-directional pedestrian flow on capacity reduction on both the facilities. Videography data is collected from six MTR stations and flow, speed are extracted manually. Travel speed and corresponding flows of pedestrians are used to calibrate travel time function of facility defined by Bureau of Public Road equation. It is observed that at lower flow pedestrian walking speeds are less evenly distributed and at high flows they are less likely to control walking speeds. Comparison of maximum flow values to that of London Underground studies showed higher values of flows due to the smaller physic and more tolerant to invasion of space of Asian people. To understand the effect of bi-directional flow effect on capacity, pedestrian directional distribution flow and corresponding reduction in effective capacity (R_{cap}) and walking speed (R_{mspd}) are observed. With increase in directional imbalance, R_{cap} and R_{mspd} increases and its affect is more significant on stairways to that of passageway as stairways involves more efforts in ascending direction.

Sarkar and Janardhan (2001) studied pedestrian flow- density- speed relationships on walkways leading to intermodal transfer terminal in Calcutta, India. Pedestrian movements are captured using video camera at a subway leading to Howrah railway station and two pedestrian bridges connecting river bank with floating ferry terminal. Density is calculated assuming the fundamental relationship q=kv prevailing for pedestrian traffic also. It is observed that flow increase with increase in density to a point and decreases with further increase.

Daamen et al. (2005c) studied the applicability of first order traffic flow theory to pedestrian flow in bottleneck. An experimental setup of bottleneck is created, and subjects are allowed to pass. It is observed that at the upstream of bottleneck, pedestrians group in the shape of funnel and the width of funnel varies over time. In the center, pedestrian density is high and speed is low. On the boundaries, pedestrian walk with free flow conditions. Hence they concluded that the fundamental diagrams of congestion part cannot be estimated from the aggregated data.

Chen et al. (2010) studied pedestrian flow characteristics on confined passageway, ascending stairway, descending stairway and two-way stairway in Shanghai metro stations. Pedestrian flow data on passageway is collected from People Square Station and stairway data is collected from Zhong-Shan Park Station. At lower densities, pedestrian speed remains constant and it tends to decrease with increase in density indicating the pedestrian interactions prevails. Pedestrian volume increases with increase in density up to optimal density and then decreases beyond it. At low densities (<1.0 p/m^2), pedestrian flow-density are tightly distributed. Free-flow speed observation on various elements revealed that the free flow speed on passageway is twice that of stairway. While the critical density on passageway is lower than that on stairway. The critical density on ascending stairway is equivalent to two-way stairway. Descending stairways has the highest critical density among all the facilities. Level passageway has lower optimal densities than stairways. Ascending stairways has higher optimal density than descending stairways.

Zhang et al. (2011) analyzed passengers macroscopic and microscopic flow characteristics on passageway in Xidan Station and Guomao Station of Beijing transfer station. Width of passageways are 5.7m and 3.6m in Xidan and Guomao stations respectively. Video recording data is collected and density, and speeds are extracted using Semi Traffic Data Collection Platform (STDCP). Passenger volume is collected using laser scan equipment for every 30 seconds. Walking speeds are observed to be following normal distribution with mean walking speed of 1.48m/s. The mean walking speeds of male and female passengers are 1.53 and 1.41m/s respectively. The mean walking speed observed is higher than the Hong Kong Mass Transit Railway Station studies. Passenger speed and density ranges are observed to be fall in low ranges and is due to the difference in arrival pattern of transfer station passenger from random pedestrian traffic with the earlier being affected by train arrival. The distribution of passenger walking speed is scattered rather than gathered together as the transfer passengers arrive at almost same time. The volume–density trend showed linear relationship where no congestion prevails.

Yao et al. (2012) analyzed demand, function and structure mapping mechanism. A quantitative relationship in design perspective between terminal structure and function was obtained. Principle of reverses engineering is used to decompose passenger demand and terminal structure into several demand units and structural elements. Time, distance and structure utility constraint are developed and function-oriented concept layout model is developed. Authors concluded that terminals functions for traffic, business and civil aviation varies and hence the layout should satisfy both demand of passengers and structure incorporating various units.

Zhang and Seyfried (2013) studied pedestrian unidirectional and bidirectional flows in corridors under control experiments in laboratory. A homogeneous group comprising of students are used for the test. Pedestrian flow-speed are studied and the results showed that ordering in bidirectional flow does not influence fundamental diagrams. The bidirectional velocities are low in comparison to unidirectional flow. A plateau is formed in bidirectional flow and the flow becomes independent of the density. With the formation of self-organized flows, head-on conflicts decrease. It increases the ordering of stream. Straight corridors have highest flow in comparison to bottlenecks. The flow is affected by the shape and geometry of the facility.

Kawasar et al. (2014) studied pedestrian flow-density-speed relationships during convocation on walkways and stairways leading to Dewan Tuanku Syed Putra (DTSP) hall room, University Sains Malaysia, an indoor facility. The free flow speed on walkways was observed as 1.41m/sec and is higher than those observed in railway stations from literature. Male walking speed (1.42m/sec) is higher than female walking speed (1.39m/sec). The walking speeds on downstairs (0.54m/sec) is higher than on upstairs (0.51m/sec). Similar to walkways, males walk faster than female, but significant difference does not exist. Authors concluded that the pedestrian speed is influenced by leading pedestrian. Pedestrian walking speeds on stairways are lower than those on walkways as the earlier needs to overcome gravity. The pedestrian flow characteristics are site and region specific and thus vary from indoor facility and outdoor facility.

Zhao et al. (2014) studied pedestrian flow characteristics on elements, long passageway (>6m), short passageway, stairway, and escalator, connecting a metro station to the commercial mall. Pedestrian data on both weekdays and weekends are collected from three stations of Guangzhou Metro. The average flow rate in weekends are higher than those on weekdays on stairways, long passageways and short passageways. Female passenger are higher than male passengers and the proportion of passengers to metro station are significantly greater than opposite direction. It is concluded that passenger speeds are affected by age and children are moving with slower speeds. Elders walking speeds are greatly affected by flow. Personal characteristic, shoes, greatly affected female walking speeds.

Voulgaris et al. (2015) studied the approaches North American rail transit operators adopt to analyze and design below-grade rail transit stations for anticipated passenger demand. Transit station design experts are interviewed to identify issues and considerations in transit station planning for pedestrians. Interview results summarized that for an anticipated passenger volume, published standards often mandate more circulation space than would be called for by an analysis. Deterministic models are used to ensure that designs meet adopted standards or design issues not accounted for in standards in determining space needs for passenger movement. Microsimulations costs beyond consultation fee. Deterministic models are simple and cost effective compared to microsimulation models. Results concluded that agencies relay on published standards in designing pedestrian circulating elements. While deterministic spreadsheets and microsimulations are used to compliment for station design.

Gao and Jia (2016) proposed a passenger flow distribution integrating model. Passenger distribution in urban rail transit hub platform are influenced by platform facilities: available area of platform, traffic capacity of passage, traffic capacity of stairs, and traffic capacity of escalators, train scheduling: arrival and departure interval and dwell times, and passenger flow: temporal and spatial distribution of passenger flows. Authors concluded that the passenger distribution morphology changes regularly with train departure interval. Beijing South station platform is simulated by using the developed model. It is observed that the model has good performance in describing passenger flow distribution dynamic variation.

Zhao and Liang (2016) studied pedestrian speeds in metro station associated with mall. Pedestrian data was collected from Guangzhou metro. It is observed that the pedestrian speeds varied with age and gender. Average walking speed of male is 1.135m/sec and female walking speeds are 1.076m/sec. Female walking speeds are slower than male pedestrians. Pedestrians carrying luggage (1.123m/sec) are found walking slower than without luggage (1.011m/sec). It is observed that female walking speeds are affected by footwear high-heeled shoes (1.066m/sec), flat shoes (1.097m/sec) and slippers (1.158m/sec). It is observed that pedestrians accompanied with others walk slower than single pedestrians but accompany of pedestrians is not significantly affecting walking speeds as the major proportion of pedestrians are young who have equivalent moving speeds.

Fang (2018) analyzed pedestrian walking microscopic characteristics on one-way passageway, two-way passageway, passageway with upper and lower slop, passageway in transfer station and passageway to and from urban rail transit station. Pedestrian data is collected on passageways from Zhujiang New Town Station, Kecun Station, Dongxiaonan Station, Guangzhou Railway station, Tiyu XIlu Station, Canton Tower Station and Haizhu Square Station of Guangzhou Metro. Authors concluded that the pedestrian travel purpose and station type effects the walking speed. Commuter station has the maximum walking speed while commercial center station and tourist center stations have slowest walking speeds. Average walking speed on two-way passageway is lower than one-way passageway. Pedestrian walking speeds in horizontal and downhill passageway are nearly equal and uphill passageway walking speeds are lower than walking speeds on horizontal passageway.

2.2.2 Studies on Stairways

Irvine et al. (1990) conducted experimental studies on pedestrian's acceptable and preferred dimensions of stairways. Pedestrians are subjected to ascend and descend 19 sets of stairways in a series of six experiments. Experimental set up stairway step rise range from 0.13 - 0.23m and step tread varied from 0.25 - 0.33m. A total of 66 pedestrians participated with different age, weight and physical dimensions. It was observed that pedestrians are more sensitive to step rise than tread. Optimum rise and tread are obtained as 0.18m and 0.28 – 0.30m respectively from both acceptable and preferred studies. Taller pedestrians accept larger dimensions while shorter pedestrians accept smaller dimensions. Range of 30^0 to 50^0 inclination are too broad and too limiting. A slop 24^0 46′ with rise 6″ and tread 13″ has higher rate of acceptance. Acceptance rate decreases with increase in slope. Authors concluded that rise and tread should not be determined from mathematical equations and studies should be conducted to arrive at realistic acceptable ranges. Riser height less than 0.15m and tread greater than 0.33 m should not be allowed.

Tanaboriboon and Guyano (1991) studied and analyzed pedestrian speeds on walkways, sidewalks, stairways, signalized crosswalks in Bangkok, Thailand. Pedestrian data is collected from video recording and pedestrian speeds with respect to gender are determined on each facility. Results showed that the walking speeds of pedestrians on descending stairs are higher than ascending stairs. Statistical test showed that increment of step rise significantly affects the walking speeds. In comparison of walking speeds, Thai pedestrian walk slower than Americans. In comparison to female, male walking speeds are higher. Authors concluded that walking speeds on stairs are affected by step rise and the Asians walking speeds are lower than the Americans.

Lam et al. (1995) studied pedestrian flow characteristics on stairways in Hong Kong. Pedestrian flow characteristics on stairways are studied in MTR and KCR. Ascending stairways from Tsim Sha Tsui and Kowloon stations are considered, mean walking speeds are 35.4 and 38.7m/min with 71 and 66ped/m/min maximum flows respectively. Two descending stairways from Wan Chai Statin and Kowloon stations are studied and 40.8 and 48.2m/min are mean walking speeds with 77 and 73ped/m/min maximum flow observed respectively. It is concluded that the mean walking speed in descending direction is greater than ascending direction.

Fujiyama and Tyler (2004) conducted experimental study to understand the pedestrian characteristics effect on their walking speed. Two group of participants classified as elders and young are divided. Participants leg extension power (LEP), age, weight and height are collected and are asked to ascend and descend stairway in normal speed and their fastest possible speed. Results showed that there exists a linear relationship between stair gradient and walking speed. LEP has a strong correlation with walking speed for elder participants.

Lee and Lam (2006) studied pedestrian walking speed variation for unidirectional and bidirectional flow condition on walkway leading to escalator and stairway in railway station. Videography data is collected recording pedestrian flow on walkway leading to escalator where pedestrian flow is unidirectional and on stairway with bidirectional flow from Causeway and Mongkok mass transit railway (MTR) stations in Hong Kong. Pedestrian walking speeds variation is higher under uncongested condition on walkway and on stairways in both ascending and descending. Mean walking speed sharply decreases and slowly decreases with standard deviation under uncongested and congested conditions respectively. Standard deviation decreases with decrease in men walking speed on both walkway and stairway. The reduction in standard deviation is higher in ascending direction than in descending direction.

Liu et al. (2008) studied pedestrian flows on up-stairways and down-stairways stairways in Chifeng road light orbit station, People’s square station and Shanghai train station. Results showed that the velocity decreases with increase in pedestrian density. Pedestrian step is consistent on stairs with step frequency quicker along down-stairway than up-stairway and hence down-stairway velocity descends faster than up-stairway velocity under same densities. Up to optimum density, with increase in density, pedestrian flow and velocity increase. Beyond optimum density, pedestrian flow and velocity declines. The optimum density is smaller for down-stairways than up-stairways. For a given density, pedestrian flow on down-stairway is higher than up-stairway and is due to the velocity being higher on down-stairways.

Hongfei et al. (2009) developed pedestrian speed-flow-density relationships on corridors and stairways in Xizhimen underground station, Beijing, China. The flow-density showed quadratic relationships on both corridors and stairways. Speed-density varied linearly. For lower space available, pedestrian flow-space showed quadratic relationship and logarithmic relation at higher space available. Results showed that the fundamental curves are similar for different facilities but with different coefficients signifying the effect of facility type on pedestrian flow characteristics. Type of facility also effects the desired speed. It is observed that the desired speed on stairway is lower than on corridors.

Tang and Liu (2009) investigated pedestrian characteristics of flow on stairways in Chifeng Road Light Orbit Station, Peoples Square Subway Station and Shanghai train station. The velocity of pedestrians on down-stairways decreases with increase in density and the range is smaller than that on level walkways. Pedestrian flow-density showed quadratic relationship. Pedestrian flow increases with increase in density up to optimum density and then descends for both up-stairways and down-stairways. Pedestrian velocity in down-stairways is more effected by density and hence the optimum density is smaller for down–stairways than up-stairways. Under free density ($<0.5 p/m^2$), pedestrian velocity on stairway is independent of density.

Zhang et al. (2009) studied pedestrian flow characteristics on passageway, up stairways, down stairway, upgrade and down grade in Xizhimen transfer hub and Fuxingmen transfer hub, Beijing, China. Results showed that the mean walking speeds on passageway is 1.33m/sec. The mean walking speeds on downstairs are higher than up stairways. Male pedestrians are found to walk with higher walking speeds than female on passageway. The young pedestrian (18-35 years) walk faster than old age (>60 years) pedestrians. It is observed that the mean walking speeds in upstairs and down stairs are higher on stairway with higher width. Authors concluded that the pedestrian walking speeds are effected by age, gender and facility type.

Fujiyama and Tyler (2011) studied the effect of stairway gradient on pedestrian walking speeds. Young pedestrians and elder pedestrians are subjected to a set of four stairs with increasing gradients. Studies are conducted under normal speeds and fast movements. Authors concluded that pedestrian speeds are affected by stair gradient and weight of pedestrian does not have significant effect on stair ascending speed.

Yang et al. (2012) studied pedestrian flow on staircase under normal and emergency conditions. Video recording data of students leaving classroom under normal conditions and under a drill for emergency evacuations are collected in main building of university of Science and Technology of China. Observations showed that under normal conditions, overtaking rarely occurs. Pedestrians slow down and follow slow moving pedestrians with patience. At the platforms connecting two stairs, pedestrians at outer sections walk along the arc and pedestrians in inner section walk shorter distances. Sub-groups walking speed is lower than individual under same density. Crowd is more constrained by slow moving pedestrians in front of them.

Flow movement speed reduces and flow increase with increase in density. Under evacuation condition, flow and speeds are higher in comparison to normal condition. Under low densities, pedestrian speeds in downwards are affected by individual characteristics. While in higher densities, it is controlled by the extent of crowd congestion.

Shah et al. (2013a) studied pedestrian speed variation on stairway in Vadodara railway station, Gujarat, India. Pedestrian's characteristics and speeds are extracted from the video recoded data. Pedestrian mean walking speed is 0.442m/s on upstairs and 0.460m/s downstairs. Average walking speed of individual is almost same as average speed of pedestrian stream. Luggage has significant effect on pedestrian walking speed. Pedestrian walking speeds are higher than their normal speeds during the arrival of train. Male pedestrian walk faster than female pedestrians. Elder pedestrian and pedestrians with luggage have walking speeds less than young pedestrians. Walking speeds are higher on down stairs than upstairs.

Shah et al. (2013b) studied pedestrian macroscopic characteristics on four stairways in Vadodara railway station, Gujarat, India. Pedestrian flow is collected using videographic survey. For lower flow rates (<10p/m/min), pedestrian walking speed range from 18.78m/min to 48.80m/min. Under lower flow rates, pedestrian speeds are governed by individual's characteristics. Speed is observed higher during afternoon than in the evening periods due to the lighting and physical state of pedestrian. With increase in flow, density increased and speed decreased. For flow greater than 10p/m/min, pedestrian speed decreased with increase in flow. The increase in flow decreased the available space per pedestrian.

Seitz et al. (2014) studied pedestrian stepping behaviour in walking straight, backward, side and on stairways under controlled experiments. The experiment was conducted under normal and fast movement scenarios. Results showed that the stepping lengths are smaller when walking in backward or sideway than that walking in forward direction. Pedestrian walking speed are lower than walking in sideways or backwards. Walking speeds on stairways under normal is 50% lesser than the walking speeds on plane. Under fast conditions, walking speed on stairs is equal to the walking speeds on plane under normal condition. When walking round the corners, pedestrians accept smaller distances from obstacles than when walking along the side.

Jiten et al. (2015a) studied macroscopic pedestrian characteristics on two stairways with bidirectional flow in Dadar suburban rail transit interchange station, largely comprising of daily commuters carrying little/no luggage, located in Mumbai, India. Videography method is adopted to collect pedestrian flow in the morning and evening for each one hour. Second degree polynomial fit best describes speed-density relationship and results showed that at densities less than 0.45ped/m^2, pedestrians achieve desired walking speeds. Pedestrian walking speed decreases with increase in density up to 4.5ped/m^2. With further increase in density, pedestrian desire to achieve desired speed reduces and follows the crowd due to increased friction between other pedestrians and adjacent handrails, walking speed became constant and stable flow is achieved. At lower densities, pedestrian flow increases with higher rate. On comparison, specific flow, average density and speed are higher on wider stairway.

Jiten et al. (2015b) studied train schedule impact by observing the pedestrian flow proportions, 90-10, 70-30, and 50-50, in ascending and descending direction on pedestrian speeds. Videography data is collected on two stairways in Dadar suburban rail transit interchange station located in Mumbai, India. Pedestrian are daily commuters with very little/no language and composition revealed that majority of users are younger age (age 15- 60) and male pedestrians (86% and 91% on two stairways). Studies resulted that the pedestrian walking speed is higher in the direction of major flow. With decrease in major flow proportion, walking speed also reduces until major flow becomes minor flow with respect to opposite direction flow. At 50-50, reduction in descending direction walking speed is higher than the ascending direction. Ascending direction flow influences speed more than the descending direction flow.

Lazi et al. (2016) reviewed various studies across the world on pedestrian flow on stairways. Pedestrian choice making depends on external and internal factors. It varies with country, culture, topography and environment. External factors include facility characteristics and pedestrian route network characteristics. While internal factors include decision making mode, personal attribute, behavioural characteristics, familiarity and travel purpose. It is observed that Asians use staircase higher than Western pedestrians. Pedestrian’s selection of stairway is also affected by width of staircase. Walking speeds of Asian pedestrians are slower in comparison to Western people in ascending direction and is due to the physical characteristics difference between Asian and Western people. Male pedestrians walk faster than female pedestrians. Korean pedestrians ascend faster, and Indian pedestrians are slowest. Walking speed reduces with increase in pedestrian age.

Jiten et al. (2016) studied the effect of stairway width and inclination on pedestrian flow characteristics. Six stairways, two from Dadar suburban railway station in Mumbai and four from Vadodara intercity railway station in Gujarat, are considered for the study with widths varying from 2.14 to 3.68 m and gradients 22.1° – 24.14°. Dadar being suburban railway station, majority of pedestrian are daily commuters and male, without carrying luggage or carrying small luggage. While reasonable proportions of all class pedestrians with respect to age, gender and luggage are observed in Vadodara intercity railway station. Walking speeds on all stairways followed normal distribution and statistical paired t-test with null hypothesis being walking speeds on stairways with different widths are equal showed that there exists a significant difference in walking speed on stairways with different widths. Pedestrian walking speeds are higher on wider stairways. With further increase in width, speed is observed to be decreased. For a given flow rate, pedestrian walking speed is high on stairways with greater width than on narrow stairs. Also for a given flow rate and width, pedestrian speed is different in both the railway stations due to the difference in proportions of different users and operational characteristics of railway stations (suburban and intercity railway stations). For a given density, pedestrian walking speed is higher on wider stairways than on narrow stairway. To certain level, flow increase with increase in density and then reduces. For a given flow rate, pedestrian space requirement various with the station characteristics, pedestrian characteristics and lifestyle. Walking speed increases with increase in available space and stabilizes from a point.

Shah et al. (2017) studied pedestrian flow characteristics on two stairways with bidirectional flow in Dadar suburban railway station in India. Large number of pedestrians, about 93% are daily commuters. Results showed that the average walking speeds in ascending direction are lower than in descending direction. It is observed that the speed decreases with increase in flow rate reaches a maximum and then declines. Capacity in ascending direction is lower than descending direction and pedestrians are more sensitive to available space in descending direction. Walking speed increases with increase in individual's available space. At higher available space, pedestrian are insensitive towards space and walks with desired speed. They occupy lesser space in descending direction. Indian pedestrians are more tolerant towards available space in comparison to Western pedestrians and higher capacity with lower walking speeds are observed. Flow rate is higher on wider stairway than on narrower one.

Jiten et al. (2017a) studied bidirectional pedestrian movement effect on variation in capacity of stairway in Dadar suburban railway station, located in Mumbai, India. Videography data of pedestrian movement on stairway is collected and flow is extracted. Capacity variation at different distribution ratio is studied. It is observed that unbalanced bidirectional flow effects mean walking speed and capacity of stairway. At lower distribution ratio, where ascending flow is major with mean walking speed less than descending direction, capacity reduction is maximum at distribution ratio of 0.1 and maximum capacity is obtained at distribution ratio 0.6. Capacity of stairway is maximum in comparison to other studied across the globe. Authors concluded that the Indian pedestrians are more tolerant to small spacing between each other while moving on stairways with bidirectional movement.

Jiten et al. (2017b) estimated pedestrian free flow walking speed on stairways in Dadar, Mumbai, sub-urban and Vadodara, Gujarat, intercity railway stations, India. Both the railway stations are functionally different with daily commuter of young age (15-60 year) carrying less or no luggage more dominant in sub-urban railway station. Videography data is collected from four stairways, two from each station, is collected and flow-density-speed are extracted manually. It was observed that at density less than 0.45ped/m^2, pedestrian walking speed variation is high. With further increase in density and corresponding flow, pedestrian speed and variation decreases. Statistical analysis results showed that there is significant difference in speeds for density <0.45ped/m^2 and >0.45 ped/m^2. Percentage cumulative frequency distribution curve of pedestrian speeds for the two density regions. Assuming vehicular operating speed of 85th percentile speed prevails for pedestrian traffic, operating speed of pedestrian facility is determined. It was observed that pedestrian operating speed at high density level is lower than at the lower density level. Walking speeds at intercity railway station significantly varied from suburban railway station because of difference in functional characteristics of rail transit station. Male pedestrians have higher free flow walking speed than female pedestrians. Younger pedestrians have higher waking speed than elder and children in descending direction in comparison to ascending direction. Walking speed reduces with increase in age.

2.2.3 Studies on Escalators

Kinesy et al. (2010) studied pedestrian evacuation behaviour on escalators. Pedestrian data pertaining to stairs/escalator choice, rider/walker preference, side preference, travel speeds and flow rates are collected from the closed-circuit television (CCTV) footage from Provence Station. An escalator moving upwards and an escalator moving downwards are considered for the study. Using EXODUS building evacuation model, eight scenarios are simulated which contained two stairs and an escalator with varying percentage of side preferences, and percentage using escalators. Choice of stair/escalator depends on personal preference, energy expenditure and level of urgency felt. Greater number of users take escalators due to higher expected speeds of escalator. Under evacuation conditions, escalator users walk down the escalator. There is a marginal increase in total evacuation time if users display equal preference for side preference.

Liao et al. (2013) studied pedestrian traffic characteristics of ticket vending machines, automatic ticket fare gates and escalators in Shanghai Railway Station, Shanghai West Railway Station, Zhongshan Park, People's Square, and Xujiahui. Pedestrian data is collected using video recording camera and pedestrian flow characteristics and pedestrian characteristics are extracted. Results showed that the headway of passengers passing automatic fare gates follow normal distribution. Service time frequency of ticket vending machines and staffed ticket booths follow Weibull and exponential distributions respectively. Escalator theoretical capacity which depends on tread width, operating speed and rate of passenger standing, and walking and practical capacity which depends on intermittent passenger arrival, passenger yielding behavior, inability to board, luggage and desire for more comfortable space are estimated and are compared. Theoretical capacity is estimated to be 7200 passengers/hr/m assuming that half the proportion of total pedestrians' walk on left side and half stand on right side of escalator and it is estimated as 9000passengers/hr/m assuming all the pedestrians are standing. The practical peak hour volumes is observed on field and observed maximum and mean volumes are 5266passengers/hr/m and 4985 passengers/hr/m respectively. Authors concluded that the practical capacity is affected by age, luggage and step leaving phenomenon due to requirement of more comfortable space.

Bodendorf et al. (2014) studied the practical handling capacity of escalators located in shopping centres and railway stations. Practical handling capacity depends on speed and density of pedestrians and however is less than the theoretical capacity. Pedestrian flows on escalators in shopping centres and railway station are observed for different time intervals varying from 10sec to 120sec. Highest flow values close to the theoretical capacity are observed for 10sec interval which are peak values and it does not lasts for longer periods. These values yield oversized and use of mean flow values underestimates. Hence authors concluded that the capacity varies with time interval observed. Smaller the time interval, higher is the capacity. Higher flows are observed in railway stations than in shopping centres. This concludes that the capacity varies with location. For a given location, pedestrian flow in downstairs escalators are higher than the upstairs escalators and is due to the subjective feeling of nearness of individuals.

Pedestrian flow on escalator depends on direction it serves and building type in which it is located.

Costescu et al. (2015) studied escalator practical capacity in Piata Victoriei and Piata Unirii, Bucharest Metro network. Studies showed that capacity is affected by speed of escalator. Results showed that the capacity is reduced because of the lesser operating speed adopted in comparison to other European metro networks. Comparison of passenger flows on escalators and stairs during morning and evening hours from the two metro stations showed that the practical capacity is affected by proportion of passengers walking/standing on the escalator, distance of escalator from platform and vertical rise.

Lazi and Mustafa (2015a) reviewed pedestrian flow characteristics studies on stairways and escalators across the world. It is observed that pedestrian flow patterns are different for different countries due to different pedestrian behaviour and type of topography. Pedestrian mean walking speed is influenced by personal attributes and environment. Mean walking speed in descending direction is higher in comparison to ascending direction. Younger pedestrians walk faster than elder pedestrians. Pedestrian emotions influence pedestrian walking speed. Pedestrians with peaceful and comfortable emotion walk slower. Height and weight have low impact on pedestrian walking speed. Stairway characteristics effects pedestrian walking speed. Pedestrians tend to move in middle on narrow stairways and tend to walk at edges holding side rails on wider stairways. Pedestrian tends to use escalator more in comparison to stairway when both the facilities are provided regardless of Asia or Western cities.

2.2.4 Studies on Sidewalks, Crosswalks and Walkways

Tanaboriboon et al. (1986) Studied pedestrian characteristics on three walkway sites with bidirectional flow in Singapore streets, orchard road and Shenton way using data extracted from video recording data. Assuming pedestrian characteristics are same across all the study areas, data is analyzed in Statistical analysis software (SAS). Mean speed of Singapore pedestrians (74m/min) is found to be less than the mean walking speed of American pedestrians (79-88m/min). Mean speed of young pedestrians (76m/min) is observed to be higher than the elder pedestrians (54m/min). It was observed that the male pedestrian (79m/min) walk faster than the female pedestrians (69 m/min). Linear relation is assumed between speed-density and speed-flow, flow-density relationships are formulated. Free flow speed and theoretical maximum flow derived from relations are 73.9m/min and 89ped/m/min. Study concluded that the Singaporean has a slower walking rate than American.

Koushki (1988) studied pedestrian walking characteristics in Riyadh, Saudhi Arabia. Pedestrian origin-destination data for 18 locations is collected covering commercial, governmental and residential land use in the study from questioner survey. Pedestrian speeds are collected on sidewalks. Results showed that pedestrians in Riyadh walk longer distances than those in New York and is due to the inefficient use of urban land, semiskilled and low-income group laborers. The mean walking speed in Riyadh is 65m/min which is lower than the Western countries. Pedestrians in Riyadh walk longer distances with slower walking speeds than Western pedestrians. Authors concluded that the pedestrian walking speeds are affected by walking distances, urban land use, social-economic conditions and trip purpose.

Morrall et al. (1991) studied pedestrian characteristics on sidewalks in central business district of Colombo, Sri Lanka. Pedestrian flow and speeds are manually counted during off peak and peak hours. Observed speed on sidewalks in Colombo are compared with that of Calgary. It is observed that male pedestrians walk faster than female pedestrians. Walking speeds in Colombian pedestrians are lower than Calgary pedestrians. Authors stated that the difference is due to the physique, cultural differences and shopping attractions. The free flow speeds of Asian pedestrians are significantly lower than Western pedestrians for all age groups. Pedestrian characteristics varies with region and location.

Koushki and Ali (1993) studied pedestrian speeds on sidewalks and indoor shopping malls in Kuwait city. Pedestrian samples were taken from 34 locations along the sidewalks, walkways and shopping malls. Pedestrian walking speeds on sidewalks 71m/min are found higher than those observed in Riyadh (65m/min). Pedestrian speeds in Riyadh and Kuwait are less than those in United Kingdom (79m/min) and United States (>80m/min). Author concluded that the difference is due to the high temperatures and hot climatic conditions. The mean walking speed in shopping malls is found to be 46m/min. The sidewalk walking speeds are found higher than the walking speeds in shopping malls. Pedestrian speeds are affected by climatic conditions, land use variations and cultural differences. Male pedestrians are found to be walking faster than female pedestrians.

Lam et al. (1995) studied pedestrian flow characteristics on walkways and crosswalks in Hong Kong. Pedestrian flow characteristics on crosswalks are studied at signalized and LRT signalized locations. Signalized locations include three sites- Yim Po Fong St, Hennessy Road and Cheung Yip Street. Mean walking speed of Signalized crosswalk in green and red phase are 76.2m/min and 90m/min respectively. It was concluded that the pedestrian walk faster in red phase to avoid conflicts with vehicular traffic. LRT signalized included one site- Tai Tong Station and mean walking speed is 98.4m/min. Bell model and Underwood model best fits for signalized and LRT crosswalks respectively. Maximum flows are 60 and 90ped/m/min for signalized and LRT crosswalks respectively. For pedestrian flow characteristics analysis on walkways, two outdoor walkways, Haiphong Road and Mody Square, and three Indoor walkways, Nan Fung, Tsuen Wan and KCR Kowloon, are studied. Mean walking speed on indoor walkway (49.8m/min) is lower than on outdoor walkway (71.6m/min). Mean walking speed of male (75m/min) is higher than the female (70.2m/min) pedestrians. Greenshields model best fitted for indoor walkways. Linear speed-density and parabolic flow-density, flow speed relationships are built. While, the Underwood model is best fitted outdoor walkways. Maximum flow rate for indoor walkway and outdoor walkway are 68 and 71ped/m/min respectively.

Lam and Cheung (2000) studied pedestrian flow characteristics on indoor and outdoor walkways, signalized and unsignalized crosswalks, Crosswalk at light rail transit station and walking facilities: stairways, escalators, passageway, concourse, and platform in Mass Transit Railway (MTR) and Kowloon-Canton Railway (KCR) stations, Hong Kong. Pedestrian travel time, flow and densities are collected from videography survey. Travel time function given by Bureau of Pubic Roads (BPR) is calibrated for each facility. Results showed that pedestrians walk faster on outdoor walkways. Walking speeds are higher on walkways without midblock than with midblock. Signalized crosswalks show higher walking speeds than at unsignalized crosswalks. Pedestrian walking speeds are affected by trip purpose.

Sarsam (2002) studied pedestrian crossing and walking speeds in Mosul central business district. Pedestrian speeds and flows are manually collected from three locations Sarachkhana, Dawasa, and Majmoaa. It is observed that the pedestrian speeds in minor flow reduces and comes to stand still. Queues build-up at higher densities in both the streams and on narrow width sidewalks. The mean crossing speed is 49.8m/min in Mosul and is found lower than Americans. It was found that age group and sex have no significant effect on walking speeds in Mosul.

Hoogendoorn and Daamen (2006) developed modified Kaplan-Meier approach to determine the pedestrian free flow speed. It is based on the distance to other pedestrian on observation area and the moment this distance occurs considering the walking directions of both the pedestrians. Free speed distributions are derived from laboratory experiments and free speeds are calculated using the modified approach. The free flow speeds calculated are higher than the literature because of unconstrained speeds considered for the estimations. In field conditions, pedestrians can be constrained even under low flows. Probability of pedestrian being constrained is higher for pedestrians with high free flow speed.

Al-Azzawi and Raeside (2007) studied pedestrian speed-density flows in six locations having different land use characteristics in United Kingdom. Pedestrian speed model defined by the Highway Capacity Manual (HCM) is calibrated from the extracted flow characteristics. The model is extended incorporating land use, pedestrian characteristics and uncountable variables time of day, day and weather. It is concluded that pedestrian speed is affected by gradient, presence of handrails and junctions. Gender and flow ratio are found insignificant. Pedestrians walking speeds are found inversely proportional to age. It is concluded that HCM over predicts at low LOS and planners should derive empirical models and calibrate to the local situations for designing walkways to cater for difference in environment conditions, pedestrian characteristics and land use characteristics.

Nazir et al. (2012) studied pedestrian flow characteristics on walkways in Khulna metropolitan city, Bangladesh. Pedestrian data is collected from video graphic technique from walkways located in Day Night College Road, K. D. Ghosh Road and Khan-A-Sabur Road. Then mean free flow speed is obtained as 51.67m/min with male and female free flow speeds 52.63m/min and 49.29m/min. The free flow speeds are lower than the Asian and American Counterparts. The young (52.83m/min) and adult (51.07m/min) walk faster than adult (47.67 m/min) pedestrians. Male pedestrians walk faster than female pedestrians. The authors concluded that pedestrian walking speeds are location dependent.

Chattaraja et al. (2013) studied pedestrian single file motion in India and Germany under controlled setup and also studied the impact of headway between pedestrians. Speed-density plots for India and Germany studies showed similar plots but with speeds higher for a given density observed in India. It is observed that Germans are more averse than Indians towards restricted personal space. Authors concluded that pedestrian flow fundamental diagrams and relationships varies with cultural differences.

Sarsam (2013) studied pedestrian walking speeds along sidewalks and crosswalks with respect to age, gender and clothing style at AL-Mansur, Al-Kadimiah, and Bab Al-Muadim located in the central business district of Baghdad. From the results it is concluded that the pedestrian walking speeds are affected by clothing tradition, gender and age. Male pedestrians walk faster than female pedestrians. Pedestrian age group 15-30 years walk faster than other age groups. Male pedestrian wearing Arabic clothing style walk faster than those wearing trousers. While crossing speeds of male pedestrians wearing trousers are higher. Female pedestrians are not influenced by the clothing style. Female pedestrians have crossing speeds less than male.

Cao et al. (2014) investigated pedestrian crossing behaviour, vehicle operating characteristics and pedestrian illegal crossing behaviour on Huanghe road segment at the Dalian Jiaotong University and compared during peak and off-peak periods. It is observed that the during peak period crossings, phenomenon of red-light runner crossing behaviour is prominent and is due to the impatience and safety consciousness of students to endure long waiting time for crossing. Mass following psychology of students is observed. Pedestrian crossing effects the vehicular traffic speeds, it decreases significantly during peak hour but vehicular flow does not change significantly.

Nazir et al. (2014) studied pedestrian flow characteristics on walkways located in Rajshahi City Corporation, Rajshahi University, and Shaheb Bazar in Rajshahi metropolitan city. The maximum flow is observed as 77ped//m/min and jam density3.75ped/m^2. Pedestrian mean walking speeds is found to be 67m/min and free flow speed 85.26m/min. Mean walking speeds is lower than Asian and American counterparts. The free flow speed is higher than Singapore, Britain and United States. Pedestrian speed significantly varies with age and gender. Free flow speeds and densities are proportional to each other. Pedestrian walking speed is significantly varied with location.

Abdulameer and Sarsam (2014) examined pedestrian speeds on sidewalks in Baghdad. Pedestrian speeds are observed along in central business district sidewalks located in Al-Karada Dakhil, a recreational and shopping zone, and Al- Sina’a Street, a commercial and educational zone. Male pedestrians (35.84m/min) are found to be walking with higher speeds than female pedestrians (33.783m/min). Adult pedestrians (18-50 years) walk faster than other age groups. Pedestrian dressing style effect, Arabic and trousers, are studied for walking speeds of male and female. Male pedestrian wearing trousers walk significantly faster than pedestrians wearing

Arabic style due to restriction in stepping length. Female pedestrians do not show significant variation in walking speeds with respect to dressing style.

Bargegol and Gilani (2015) studied pedestrian walking speeds variation on sidewalks in Rasht city of Iran. Pedestrian flow along the sidewalk is collected using videography survey and speeds are determined for male and female in normal and rainy day. Statistical t-test is conducted to observe the significant difference in walking speeds. Results showed that male pedestrians walk faster than female pedestrians. Walking speeds significantly differ on a rainy day and normal weather conditions. Pedestrian walking speeds does not vary with the usage of umbrella. Authors concluded that weather of the day significantly effects pedestrian walking speeds while umbrella does not affect pedestrian walking speeds.

Sarsam and Abdulameer (2015) studied pedestrian walking characteristics on sidewalks located along Al-Qalat, a tourist zone, and Ainkawa, a recreational and shopping zone in Erbil. Results showed that male pedestrians walk significantly faster than female pedestrians. Pedestrians aged 18-50 years walk faster than the older pedestrians. The mean free flow speed is observed to be 51.3m/m for Erbil and is lower than the Western countries in comparison. Male pedestrians wearing Kurdish style walk faster than western style wearing pedestrians. Female pedestrians showed no significant difference in walking speeds with respect to dressing styles. Authors concluded that the walking speeds varies with land use, location and dressing style.

Sarsam and Marwa (2015) studied pedestrian walking characteristics on sidewalks at Al-Qalat, a tourist zone and Ainkawa, a recreational and shopping zone located in the central business district of Erbil. Pedestrian data is collected using videography technique. Pedestrian speeds flow and density are extracted and analyzed. Results showed that the male pedestrians walk faster than female pedestrians. Pedestrian speeds are found to be lower in comparison to western countries signifying the effect of land use characteristics. Authors concluded that the walking speed depends in surrounding environment. Elders have the least walking speed while adults have the higher walking speeds. It was found that the male pedestrians wearing Kurdish style of clothing walk faster than the pedestrians wearing trousers. Female pedestrians with different clothing styles has no significant difference in walking speeds. Authors concluded that Pedestrian walking speeds are affected by clothing style and land use characteristics.

Jamshidpour et al. (2017) studied pedestrian intersection crossing speed, volume and density relationships in the metropolis of Rasht, Iran. Video recording data is collected from four intersections of which two intersections have traffic lights. Pedestrian speed and flow is extracted from the video. Pedestrian flow rate-density and speed-density showed linear relation while speed-flow rate showed square parabolic relation. Authors concluded that the flow rate and density does not influence crossing speed but density increases with increase in flow rate.

Gupta et al. (2017) studied the effect of gradient on pedestrian walking speed in central business district (CBD) areas of Dharamshala, India. Pedestrian movement data from areas Bus stand, Meera Restaurant and Asian Hotel is collected from videography survey. The gradient was collected from the Global Positioning System (GPS) device. Pedestrian’s walking speed and respective age, gender, luggage is extracted from the video data. Mean pedestrian uphill and downhill walking speeds were determined. From the results it was observed that for uphill and downhill pedestrian flows, males walk faster than female. Young pedestrians are found to walk faster and elders with least walking speeds. Pedestrians carrying luggage walk slower than without luggage. It was found that increasing gradient does not slow down speeds and is due to the difference in land use characteristics of CBD areas. Speed-density followed linear trend while flow-density, speed-flow and flow-area module followed quadratic. The speed-density trends for uphill and downhill are compared with the plain area research. It is observed that the uphill walking speeds are less than that on flat gradients.

Emtenan and Shahid (2017) studied pedestrian flow characteristics on exclusive sidewalks in urban areas Farmgate, Shahbag and Shukrabad of Dhaka. Pedestrian speed-density-flow studies showed negative linear relationship for speed-density and second degree polynomial relation for slow-density and speed-flow. It is observed that the jam density is effected by the land use characteristics. The free flow speed (1.18m/sec) is lower than the Western countries and is due to difference in cultural values. Pedestrian tend to escape side friction and walking speeds are high upon identification of side friction and walking speeds reduces when obstructed by high density. Pedestrian in groups walk slower than individuals. Pedestrian walking speeds are effected by width of sidewalk, density, side friction, groups, age and gender.

Vanumu et al. (2017) reviewed pedestrian flow studies on corridors, bottlenecks, T-Junctions, stairs and escalators. Authors stated that width of bottleneck and slop of stairs plays a vital role in deciding capacity of an element. Pedestrian speed is influenced by individual’s characteristics and external conditions. It greatly affects the level of service offered and capacity of the system. Authors concluded that the literature on empirical findings are limited and most research is focused on experiments. Experimental works do not capture actual behavior that exists in real life situations. Experimental research cannot be justified unless compared with field studies. Experimental, simulation and field studies are to be compared across various environments and cultures to establish a suitable adjustment factors. Fundamental diagrams are different for different elements. Flow parameters across various regions is to be studied to capture the effect of cultural differences. Pedestrian walking speeds varies with trip purpose and type of facility. Application of walking speeds of one facility design to other facility will not yield good results.

2.3 Studies on Pedestrian Level of Service

Polus et al. (1983) studied pedestrian flow characteristics on sidewalks in central business district of Haifa, Israel. Video recording data is collected and pedestrian flow characteristics are extracted. Results showed that female pedestrians have lower walking speeds than male pedestrians. Speed-Density plots for aggregated data is developed from the series of uniform width density ranges and corresponding speeds. At low speeds, speed is not affected by density, at moderate densities speed significantly reduced with increase in density. At higher densities, speeds steadily decreases with density. A single regime model and three regime models are constructed of which single regime model has qualitatively better statistical measures. From the three regime model for speed-density, four boundaries defining four level of services are determined for the walkways.

Seneviratne and Morrall (1985a) analyzed pedestrian travel studies in Calgary, Albeta, Canada on various facilities- sidewalks, pedestrian mall, intersection crosswalk, ramps, stairs, walkways located along central business district. Pedestrian speed, flow and origin-destination studies are collected. Authors concluded that the flow characteristics are significantly influenced by the time interval chosen for analysis and hence the regular variations should be considered in design phase. Pedestrians have more degree of freedom and hence can accept comparatively higher flows before movement is restricted than vehicular traffic. A large variance in average speed can be observed for a given flow rate due to pedestrian distribution over the section. Authors concluded that the high density and flow show less influence in route selection and is mainly dependent on walking distance. Pedestrian level of service are more subjective and should consider pedestrian perception in evaluation of facilities.

Tanaboriboon and Guyano (1989) developed LOS standards for the walkways in Bangkok. Using video graphic data, pedestrian flow along four sidewalks in central business district is collected for one week. Pedestrian travel time and number of pedestrians occupied between two reference lines are extracted from playback videos. Pedestrian speed and density relationship analyzed and found to follow linear relationship. Flow-density and flow-area module relationships are developed from the linear relationship of speed-density and classic equation, q= kv. Fruin's LOS design standards are used as guidelines where free flow condition defines LOS A and jammed conditions defines LOS E. Area occupancy and volume to capacity are used to obtain LOS threshold values. Pedestrian flow rate increases, and space occupancy decreases from LOS A to F. Comparison of LOS standards developed with that of United States revealed that the Thai pedestrians are observed to be more tolerate and occupy less space than Western pedestrians and achieve high flow. They concluded that Asian pedestrian require less personal space and more tolerate to the invasion of the space.

Al-Masaeid et al. (1993) studied pedestrian speed-flow relationships at central business district in Irbid, Jordan. Pedestrian flow and travel time are counted manually. Using regression analysis, pedestrian flow models to estimate one-minute flow are determined from average 5min, 10min and 15min flows. The relations ships are linear and it is concluded that the use of average 5min flow interval has lower variance and higher coefficient of determination to estimate the average one minute flow. Speed-flow relation showed a polynomial second degree fit with free flow speed of 1.463m/sec and maximum flow was 18.22ped/min/ft. Pedestrian responses and engineering judgment on the level of convenience offered by the sidewalks are collected from questionnaire survey. The correlation between engineering judgment and pedestrian responses is very low indicating the perception of pedestrians and engineers varies. Engineers evaluate as space available per pedestrian while pedestrians are found to evaluate based on walking conditions throughout the trip than confining to the specified section. With increase in sidewalk volume to capacity ratio (V/C), pedestrians walking along streets increases substantially seeking higher level of service.

Henson (2000) reviewed level of service evaluations for freeways, multi-lane highways, two lane highways, signalized intersections, unsignalized intersections, arterials, terminals and pedestrians. Authors concluded that the existing level of service for pedestrians are evaluated on space available per pedestrian. Pedestrian perceived factors comfort, convenience, safety, security and economy are also to be considered which affects pedestrian perception on overall quality. Average delay per pedestrian and quantitative relationship between delay and pedestrian LOS is required.

Landis et al. (2001) developed pedestrian perception towards safety and comfort on road segments in Florida using stepwise multivariable regression analysis. Various factors affecting safety and comfort are identified and segregated as Lateral spacing, Motor vehicle traffic volume, effect of speed, motor vehicle mix and driveway access frequency and volume. A group of individuals where asked to walk along the road segments and rate their perception towards safety and comfort on a scale of A (most safe and comfortable) to F (least safe and comfortable) considering the factors listed. It was observed that pedestrian's sense of safety is strongly influenced by sidewalk presence. As the motor vehicle volume passing by and speed of motor vehicles increases, pedestrian's sense of safety decreases. Pedestrian's sense of safety also reduces with uncontrolled vehicular access to adjoining properties.

Lee and Lam (2003) developed pedestrian LOS standards for stairways in MTR station, Hong Kong. A total of 16 qualitative factors are listed and respondents are asked to rank from 1(Not Important) -5(Very Important). Of these, seven factors are identified that respondents are most bothered. A set of photographs with various density levels on stairways are taken. Pedestrians accessed stairway are selected for survey to give their response on degree of importance of the seven factors identified and pick a photograph to represent the congestion level which represents the lower break point of the LOS they perceive. The indices of each factor are calculated and the lower break point for each LOS are arrived. It was observed that Lighting/clear visibility of stairways are most concerned and environment is least bothered.

Muraleetharan et al. (2003) evaluated pedestrian sidewalks and intersection crosswalks located around Hokkaido University, Sapporo. A questionnaire survey is conducted for pedestrians' willingness in using a facility under eight attribute and three level for each attribute. For sidewalks, the levels includes obstruction, flow rate and bicycle events. For intersection, the levels include crossing facilities, turning vehicles and delay. A total of 531 responses are obtained and conjoint analysis revealed that the flow rate of pedestrian is most significant attribute in using sidewalk. Pedestrians are also influenced by width, separation and percentage of cyclists.

Petritsch et al. (2006) developed pedestrian LOS model for the evaluation of arterials with sidewalks from the real time pedestrian participant's evaluation scorecards. A total of 11 urban arterials within and around downtown of Sarasota are evaluated from 100 participants.

Demographic characteristics of the participants are considered, and a statistical t-test revealed that there does not exists significant difference in the score assigned by pedestrians with respect to their attributes. A regression model is developed from the evaluation of participants with the influencing variable, identified from the Pearson correlations, total width of crossings at conflict locations and average 15-minute volume on adjacent roadway.

Wen et al. (2007) analyzed pedestrian flow and speed on walkways and stairways in People Square station and Shanghai Railway station, transfer stations of Shanghai metro to investigate level of service (LOS) standards empirically and compare with those that of thresholds given by Transit Capacity and Quality of Service Manual (TCQSM) . Pedestrian speed and flow are observed from moving observer method. The level of service experienced in the flow is acquired from the observer. Separate studies are conducted for walk ways, down stairs and up-stairs during morning and evening peak hours in weekdays. On walkways, it is observed that the pedestrian average speed, flow rate are higher for a given LOS and require smaller space in Shanghai in comparison to TCQSM. On upstairs, pedestrian's space thresholds in Shanghai are higher with lower walking speeds and flow rate for a given LOS. It is observed that the LOS A has lower walking speeds than LOS B and is due to pedestrians feeling a push force on upstairs. On downstairs, pedestrian's space requirement is higher and flow is higher than TCQSM for a given LOS. Difference in threshold limits are not observed for up-stairs and down-stairs.

Shouhua et al. (2009) developed LOS standards for passages in Xizhimen station of Beijing urban rail transit from stated preferences. They analyzed pedestrian perception towards passageway difference with respect to male - female, two age categories 0-20years and 20-40years. Female pedestrians and pedestrians under age group 0-20years perceive relatively lower LOS. Difference in culture background and smaller body size in comparison to east, LOS standards developed for Beijing URT is lower than the HCM 2000.

Yang et al. (2010) observations of Chinese pedestrian flow characteristics on stairways in passenger terminal showed maximum flow is lower and the corresponding space is larger in comparison to Western pedestrians. Chinese pedestrians are relatively less likely to concede space and maintain public order compared with occidentals. The space needed for a pedestrian to walk freely is smaller because of smaller body size and smaller pacing of steps than that of foreign pedestrians. Hence they stated that, as the average size of space occupied by a pedestrian is an important index, for evaluating the LOS, LOS standards are to be established considering pedestrian traffic and behavior. They vary with culture, region and surrounding and the LOS classification standards of facilities should reflect this variation. Based on Fruin's LOS development guidelines, LOS standards for stairways and walkways in Chinese Passenger terminal are developed and compared.

Christopoulou and Pitsiava-Latinopoulou (2012) developed pedestrian level of service model considering both qualitative and quantitative variable for Greek urban areas. Total of 18 parameters headed under three categories traffic parameter, geometry/environment/sidewalk parameters and pedestrian movement parameters are considered. Based on questionnaire survey the importance of each parameter are identified and assigned weightage and final model is developed. The model is compared with five more models from literature by validating it to the city of Thessaloniki. Results showed that the model yielded lower Level of service in comparison to the other model including the highway capacity manual as it takes qualitative parameters into account. They concluded that inclusion of qualitative parameters in level of service estimation reflects better results in perception to users. Level of service is overestimated or underestimated by quantitative parameters. The qualitative variables are determinative despite variations in pedestrian and traffic volumes for the estimation of level of service.

Yao et al. (2012) analyzed pedestrian behavior and flow characteristics on corridors, stairway and platforms. Pedestrian data is collected from Jianguomen subway station, Dongzhimen subway station, and Haidianhuangzhuang subway station, China which are constructed in early, midterm and newly. Critical observations made are that pedestrians slow down approaching stairs or corridor leading to congestion and queue formation. Pedestrian density and walking space significantly changes on platform with intertwined pedestrian flow occurring frequently from all directions. Pedestrian characteristics on stairs are influenced by stairway width, gravity and interactions. Walking speed decreases along downstairs. Maximum flow is obtained as 0.97persons/m/s with corresponding density 1.98persons/m^2. Speed-density showed logarithmic fit while density-volume showed quadratic fit. Authors concluded that the systematic analysis is important in enhancing the overall performance of a subway station.

Kang et al. (2013) studied pedestrian perceived LOS for sidewalks in China Shanghai, Beijing, Hangzhou and Hefei. An ordered probit model was developed. Individuals are shown with 15 video clips each of 60seconds actually taken from the field. After watchng, responses are collected from a questionnaire survey on pedestrain perception towards level of service offered by sidewalks shared with bicycles on urban streets for each video. A total of 114 repondants participated and from the responses it is found that pedestrian perceived LOS of sidewalks is significantly affected by pedestrian flow rate, sidewalk width, presence of a barrier separating the sidewalk from motor-vehicle traffic, presence of parking next to the sidewalk, presence of businesses along the sidewalk, bicycle flow rate, speed of bicyclist, whether or not bicycles were riding against the flow of pedestrians, weather conditions, time of day, and age of the respondent.

Sahani and Bhuyan (2013) developed pedestrian level of service (PLOS) standards for sidewalks in Bhubaneswar and Rourkela, India. They developed six PLOS (A to F) ranges from the pedestrian data: walking speed, flow rate, space and volume to capacity ratio, using affinity propagation technique. They concluded that the PLOS ranges are significantly different from that of HCM 2010 because of highly heterogeneous traffic flow on main carriageway, poor enforcement of traffic laws, varying road geometry, unauthorized vendors activities, unwanted obstructions from utilities and illegal parking on off-street facilities. Considering the local condition, data collection method using video cameras and affinity propagation clustering techniques can be applied in other countries to define the PLOS categories.

Rastogi et al. (2014) developed pedestrian level of service criterion for pedestrian movement along carriageway and on sidewalk. Pedestrian characteristics on these facilities are obtained from video recording data. Land use are classified as recreation, shopping and leading to railway or bus station. Pedestrian speed studies showed that the walking speeds are affected by land use characteristics. Walking speeds are higher at railway or bus stations. From the flow-area module plots are developed and the abrupt change points in slope are determined as the limits for various level of service standards. It is observed that the width effects the pedestrian speed significantly. Pedestrian speeds are higher on narrow width as they feel depart of the friction as early as possible. With increase in width, pedestrian trip purpose becomes significant in governing individuals speed. A LOS standards for facilities with different widths is also developed based on speed ratio-density plot.

Kadali and Vedagiri (2015) developed a probit model to evaluate crosswalk level of service in perspective of land use type. Pedestrian perception on crosswalk safety, difficulty and level of service offered are gathered from questionnaire survey from pedestrians crossing unprotected midblock. The same individual’s speed and interaction with vehicular traffic is collected from video recording data. Data is collected from eight unprotected mid-block crosswalks with varied land-use types in Mumbai, India. An ordered probit model is developed from the significant variables effecting safety, difficulty and level of service with respect to land use type. Authors stated that the pedestrian behavior changes with land use and this reflects in perceived LOS.

Kadali and Vedagiri (2016) reviewed the current literature on pedestrian level of service at midblock, crosswalks and sidewalks. The key observations are that the evaluation methods are changing from quantitative methods to qualitative methods in evaluating pedestrian LOS. Pedestrian LOS models combining qualitative and quantitative variables are developed for homogeneous traffic conditions and are to be extended for heterogeneous traffic conditions. The impact of persons with disabilities are not studied. Existing studies does not cover unprotected midblock crosswalks where pedestrian-vehicle interactions decrease the quality of crosswalk in developing countries. Many studies are confined for university campus and does not represent field conditions and heterogeneous traffic conditions. Pedestrian LOS with combined qualitative, quantitative methods and noncompliant behaviour of pedestrians are not addressed. Authors concluded that the pedestrian LOS models should consider traffic parameter, geometric parameters, vehicle characteristics effect in developing countries with heterogeneous traffic flow conditions.

Shah et al. (2016) developed pedestrian LOS standards for undivided stairways at suburban rail station. Pedestrian speed, flow, density and space are obtained from the pedestrian movement on undivided stairways in Dadar railway station, India. Pedestrian speed, dependent variable, variation with flow, density and space, independent variables are plotted and using k-means clustering, LOS thresholds are determined. It is observed that the pedestrian LOS for undivided stairway are different with those defined for Western countries and Chinese. Pedestrian space requirement are higher than Chinese. Authors concluded that the flow characteristics on stairways in India are different in comparison with Western and Chinese due to different physic and personal space requirements. Indian pedestrians walk closer creating denser region with heavy flow rate and this results in drop in average walking speed.

Banerjee et al. (2018) reviewed pedestrian flow characteristics and level of service studies on sidewalks, walkways, crosswalks, stairways, and escalators. Studies showed that the pedestrian flow characteristics varies with facility type and significant difference in speeds exists. In general, male pedestrians walk faster than female pedestrians. With respect to age, elder pedestrians walk slower than young pedestrians. It is observed that the speed-density varies in ascending and descending directions on stairways. Higher speeds and lower densities are observed in descending directions due to risk of falling and less effort involved to descend. Pedestrians maintain lower gaps in ascending direction. Pedestrian flow characteristics are affected by type of facility, dimensions, pedestrian age, gender, luggage, location, physique, culture, attractions, and trip characteristics. Determination of Pedestrian level of service includes both qualitative and quantitative variable in USA and Japan while in India, China and Malaysia qualitative variables are used.

2.4 Studies on Pedestrian Route Choice

Seneviratne (1985b) studied pedestrian origin-destination studies to analyze the pedestrian route choice effecting factors in central business district of Calgary, Alberta, Canada. A Questioner survey is adapted to acquire the trip maker characteristics, trip characteristics and location characteristics. Factors affecting route choice are ranked according to the most considered by the maximum number of persons. Shortest route is the most concerned factor by pedestrians as walking involves physical effort. Level of congestion, safety and visual attraction are secondary factors in choosing a route.

Cheung and Lam (1998) studied pedestrian choice between escalator and stairway in mass transit stations (MTR) stations. Pedestrian flow data on stairways, escalators and walkway leading to stairway/escalator are collected using video graph technique. Travel time of pedestrians are extracted, and the travel function based on Bureau of Public Roads is calibrated. Video recording data is collected from six MTR stations Admiralty, Kowloon Tong, Prince Edward, Wanchai, Tsuimshatui, and Mongkok in Hongkong. Travel time, flow and density are extracted semi automatically. Travel time comprises of travel time on walkway leading to facility and travel time on the facility. It is assumed that pedestrians perceive relative delays in choosing between stairway and escalator. Walking speeds on walkway leading to facilities is lower than the indoor walking speeds as pedestrians decelerate approaching to facility. From the results, it is observed that pedestrians are more sensitive to relative delays on descending facilities than in ascending direction. Pedestrians’ use of escalator is higher than escalator in descending direction for same travel time and is due to the effort involved in traverse. Hence it is also concluded that the pedestrians are also affected by the effort in walking stairway. Results also showed that the capacity of stairways is also higher than the European cities and is due to the smaller Asian physique requiring less space for movement. It is observed that the free flow walking speeds descending direction is higher than the ascending direction. Pedestrian speeds are less evenly distributed at lower flow rates as they are free to control their speeds.

Faskunger et al. (2003) studied pedestrian use of stairway and escalator under escalator favoured condition in which two escalators are operated and stairway favoured condition in which on escalator is being operated in a suburb commuter station in Stockholm, Sweden. Pedestrian volume count for each condition resulted that the stairwell use dropped by half and the use of escalator increase by nearly one third when two escalators are operated. It is concluded that the constructed environment influences the decision to use stairway.

Daamen et al. (2005a) developed a path-size logit model to replicate the passenger rout choice in a railway station. Pedestrian track data is collected from Delft and Breda railway stations, Dutch. Passenger characteristics, trip characteristics, route characteristics and environment data are collected. Pedestrian route choice is independent of the facility a route consists of and is dependent on walking time and effort involved. Escalators and ramps are much valued to stairs as stairs involves more effort in climbing. For lower level heights, stairs are preferred and with increase in height passengers shift to escalators. Trip characteristics, boarding or alighting, does not influence passenger's behaviour. Passengers' behaviour is independent of time of day. Bad weather conditions makes passengers to choose shortest route.

Daamen et al. (2005b) studied passenger route choice behaviour in Delft and Breda, Dutch railway stations. Passenger's route is tracked noting route characteristics, trip characteristics, facility used, personal characteristics, environmental characteristics, day and weather are collected. A path-size logit model is developed for the passenger route choice. Results indicated passengers choose routes with shortest walking time. Walking on vertical facility has higher disutility than walking on level facility. Escalators and ramps are valued higher than stairways. Long or steep ramps are lower valued than ramps with low grade. Facility characteristics along with length also affects the route choice. Pedestrians often use stairs for limited level changes and shift to escalators increases with increase in level change height because of the effort it includes in stair climbing.

Daamen et al. (2006) studied pedestrian route choice behaviour and developed an extended rout choice model based on path-size logit model. Pedestrian origin-destination paths, pedestrian attributes age, gender and corresponding travel time, choice between escalator, ramp and stairways in the path are observed from two railway stations Delft and Breda of Dutch railway stations. It is observed that the travel time is influencing factor in route choice. It is also observed that the route choice is also affected by type of facility level element, stairs, escalators and ramps. Use of escalator is higher than stairs. Stairs are least valued than ramps and escalator. Escalators are preferred to ramps. Escalators and ramps are much preferred in descending direction. Pedestrian attributes age, gender and luggage effect on rout choice reveled that adults prefer shortest route. There existed no difference in rout choice during morning and evening peak. However pedestrians choose shortest route in bad weather condition.

Rasanen et al. (2007) studied the pedestrian usage of foot over bridges to cross roads in central business district of Anakara, Turkey. The use of five pedestrian bridges using a questioner survey among the users and non-users of same bridge is conducted to understand the factors affecting the use rate of bridge. From the results it is observed that the respondent's bridge use has positive relation with the user perception of using bridge as safe and time saving. With increase in frequency of pedestrian to visit the CBD, use of pedestrian bridge decreases. Studies showed that the use or non-use of pedestrian bridge is a habit and not a coincidental behaviour. Pedestrian bridge use increases with increase in legs leading to bridge while provision of signals under the bridge decrease the use rate. User perception on safety and convenience to use bridge without considerable time loss increases the use rate.

Suhua et al. (2010) calibrated impedance function model derived from Bureau of Public roads (BPR) model for pedestrian flow in urban rail transit station, Nanjing Station. Layout pattern of escalator and stairway, technique parameters of escalator and stairway, pedestrian flow, and pedestrian traffic characteristics are the factors effecting impedance functions. Impedance functions are calibrated for walkway leading to escalator, walkway leading to stairway, escalator (upward) and stairway (upward). Pedestrian route choice model for stairway and escalator use is developed based on impedance function and results showed that few pedestrians choose stairway for a reasonable delay time. With increase in delay time, pedestrians shift towards stairways increases.

Eves et al. (2008) studied the passenger's choice between stairways and escalators. Number of Passengers using the stairway and escalator are counted and the total time taken for the passengers to exit the facilities are noted for every train arrival. The transport rate of escalator and stairs are modelled using regression analysis from the total number of passengers leaving for every train arrival. For an aggregated data, proportion of stair use and escalator use are determined. For a stair width doubled, proportions of stairway use and escalator use estimated. It is observed that passengers using stairway increases with increase in stairway width. Authors concluded that stairway width increases increase the proportion of stairway use.

Kang et al. (2009) studied pedestrian choice among stairs, escalator and elevator in Gwangmyeong station in South Korea. Pedestrian revealed preferences are collected travel route times, travel time on facilities are collected. Utility function is estimated on each of the facilities. Pedestrian route choice models are developed using multinomial logit model. Results showed that elevators use increased with increase in moving times on escalator. With the moving time increase on stairs, pedestrians using escalators and elevators increased. Pedestrian’s choosing escalators increases with increase in moving time route and rate of level change facility on route. Pedestrian’s choice of elevators is little with increase in travel time on escalators because of confusion or delay.

Ji et al. (2013) developed logit model to replicate pedestrian choice between escalator and stairway in Shanghai transfer station. Both quantitative and non-quantitative factors, reflected by familiarity, walking disutility and time pressure are considered for model development. Familiarity determines the pedestrian’s familiar with the area and facility. Larger the parameter, pedestrian more likely make a choice based on familiarity. Walking disutility is generalized cost a pedestrian spends for facility and is calculated considering pedestrian age and luggage. Congestion disutility represents the crowd ahead of stairway or escalator. Walking disutility and congestion disutility together defines the pedestrian perceived disutility in making choice. Time pressure parameter define the pressure a pedestrian is subjected to, which is more dominant during peak hour. The more pedestrian feel, the bigger the eager to transfer. The time pressure parameter is found to be more fluctuating because of the pedestrian hesitate between saving time and saving energy.

Li et al. (2014) studied the effect of height between layers on pedestrian choice between stairway and escalator in transfer station. Video data of pedestrian flow on stairway and escalator from four transfer stations Xizhimen subway station, Zoo Station, Beijing South Railway station and Zhichun Road station is collected. Peak time, direction, structure of facility: height, length and width, speed of escalators, queue, and luggage carrying factors are obtained. Walking time, delay, interlayer height and luggage carrying are found to be influencing variables. A binary logit model is developed from the significant variables identified. From the results, it is concluded height significantly affects pedestrian choice behaviour between escalator and stairway. They are much sensitive to facility height in ascending than in descending direction. With the increase in interlayer height, pedestrian shift towards escalator use increases. With the increase in interlayer height, pedestrian acceptable delay time increases and probability of choosing stairway reduces.

Wu et al. (2014) studied factors affecting pedestrian choice of overpass usage and a binary logit model is developed from the significant factors identified. Pedestrian concerning factors for overpass usage are identified from questionnaire survey constituting the individual information, pedestrian consciousness and characteristics of over pass and environment. Data is collected from both users and non-users of overpass during weekdays on a fine weather day from eight overpass locations situated in Second Circular Road of Xi'an, Wild Goose Pagoda Square and Xiaozhai Road. From the results, gender, age, career, education level, license, detour wishes, detour distance, and crossing time are identified as significant variables. Overpass characteristics and street under overpass showed no effect on overpass selection.

Srikukenthiran et al. (2014) developed mixed logit model to replicate pedestrian vertical transport choice in Toronto subway Stations. Pedestrian movement on stairway and escalators is collected from video data from six stations of which three are located in the downtown core, Bloor, St. George and Union, and three suburban stations, Finch, Downsview and York Mills. Stairway use factor, opposing density, escalator use factor, queue factor, stair approach and height are the variables considered for model development. Significant variables are identified from step-wise backward elimination process and significant variables are included in the final model. Individual models are developed from ascending and descending direction. It is observed that pedestrians mimic or follow-the-leader behaviour in stairway and escalator use. Opposing stair flow and queuing show negative affect in stair use.

Das and Barua (2015) investigated pedestrian concerned factors in using existing foot over bridges for road crossings and possible causes of reluctance in usage. A questionnaire survey is conducted at busy intersections Banani, Mirpur, Farmgate, Bangla Motor, Uttara and Notun Bazar in Dhaka, Bangladesh. Results showed that foot over bridge height, occupancy of hawker, congestion, dirt, lack of security and uneasy are insignificant factors in using a foot over bridge. A regression model for overall rating is developed from significant factors time consuming, long walk, poor access and inappropriate position.

Lazi and Mustafa (2015b) studied pedestrian flow proportion variation between escalator and staircase in Masjid Jamek Terminal. Pedestrian flows over a week during peak hours and non-peak hours is collected. It is observed that over 90% of pedestrian prefer to use escalator. Pedestrians using staircase during morning are higher than in evening. It is concluded that the Malaysian pedestrians prefer escalator to staircase in descending direction.

Xu et al. (2015) developed passenger path control route choice model during peak periods for the Kecun station layout of Guangzhou subway. Utility function is estimated from the difference of waiting time and walking time on passageway, stairways in ascending and descending, and escalators of infrastructure and overlap factors. Travel time function given by the Bureau of Public Roads (BPR) is calibrated for each element. It was observed that the walking time at a facility is related to the passenger density and pedestrian route choice is affected by the crowdedness.

Zacharias and Ling (2015) studied pedestrian use of escalator and stairway in shopping centres to understand the effect of location of facilities. A total of 13 stairway and 12 pairs of escalators from seven shopping centres are studied in the downtown of Montreal, Canada. The pedestrian movement is manually counted for every five minutes and the distance from the stairway to nearest escalator, height of the facility is collected from each study site. An ordinary least squares regression model is developed with stair count being independent variable and dependent variables being distance between stairway and nearest escalator, height between levels in individual centres and 5-minutes count totalled for all channels. From the results it is observed that the distance has positive impact and height has negative impact on stair use. For a 100% increase in height reduced stair use by 50%. Increase in distance between stairway and escalator increase the variance in stairway use.

Zacharias and Tang (2015) studied the effect of pedestrian volume, height, and distance between stairway and escalator on pedestrian’s choice between stairs and escalators in China near electronic market and inside shopping centres. A linear regression model is developed with each independent variable entered successively to study the relative contribution to variance in prediction in both ascent and descent models. A variance of 40.9% and 45.5% is explained in descent and ascent models respectively with all the three variables. It is concluded that separating stairway and escalator increases stairway use effectively. Increasing height between floors has reduces stairway use. Pedestrians tend to use stairway in descending direction than in ascending direction when pedestrian volume increases.

Zhang et al. (2015) developed pedestrian route choice, binary logit, model for the vertical facilities between rail station platform and station hall. Reveled preference data is collected from three rail transit stations Xinjiekou, Gulou and Nanjingzhan stations. Station static data, pedestrian characteristics and travel characteristics are collected. Of the factors, walking distance, walking time and age are found to be influencing choice between stairway and escalator. Separate models for ascending and descending directions. With increase in pedestrian flow and delay, pedestrians using stairway increases giving up escalator. Pedestrians are more sensitive to relative delays in descending direction than in ascending direction. Pedestrian getting of train often uses the facility (stairway/ escalator) near to them.

Li et al. (2016) developed pedestrian vertical choice model between stairway and escalator using support vector machine. Video data is collected from Changchun light-rail transfer station and Beijing Xizhimen transfer station. Four factors interlayer height, luggage, the difference between queuing pedestrians and walking facility speed are considered as influencing variables selected using Regression Analysis Stepwise (RSA) to establish choice model. Model predictability is found to be good with mean accuracy of 89.38 %.

2.5 Summary of Literature

Researchers across the globe addressed pedestrian flow characteristics on various facilities such as sidewalks, walkways, crosswalks, passageways, stairways and escalators at various locations. Empirical relations are built among flow characteristics. The fundamental curves are similar for different facilities but with different coefficients signifying the effect of facility type on pedestrian flow characteristics. Pedestrian flow studies on sidewalks, walkways and crosswalks showed that the pedestrian speed-flow-densities varies with location and region. The pedestrian flows are found to increase with increase in density up to optimal density. However their walking speeds are influenced by flow, density as well as various pedestrian characteristics, facility characteristics, environmental characteristics and trip characteristics. Pedestrian walking speeds are effected by width of sidewalk, density, side friction, groups, age and gender. Existence of side friction causes pedestrian a psychological fell of unsecure and tries to get of it as early as possible. Pedestrians in group walk slower than individuals and female pedestrians walk slower than male pedestrians. It was found that the walking speed is inversely proportional to age. Pedestrian walking speeds recorded over the Eastern-Asian countries are lower than the Western countries signifying the cultural and social values along with body physic effecting the pedestrian flow characteristics. The walking speeds are found to vary with the trip purpose, land use characteristics and weather conditions. Pedestrian dressing style influence showed significant effect on male pedestrians walking speed. The flow rates are observed to vary with type of facility.

Pedestrian flow characteristics on passageways in metro stations, subways leading to railway stations and passageways connecting metro stations with malls are studied. The walking speeds are found to vary with the type of station. The speeds and densities are found to fall in low ranges due to random pedestrian movements caused by arrival of trains. Flow characteristics on one-way passageway varies with the two-way passageway. The free flow speed are higher with lower critical densities on passageways than on stairways.

Pedestrian behaviour on stairways are studied by researchers by both controlled experiments and in real conditions at metro stations, suburban and intercity railway stations. Pedestrian speeds are observed to be influenced by stairway gradient and direction of movement. Their step is consistent on stairs with higher step frequency in down-stairs than on up-stairs resulting higher walking speeds in ascending direction than on descending direction. They are more sensitive to space in descending direction and the observed capacity is lower than ascending direction. At lower densities, pedestrian available space is higher and walks with desired speed. With increase in density and flow, speed increases, attains maximum and declines. Higher capacity with lower speeds are observed on stairways in India in comparison to Western due to higher tolerance in available space by the Indian pedestrians. Proportion of flow in bidirectional stairways showed higher walking speeds in the direction of major flow. Pedestrian walking speeds for a given flow rate and width are observed to be varying by the functionality of station. The individual attributes like gender, age and luggage have significant effect on walking speeds with male and pedestrians walking without carrying luggage walking faster than their counterparts. It is also influenced by the time of day and weather. Walking speeds are observed higher in afternoon than the evening due to lighting and physical state of pedestrians. The walking speeds on wider stairways are higher than on narrow stairways and further increase in width showed slower walking speeds. An increment of step rise significantly affects the walking speeds. Also speeds varies with culture, topography, environment and hence realistic acceptable ranges of stairway dimensions are to be concluded from the pedestrian flow behaviour studies with respect location and purpose it serves.

Escalators are expected to carry large number of pedestrians than stairways due to its higher operating speed and the capacity varies with operating speed. It is observed that the escalator use is higher in Western countries. The practical capacity is observed to be less than the theoretical capacity. It is influenced by the building type it serves, location, proportion of standing/walking pedestrians and direction it serves. The flows are observed to be higher in metro stations than in shopping centers. Pedestrian flow in descending direction is observed to be higher than in ascending direction because of the subjective feeling of nearness in ascending direction.

Pedestrian choice between stairway and escalator, and route choice from entrance to exit are analyzed to understand the factors influencing and are modeled to mimic the same. Linear regression, path size logit model, binary logit model are used to model the pedestrian behaviour in route choice in metro stations and shopping malls. The choice between stair and escalator is effected by the delay caused on each facility including the delay on the walkway leading to each facility. Pedestrians are more sensitive to relative delays in descending direction. Pedestrian route choice involves vertical movement on stairways, escalator and is influenced by the crowdedness and shortest path, with lower walking times is the most concerned factor in choosing a route. Congestion level, safety and visual attraction are secondary factors.. Separating stair and escalators increases stair use effectively while height, opposing stair flow and queuing have negative effect in stair use. Study of transport capacity of stairway and escalator showed the increase in stairway use with increase in stairway width. Trip purpose and time of day has no influence while weather and day of week effects choice between escalator and stairs in choosing shortest paths.

Level of service (LOS) on pedestrian facilities intersection, sidewalks, crosswalks, walkways on urban streets and stairways in metro stations are determined and evaluation models are developed using ordered probit model, weighted regression model, k-mean clustering analysis, affinity propagation. LOS standards given by the HCM and TCQSM are derived from the space available and speeds for various flow ranges and are purely quantitative. The LOS standards developed for various faculties are compared with the standards of HCM and TCQSM. Thresholds varied with type of facility, region and location. LOS standards are to be established considering pedestrian traffic and behavior. Studies concluded that the pedestrian LOS models should consider traffic parameter and geometric parameters in developing countries with heterogeneous traffic flow conditions. They vary with culture, region and surrounding and the LOS classification standards of facilities should reflect this variation. Pedestrian LOS standards for stairways in suburban railway station from the quantitative variables speed-flow-density-space concluded that the flow characteristics on stairways in India are different in comparison with Western and Chinese due to different physic and personal space requirements. Indian pedestrians walk closer creating denser region with heavy flow rate and this results in drop in average walking speed. Pedestrian level of service are more subjective and should consider pedestrian perception in evaluation of facilities. Level of service overestimates or underestimates by quantitative parameters. The qualitative variables are determinative despite variations in pedestrian and traffic volumes for the estimation of level of service. Pedestrian perceived factors comfort, convenience, safety, security and economy are also to be considered which affects pedestrian perception on overall quality.

In the next chapter, detailed methodology adopted for the present study is explained with a methodological flow chart. Detailed description of study areas selected, data collected and data extraction are presented.

CHAPTER 3

METHODOLOGY AND DATA COLLECTION

3.1 General

This chapter presents the detailed methodology followed to work out the objectives framed from the literature review and the data collected. The sub sections gives adopted methodological flow chart from the objectives set to the final conclusions. To aptly suit with the requirements of the objectives defined, intercity railway stations are selected for the study. Level changing facilities such as elevated passageway which have stairway along with escalator are selected for the study. Passageways and stairways provide bidirectional flow while escalators serve in ascending direction only.

3.2 Study Methodology

The methodological flow chart adopted in this research work is presented in figure 3.1. The objectives of the work are derived from a thorough literature review on level changing facilities: passageway, stairway and escalator. Study areas that suit the defined objectives and data requirements are selected. Dimensions of each level changing facility infrastructure element are collected from the study area. Dimensional data includes passageway width, length and platforms it serves, Stairway width, step rise and tread, intermediated landing length, stair gradient and platforms it serves, escalator width, step rise and tread, slope and platforms it serves are collected. Trap lengths on facilities are marked using a colored stick tape. Video recording cameras are positioned on a suitable location to capture pedestrian movement on the facility covering the trap length without any obstructions and interruptions.

Video recording data is chosen as it provides,

- A permanent record of data to refer where and when required.
- Manual and moving observer yields small data set in comparison to video recording data.
- For a flow rate and density, large number of pedestrian's speeds with different attributes: age, gender, luggage, and moving direction, can be obtained from play back videos.

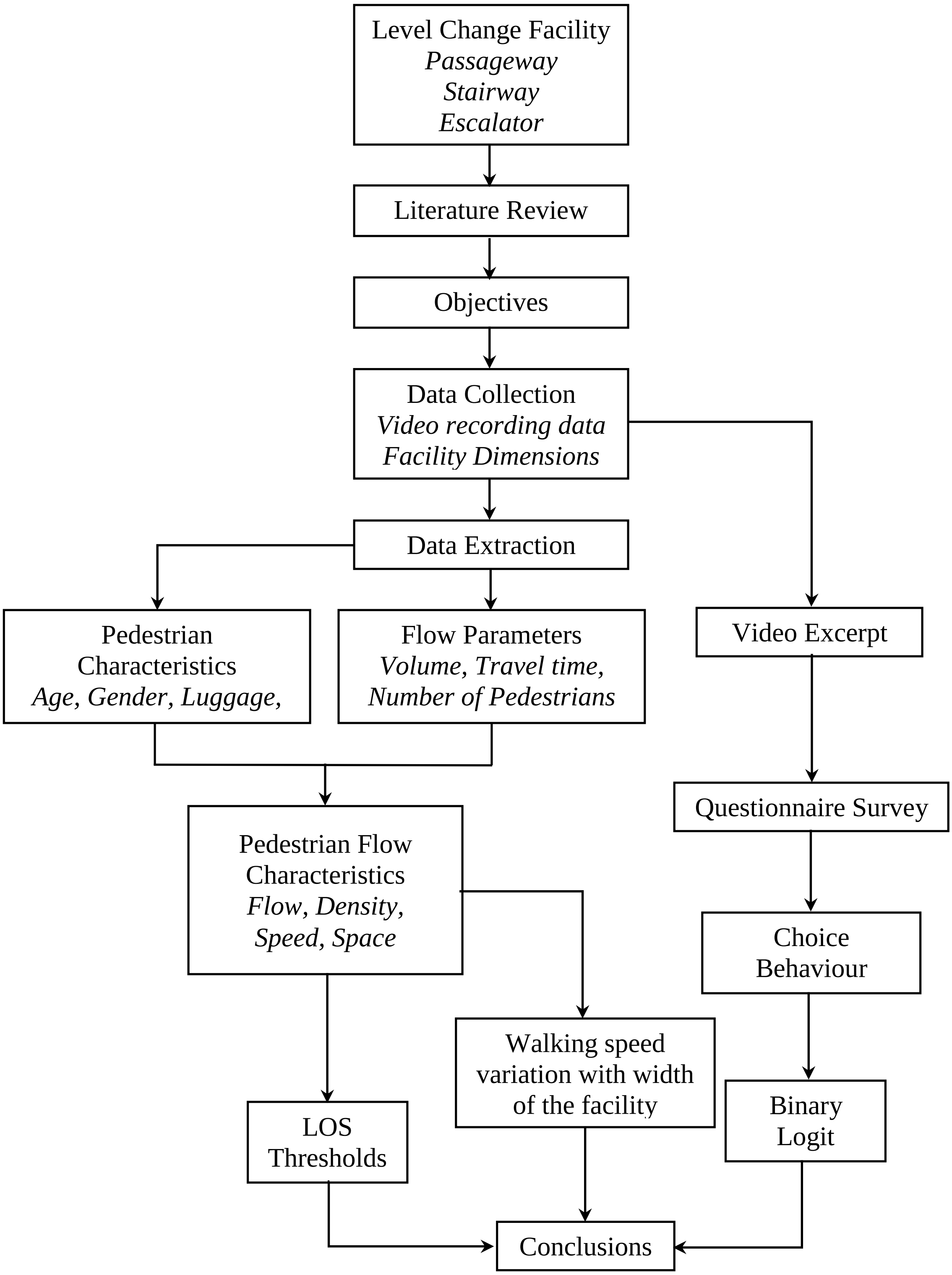


Figure 3.1 Methodology Flow Chart

- Manual and moving observer method involve human errors due to tiredness and fatigue feeling of observers.

- Accuracy of video data is relatively greater over other two methods as the play back videos provide travel times to three decimals.
- Low cost and lesser number of observers are required for video recording method in comparison to other two methods.

The recorded videos are played back using Media Player Classis Home Cinema (MPC-HC) player. It gives the time to near micro seconds. From the play back videos, pedestrian volume crossing, number of pedestrians occupying trap area created by trap length and width of facility, and travel time of pedestrians with their personal attributes like age, gender, luggage and direction are extracted. From the extracted data, pedestrian flow (ped/m/min), density (ped/m^2) and speed (m/min) are determined for each minute of flow.

Pedestrian flow characteristics relationships flow-density and flow-space are established and appropriate curves are fitted. The maximum flow, optimal density, mean speed and free flow speed are obtained. The pedestrian flow characteristics on passageway with horizontal movement is compared with the vertical movement on stairways. Pedestrian walking behaviour on stairways, escalator and passageway are compared with earlier studies. The pedestrian walking speed variation with width of facility are studied. Pedestrian level of service thresholds are determined from the pedestrian flow characteristics for the passageway and stairway. A stated preference questionnaire survey is conducted for the excerpts of videos cropped from the video data collected to obtain the perception of pedestrian and analyze their choice behaviour. A binary logit models is developed to replicate the pedestrian perception of choice between stairway and escalator in ascending direction. Final conclusions are made for the objectives from the results obtained.

3.3 Study Area

Three major intercity railway stations Secunderabad, Warangal and Vijayawada are selected for the present study. These stations are located along the Secunderabad-Vijayawada corridor of south central railway zone.

3.3.1 Secunderabad Railway Station

The Secunderabad Railway Station (Station Code: SC) is located in the urban area of Hyderabad City, the capital of Telangana State, India, and is one of the biggest and busiest railway station of Indian railways. It has integrated Multi Modal Transport System (MMTS) of sub-urban rail system. The MMTS, Telangana State Road Transport Corporation buses and Hyderabad Metro connects various parts of twin cities of Secunderabad and Hyderabad. The station has ten platforms each serving a variety of train services and all connected with four foot over bridges for pedestrians' access.

3.3.2 Warangal Railway Station

Warangal Railway Station (Station Code: WL) is located in the Warangal city, Warangal Urban district of Telangana falling under the administration of Secunderabad railway division. The station has three platforms connected with two foot over bridges. One is located near to the entry/exit and ticketing service of the station while other is located at one end of the station.

3.3.3 Vijayawada Railway Station

Vijayawada Railway station (Station Code: BZA) is located in the Vijayawada City under Vijayawada Division and is the fourth busiest railway station in India. It has ten platforms connected with four foot over bridges for pedestrian to access among platforms. All are being associated with adjacent ticketing services, food stalls and entry/exit points.

3.4 Data Collection

In SC, pedestrian flow data is collected as Closed Circuit Television (CCTV) footage on two passageways SC_{P1} and SC_{P2}. Of these, S_{P1} has central rail to separate directional flow. The SC_{P1} and SC_{P2} serves platform 10. In WL, pedestrian flow data is captured using a hand held video camera on one passageway WL_{P} located between platforms 1-2. In BZA, pedestrian flow data is recorded on four passageways BZA_{P1}, BZA_{P2}, BZA_{P3}, and BZA_{P4}, of which BZA_{P1} connects platforms 3-4 and BZA_{P3} connects platforms 7-8 on one foot over bridge. While BZA_{P2} is connecting platforms 3-4, and BZA_{P4} connecting 1-2 platforms on another foot over bridge. The dimensional details of the passageways, stairway and escalator are measured in the railway station using a measuring tape. Table 3.1 shows the dimensional description of passageways. Figure 3.2 shows the snapshots of passageways from the intercity railway stations SC, WL and BZA.

Table 3.1 Dimensional Description of Passageways

Passageway	SC_{P1} (With Central rail)	SC_{P2} (Without Central rail)	WL_{P}	BZA_{P1}	BZA_{P2}	BZA_{P3}	BZA_{P4}
Length (m)	14	14	25.7	17.8	17.8	58.1	28.4
Width (m)	4.5	4.5	2.1	3.5	2.3	2.3	3.4

3.2(a): SC_{P1}- Secunderabad without central rail

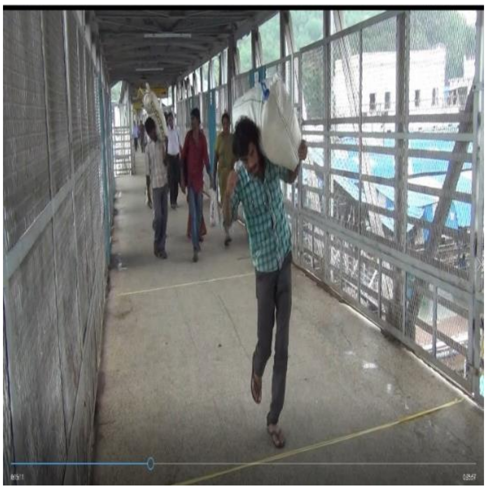
3.2(b): SC_{P2}- Secunderabad with central Rail

3.2(c): WL_{P}- Warangal Passageway

3.2(d): BZA_{P1}- Vijayawada Passageway 1

3.2(e): BZA_{P2}- Vijayawada Passageway 2

3.2(f): BZA_{P3}- Vijayawada Passageway 3



3.2(g): BZA_{P4}- Vijayawada Passageway 4

Figure 3.2 Snapshots of passageways in intercity railway stations

In SC, pedestrian flow data from the CCTV is collected on one stairway SC_S serving platform 1. Video recording data of pedestrian movement on one stairway WL_S serving platform 1 in WL is collected. Four stairways BZA_{S1}, BZA_{S2}, BZA_{S3}, and BZA_{S4} are taken for pedestrian flow data recording from BZA. Of these, BZA_{S1} serves platform 1, BZA_{S2} serves platform 2-3, BZA_{S3} serves platform 4-5, and BZA_{S4} serves 6-7. Table 3.2 shows the dimensional description of stairways. Figure 3.3 show the snapshots of stairways from the intercity railway stations SC, WL, and BZA.

Table 3.2 Dimensional Description of Stairways

Description	SC_S	WL_S	BZA_{S1}	BZA_{S2}	BZA_{S3}	BZA_{S4}
Width of stairway (m)	3.5	2.4	3.6	2.0	2.0	3.5
Step foot (m)	0.40	0.35	0.30	0.30	0.30	0.30
Step riser (m)	0.22	0.15	0.15	0.15	0.15	0.15
Number of steps	41	33	41	41	41	41
Length of intermediate landing (m)	1.76	1.45	1.50	-NP-	1.40	2.5
Inclination (degrees)	32^0	34^0	30^0	30^0	30^0	34^0

NP- Not Provided

3.3(a): SC_S- Secunderabad Stairway

3.3(b): WL_S-Warangal Stairway

3.3(c): BZA_{S1}- Vijayawada Stairway 1

3.3(d): BZA_{S2}- Vijayawada Stairway 2

3.3(e): BZA_{S3}-Vijayawada Stairway 3

3.3(f): BZA_{S4}-Vijayawada Stairway 4

Figure 3.3 Snapshots of stairways in intercity railway stations

Pedestrian flow on escalators is collected from on escalator SC_E serving platform 1 in SC from CCTV footage. In WL, escalator WL_E serving platform 1 is video recorded to capture pedestrian flow. In BZA, Pedestrian flow data on four escalators BZA_{E1}, BZA_{E2}, BZA_{E3}, and BZA_{E4} are captured. BZA_{E1} serves platform 2-3, BZA_{E2} serves platforms 4-5, BZA_{E3} serves platform 10, and BZA_{E4} serves platform 1. Thus pedestrian data on a total of seven passageways, six stairways and six escalators is collected. Figure 3.4 show the snapshots of escalators from the intercity railway stations SC, WL, and BZA. Dimensional description of escalators are given in table 3.3. The S_{P1}, S_S, and S_E located on same foot over bridge while S_{P2} is from adjacent foot over bridge. In WL, WL_P, WL_S, and WL_E all serving platform 1 for same foot over bridge located near to the entry/exit of station and ticket booking center. In BZA, passageway $BZAP_2$ and $BZAP_4$ are from one foot over bridge. While BZA_{P1} and BZA_{P3}, all escalators and stairways are from same foot over bridge.

Table 3.3 Dimensional description of Escalators

Description	SC_E	WL_E	BZA_{E1}	BZA_{E2}	BZA_{E3}	BZA_{E4}
Width (m)	1.0	1.0	1.0	1.0	1.0	1.0
Step Foot (m)	0.46	0.4	0.4	0.4	0.4	0.4
Step Rise (m)	0.285	0.27	0.20	0.20	0.20	0.20
Inclination	32^0	34^0	30^0	30^0	30^0	34^0
Number of steps	25	30	40	40	40	31

3.4(a): SC$_E$-Secunderabad Escalator

3.4(b): WL$_E$-Warangal Escalator

3.4(c): BZA$_{E1}$-Vijayawada Escalator 1

3.4(d): BZA$_{E2}$-Vijayawada Escalator 2

3.4(e): BZA$_{E3}$-Vijayawada Escalator 3

3.4(f): BZA$_{E4}$-Vijayawada Escalator 4

Figure 3.4 Snapshots of escalators in intercity railway stations

3.5 Data Extraction

Video recorded data of pedestrian flow on each facility is play backed using Media classic player home classic. Under normal pedestrian densities and flow, videos are played at normal speeds but at higher densities and flows, it is difficult to extract required data and hence slow speed playing of videos is adopted. From the play back videos, pedestrian flow characteristics: flow, density and speed are determined for one minute interval. The detailed procedure of determination of each flow parameter is as follows:

3.5.1 Pedestrian Flow

The number of pedestrians passing a line of sight across the width of facility is counted for one minute. On passageway and stairways, pedestrian flow is bidirectional and hence the number of pedestrians counted refers to the total number of pedestrians in the two directions. The bidirectional pedestrian flow rate (ped/m/min) is obtained as the number of pedestrians crossing divided by the width of the facility for each minute. On escalators, pedestrian flow rate refers to ascending direction as it serves in ascending direction.

3.5.2 Pedestrian Density

Pedestrian density (ped/m^2) is defined as the number of pedestrian occupying a unit area. To determine the pedestrian density corresponding to a flow rate, from the play back videos, for a minute, video is paused randomly at random instances and number of pedestrians occupying trap area, created by the product of distance between two reference lines across the facility and width of the facility, are counted. The number is divided by the trap area to obtain the pedestrian density for that instance of time. The arithmetic mean of five instances in a minute is taken as the pedestrian density for the corresponding flow rate of that minute.

3.5.3 Pedestrian Walking Speed

Pedestrian walking speed is obtained by dividing the distance between two reference lines with the travel time to cross the two reference lines. The travel time for a pedestrian is extracted from the play back video manually. As it is laborious and time taking to determine the travel time and computing speeds of all pedestrians, a sample of three to five pedestrians are taken as representatives in each direction per minute, who walk along with the crowd, neither surpass nor surpassed, are chosen to determine the average walking speed of all the pedestrians for corresponding flow rate of a minute.

Pedestrian individual's characteristics age, gender, luggage and direction of movement are collected for the same pedestrian whose speed is determined from extraction. Pedestrian age groups are classified into four as children/kid (<15 years), young/youth (15-30 years), Adult/middle age (30-60 years) and elder/aged (>60 years). Luggage attribute corresponds to an individual pedestrian handling considerable luggage or not. Pedestrian's direction of movement corresponds to ascending and descending on stairways. Thus the pedestrian speed with respect to individual characteristics is determined and average walking speed for each minute is obtained.

3.6 Questionnaire Survey

From the collected video recordings of pedestrian flow on stairway in SC, WL and BZA, one minute videos are cropped and pedestrian flow characteristics are determined for the one minute Pedestrian. A questionnaire is prepared to collect respondent's characteristics and perception on their choice between stairway and escalator to ascend passageway for the flow conditions in the video exhibit.

3.7 Summary

This chapter deals with the methodology adopted to study the pedestrian behaviour in intercity railway stations. The detailed approach for conducting the study was explained using flow chart. A brief description of intercity railway stations considered for the study is given. The detailed process of data collection method adopted with sample screenshots of passageways, stairways and escalators is presented. Dimensional details of the level changing facilities are tabulated. Flow characteristics parameter determination from the data extraction for further analysis is described in detail.

In the next chapter, pedestrian flow characteristics on foot over bridge passageway, stairway and escalator are determined and are compared literature.

CHAPTER 4

Pedestrian Flow Characteristics

4.1 General

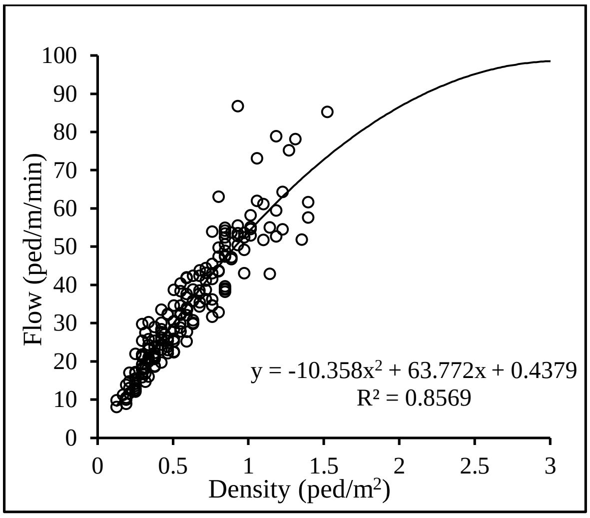
Foot over bridge, an elevated passageway connected with stairways and escalators, are typical infrastructures which provides a common means of access to various platforms for pedestrians in intercity railway stations. Since pedestrian ease of walking varies on horizontal and inclined surfaces, flow characteristics varies on passageway, stairway and escalator. These variations causes the bottlenecks at the connecting points. Understanding the flow variations provide basis to designing tool in arriving at appropriate design standards. In this chapter, pedestrian flow characteristics on passageway, stairway and escalator in intercity railway station are determined and are compared with those of literature to understand pedestrian flow behaviour.

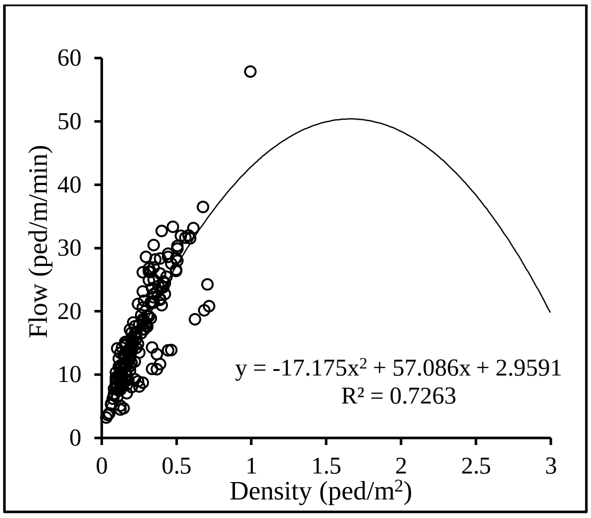
4.2 Pedestrian Flow Characteristics on Passageway

For the flow-density-speed data extracted from the video-graphic survey of pedestrian flow on the passageways in the intercity railway stations SC, WL and BZA, fundamental relationships of flow-density and flow-space are developed.

4.2.1 Pedestrian Flow (q)-Density (k) on Passageway

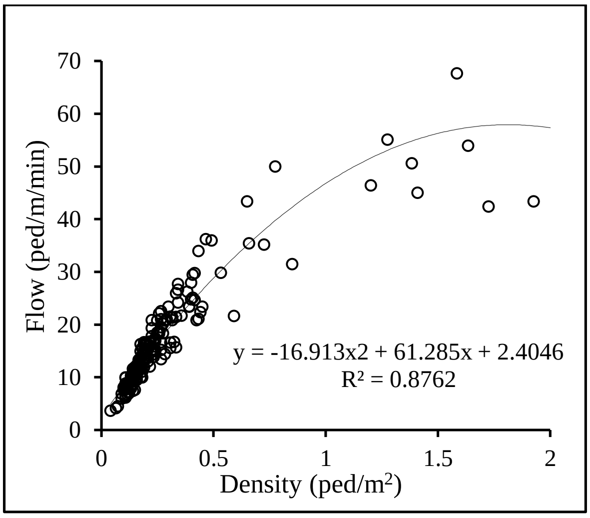
Flow (ped/m/min) and density (ped/m^2) are computed from the volume (ped/min) and average number of pedestrians occupying known area for each minute interval. From the data set obtained for the survey period, flow- density plots are constructed. Figure 4.1 shows the flow-density plots developed from the extracted data points for the seven passageways.

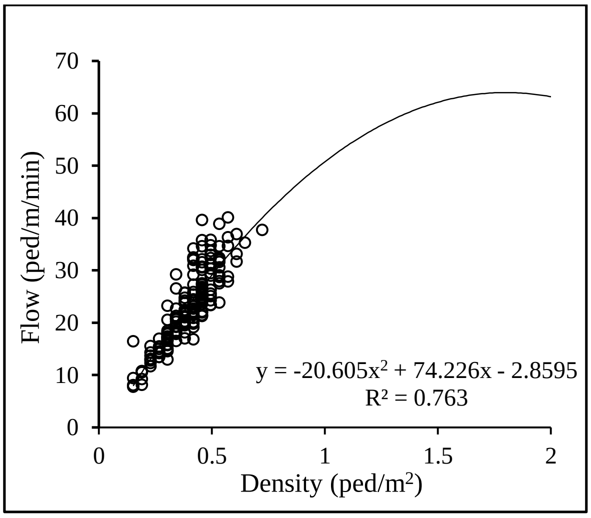




4.1(a) q-k Plot on SC_{P1}

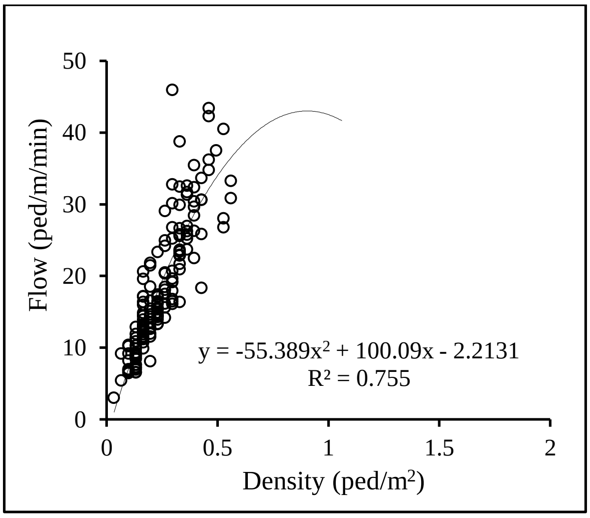
4.1(b) q-k Plot on SC_{P2}

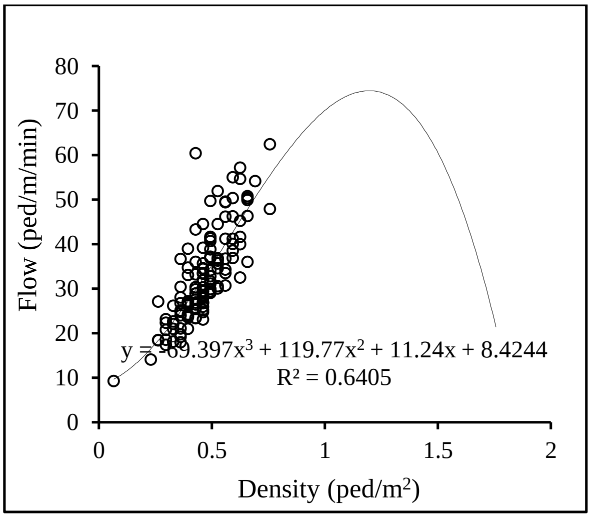




4.1(c) q-k Plot on WL_{P}

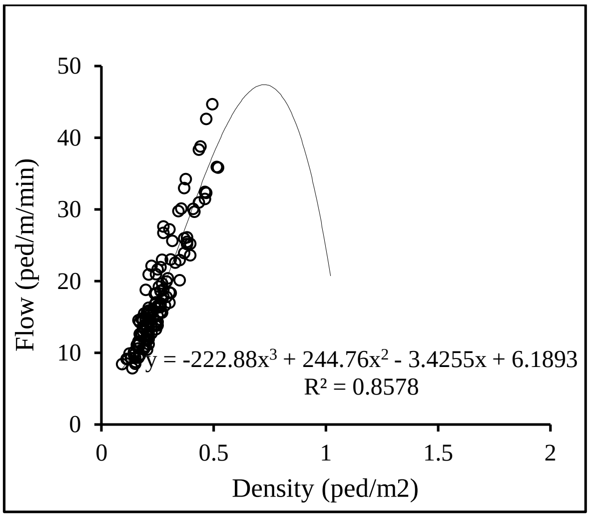
4.1(d) q-k Plot on BZA_{P1}





4.1(d) q-k Plot on BZA_{P2}

4.1(d) q-k Plot on BZA_{P3}



4.1(d) q-k Plot on BZA_{P4}

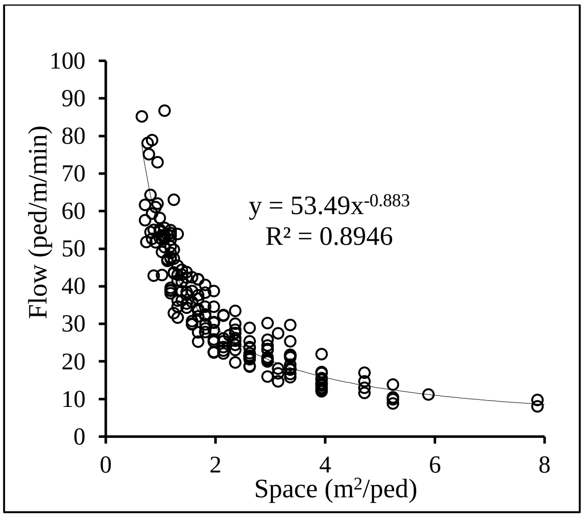
Figure 4.1 Pedestrian Flow (q)-Density (k) Plots on Passageways

A maximum flow of 99 and 50ped/m/min is observed on SC_{P1} and SC_{P2}. The observed optimal densities are 3.07 and 1.66ped/m^2 on SC_{P1} and SC_{P2}. Before arrival of train on to a platform, pedestrian flow is higher in the direction of platform on passageway. After the arrival of train, the pedestrian flow is higher in the other direction on passageway. Hence the flow is high in one direction before train arrival and is high in other direction after the train arrival. On passageway without central rail to separate directional flow, major flow occupies major width of passageway thus having more effective width to traverse. On passageway with central rail, irrespective of flow ratio, passengers are ought to use width limited by central rail. Hence higher density is observed in passageway with central rail than that of passageway without directional flow separating partition central rail. A maximum flow of 58 ped/m/min is observed with optimal density 1.80ped/m^2 on passageway WL_P. Warangal railway station has only two foot over bridges connecting the three platforms. Maximum flow observed are 64, 43, 74 and 48ped/m/min on the four passageways BZA_{P1}, BZA_{P2}, BZA_{P3} and BZA_{P4} respectively with optimal densities 1.80, 0.90, 1.20 and 0.73ped/m^2 respectively.

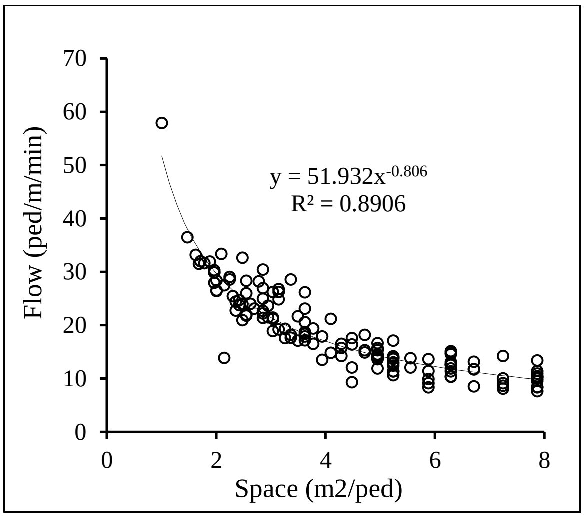
4.2.2 Pedestrian Flow (q)–Space (s) on Passageway

Space available per pedestrian is determined as the inverse of density. Flow-space plots are constructed from the data set for the survey period. Figure 4.2 shows the flow–space plots for the seven passageways considered for the study. Power function best defined the relationship between pedestrian flow and space. The space per pedestrian at maximum flow for

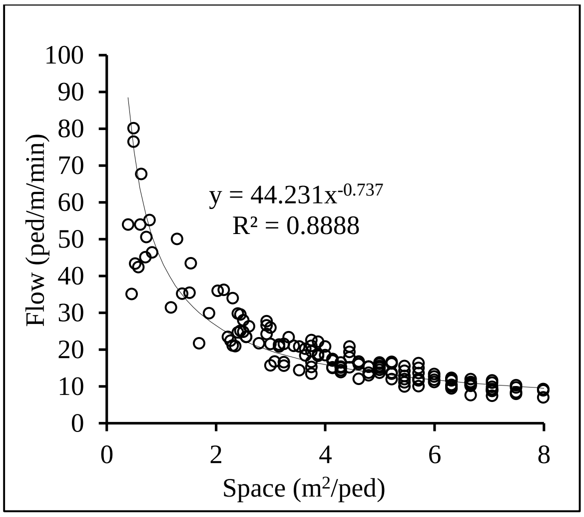
SC_{P1} and SC_{P2} are 0.48 and 1.04 m^2/ped. It is clear that central rail restricts the pedestrian accessible space and hence more space is available per pedestrian in case of absence of central rail. Minimum space available in case of WL_{P1} is 0.69 m^2/ped. In BZA, the space available are 0.91, 1.60, 0.86 and 1.45 m^2/ped on BZA_{P1}, BZA_{P2}, BZA_{P3} and BZA_{P4} passageways respectively. This is because of more uniformly distributed pedestrian flows on all the foot over bridges giving more room for each pedestrian to traverse. Power function best defined the relationship between pedestrian flow and space.



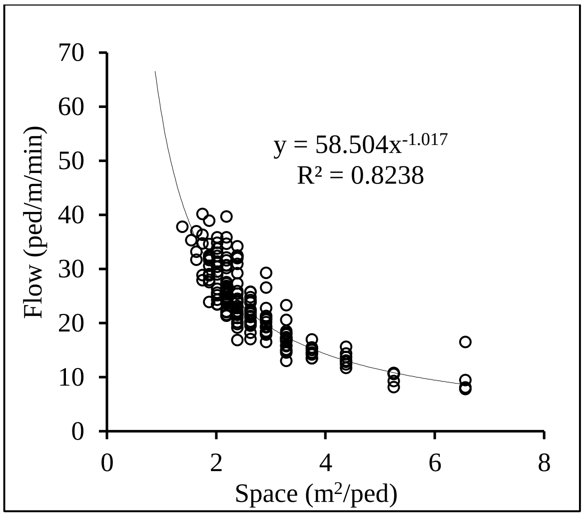
4.2(a) q-s Plot on SC_{P1}



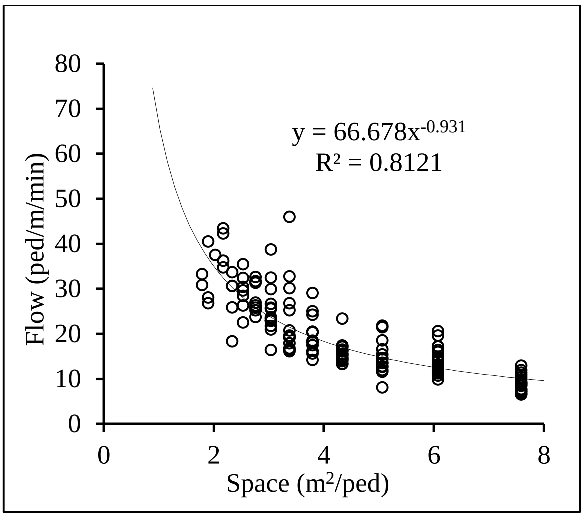
4.2(b) q-s Plot on SC_{P2}

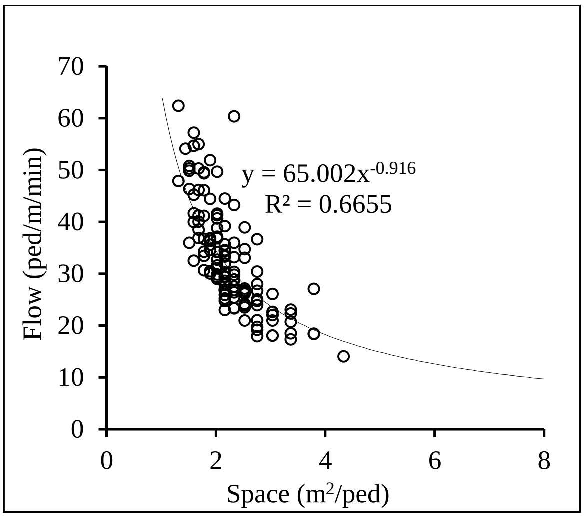


4.2(c) q-s Plot on WL_P



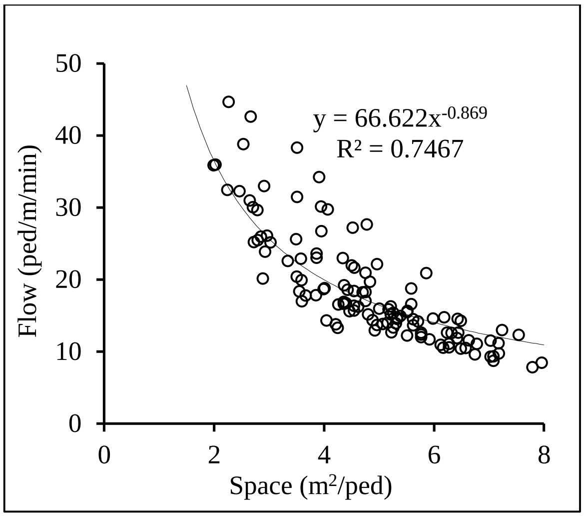
4.2(d) q-s Plot on BZA_{P1}





4.2(e) q-s Plot on BZA_{P2}

4.2(f) q-s Plot on BZA_{P3}



4.2(g) q-s Plot on BZA_{P4}

Figure 4.2 Pedestrian Flow (q)-Space(s) Plots on Passageways

4.2.3 Pedestrian Walking Speed on Passageway

The mean walking speed on SC_{P1} and SC_{P2} are 58.51 and 71.18 m/min. It is observed that the mean walking speed in presence of flow separating central rail is lower. This is because of restriction in pedestrian space which affects the pedestrian ability to pass by a slow moving pedestrian. The mean walking speed observed on WL_{P1} is 66.10 m/min. On BZA_{P1}, BZA_{P2}, BZA_{P3} and BZA_{P4}, mean walking speeds are 58.18, 75.68, 70.86 and 70.78 m/min respectively.

The free flow speed corresponding to the 85th percentile speed from the cumulative distribution curves for speeds, on SC_{P1} and SC_{P2} are 69.06 and 84.31 m/min respectively. On WL_{P1}, free flow speed is obtained as 77.70m/min. On BZA_{P1}, BZA_{P2}, BZA_{P3} and BZA_{P4} the free flow speeds are obtained as 66.94, 91.77, 83.92 and 94.64m/min respectively.

Table 4.1 Comparison of Flow characteristics on passageway with literature

S.No	Reference	Country	Station	Facility	Width (m)	Maximum Flow (ped/m/min)	Mean Walking Speed (m/min)	Free flow Speed (m/min)
1	Daly et al. 1991	London Underground Station	-	Passageway	-	86.00	-	-
2	Cheung and Lam 1997	Hong Kong, China	MTR Station	Passageway	2.5	92.00	-	82.26
3	Lam and Cheung 2000	Hong Kong, China	MTR Station	Passageway	2.5-3.3	92.00	-	82.26
			KCR Station	Passageway	3.23	88.00		79.45
4	Sarkar and Janardhan 2001	Howra, Culcutta, India	Howrah Station Subway	Subway	5.4	92.00	87.51	-
			Howrah Ferry Ghat Bridge 1	Passageway	1.8		50.55	
			Howrah Ferry Ghat Bridge 2	Passageway	2.0		74.46	
5	Zhang et al. 2009	Beijing, China	Xizhimen transfer hub Fuxingmen Transfer hub	Passageway	-	-	79.8.	-
6	Chen et al. 2010	Shanghai, China	People Square Station	Passageway	7.07	70.00	-	81.37
7	Yang et al. 2010	China	Xizhimen Subway Station	Walkway	-	70.00	-	92.00
8	Zhang et al. 2011	Beijing, China	Xidan Station	Passageway	5.7	-	-	88.80
			Guomao Station	Passageway	3.6	-	-	
9	Yao et al. 2012b	Beijing, China	Jianguomen	Corridor	3.5	62.40	73.20	-
			Dongzhimen	Corridor	4.0		60.60	-
			Haidianhuangzhuang	Corridor	3.0		70.20	-

Contd.,

S.No	Reference	Country	Station	Facility	Width (m)	Maximum Flow (ped/m/min)	Mean Walking Speed (m/min)	Free flow Speed (m/min)
10	Xu et al. 2015	Guangzhou Subway	Kecun Station	Passageway	-	92	-	-
11	Fang 2018	Guangzhou, China	Zhujiang New Town Station (Office Commuter)	Passageway	-	-	82.80	-
			Kecun Station (Transfer)	Passageway			76.80	
			Dongxiaonan Station (Living Residential Station)	Passageway			75.60	
			Guangzhou Railway Station (Large Integrated Transport Hub)	Passageway			76.80	
			Tiyu Xilu Station (Commercial Center Station)	Passageway			68.40	
			Canton Tower Station (Tourist Sight Seeing Station)	Passageway			69.60	
			Haizhu Square Station (Ordinary transfer station)	Passageway			76.80	
12	This Study	India	Secunderabad Intercity Railway Station	Passageway (With Central Rail) SC_{P1}	4.5	99	58.51	69.06
				Passageway SC_{P2}	4.5	50	71.18	84.31
			Warangal Intercity Railway Station	Passageway WL_{P}	2.1	58	66.10	77.70
			Vijayawada Intercity Railway Station	Passageway BZA_{P1}	3.5	64	58.18	66.94
				Passageway BZA_{P2}	2.3	43	75.68	91.77
				Passageway BZA_{P3}	2.3	74	70.86	83.92
				Passageway BZA_{P4}	3.4	48	70.78	94.64

Table 4.1 shows the comparison of pedestrian flow characteristics on passageways and subway leading to railway terminals. It is clear that the pedestrian maximum flow are lower than the metro and subway passageways where daily commuters are more. The maximum flows observed on the passageway in intercity railway station are quit less in comparison to metro stations. The mean walking speed on subway connecting the Howra intercity railway station, Calcutta, India is 70.84m/min (Sarkar and Janardhan 2001). The mean walking speeds in SC, WL and BZA are 64.76, 66.1, and 68.87 m/min respectively with an overall mean of 67.304 m/min. The speeds in the present study are in range with the speeds on subways of Howra, intercity railway station, Calcutta, India, where pedestrians access ferry boat services and train station. The speeds of pedestrians in the present study, intercity railway stations are lower than the pedestrian in metro and subway passageways. This is because of the pedestrian strain due to long hauling trip, relatively large proportion of luggage carrying pedestrians, relatively more group behaviour and personal characteristics. The pedestrian in intercity require more space and walk slowly influenced by their personal characteristics like age and luggage. The flows are lower in the present study than on passageways in metro stations. Hence it is clear that the pedestrian speeds and flow rates varies with station characteristics, pedestrian characteristics and trip characteristics

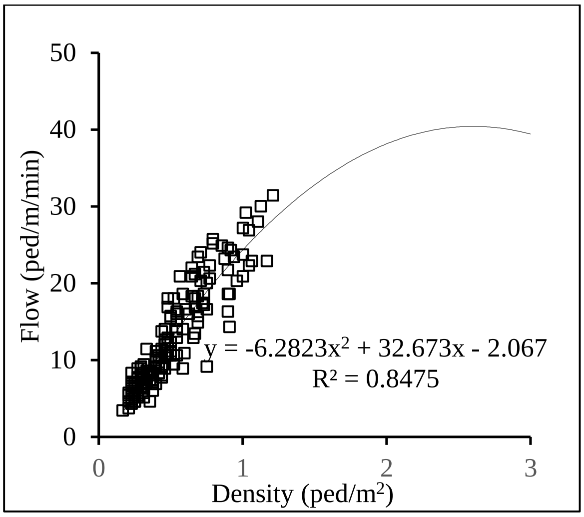
4.3 Pedestrian Flow Characteristics on Stairway

Stairways provide vertical movement connecting platform and elevated passageway in intercity railway stations. Empirical relationships for the flow-density-speed are developed for the extracted data from the video recordings of pedestrian movement on stairways in SC, WL and BZA railway station.

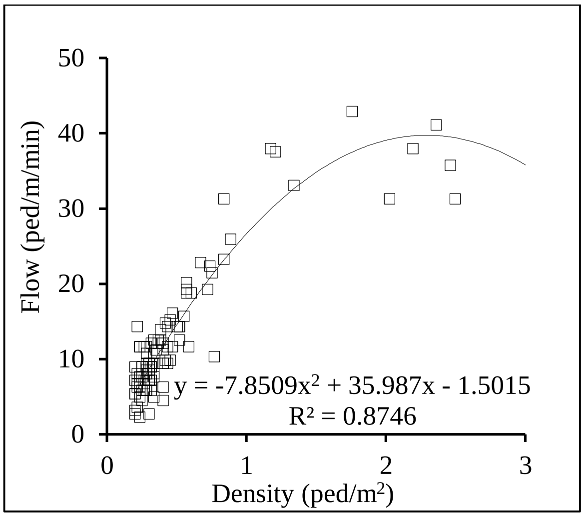
4.3.1 Pedestrian Flow (q)–Density (k) on Stairway

To understand the pedestrian flow rate variation with density and relating trend, pedestrian flow and corresponding average density observed for each minute is plotted. Figure 4.3 shows the pedestrian flow - density plots for the six stairways from SC, WL and BZA intercity railway stations. Maximum flows are observed as 40 and 40 ped/m/min on the SC_S and WL_S and optimal densities observed are 2.60 and 2.29 ped/m^2. While the pedestrian flows are 26, 26, 34 and 28 ped/m/min on four stairways BZA_{S1}, BZA_{S2}, BZA_{S3} and BZA_{S4}

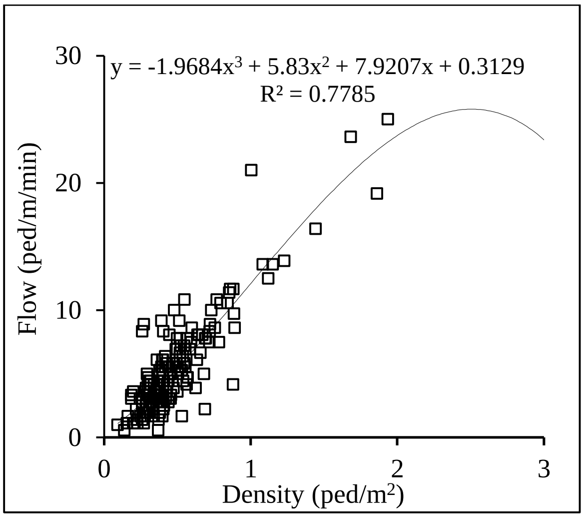
respectively. Optimal densities observed on Vijayawada stairways are 2.51, 1.00, 2.93 and 2.56 ped/m^2 on BZA_{S1}, BZA_{S2}, BZA_{S3} and BZA_{S4} respectively



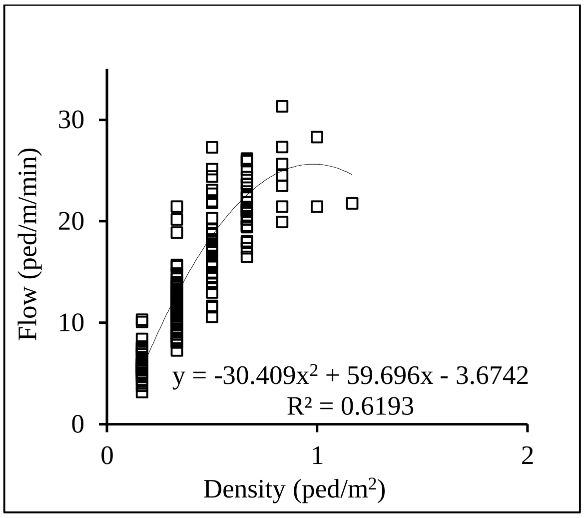
4.3(a) q-k Plot on SC_S



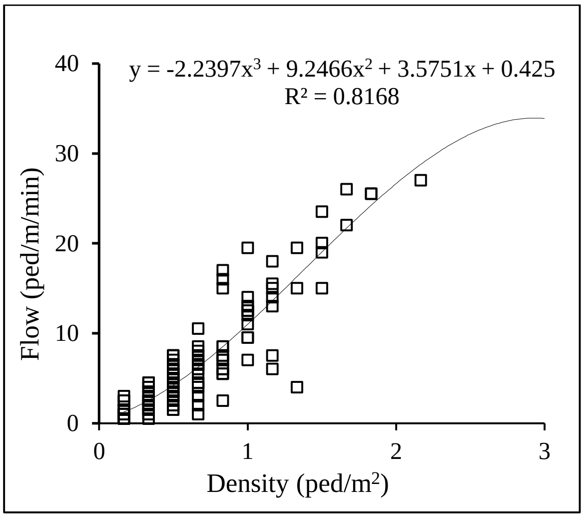
4.3(b) q-k Plot on WL_S



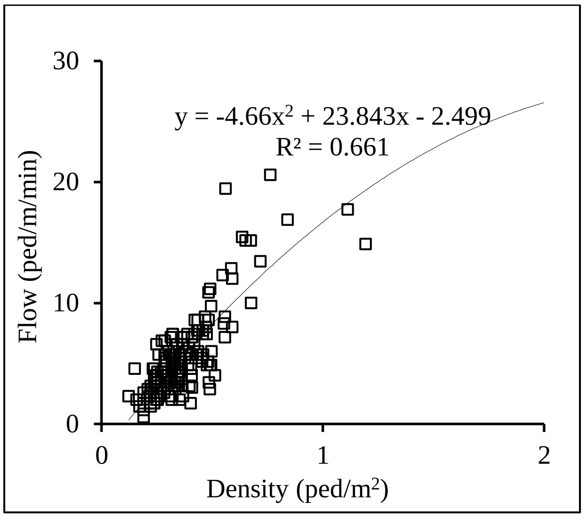
4.3(c) q-k Plot on BZA_{S1}



4.3(d) q-k Plot on BZA_{S2}



4.3(e) q-k Plot on BZA_{S3}

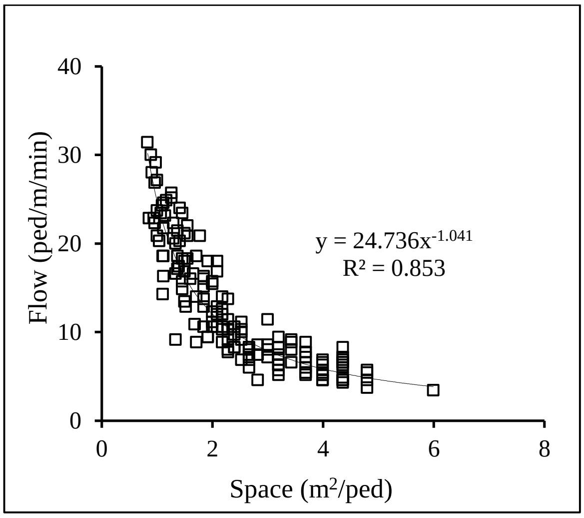


4.3(f) q-k Plot on BZA_{S4}

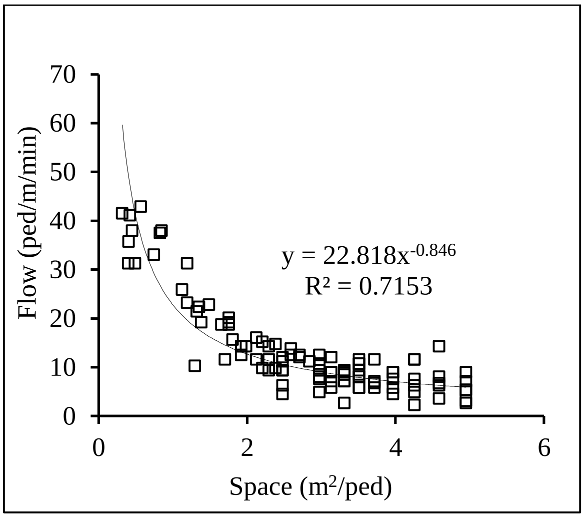
Figure 4.3 Pedestrian Flow (q)–Density (k) Plots on Stairway

4.3.2 Pedestrian Flow (q)–Space (s) on Stairway

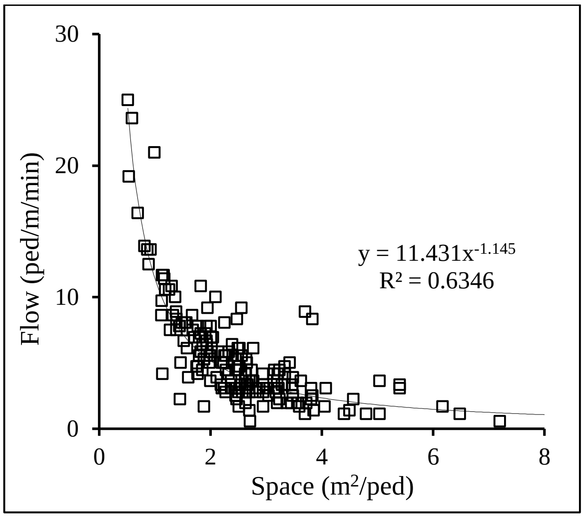
Flow-space plots are constructed from the data sets of average space in m^2 available per person for the flow rate observed for each minute of the survey period. Figure 4.4 shows the flow–space plots for the six passageways considered for the study. For the maximum flow on stairway, space available per pedestrian are 0.63 and 0.51 m^2/ped on SC_S and WL_S. In Vijayawada the space available are 0.48, 1.27, 0.39 and 0.68 m^2/ped on BZA_{S1}, BZA_{S2}, BZA_{S3} and BZA_{S4} respectively. It is observed that power function best defines pedestrian flow rate-space relation. With increase in flow, space available per pedestrian decreases.



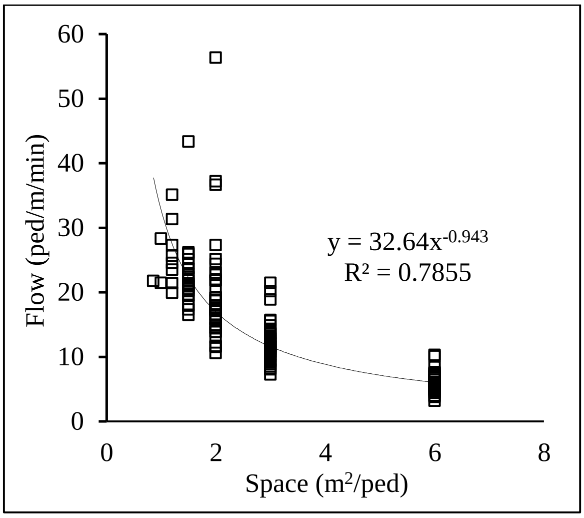
4.4(a) q-s Plot on SC_S



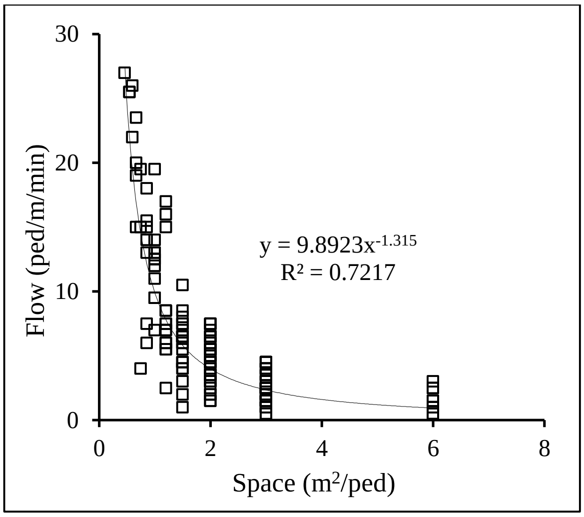
4.4(b) q-s Plot on WL_S



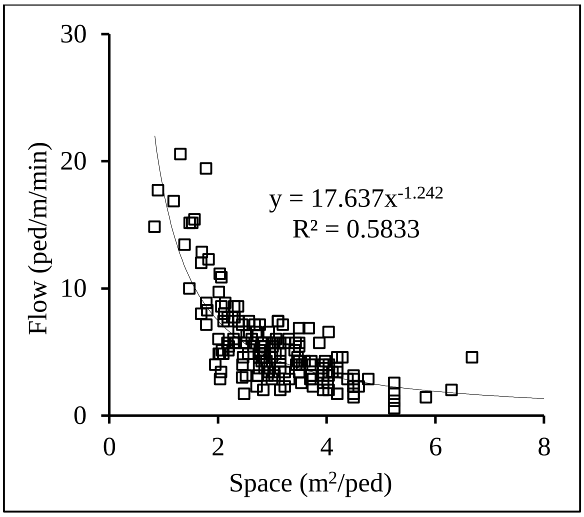
4.4(c) q-s Plot on BZA_{S1}



4.4(d) q-s Plot on BZA_{S2}



4.4(e) q-s Plot on BZA_{S3}



4.4(f) q-s Plot on BZA_{S4}

Figure 4.4 Flow (q) – Space (s) Plots on Stairways

4.3.3 Pedestrian Walking Speed on Stairway

The mean walking speed on SC_S and WL_S are 41.76 and 43.35 m/min. On BZA_{S1}, BZA_{S2}, BZA_{S3} and BZA_{S4}, the mean walking speed are 35.53, 35.72, 34.14 and 40.45 m/min respectively. The free flow speed corresponding to the 85th percentile speed on SC_S and WL_S are 50.76 and 48.71m/min respectively. On BZA_{S1}, BZA_{S2}, BZA_{S3} and BZA_{S4}, the free flow speeds are obtained as 42.26, 42.83, 42.38 and 48.24m/min respectively.

Table 4.2 Pedestrian flow characteristics comparison on stairways with literature

S. No	Reference	Country	Station	Width (m)	Step Rise (m)	Step Foot (m)	Inclination (degrees)	Maximum Flow (ped/m/min)		Mean Walking Speed (m/min)	
								Asc	Dsc	Asc	Dsc
1	Daly et al. 1991	United Kingdom	London Underground Station	-	-	-	-	62	68		
2	Lam et al. 1995	Hong Kong, China	Tsim Sha Tsui (MTR), Wan Chai Station (MTR)	-	0.158	0.292	28.40	71	77	35.4	40.8
			Kowloon Station (KCR)	-	0.152	0.285	28.10	66		38.7	
					0.148	0.294	26.70		73		48.2
3	Cheung and Lam 1997, Lam and Cheung 2000	Hong Kong, China	MTR Station	1.80	0.15	0.305	-	70	80	-	
			KCR Station		0.163	0.271		70	73		
4	Zhang et al. 2009	Beijing, China	Xizhimen Transfer hub Fuxingmen Transfer hub	2.40	-	-	-	-		42.60	54.00
				1.20						42.60	40.80
5	Chen et al. 2010	Shanghai, China	Zhong-Shan Park Station	1.77	0.15	0.31	25.8	73	-	-	
				2.10	0.15	0.33	24.4	-	68		
6	Suhua et al. 2010	Xinjiekou, China	Nanjing Xinjiekou stations	3.60	-	-	26.57	65	-	-	
7	Yang et al. 2010	China	Xizhimen Subway Station	-	-	-	-	67	65	-	
8	Yao et al. 2012b	Beijing, China	Jianguomen	2.50	-	-	-	58		25.20	
			Dongzhimen	3.50						27.60	
			Haidianhuangzhuang	4.00						30.60	

Contd.,

S. No	Reference	Country	Station	Width (m)	Step Rise (m)	Step Foot (m)	Inclination (degrees)	Maximum Flow (ped/m/min)		Mean Walking Speed (m/min)	
								Asc	Dsc	Asc	Dsc
9	Xu et al. 2015	Guangzhou Subway, China	Kecun Station	-	-	-	-	70	80	-	
10	Shah et al. 2017 Jiten et al. 2016b	India	Dadar, Mumbai (Suburban)	2.67	0.13	0.29	22.1	88		30.49	
				2.15	0.13	0.30	24.1	77		28.25	
			Vadodara (Intercity)	3.68	0.15	0.31	23.3	51		37.46	
				2.45	0.15	0.30	23.6	33		38.09	
				2.14	0.15	0.28	23.8	49		33.70	
				2.26	0.13	0.28	23.8	49		17.96	
11	This Study	India	Secunderabad (Intercity)	3.50	0.22	0.40	32.0	40		40.74	43.58
			Warangal (Intercity)	2.40	0.15	0.35	34.0	40		45.98	41.55
			Vijayawada (Intercity)	3.60	0.15	0.30	30.0	26		33.79	37.90
				2.00	0.15	0.30	30.0	26		37.43	34.56
				2.00	0.15	0.30	30.0	34		34.41	34.10
				3.50	0.15	0.30	34.0	28		35.66	45.01

Note: Asc : Ascending, Dsc : Descending

Table 4.2 shows the comparison of pedestrian flow characteristics on stairways in terminals. It can be seen that in the present study speeds of pedestrians on Vijayawada stairways are in range with the studies of Vadodara, which is also an intercity railway station. The speeds in Secunderabad and Warangal are higher than those in Vadodara. This is due to the integrated MMTS facility in Secunderabad, which is used by relatively higher proportion of daily commuter with no luggage. Similarly higher speeds are observed in Warangal than Vadodara and is due to the relatively higher flow rates, near to capacity till which the speed increases with flow rate, in comparison to Vijayawada and Secunderabad due to which pedestrians tend to escape the congestion as early as possible. The speeds on stairways in Secunderabad are in range with the speeds in Dadar, a suburban railway station where daily commuters are more. The pedestrian speeds in this study are in range with the pedestrian speeds in China however the flow rates are lower in the present study. This can be attributed to the trip purpose, social and cultural difference of Indians and Chinese. The pedestrians carrying luggage in intercity railway stations are relatively in higher proportions to that of daily commuters in metro stations and suburban stations. Intercity pedestrians require more space to cater for the luggage and hence the flow rates are lower for the similar walking speeds. With similar characteristics of Dadar suburban station and Secunderabad station, in the present study, similar speeds are observed with relatively lower flow in Secunderabad due to more dominant intercity pedestrian trip makers. Hence it is clear that the station characteristics effects the pedestrian speeds on stairways. It can also be observed that the flow rate is higher for metro and suburban facility with similar walking speeds however integrated MMTS in Secunderabad has lower flows in comparison to metro and suburban stations with similar speeds.

4.4 Pedestrian Flow Characteristics on Escalator

Escalators are moving stairs operated under a prefixed speed of 0.50-0.75m/s (Planning guide for escalators and moving walks, Schindler). For the escalators, flow-density relationships are built for the extracted datasets from the video recording data of pedestrian flow on escalators in intercity railway stations SC, WL and BZA. On escalator, the flow-density scatter plot is developed for the data points of pedestrian flow on escalators on the six escalators in three intercity railway stations. Figure 4.5 shows the pedestrian flow-density data points. A maximum flow of 51ped/m/min is attained with an optimal density of 3.55ped/m^2.

Table 4.3 Pedestrian flow characteristics comparison on escalators with literature

S.No.	Reference	Country	Station	Facility	Maximum Flow (ped/m/min)
1	Daly et al. 1991	London Underground Station, United Kingdom	-	Escalator (Ascending)	120.00
				Escalator (Descending)	120.00
2	Lam and Cheung 2000	Hong Kong, China	MTR Station	Escalator (up)	120.00
				Escalator (Down)	120.00
			KCR Station	Escalator (up)	118.00
				Escalator (Down)	118.00
3	Liao et al. 2013	Shanghai Metro, China	Shanghai Railway Station	Escalator	78.2 – 87.76
			Shanghai West Railway Station		
			Zhongshan Park		
			people's Square		
			Xujiahui		
4	Xu et al. 2015	Guangzhou Subway, China	Kecun Station	Escalator	120.00
5	This Study	India	Intercity railway station	Escalator (up)	51.00

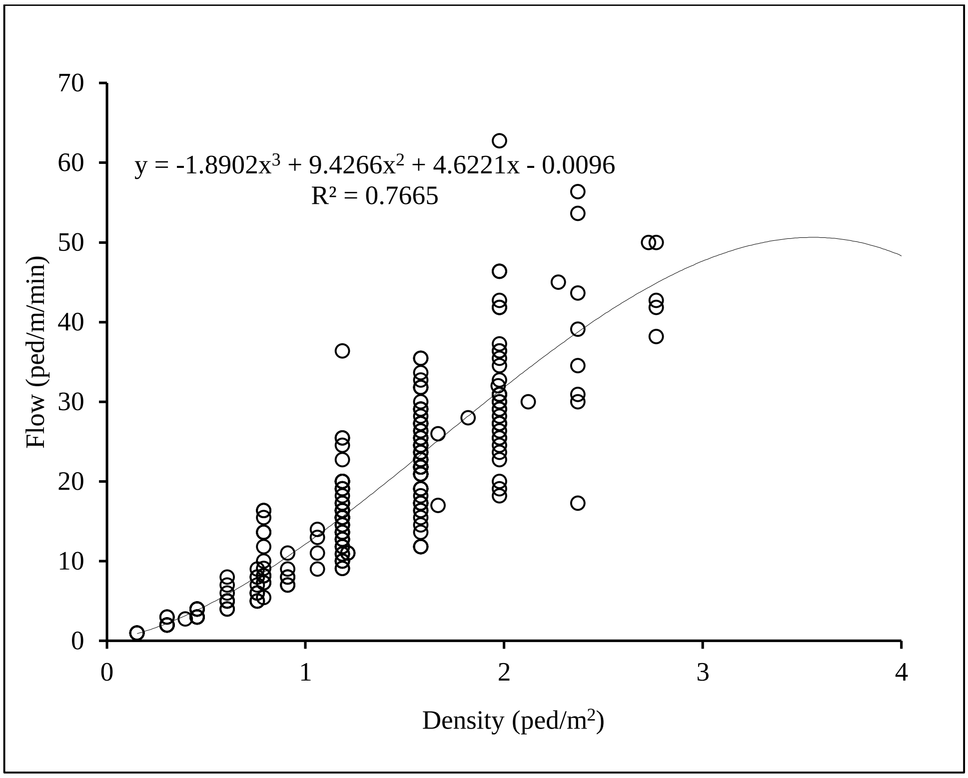


Figure 4.5 Pedestrian Flow(q)–Density(k) Plots on Escalators

Table 4.3 shows the comparison of pedestrian flow on escalators from various studies. It is observed that the pedestrian flow on escalators in intercity railway stations are less in comparison to China and London metro stations (Daly et al. 1991, Lam and Cheung 2000, Liao et al. 2013, Zhao 2014, Xu et al. 2015). This is due the luggage characteristics of pedestrians. Metro stations are accessed by more daily commuters with less or no luggage and are more used to the infrastructure facilities. The pedestrians in intercity railway stations are rare trip makers and carry luggage. This requires more personal space and hesitation to mount the escalator immediate to the lead pedestrian. Hence the escalator flows are effected by the station characteristics and type of train service the platform serving.

4.5 Results and Discussions

For width 2.1 to 4.5m, the maximum flow range from 43-99ped/m/min with optimal density ranging from 0.73 - 3.07ped/m^2. The mean walking speed on passageways in SC, WL and BZA are 64.85, 66.10 and 68.88 m/min.

For width 2.0 to 3.5m, the maximum flow range from 26 - 40 with optimal density ranging from 1.00 - 2.29ped/m^2. The mean walking speed on stairway in SC, WL and BZA are

41.76, 43.35 and 36.46 m/min. The mean walking speed on stairways in BZA are all near equal. While higher mean speeds are observed on stairways in SC and WL. SC has integrated MMTS facility and the daily commuters are relatively higher, who are well familiar making local trips handling less or no luggage, in comparison to BZA.

The mean walking speed of pedestrians on passageway and stairway is 66.61 and 40.52m/min. Similarly, the mean free flow speeds are 79.58 and 47.80m/min on passageway and stairway. The mean walking speed and free flow walking speed difference on stairway to passageway are 39.16% and 39.93%.

The theoretical transportation capacities of escalators depend on the width and speed of the escalators. The theoretical capacity of escalators given as 9000 persons/hr for step width of 1.0m and operating speed 0.5m/s. (Planning guide for escalators and moving walks, Schindler). The maximum volume that can be handled under the observed maximum flows are 3060ped/hr. In comparison to the theoretical capacities, the observed capacity is lower and the difference is due to the headway between the trains in intercity railway stations being higher than in metro stations.

Similarly it is affected by pedestrian attribute age, gender, and luggage. Pedestrians feel discomfort standing on very next step of preceding passenger. Pedestrians carrying luggage require more headway to the preceding pedestrian. This caused to maintain step headway between preceding pedestrian.

4.6 Summary

In this chapter, pedestrian flow characteristics on foot over bridge elements passageway, stairway and escalator in intercity railway stations are determined. The observed pedestrian flow characteristics on each facility are compared with the corresponding literature. Pedestrians in intercity railway stations require higher personal space in comparison to other functional railway stations however walk with similar walking speeds. Hence lower flow rates are observed than other functional railway stations.

In the next chapter, pedestrian walking speeds variation with width of the passageway and stairway are studied.

CHAPTER 5

PEDESTRIAN WALKING SPEED VARIATION WITH WIDTH OF FACILITY

5.1 General

Foot over bridge, a level changing facility, includes horizontal movement on passageways and vertical movement on stairways. The flow characteristics varies on passageway and stairway as the effort involved in traversing them are different. It depends on wide variety of attributes such as pedestrian characteristics, infrastructure characteristics, environmental characteristics and trip characteristics. This causes jams and bottlenecks at connecting points of the facilities for pedestrian movement. Provision of improper width of the stairway to that of passageway causes non-uniform pedestrian flow. The study of pedestrian flow behavior on these elements is the primary key to plan and design new facility and maintenance of existing facility.

Physical dimensions of these facilities play major role in flow variation. Width is a primary variable which affects the pedestrian flow characteristics. Understanding the effect of width on pedestrian walking speed at normal conditions helps in attaining at the appropriate width required for an anticipated pedestrian demand in an intercity railway station. An appropriate width for passageway and stairway is of greater importance regarding comfort, convenient, efficient, aesthetic, cost effective, environment friendly and well integration with other elements of infrastructure.

In this chapter, pedestrian walking speed variation with respect to width of passageway and stairway are studied. Pedestrian speed variations with pedestrian attributes such as age, gender, luggage and direction are analyzed.

5.2 Pedestrian walking speed variation with width of Passageway

A statistical t-test: Two-sample assuming unequal variances is conducted to compare the means of walking speeds observed on different passageways at 95% confidence level to observe the effect of passageway width on pedestrians walking speeds. Null and alternate hypothesis respectively are assumed to be as

$$H_o\ ;\ \mu_{passageway1} = \mu_{passageway2}$$

$$H_1\ ;\ \mu_{passageway1} \neq \mu_{passageway2}$$

Where μ is the pedestrians mean walking speed on passageway. The t-value obtained is compared with the t critical two-tail value. If the t-value is higher that the t-critical, it signifies that there exists a significant difference in means of pedestrian walking speeds on the two passageways compared.

Table 5.1 Statistical t-test results for comparison of pedestrians walking speeds on passageways

Passageway Combination	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical	Significance
SC_{P1}-SC_{P2}	180	180	58.51	71.18	111.52	198.62	-9.530	1.967	S
SC_{P1}-WL_P	180	170	58.51	66.10	111.52	197.11	-5.688	1.968	S
SC_{P1}- BZA_{P1}	180	177	58.51	58.18	111.52	84.69	0.312	1.967	--
SC_{P1}-BZA_{P2}	180	156	58.51	75.68	111.52	313.83	-10.587	1.970	S
SC_{P1}-BZA_{P3}	180	130	58.51	70.86	111.52	220.33	-8.117	1.971	S
SC_{P1}-BZA_{P4}	180	133	58.51	70.78	111.52	425.91	-6.274	1.973	S
SC_{P2}-WL_P	180	170	71.18	66.10	198.62	197.11	3.273	1.967	S
SC_{P2}-BZA_{P1}	180	177	71.18	58.18	198.62	84.69	10.206	1.968	S
SC_{P2}-BZA_{P2}	180	156	71.18	75.68	198.62	313.83	-2.642	1.968	S
SC_{P2}-BZA_{P3}	180	130	71.18	70.86	198.62	220.33	0.096	1.969	--
SC_{P2}-BZA_{P4}	180	133	71.18	70.78	198.62	425.91	0.118	1.971	--
WL_P-BZA_{P1}	170	177	66.10	58.18	197.11	84.69	6.183	1.968	S
WL_P-BZA_{P2}	170	156	66.10	75.68	197.11	313.83	-5.383	1.968	S
WL_P-BZA_{P3}	170	130	66.10	70.86	197.11	220.33	-2.819	1.969	S
WL_P-BZA_{P4}	170	133	66.10	70.78	197.11	425.91	-2.240	1.971	S
BZA_{P1}-BZA_{P2}	177	156	58.18	75.68	84.69	313.83	-11.090	1.971	S
BZA_{P1}-BZA_{P3}	177	130	58.18	70.86	84.69	220.33	-8.599	1.972	S
BZA_{P1}-BZA_{P4}	177	133	58.18	70.78	84.69	425.91	-6.564	1.974	S
BZA_{P2}-BZA_{P3}	156	130	75.68	70.86	313.83	220.33	2.506	1.968	S
BZA_{P2}-BZA_{P4}	156	133	75.68	70.78	313.83	425.91	2.149	1.969	S
BZA_{P3}-BZA_{P4}	130	133	70.86	70.78	220.33	425.91	0.038	1.970	--

Note: n: number of samples, μ: mean, σ^2: Variance, S: Significant at 95% Confidence Interval, --: Not Significant

Table 5.1 shows the t-test results for comparison of means of walking speeds observed on various passageways. Results showed that there existed a significant difference in means of pedestrian walking speeds on passageway with central rail and without central rail. This is because, the effective width available for pedestrian is restricted by the presence of central rail and has a lower chance to pass by slow moving pedestrian ahead. Significant difference existed in most of the passageway combinations. This signifies that the pedestrian mean walking speeds are affected by the infrastructure characteristics. Significant difference also existed on passageways with equal widths. This may be due to station characteristics and proportion of different class of pedestrian with respect to age, gender, and luggage usage.

To further investigate the pedestrian walking speeds variation with respect to various attributes on passageways with width, the mean walking speeds are compared from the statistical t-test. The statistical t-test results for comparison of pedestrians walking speeds with respect to pedestrian attributes gender, age and luggage on passageways are presented in APPENDIX-A.

Table 5.2 Statistical t-test results for comparison of pedestrians walking speeds on passageways with respect to pedestrian attributes.

Passageway combination	M	F	YM	YF	MM	MF	AM	AF	NLM	NLF	LM	LF
SC_{P1}-SC_{P2}	S	S	S	--	S	S	S	S	S	S	S	S
SC_{P1}-WL_{P}	S	S	--	--	S	S	S	S	S	S	S	S
SC_{P1}- BZA_{P1}	--	S	--	--	--	S	--	S	--	--	--	S
SC_{P1}-BZA_{P2}	S	S	S	--	S	S	--	--	S	S	--	S
SC_{P1}-BZA_{P3}	S	S	S	--	S	S	S	S	S	S	S	S
SC_{P1}-BZA_{P4}	S	S	S	--	S	S	S	S	S	S	--	--
SC_{P2}-WL_{P}	S	S	S	--	--	--	--	S	--	S	--	--
SC_{P2}-BZA_{P1}	S	S	S	S	S	--	S	--	S	S	S	S
SC_{P2}-BZA_{P2}	S	--	--	S	S	--	S	S	S	--	S	--
SC_{P2}-BZA_{P3}	--	--	--	--	--	--	--	S	--	--	--	S
SC_{P2}-BZA_{P4}	--	S	--	--	S	--	--	S	--	--	S	S
WL_{P}-BZA_{P1}	S	S	--	S	S	S	S	S	S	S	S	S
WL_{P}-BZA_{P2}	S	--	S	S	S	--	S	S	S	--	S	--
WL_{P}-BZA_{P3}	S	S	S	--	--	--	--	S	--	S	S	--
WL_{P}-BZA_{P4}	S	S	S	--	--	S	--	S	--	S	S	S
BZA_{P1}-BZA_{P2}	S	S	S	S	S	--	--	--	S	S	--	--
BZA_{P1}-BZA_{P3}	S	S	S	S	S	--	--	--	S	S	S	S
BZA_{P1}-BZA_{P4}	S	--	S	S	S	--	S	--	S	--	--	S
BZA_{P2}-BZA_{P3}	--	--	--	S	S	--	S	--	S	--	S	--
BZA_{P2}-BZA_{P4}	--	S	--	S	--	--	S	--	S	--	--	S
BZA_{P3}-BZA_{P4}	--	S	--	--	--	--	--	--	--	--	S	S

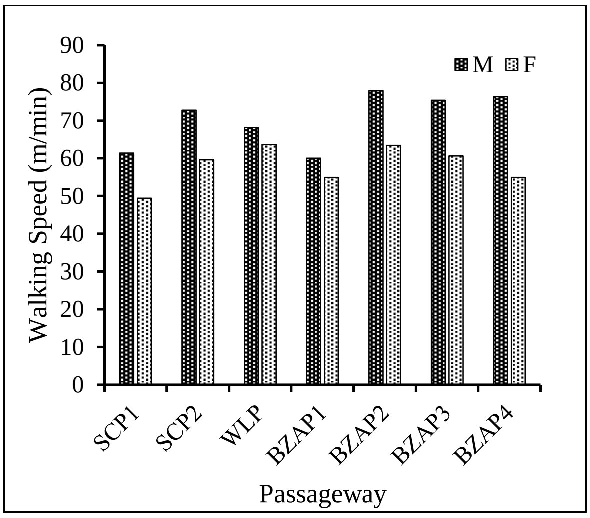
Note: M: Male; F: Female; YM: Young Male; YF: Young Female; MM: Middle age Male; MF: Middle age Female; AM: Aged Male; AF: Aged Female; NLM: Male without carrying luggage; NLF: Female without carrying luggage; LM: Luggage carrying Male; LF: Luggage Carrying Female; S: Significant at 95% Confidence Interval; --: Not Significant

Table 5.2 shows the statistical test results for the comparison of means of walking speeds with respect to pedestrian attributes- gender, age, and luggage on various passageway combinations. From the table 5.2, considering Secunderabad station, it is observed that provision of central rail for directional flow separation has significant effect on pedestrian mean walking speed with respect to all attributes. The comparison of pedestrian walking speeds, on passageways in Vijayawada railway station, with different attributes showed that the walking speeds of middle aged female and aged female are similar and there does not exist a significant difference in their walking speeds. The mean walking speeds on passageway widths of 4.5, 3.5-3.6 and 2.1-2.3m are 64.85, 64.48 and 70.88m/min.

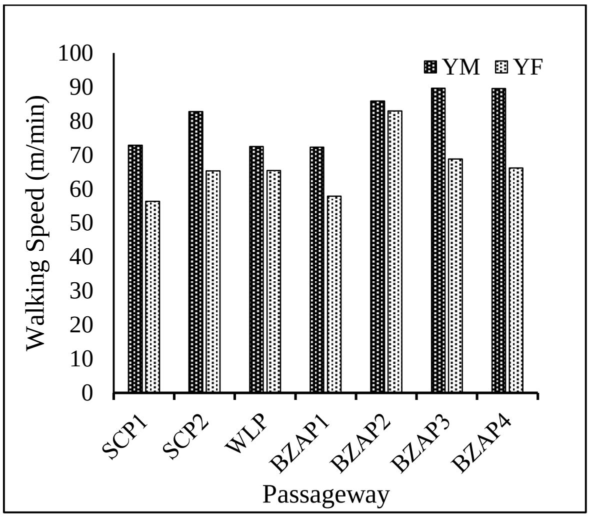
Table 5.3 Pedestrian Flow Characteristics observed on passageway

Description	SC_{P1}	SC_{P2}	WL_P	BZA_{P1}	BZA_{P2}	BZA_{P3}	BZA_{P4}
Width (m)	4.5	4.5	2.1	3.5	2.3	2.3	3.4
Maximum Flow (ped/m/min)	99	50	58	64	43	74	48
Optimal Density (ped/m^2)	3.07	1.66	1.80	1.80	0.90	1.20	0.73
Space available at maximum flow (m^2/ped)	0.82	2.21	2.21	0.85	2.01	1.26	2.30
Sample	180	180	170	177	156	130	133
Average Speed (m/min)	58.51	71.18	66.10	58.18	75.68	70.86	70.78
M (m/min)	61.41	72.79	68.15	60.05	77.91	75.36	76.33
F (m/min)	49.43	59.65	63.67	54.94	63.45	60.62	54.93
K (m/min)	48.42	63.40	65.80	61.86	86.54	64.83	62.11
YM (m/min)	72.83	82.70	72.46	72.24	85.88	89.60	89.47
YF (m/min)	56.35	65.33	65.40	57.85	82.88	68.83	66.12
MM (m/min)	56.17	67.36	67.94	56.26	75.91	68.87	71.74
MF (m/min)	48.36	59.87	63.14	57.25	63.48	60.27	55.11
AM (m/min)	46.31	57.62	60.34	51.08	45.44	56.67	56.77
AF (m/min)	34.04	52.07	59.30	46.35	40.73	42.91	40.80
NLM (m/min)	58.01	74.21	72.05	57.71	85.52	70.77	76.03
NLF (m/min)	49.75	58.87	66.38	52.48	66.76	60.17	57.85
LM (m/min)	60.11	67.53	65.56	57.25	60.57	72.54	60.36
LF (m/min)	43.72	58.50	61.94	51.94	56.03	58.30	46.37

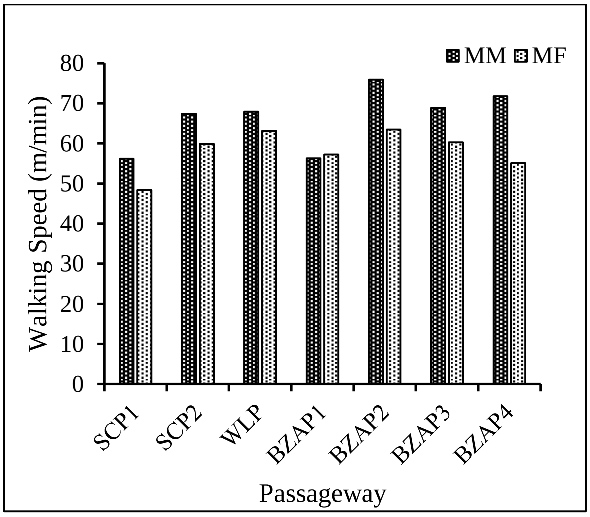
Note: M: Male; F: Female; K: Kids; YM: Young Male; YF: Young Female; MM: Middle age Male; MF: Middle age Female; AM: Aged Male; AF: Aged Female; NLM: Male without carrying luggage; NLF: Female without carrying luggage; LM: Luggage carrying Male; LF: Luggage Carrying Female



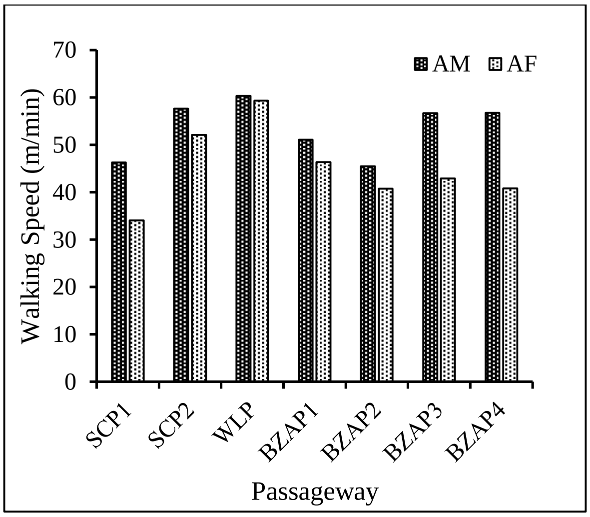
5.1(a) Gender



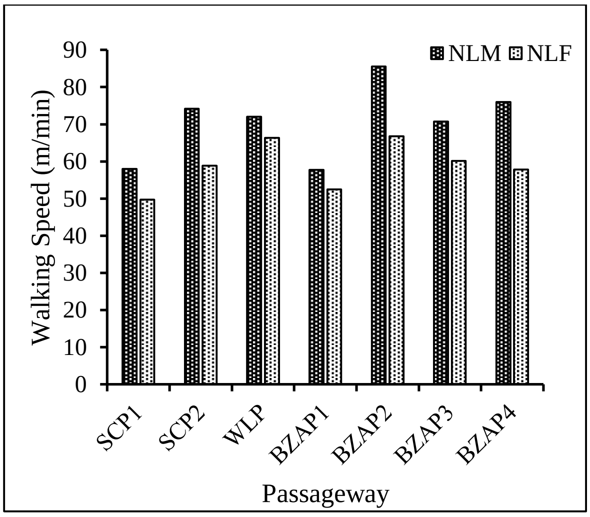
5.1(b) Young



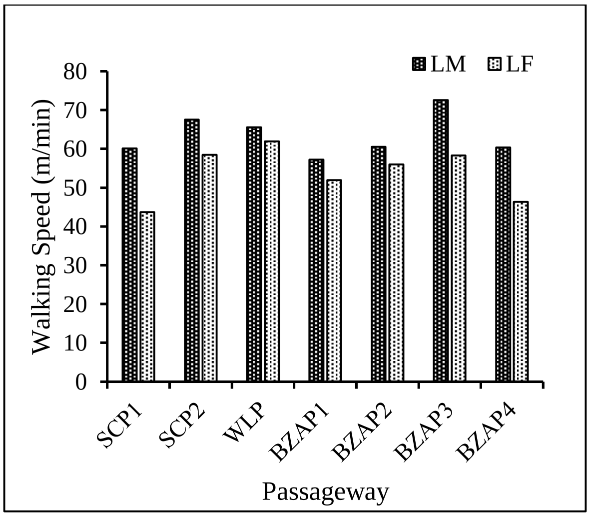
5.1(a) Middle Age



5.1(b) Aged



5.1(a) No Luggage



5.1(b) Luggage

Figure 5.1 Pedestrian Mean Walking speeds with respect to various attributes on passageways

Table 5.3 shows the pedestrian walking speeds on passageways with respect to attributes age, gender and luggage. The mean walking speed of female pedestrians is lower than that of male pedestrians on all passageways. Male pedestrians with respect to age and luggage show higher walking speeds than that of female counterparts on all passageways. The mean walking speed of male and female pedestrians are 70.28 and 58.10 m/min. The walking speed of kids is obtained as 64.71m/min. The mean walking speeds of male pedestrians with age classified as young, middle aged and aged are 80.74, 66.32 and 53.46m/min. Similarly female walking speeds of young, middle aged and aged are 66.10, 58.21 and 45.17m/min. Luggage carrying males and females pedestrians have mean walking speeds of 63.41 and 53.83m/min. While male and female pedestrians without carrying luggage have mean walking speeds of 70.62 and 58.90 m/min. Figure 5.1 shows the variation of mean walking speed of pedestrians with attributes with width of passageways. The mean walking speeds of young male is found to be highest of all the other pedestrians and aged female have the least mean walking speeds. The mean walking speeds of male pedestrians observed as aged male< Luggage male< middle aged male< no luggage male< young male. Similarly, mean walking speeds of female pedestrians are observed as aged female< luggage female<middle aged female< no luggage female< young female. The mean walking speed is observed to be reducing with age. This is because, young pedestrians are more aggressive and perceive flow condition faster and act accordingly. With age, pedestrian's effort in traverse increases and hence walking speed decreases. Effort involved in traversing increases with luggage handling and hence luggage carrying pedestrians are found to walk slower than their counter pedestrians walking without carrying luggage. The pedestrians with respect to attributes shows that the mean walking speed of aged female< aged male< luggage female< middle aged female< female with no luggage< luggage carrying male< young female< middle aged male< male carrying no luggage< young male.

5.3 Pedestrian walking speed variation with width of stairway

A statistical t-test: Two-sample assuming unequal variances is conducted to compare the means of walking speeds observed on different passageways at 95% confidence level to observe the effect of stairway width on pedestrians walking speeds. Null and alternate hypothesis respectively are assumed to be as

$$H_o ; \mu_{Stairway1} = \mu_{Stairway2}$$

H_1 ; $\mu_{Stairway1} \neq \mu_{Stairway2}$

Where μ is the pedestrians mean walking speed on a stairway. The t-value obtained is compared with the t-critical two-tail value. If the t-value is higher that the t-critical, it signifies that there exists a significant difference in means of pedestrian walking speeds on the two stairways compared.

Table 5.4 shows the t-test results for comparison of means of pedestrians walking speeds observed on different stairway combinations. Statistical t-test showed there exists a significant difference in means of pedestrian walking speeds on stairways of different station combinations. It signifies the pedestrian walking speed varies with infrastructure characteristics, station layout, pedestrian composition and various other factors. To understand the pedestrian walking speed variation with width, pedestrian walking speeds in Vijayawada are compared on BZA_{S1} (3.6m) with BZA_{S2} (2.0m) and BZA_{S3} (2.0m) having inclination of 30^0. Results showed the pedestrian walking speeds does not vary significantly on stairways of width 2.0m to 3.6m where pedestrian densities are less than 1ped/m^2.

Table 5.4 Statistical t-test results for comparison of pedestrians walking speeds on stairway

Stairway combination	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-test	t-critical	Significance
SC_S-WL_S	163	104	41.76	43.35	53.78	94.49	-1.434	1.973	--
SC_S-BZA_{S1}	163	181	41.76	35.53	53.78	60.00	7.658	1.967	S
SC_S-BZA_{S2}	163	170	41.76	35.72	53.78	120.42	5.919	1.968	S
SC_S-BZA_{S3}	163	153	41.76	34.14	53.78	88.78	7.985	1.968	S
SC_S-BZA_{S4}	163	167	41.76	40.45	53.78	82.46	1.444	1.967	--
WL_S-BZA_{S1}	104	181	43.35	35.53	94.49	60.00	7.025	1.973	S
WL_S-BZA_{S2}	104	170	43.35	35.72	94.49	120.42	5.998	1.970	S
WL_S-BZA_{S3}	104	153	43.35	34.14	94.49	88.78	7.551	1.971	S
WL_S-BZA_{S4}	104	167	43.35	40.45	94.49	82.46	2.454	1.971	S
BZA_{S1}-BZA_{S2}	181	170	35.53	35.72	60.00	120.42	-0.193	1.968	--
BZA_{S1}-BZA_{S3}	181	153	35.53	34.14	60.00	88.78	1.456	1.968	--
BZA_{S1}-BZA_{S4}	181	167	35.53	40.45	60.00	82.46	-5.414	1.967	S
BZA_{S2}-BZA_{S3}	170	153	35.72	34.14	120.42	88.78	1.398	1.967	--
BZA_{S2}-BZA_{S4}	170	167	35.72	40.45	120.42	88.78	1.398	1.967	--
BZA_{S3}-BZA_{S4}	153	167	34.14	40.45	88.78	82.46	-6.087	1.968	S

Note: n: number of samples, μ: mean, σ^2: Variance, S: Significant at 95% Confidence Interval, --: Not Significant

The walking speeds of pedestrians with respect to various attributes age, gender and luggage observed on different stairways are compared to study their variation with width of stairway. Statistical t-test results for comparison of pedestrians walking speeds with respect to pedestrian attributes gender, age and luggage on stairways are presented in APPENDIX-B. Table 5.5 shows the statistical test results of pedestrian walking speeds with respect to various attributes on stairways. On comparison of walking speeds on stairways in Vijayawada, it is observed that the width has less influence on walking speeds of aged female and luggage carrying female pedestrians.

Table 5.5 Statistical t-test results for the comparison of pedestrian walking speeds on stairway with respect to pedestrian attributes.

Stairway Combination	Mean Speed	M	F	YM	YF	MM	MF	AM	AF	NLM	NLF	LM	LF
SC_S-WL_S	--	--	S	--	S	S	--	--	--	--	S	--	--
SC_S-BZA_{S1}	S	S	S	S	S	S	S	S	S	S	S	S	S
SC_S-BZA_{S2}	S	S	--	S	--	S	S	S	S	S	S	S	S
SC_S-BZA_{S3}	S	S	S	S	S	S	S	S	S	S	S	S	S
SC_S-BZA_{S4}	--	S	S	--	--	--	S	S	S	S	S	S	--
WL_S-BZA_{S1}	S	S	S	S	S	S	S	S	--	S	S	S	S
WL_S-BZA_{S2}	S	S	S	S	S	S	S	S	S	S	S	S	S
WL_S-BZA_{S3}	S	S	S	S	S	S	S	S	S	S	S	S	S
WL_S-BZA_{S4}	S	S	S	S	S	S	S	--	S	S	S	S	--
BZA_{S1}-BZA_{S2}	--	--	S	--	S	--	--	--	S	--	--	--	--
BZA_{S1}-BZA_{S3}	--	S	S	S	--	--	S	--	S	S	S	--	--
BZA_{S1}-BZA_{S4}	S	S	--	S	S	S	--	S	--	S	--	S	--
BZA_{S2}-BZA_{S3}	--	S	S	--	--	--	S	--	--	--	S	--	--
BZA_{S2}-BZA_{S4}	--	S	--	S	--	S	--	S	--	S	--	S	--
BZA_{S3}-BZA_{S4}	S	S	S	S	S	S	S	S	--	S	S	S	--

Note: M: Male; F: Female; YM: Young Male; YF: Young Female; MM: Middle age Male; MF: Middle age Female; AM: Aged Male; AF: Aged Female; NLM: Male without carrying luggage; NLF: Female without carrying luggage; LM: Luggage carrying Male; LF: Luggage Carrying Female; S: Significant at 95% Confidence Interval; --: Not Significant

The overall mean walking speed of male pedestrians are higher than that of female pedestrians. Female pedestrian of various age groups and luggage have lower walking speeds than their counterparts. Table 5.6 shows the critical values observed on all the six stairways. Male and females have mean walking speed of 40.49 and 32.96m/min. Kids are observed to be walking with mean speed 35.89m/min. Male pedestrians of young, middle aged and aged have mean walking speeds of 47.10, 38.03 and 29.86m/min. Similarly, female pedestrians have walking speeds of 37.69, 32.06 and 24.00m/min for age class young, middle aged and aged respectively. The mean walking speed of male and female pedestrians is observed to be reducing with increase in age. Luggage carrying male and female pedestrians have walking speed of 36.54 and 30.77m/min. While male and female pedestrians without luggage have walking speeds of 42.91 and 34.24m/min. Male pedestrians with and without luggage are observed to walk with higher walking speeds than their female counterparts. Figure 5.2 shows the speed variations of pedestrian with respect to attributes age, gender and luggage on stairways. The walking speeds in descending order are observed as young male> male without carrying luggage> middle age male> young female> luggage carrying male> female carrying no luggage> middle age female> luggage carrying female> aged male> aged female.

Table 5.6 Pedestrian Flow Characteristics observed on stairways

Description	SC_S	WL_S	BZA_{S1}	BZA_{S2}	BZA_{S3}	BZA_{S4}
Width (m)	3.5	2.4	3.6	2	2	3.5
Maximum Flow (ped/m/min)	40	40	26	26	34	28
Optimal Density (ped/m^2)	2.60	2.29	2.51	1.00	2.93	2.56
Space available at maximum flow (m^2/ped)	0.53	1.00	0.27	1.51	0.31	0.28
Sample	163	104	181	170	153	167
Average Speed (m/min)	41.76	43.35	35.53	35.72	34.14	40.45
M (m/min)	45.38	47.53	36.64	36.61	34.87	41.89
F (m/min)	35.61	38.45	30.26	33.79	28.25	31.41
K (m/min)	43.05	42.63	32.32	33.02	29.73	34.57
YM (m/min)	52.21	54.66	43.16	43.11	39.69	49.77
YF (m/min)	39.61	43.88	32.84	36.93	34.10	38.80
MM (m/min)	41.12	44.66	35.00	34.51	33.86	39.02
MF (m/min)	34.67	36.03	30.95	31.41	28.05	31.25
AM (m/min)	34.22	32.52	27.65	27.46	26.51	30.80
AF (m/min)	26.41	26.28	24.29	20.92	21.17	22.51
NLM (m/min)	50.62	51.82	37.65	37.56	35.62	44.18
NLF (m/min)	38.99	42.46	30.93	32.91	28.42	31.75
LM (m/min)	41.31	42.96	33.02	31.57	32.84	37.52
LF (m/min)	34.08	34.73	28.14	29.01	27.79	30.85

Note: M: Male; F: Female; K: Kids; YM: Young Male; YF: Young Female; MM: Middle age Male; MF: Middle age Female; AM: Aged Male; AF: Aged Female; NLM: Male without carrying luggage; NLF: Female without carrying luggage; LM: Luggage carrying Male; LF: Luggage Carrying Female

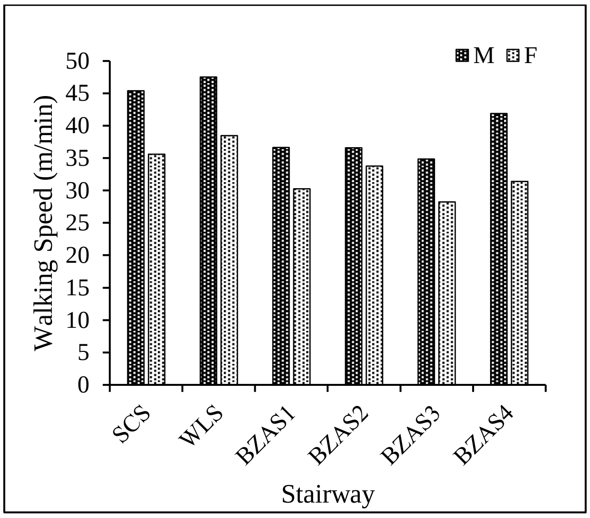


Fig 5.2 (a) Gender

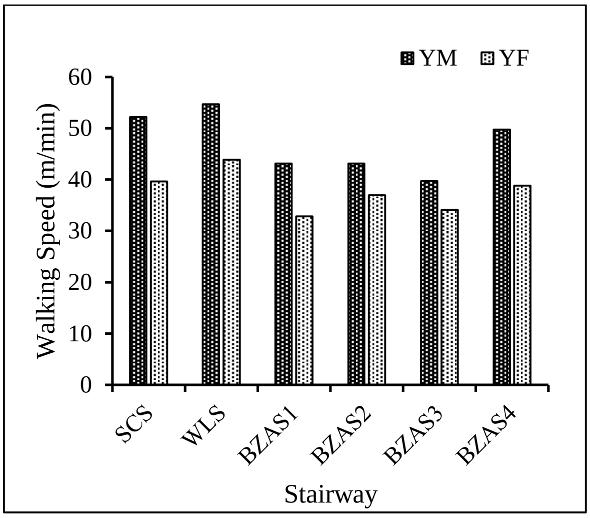


Fig 5.2 (b) Young age

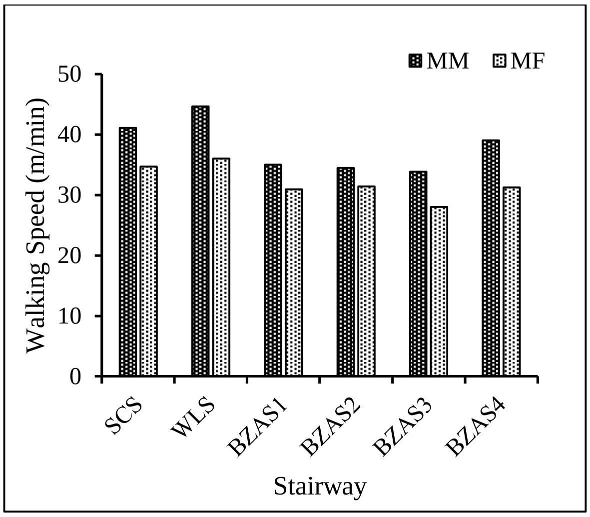


Fig 5.2 (c) Middle age

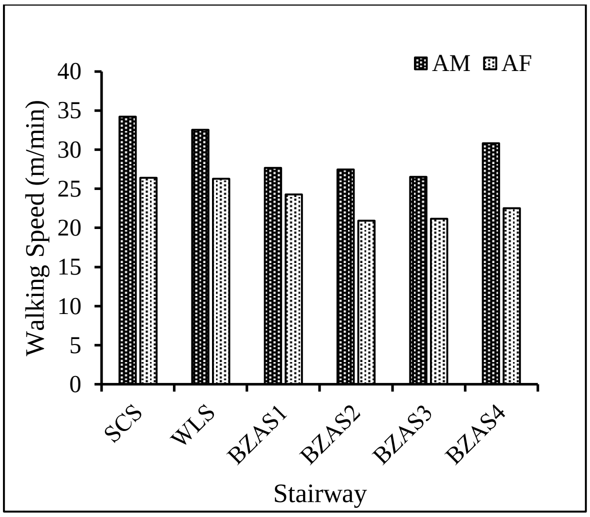


Fig 5.2 (d) Aged

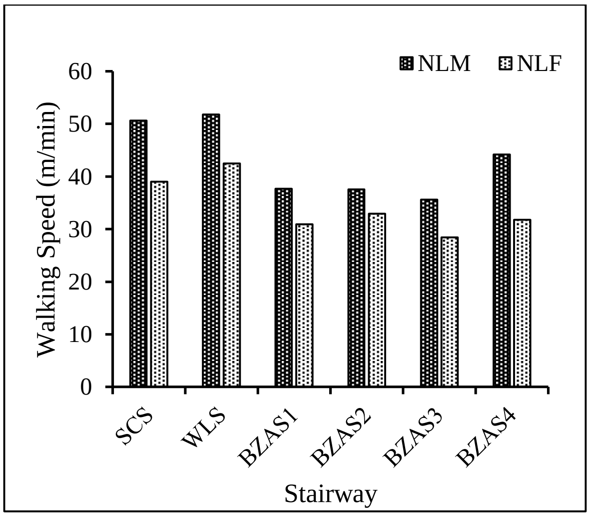


Fig 5.2 (e) No Luggage

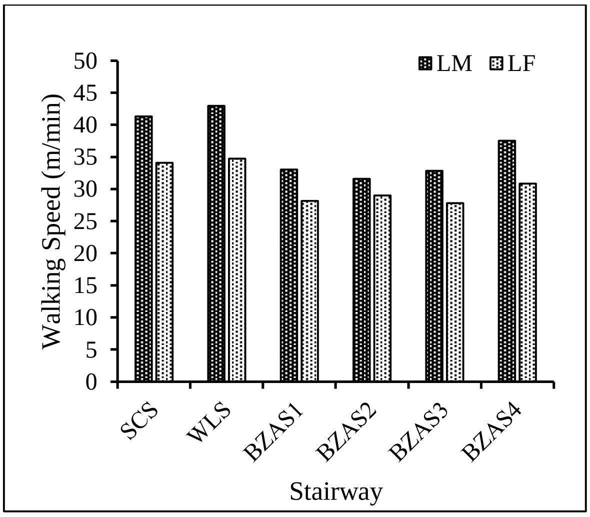


Fig 5.2 (f) Luggage

Figure 5.2 Pedestrian Mean Walking speeds with respect to various attributes on stairways

5.3.1 Pedestrian walking speed variation in ascending direction with width of stairway

Pedestrian movement on stairways, a vertical facility, offers movement in ascending and descending direction. The effort involved in ascending and descending stairways varies for pedestrian. It is higher in ascending direction to overcome the gravity. Statistical t-test results for comparison of pedestrians walking speeds with respect to pedestrian attributes gender, age and luggage on stairways in ascending direction are presented in APPENDIX-C. Table 5.7 and table 5.8 shows statistical test results for significance in means of walking speeds and pedestrian mean walking speeds observed on the six stairways in ascending direction with respect to various pedestrian attributes. From the table 5.7, observing the stairways combinations in Vijayawada, it is clear that the stair width has no effect on pedestrian walking speed in ascending direction.

Table 5.7 Statistical t-test results for comparison of pedestrians walking speeds in ascending direction with respect to pedestrian attributes

Stairway Combination	Mean Ascending Speed	M	F	YM	YF	MM	MF	AM	AF	NLM	NLF	LM	LF
SC_S-WL_S	S	S	S	--	S	S	S	--	--	S	S	S	--
SC_S -BZA_{S1}	S	S	S	S	S	S	--	S	--	S	S	S	S
SC_S –BZA_{S2}	--	S	--	--	--	S	--	S	--	S	--	S	--
SC_S –BZA_{S3}	S	S	S	S	S	S	S	S	S	S	S	S	S
SC_S –BZA_{S4}	S	S	S	S	--	S	--	S	S	S	S	S	--
WL_S -BZA_{S1}	S	S	S	S	S	S	S	--	--	S	S	S	S
WL_S - BZA_{S2}	S	S	--	--	--	S	--	S	--	S	--	S	--
WL_S - BZA_{S3}	S	S	S	S	S	S	S	S	--	S	S	S	S
WL_S - BZA_{S4}	S	S	S	S	S	S	S	--	--	S	S	S	--
BZA_{S1}- BZA_{S2}	--	--	--	--	S	--	--	--	--	--	--	--	--
BZA_{S1}- BZA_{S3}	--	--	S	--	--	--	S	--	S	--	S	--	--
BZA_{S1}- BZA_{S4}	--	--	--	--	--	--	--	--	S	--	S	--	--
BZA_{S2}- BZA_{S3}	--	--	S	--	S	--	--	--	--	--	S	S	--
BZA_{S2}- BZA_{S4}	--	--	S	--	--	--	--	--	--	--	S	--	--
BZA_{S3}- BZA_{S4}	--	--	--	S	--	--	--	--	--	S	--	--	--

Note: M: Male; F: Female; YM: Young Male; YF: Young Female; MM: Middle age Male; MF: Middle age Female; AM: Aged Male; AF: Aged Female; NLM: Male without carrying luggage; NLF: Female without carrying luggage; LM: Luggage carrying Male; LF: Luggage Carrying Female, S: Significant at 95% Confidence Interval; --: No Significant

To understand the pedestrian walking speed variation with width, pedestrian walking speeds in Vijayawada are compared on BZA_{S1} (3.6m) with BZA_{S2} (2.0m) and BZA_{S3} (2.0m) having inclination of 30^0. The comparison of pedestrian ascending walking speeds on BZA_{S1} with BZA_{S2} and BZA_{S3} showed no significant difference in mean walking speeds on stairways with width.

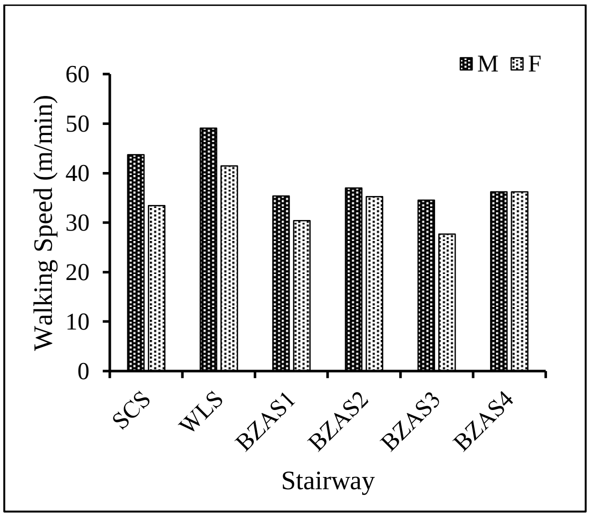
However significant difference in means of walking speeds on stairway combinations of different stations existed. And of the significance results, the walking speeds of male and female pedestrians with respect to various attributes showed significant difference in means in ascending direction only when stairs of different stations are compared. This may be due to the difference in station characteristics and layout. The mean walking speed is observed to be near equal irrespective of width. This is because, ascending involves more effort with the increasing in the rate of pacing power which is restricted by individual's attributes.

Table 5.8 Pedestrian mean walking speeds in ascending direction with respect to various attributes

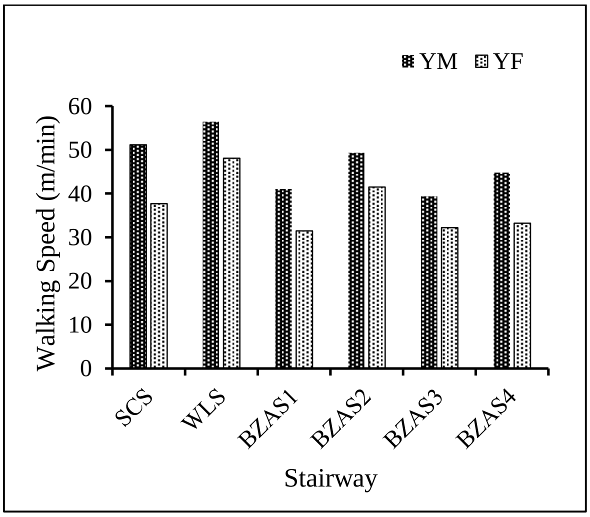
Description	SC_S	WL_S	BZA_{S1}	BZA_{S2}	BZA_{S3}	BZA_{S4}
Width (m)	3.5	2.4	3.6	2	2	3.5
Mean walking Speed (m/min)	40.74	45.98	33.79	37.43	34.41	35.66
M (m/min)	43.70	49.07	35.38	37.02	34.56	36.24
F (m/min)	33.45	41.46	30.39	35.28	27.67	27.70
K (m/min)	40.74	41.94	31.30	34.73	29.02	29.37
YM (m/min)	51.17	56.42	41.04	49.32	39.37	44.80
YF (m/min)	37.66	48.06	31.44	41.48	32.21	33.24
MM (m/min)	39.63	44.71	33.93	34.33	33.96	32.36
MF (m/min)	32.39	37.03	31.62	34.35	27.97	28.46
AM (m/min)	31.81	31.76	27.76	24.15	26.02	27.75
AF (m/min)	25.36	22.16	25.19	24.85	19.74	20.52
NLM (m/min)	48.08	52.69	36.69	40.27	35.30	38.86
NLF (m/min)	37.38	45.50	31.04	37.91	28.14	27.65
LM (m/min)	39.71	46.18	30.84	28.02	32.24	31.40
LF (m/min)	32.59	33.45	28.23	28.92	26.27	27.77

Note: M: Male; F: Female; K: Kids; YM: Young Male; YF: Young Female; MM: Middle age Male; MF: Middle age Female; AM: Aged Male; AF: Aged Female; NLM: Male without carrying luggage; NLF: Female without carrying luggage; LM: Luggage carrying Male; LF: Luggage Carrying Female

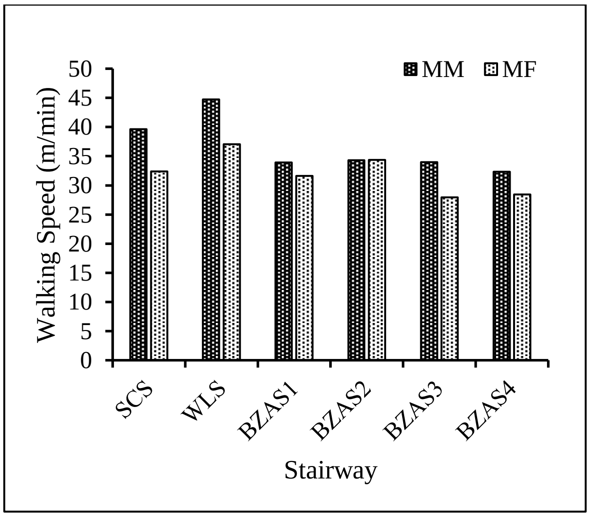
The mean walking speed in ascending direction is observed to be 38.00m/min. Mean walking speed of male (39.33m/min) is found to be higher than the female pedestrians (32.66m/min). Kids are found to be walking with mean speed of 34.52m/min. Male pedestrians with age groups young, middle aged and aged are ascending with mean speeds of 47.02, 36.49 and 28.21m/min. While their female counterparts are having means ascending speeds of 37.35, 31.97 and 22.97m/min respectively. The mean walking speeds of female pedestrians with respect to age groups is lower than the male pedestrians. The mean ascending speed of male and female pedestrians carrying no luggage have mean ascending speeds of 41.98 and 34.60m/min. While 34.73 and 29.54m/min are mean ascending speeds of male and female carrying luggage. Figure 5.3 shows the pedestrian mean walking speed variation with respect to various attributes with width of stairways in ascending direction. The mean ascending speeds of male are higher than the female with respect to luggage attribute. The mean walking speeds in ascending direction are as young male> male carrying no luggage> male> young female> middle age male> luggage carrying male> female carrying no luggage> middle age female> luggage carrying female> aged male> aged female pedestrians.



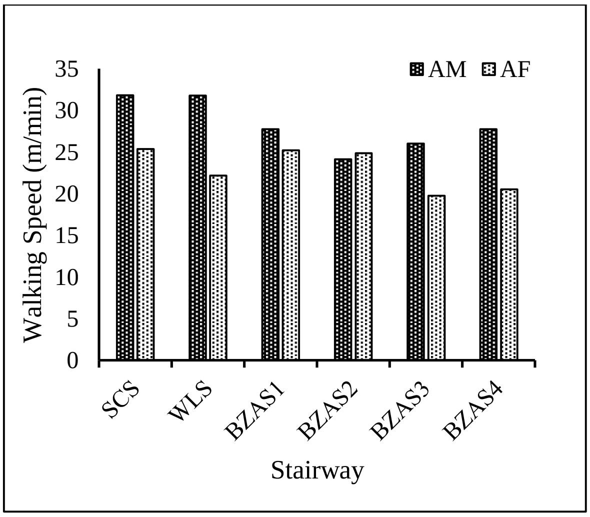
5.3 (a) Gender



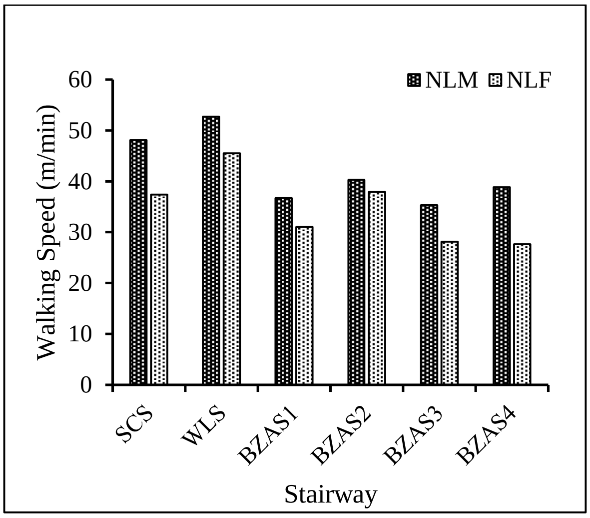
5.3 (b) Young Age



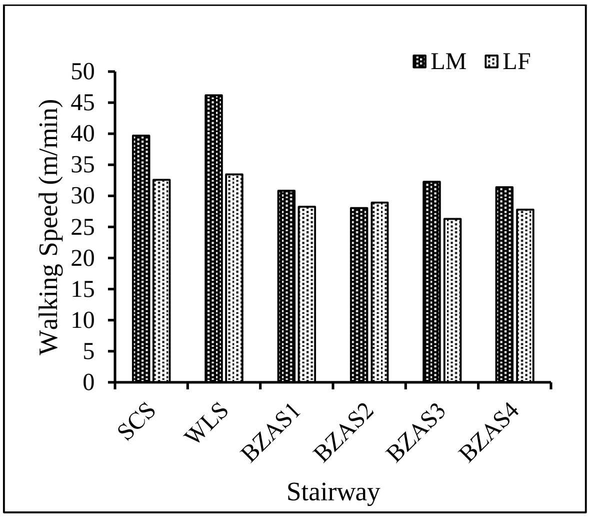
5.3 (c) Middle age



5.3 (d) Aged



5.3 (e) No Luggage



5.3 (f) Luggage

Figure 5.3 Pedestrian Walking speeds with respect to various attributes on stairways in ascending direction

5.3.2 Pedestrian walking speed variation in descending direction with width of stairway

Statistical t-test results for comparison of pedestrians walking speeds with respect to pedestrian attributes gender, age and luggage on stairways in descending direction are presented in APPENDIX-D. The t-test results for comparison of pedestrians walking speeds in descending direction are shown in table 5.9. To understand the pedestrian walking speed variation with width, pedestrian walking speeds in Vijayawada are compared on BZA_{S1} (3.6m) with BZA_{S2} (2.0m) and BZA_{S3} (2.0m) having inclination of 30^0.

The comparison of descending speeds showed significant difference in walking speeds on BZA_{S1} with BZA_{S2} and BZA_{S3} with higher walking speeds on wider stairways. The mean descending walking speeds are 34.33m/min and 37.90m/min on 2.0m and 3.6m stairways with inclination 30^o. The effort involved in descending is lower than the effort involved in ascending direction. Similarly, with increase in width, personal space increase and the desired speed is achieved. Hence means descending speed is affected by width of stairway.

The further investigation of pedestrian walking speeds with respect to attributes age, gender and luggage, the walking speeds of different pedestrian classes are compared on BZA_{S1} with BZA_{S2} and BZA_{S3}. Results showed the walking speeds of male pedestrians significantly vary and female pedestrians show insignificance in descending walking speeds with width. Female pedestrians descend with similar walking speeds on stairways of width 2.0m and 3.6m having inclination of 30^0 with mean descending walking speed of 30.70m/min. The male descending walking speeds are 35.78m/min and 38.44m/min on stairways of width 2.0m and 3.5m having inclination of 30^0. With respect to age attribute, aged male pedestrians descend with similar walking speeds irrespective of width of stairway with mean descending walking speed of 27.57m/min. The young male and middle aged male show significant difference in mean walking speeds with higher walking speeds on stairway of width 3.6m than on 2.0m width stairway. The mean descending walking speeds of young male and middle age male are 40.76m/min and 34.18m/min on stairway of width 2.0m while the walking speeds are 45.92 and 36.56m/min on stairway of width 3.6m. The mean walking speeds of male pedestrians with respect to luggage show significant difference on stairways of width 3.6m and 2.0m. The walking speeds of male pedestrians descending without luggage are 36.32m/min and 39.00m/min on 2.0m and while the luggage carrying male pedestrians descend with 32.85m/min and 36.34m/min on 2.0m and 3.6m.

Table 5.9 Statistical t-test Results for comparison of pedestrian walking speeds in descending direction with respect to Pedestrian attributes

Stairway Combination	Mean Descending Speed	M	F	YM	YF	MM	MF	AM	AF	NLM	NLF	LM	LF
SC_S-WL_S	--	--	--	--	--	--	--	--	--	--	--	--	--
SC_S -BZA_{S1}	S	S	S	S	S	S	S	S	S	S	S	S	S
SC_S –BZA_{S2}	S	S	S	S	S	S	S	S	S	S	S	S	S
SC_S –BZA_{S3}	S	S	S	S	S	S	S	S	S	S	S	S	S
SC_S –BZA_{S4}	--	--	--	--	--	--	--	--	--	S	S	--	--
WL_S -BZA_{S1}	S	S	S	S	--	S	S	S	S	S	S	S	S
WL_S - BZA_{S2}	S	S	--	S	--	S	S	S	S	S	S	S	S
WL_S - BZA_{S3}	S	S	S	S	--	S	S	S	--	S	S	S	S
WL_S - BZA_{S4}	S	--	--	--	--	--	--	--	--	--	--	--	--
BZA_{S1}- BZA_{S2}	S	S	S	S	--	S	--	--	--	S	--	S	--
BZA_{S1}- BZA_{S3}	S	S	--	S	--	S	--	--	--	S	--	S	--
BZA_{S1}- BZA_{S4}	S	S	S	S	S	S	S	S	--	S	S	S	S
BZA_{S2}- BZA_{S3}	--	--	S	--	--	--	S	--	--	--	S	--	--
BZA_{S2}- BZA_{S4}	S	S	--	S	S	S	S	S	S	S	S	S	S
BZA_{S3}- BZA_{S4}	S	S	S	S	S	S	S	S	--	S	S	S	S

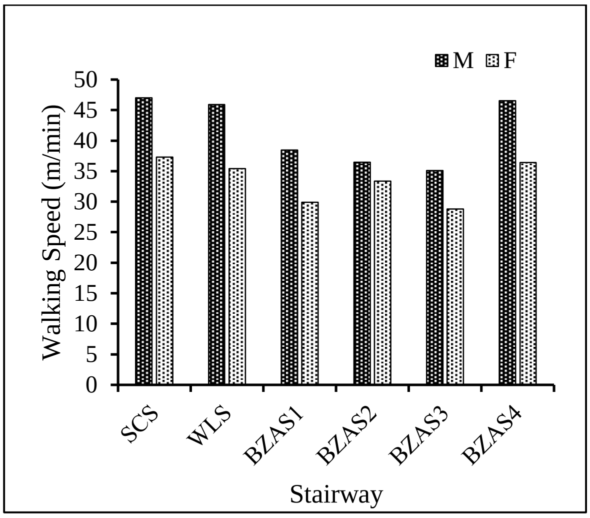
Note: M: Male; F: Female; YM: Young Male; YF: Young Female; MM: Middle age Male; MF: Middle age Female; AM: Aged Male; AF: Aged Female; NLM: Male without carrying luggage; NLF: Female without carrying luggage; LM: Luggage carrying Male; LF: Luggage Carrying Female S: Significant at 95% Confidence Interval; --: Not Significant

Table 5.10 shows the pedestrian mean walking speeds with respect to various attributes. The mean walking speed in descending direction is observed to be 39.45m/min. Mean walking speed of male (41.57m/min) is found to be higher than the female pedestrians (33.53m/min). Male pedestrians with age groups young, middle aged and aged are descending with mean speed of 47.90, 39.34 and 30.92m/min. While their female counterparts are having means descending speeds of 38.13, 32.47 and 24.18m/min respectively. The mean walking speeds of female pedestrians with age groups is lower than the male pedestrians. The mean descending speed of male and female pedestrians carrying no luggage are 43.98 and 34.39m/min. While 37.99 and 31.97m/min are mean descending speeds of male and female carrying luggage. Figure 5.4 shows the pedestrian mean walking speeds with respect to various attributes with width of stairway. The mean descending speeds of male are higher than the female with respect to attribute luggage. The mean descending speeds are as young male> male carrying no luggage> male> middle age male >young female > luggage carrying male> female carrying no luggage> middle age female> luggage carrying female> aged male> aged female pedestrians.

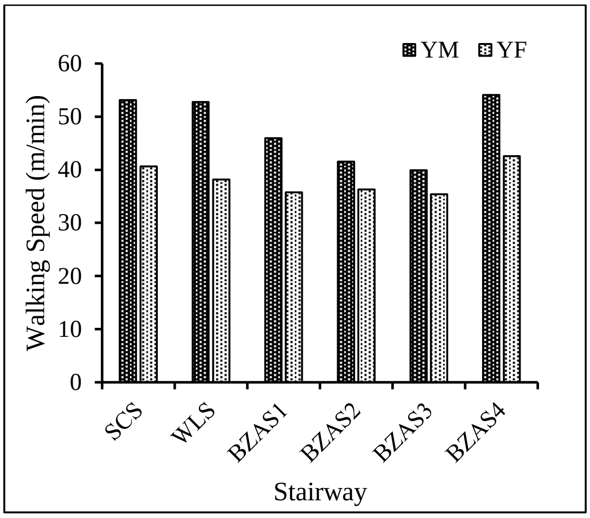
Table 5.10 Pedestrian mean walking speeds in descending direction with respect to various attributes

Description	SC_S	WL_S	BZA_{S1}	BZA_{S2}	BZA_{S3}	BZA_{S4}
W (m)	3.5	2.4	3.6	2	2	3.5
Mean Speed (m/min)	43.58	41.55	37.90	34.56	34.10	45.01
M (m/min)	47.02	45.90	38.44	36.48	35.08	46.54
F (m/min)	37.29	35.40	29.93	33.39	28.80	36.39
K (m/min)	45.36	43.32	33.35	31.30	30.44	39.77
YM (m/min)	53.14	52.77	45.92	41.52	39.93	54.10
YF (m/min)	40.61	38.18	35.73	36.28	35.39	42.58
MM (m/min)	42.40	44.60	36.56	34.56	33.80	44.10
MF (m/min)	36.03	35.07	29.31	30.65	28.14	35.61
AM (m/min)	36.26	32.85	27.52	28.30	26.89	33.71
AF (m/min)	27.63	27.08	21.88	20.43	22.15	25.90
NLM (m/min)	52.91	50.89	39.00	36.79	35.84	48.46
NLF (m/min)	39.95	38.34	30.64	31.63	28.69	37.07
LM (m/min)	42.52	40.62	36.34	32.52	33.18	42.77
LF (m/min)	35.01	35.50	27.96	29.03	29.10	35.23

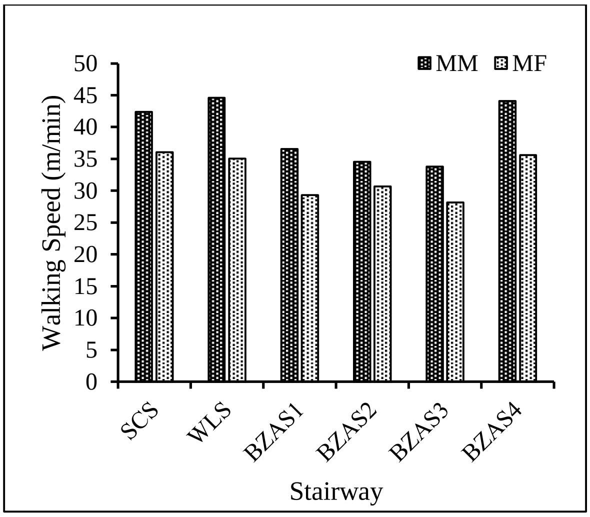
Note: M: Male; F: Female; K: Kids; YM: Young Male; YF: Young Female; MM: Middle age Male; MF: Middle age Female; AM: Aged Male; AF: Aged Female; NLM: Male without carrying luggage; NLF: Female without carrying luggage; LM: Luggage carrying Male; LF: Luggage Carrying Female



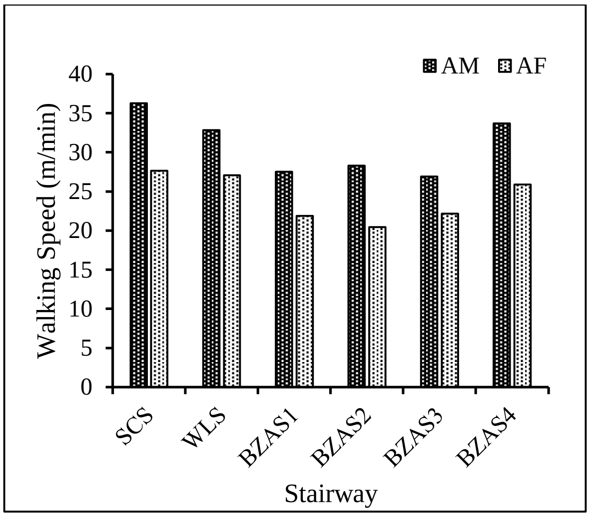
5.4 (a) Gender



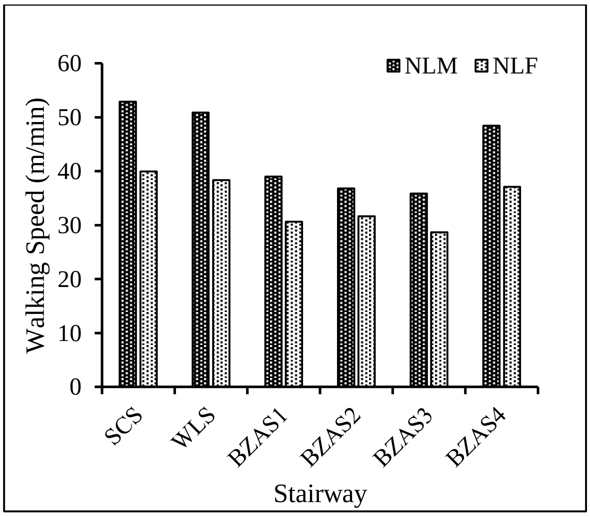
5.4 (b) Young Age



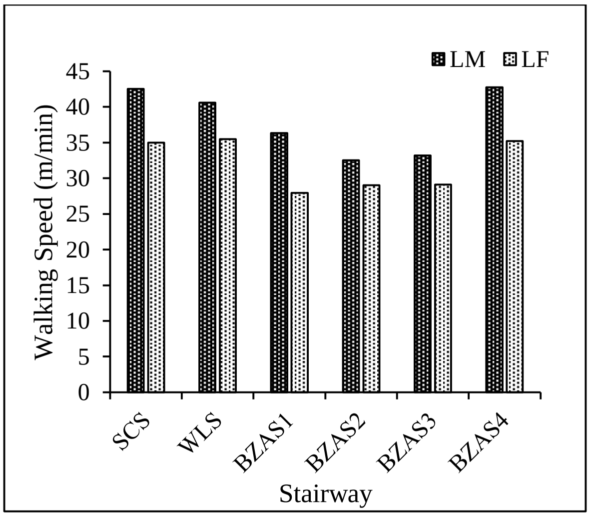
5.4 (c) Middle Age



5.4 (d) Aged



5.4 (e) No Luggage



5.4 (f) Luggage

Figure 5.4 Pedestrian Walking speeds with respect to various attributes on stairways in descending direction

5.4 Results and Discussions

On passageways, the mean walking speed is observed as 67.33m/min with male and female pedestrians' average walking speeds of 70.28 and 58.10m/min. Pedestrian mean walking speeds with respect to age attribute classification young, middle age and elders are 73.42, 62.27 and 49.32m/min respectively. The walking speeds of pedestrian walking without carrying luggage and walking with luggage are 64.756 and 58.62m/min. The walking speeds of male pedestrians with respect to attributes age, gender and luggage walk with higher speeds than their female counterparts.

Pedestrian mean walking speed in on stairways in ascending direction is lower than in descending direction. Their mean walking speeds on stairways in ascending and descending direction are 38.00 and 39.45m/min. The mean walking speed of female pedestrians are lower than the male pedestrians in both ascending and descending directions. The mean walking speeds of male are 39.33 and 41.58m/min in ascending and descending directions respectively. For female pedestrians, the walking speeds in ascending and descending direction are 32.66 and 33.53m/min respectively. The mean walking speed of pedestrians without luggage and luggage carrying are 38.29 and 32.14m/min in ascending direction. In descending direction, the walking speeds of pedestrians without luggage and carrying luggage, 39.18 and 34.98 respectively, are higher than the ascending speeds with luggage attribute. In ascending direction, the mean walking speeds of young, middle age and elder pedestrians are 42.19, 34.23 and 25.60m/min respectively. The mean walking speeds of young, middle aged and elder pedestrians are 43.01, 35.90 and 27.55m/min respectively in descending direction on stairways. The walking speeds of younger pedestrians are higher and elder pedestrians are observed to have the least walking speeds with respect to age attribute classification.

The walking speeds on horizontal level passageway are higher than the inclined level stairway in both ascending and descending directions. This is because of the effort involved in traversing being higher and restriction in pace length due to steps on stairways. The mean walking speed is lower for pedestrians carrying luggage than the pedestrian walking with luggage. Walking speed is observed to be lower for pedestrians of elder age group.

5.5 Summary

In this chapter, pedestrian flow characteristics variation with width of passage and stairway are analyzed. On stairway, width has significant effect on pedestrian walking speeds in descending direction and has no effect in ascending direction for pedestrian densities less than 1ped/m^2. Pedestrian speeds variation with respect to characteristics age, gender, and luggage with width on both passageway and stairways are analyzed. Pedestrian mean walking speeds, critical values are determined for passageway and stairway.

In the next chapter, pedestrian level of service thresholds are determined for the foot over bridge passageway and stairway in intercity railway station.

CHAPTER 6

PEDESTRIAN LEVEL OF SERVICE ON PASSAGEWAY AND STAIRWAY

6.1 General

Unlike metro stations, wide diversities exist in pedestrian characteristics- age, gender, luggage carrying, trip purpose, socioeconomic characteristics, environmental characteristics, infrastructure characteristics, etc., in intercity railway stations, built decades ago which are nodal points of the rail network. With the increase in passengers using rail transportation over the decades, there arise a need of planning, management, design, construction and renovation of intercity railway station facilities. Level changing passageways and connecting stairways to various platforms are the confined areas where pedestrians conflict with the opposing flow leading to bottlenecks affecting pedestrian flow characteristics and evacuation. Assessing the pedestrian flow characteristics and development of LOS for pedestrian facilities is of primary importance in planning, management and making design policies of infrastructure. In this research work, an attempt is made to develop pedestrian level of service standards for the foot over bridge stairway and passageway in intercity railway stations.

6.2 Pedestrian Level of Service

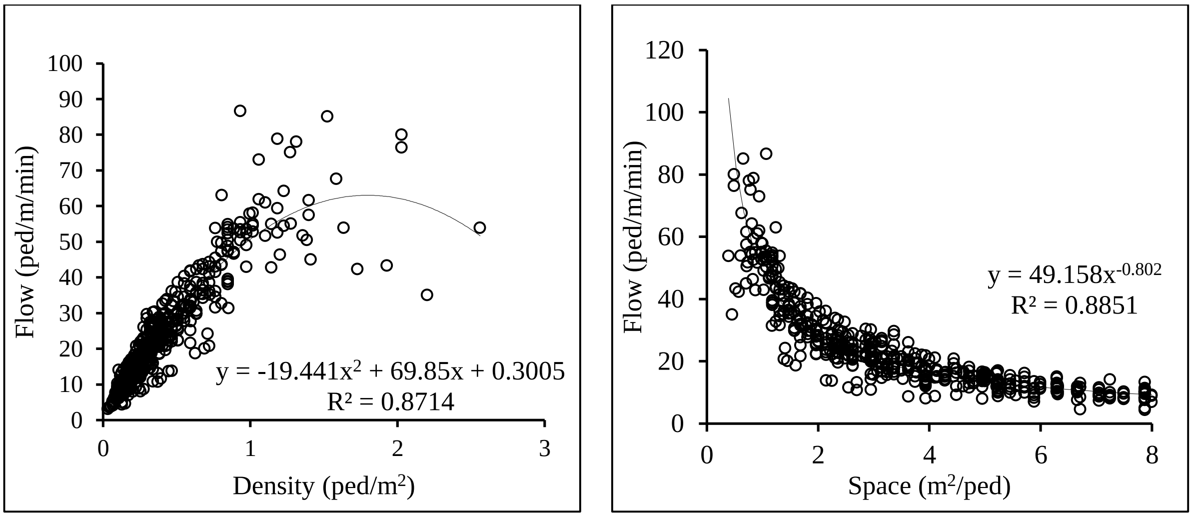
In intercity railway stations, pedestrians often walk, wait, board and alight trains. The pedestrian walking behavior varies with the trip purpose and time pressure. The number of platforms in intercity railway stations are more in number than metro and suburban transit stations. The pedestrians are under different psychological and physiological strain. They access different platforms using foot over bridges. Pedestrian flow behavior varies on level passageway and stairway, both offering bidirectional flow. Assessment of the stairway and passageway performance is a key step to plan accordingly for better pedestrian facility management and design. In this regard there is a need for level of service (LOS) thresholds development for the passageway and stairway.

In the past, many researchers have developed pedestrian LOS standards for different countries. The criteria for deciding on different levels for pedestrian flow are based on subjective (qualitative) and objective (quantitative) measures. For quantitative measures, the performance of facilities is taken into account in designing or improving any pedestrian facilities by using pedestrian speed, flow, space, and density. Qualitative measures define the pedestrian walking experience on the basis of comfort, safety, walking environment, and quality of surface and with these measures a grade or rank is assigned to the facility. In both types of measures, there is no agreement among different researchers (Shah et al. 2016). Currently, limited guidelines are available for assessing the LOS on undivided passageways and stairways in South Asian countries. In this research work, an attempt is made to develop LOS thresholds for passageway and stairway in intercity railway stations.

To develop pedestrian LOS thresholds for the passageway and stairway, pedestrian flow-density, flow-space plots are developed using the data collected. The minimum space at which pedestrian attains free flow walking speed defines the LOS A while minimum space occupancy per pedestrian available at maximum flow defines the LOS F of a facility with the proportion of space units range from level B to E at 2:2:1:1 (Fruin 1971, Lee 2003).

6.2.1 Pedestrian Level of Service on Passageway

The flow-density relationship on passageway showed polynomial trend with maximum flow of 63ped/m/min attained at an optimal density of 1.80ped/m^2. Figure 6.1 shows the pedestrian flow (q)-density (k) and flow (q)-space(s) developed for passageway.



6.1 (a) Flow (q) – Density (k) 6.1 (b) Flow (q) – Space (s)

Figure 6.1 Pedestrian Flow (q) – Density (k) – Space (s) for Passageway

For the maximum flow, the space available per pedestrian from the space-flow plot following power function trend is obtained as 0.73m^2/ped defining the space per pedestaling at LOS F. The free flow speed is observed as 72.87m/min. The pedestrian walking speeds are observed to achieve free flow speeds and above at average density of 0.244 ped/m^2 translating to a space of 4.10m^2/ped defining the space per pedestrian at LOS A. Table 6.1 shows the pedestrian LOS thresholds for passageway and comparison with the literature. A given LOS corresponds to the space available per pedestrian greater than the lower limit and equal to upper limit. For example, the space available per pedestrian in LOS C is >1.85m^2 and <=2.97m^2.

Table 6.1 Comparison of Pedestrian LOS standards for Passageway with Literature

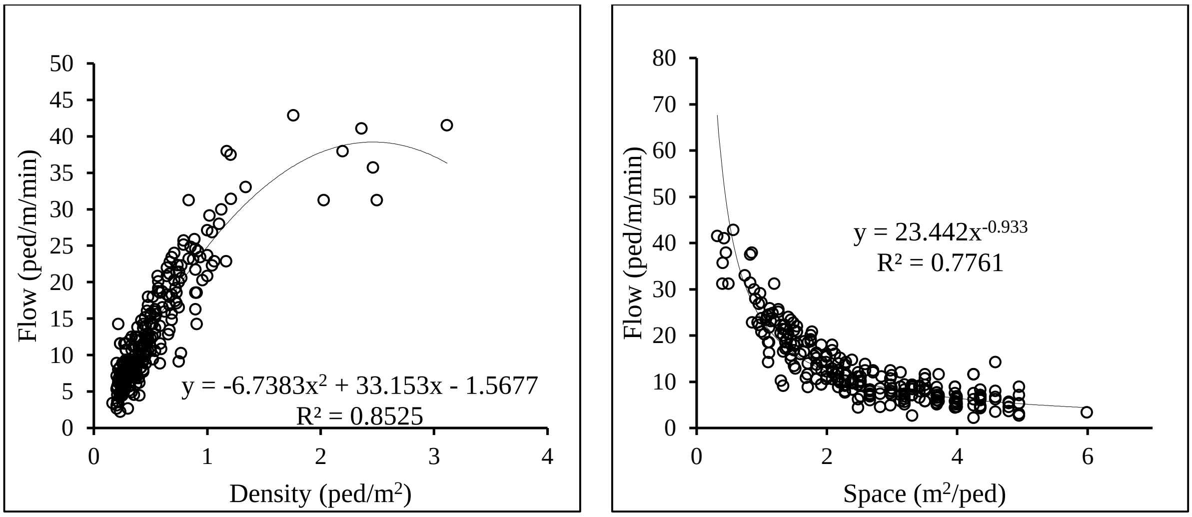
LOS	Fruin 1971	TCQSM 2007	Shouhua et al. 2009	Yang et al. 2010	HCM 2010	This study
A	> 3.24	>= 3.3	>4.76	>3.20	>5.57	>=4.10
B	2.32 – 3.24	2.3 – 3.3	3.40 - 4.76	2.33 - 3.20	3.71 – 5.57	2.97 – 4.10
C	1.39 – 2.32	1.4 – 2.3	1.99 -3.40	1.46 - 2.33	2.23 – 3.71	1.85 – 2.97
D	0.93 – 1.32	0.9 – 1.4	1.35 -1.99	1.03 - 1.46	1.39 – 2.23	1.29 – 1.85
E	0.46 – 0.93	0.5 – 0.9	0.62 - 1.35	0.60 - 1.03	0.74 – 1.39	0.73 – 1.29
F	< 0.46	>=0.5	<0.62	<0.60	<0.74	<= 0.73

Pedestrian space thresholds for a respective LOS on passageway in metro (Fruin 1971, TCQSM 2007, Yang et al. 2010) to that of passageways in intercity railway stations fall on lower side. The difference in LOS thresholds are due to the study area difference where the former relates to metro studies where the proportion of luggage carrying are very low and majority are daily users. The pedestrians in intercity railway stations are rare trip makers with majority proportions carrying luggage. Therefor the pedestrian space requirement is higher on passageway in India than in China. The LOS thresholds are in close range to Shouhua et al. 2009 studies where the space occupancy is obtained by the stated preferences of respondents for different congestion levels.

Comparison of space occupancy with HCM 2010 show that the space occupancy thresholds for passageways in intercity railway stations are lower. This may be due to the pedestrians to cater for luggage and does not prefer one-to-one contact due to their physical strain and social behaviour. For available space 4.10m^2/ped, pedestrians can achieve their desired walking speed and can reach up to a maximum possible speed of 72.87m/m.

6.2.2 Pedestrian Level of Service on Stairway

The flow-density relationship on stairway showed polynomial trend with maximum flow of 40ped/m/min attained at optimal density of 2.46ped/m^2. Figure 6.2 shows the pedestrian flow (q)-density (k) and Flow (q)-Space(s) developed for stairway. For the maximum flow, the space available per pedestrian from the space-flow plot following power function trend is obtained as 0.57m^2/ped. The free flow speed is observed as 50.35m/min. The pedestrian walking speeds are observed to achieve free flow speeds and above at an average density of 0.33ped/m^2 translating it to a space of 3.03m^2/ped.



6.2 (a) Flow (q) – Density (k) 6.2 (b) Flow (q) – Space (s)

Figure 6.2 Pedestrian Flow (q) – Density (k) – Space (s) for stairway

Table 6.2 shows the comparison of pedestrian level of service thresholds for the stairway from various studies. A given LOS corresponds to the space available per pedestrian greater than the lower limit and equal to upper limit. For example, the space available per pedestrian in LOS C is >1.39m^2 and <=2.21m^2. The minimum space requirement per pedestrian in intercity railway stations in India is observed to be higher than those of Chinese and American pedestrians in metro transit stations. However the LOS standards are in a close range to those of Lee and Lam 2003. This is because the LOS standards defined in the earlier studies are for unidirectional stairway (ascending direction) and for the metro stations where the daily commuters with no/less luggage are more in proportions.

The comparison of pedestrians LOS for stairways in suburban railway station (Shah et al. 2016) to this study in intercity railway station shows higher space requirements per pedestrian for a given LOS. This is because of the station characteristics and proportion of pedestrian classes for both the studies. Shah et al. 2016 studied Dadar railway station- a suburban railway station with 93% of daily commuters with no luggage. Whereas this study reflects pedestrian behaviour in intercity railway stations where the users are mostly luggage carrying, making long hauling trips with various trip purposes and are not frequent visitors or users of railway stations. Hence the higher space is required to cater for the luggage and individuals require more room for free movement. For the available space 3.03m^2/ped, pedestrians can achieve their desired walking speed and can reach up to a maximum possible speed of 50.35m/min. This finding reveals that pedestrians in India need higher space requirement to access stairways due to the physical strain in making long hauling trips, bidirectional movement and luggage.

Table 6.2 Comparison of Pedestrian LOS standards for Stairway with Literature

LOS	Fruin 1971	TCQSM 2007	Lee and Lam 2003	Yang et al. 2010	HCM 2010	Shah et al. 2016	This study
A	> 1.85	>= 1.90	>2.84	> 1.73	>1.86	>2.50	> 3.03
B	1.39 – 1.85	1.40 – 1.90	1.71-2.84	1.34 – 1.73	1.58 – 1.86	1.50 – 2.50	2.21 – 3.03
C	0.93 – 1.39	0.90 – 1.40	1.02-1.71	0.75 – 1.34	1.11 – 1.58	0.75 – 1.50	1.39 – 2.21
D	0.65 – 0.93	0.70 – 0.90	0.68-1.02	0.72 – 0.95	0.74 – 1.11	0.39 – 0.75	0.98 – 1.39
E	0.37 – 0.65	0.40 – 0.70	0.42-0.68	0.49 – 0.72	0.46 – 0.74	0.20 – 0.39	0.57 – 0.98
F	< 0.37	>=0.40	<0.42	< 0.49	<0.46	<0.20	< 0.57

6.3 Summary

In this chapter, pedestrian level of service thresholds were developed for the stairway and passageway of foot over bridge in intercity railway stations. The level of service thresholds are compared with those of the standards developed for the other transit stations. The results showed that the thresholds vary with functionality of transit station. Pedestrians in intercity railway stations require higher personal space in comparison to other functional railway stations.

In the next chapter, pedestrian choice behavior between stairway and escalator is studied and a model is developed.

CHAPTER 7

PEDESTRIAN CHOICE BETWEEN STAIRWAY AND ESCALATOR TO ASCEND A FOOT OVER BRIDGE

7.1 General

Pedestrians' routes in an infrastructure includes movement on horizontal levels and movement on vertical levels. They often use the shortest path or routes with shortest walking time in horizontal level. When they arrive at a point in route where to make a vertical traverse, there comes a decision making scenario in choosing among different facilities such as stairs, escalator and ramps.

Researchers across the world studied pedestrian route choice behavior including various quantitative and qualitative factors at various locations; transfer stations, shopping centers, and metro stations. The choice of vertical walking facilities is the result of the interactions between pedestrians' rational decision-making and habitual behaviors under the combined effect of a variety of internal and external factors (Zhang et al. 2015). External factors include route network characteristics: number of routes available and redundancy among routes; facility characteristics: walking distance, walking time, congestion level. Internal factors include decision making, personal attributes: age, gender, luggage carrying; behavioral habit: selection of route, following the line, avoiding conflicts, and avoiding physical exertion; familiarity and travel purpose. Regression models, logit models are used to predict pedestrian choice behavior based on revealed preferences and tracking the pedestrians along the path. Studies addressing pedestrian choice between vertical facilities in intercity railway stations, particularly in developing countries like India are not addressed. Pedestrians using urban railway stations/intercity railway stations make longer trips, comprises of trip made and trip yet to be made pedestrians subjected to various time pressures, luggage/child carrying, group size, uncertainty in knowing the platform on to which the train arrives, unfamiliar in using automated vertical facility. A greater heterogeneity in pedestrian traffic exits in intercity railway stations with respect to trip characteristics, personal attributes, and familiarity to facility use. However all are subjected to use common level changing facility associated with a stairway and escalator. Hence heterogeneity causes unbalanced usage of the vertical facilities resulting in capacity reduction. In this chapter, an attempt is made to understand the factors affecting the individual's perception in making choice between stairway and escalator.

7.2 Pedestrian Choice between Stairway and Escalator

To understand the perception of pedestrians in making a choice between stairway and escalator, six videos each of a minute duration are cropped form the video recording data of pedestrian flows collected on the selected stairways from the three intercity railway stations. Figure 7.1 shows the snapshots of video excerpts of pedestrian flows on each stairway. From the figure 7.1 it can be observed that the side friction due to waiting pedestrians sitting on the stairways is present on SC_S, BZA_{S2} and BZA_{S3} causing the reduction in usable width of stairway.

7.1(a): SC_S-Secunderabad Stairway

7.1(b): WL_S-Warangal Stairway

7.1(c): BZA_{S1}-Vijayawada Stairway 1

7.1(d): BZA_{S2}-Vijayawada Stairway 2

7.1(e): BZA_{S3}-Vijayawada Stairway 3

7.1(f): BZA_{S4}-Vijayawada Stairway 4

Figure 7.1 Snapshots of stairways from the video excerpts for questionnaire survey

Flow characteristics on each stairway for one minute video are tabulated in table 7.1. Level of Service (LOS) of the stairway is determined from the Transit Capacity and Quality of Service Manual (TCQSM 2007).

Table 7.1 Pedestrian flow characteristics observed in one minute video exhibit for the questionnaire survey on stairways

Description	SC_S	WL_S	BZA_{S1}	BZA_{S2}	BZA_{S3}	BZA_{S4}
Flow (ped/m/min)	20	16	21	16	22	18
Density (ped/m^2)	0.70	0.55	1.00	0.67	1.67	1.11
Space (m^2/ped)	1.41	1.81	1.00	1.50	0.60	0.90
Mean Speed (m/min)	42.79	39.79	44.91	31.70	23.03	27.12
LOS (As per TCQSM 2007)	B	B	B	B	B	B

To evaluate the video clips, a questionnaire survey form as shown in APPENDIX-E is prepared to collect respondent's stated preference in choosing between stairway and escalator when subjected to the condition in the excerpt. Table 7.2 shows the variable description for the questionnaire survey adapted. Respondent's characteristics included age, gender, educational qualification, employment status, marital status, and frequency of visiting railway station. Stairway characteristics: width, inclination with horizontal, step rise, and step foot. Flow Characteristics: flow, density, speed observed on each stairway for each video. A respondent is shown the video excerpt of a stairway and provided with the flow characteristics of that facility. After watching the video, respondent's choice between stairway/escalator is collected.

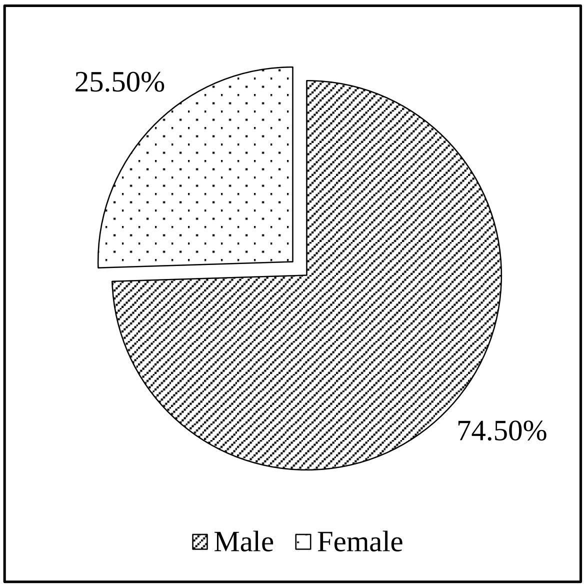
Table 7.2 Variables description for Questionnaire Survey

Characteristics	Variables	Description
Dependent Variables	Pedestrian perceived choice between stairway and escalator	1- Stairway 2- Escalator
Pedestrian Characteristics	Age	1- >30 2- else
	Gender	1- Male 2- Female
	Education	1- Under graduate 2- Graduate and higher
	Employment Status	1- Unemployed 2- Employee/employer
	Marital Status	1- Unmarried 2- Married
	Frequency of using intercity railway station	1- Frequent 2- Daily
Stairway characteristics	Width	in meters (m)
	Step rise	in meters(m)
	Step foot	in meters(m)
	Inclination	in degrees (°)
Flow characteristics	Flow	in ped/m/min
	Density	in ped/m^2
	Mean walking speed	in m/min
	Space	in m^2/ped

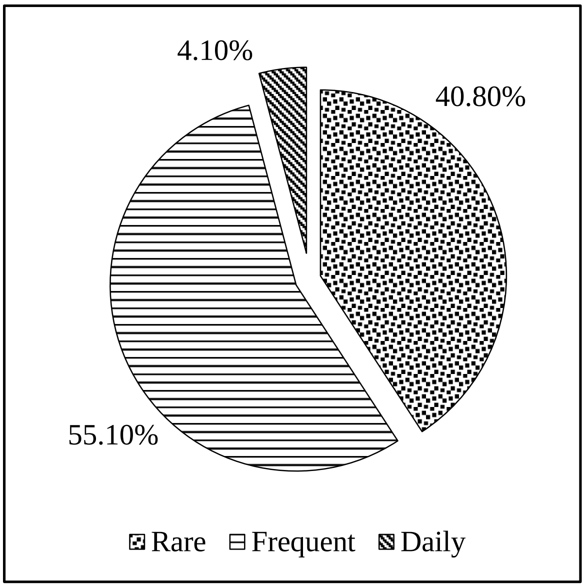
A total of 564 responses are collected. An overview of respondent's characteristic distribution is shown in figure 7.2. Of the respondents, 25.50% are female and 38.80% are married. The frequency of visiting railway station gives the respondents association with familiarity in using various facilities. Familiarity distribution in present study included 40.80% rare visitors and 55.10% frequent visitors. Employed respondents contributed to 59.20%. Respondent's choice distributions on each stairway are shown in table 7.3.

Table 7.3 Pedestrian perceived choice distribution between stairway and escalator for the video exhibit

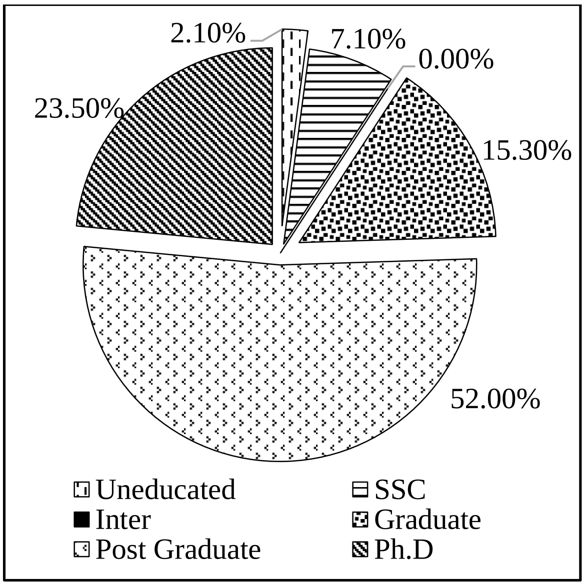
Stairway	SC_S	WL_S	BZA_{S1}	BZA_{S2}	BZA_{S3}	BZA_{S4}
Side friction due to waiting pedestrians	Yes	No	No	Yes	Yes	No
Percentage of choosing Stairway	36.7	32.7	22.4	29.6	21.4	55.1
Percentage of choosing Escalator	63.3	67.3	77.6	70.4	78.6	44.9



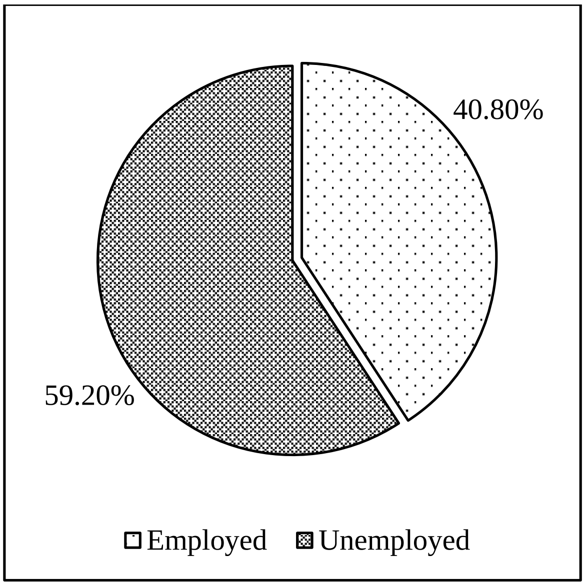
7.2(a) Gender Distribution



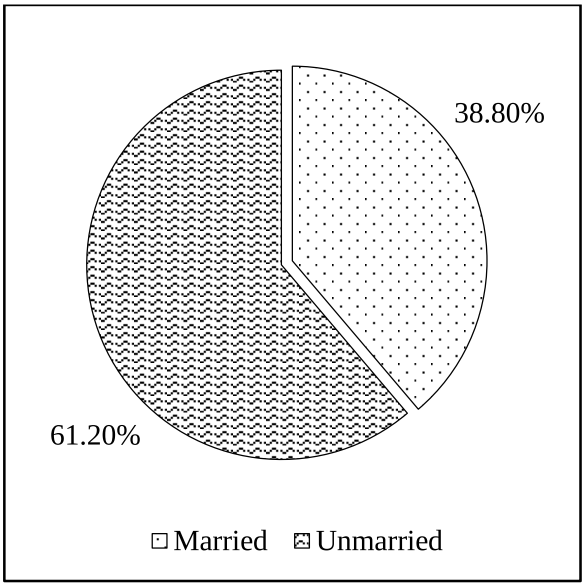
7.2(b) Frequency of visiting railway station



7.2(c) Education qualification



7.2(d) Employment distribution



7.2(e) marital status distribution

Figure 7.2 Respondents characteristics distribution

In comparison of SC_S and BZA_{S4}, for similar width, percentage of respondents choosing stairway increased with the absence of side friction. In comparison of percentage of respondents choosing stairways on all stairway with respect to width, preference of using stairway is lower on stairway with lower widths.

7.3 Binary Logit Model Development

A pedestrian perception to choose between stairway and escalator is a binary event where the probability of choosing lies between 0 and 1.

$$y_i = \begin{cases} 0, & if\ i^{th}\ respondent\ choose\ stairway \\ 1, & else \end{cases}$$

Factors affecting pedestrian's choice set are considered, and influencing factors are identified from statistical significance test for model development. Coefficients of influencing variables are estimated using the maximum likelihood function, and utility functions are defined. Probability of choosing stairway or escalator is given by equation 1 & 2

$$\Pr(y_S = 0) = P_S = \frac{e^{V_S}}{e^{V_S} + e^{V_E}} \tag{1}$$

$$\Pr(y_E = 1) = P_E = \frac{e^{V_E}}{e^{V_S} + e^{V_E}} = 1 - P_S \tag{2}$$

As the respondents are independent of one another, maximum likelihood is given by the product of the probabilities and Log transformation is given by equation 3.

$$\ln L = \sum_i y_S \ln(P_S) + (1 - y_S)\ln(1 - P_S) \qquad (3)$$

Where P_S and P_E are probabilities of choosing stairway and escalator respectively

V_S and V_E are vectors of the influencing variables as described in table 7.2. Measured characteristics influencing the choice between stairway and escalator and are given by the following equation 4,

$$V_{in} = \sum_{t=1}^{n} a_{it} x_{int} \qquad (4)$$

Where x_{int} is the tth characteristics variable of selecting mode i for an individual n and

a_{it} is the coefficient of tth variable for mode i (stairway/escalator)

It is to be noted that escalators provision inside intercity railway stations is given only in ascending direction. Hence pedestrian's choice prediction model to choose between stairway and escalator is developed for ascending direction only. Data collected from the questionnaire survey is exported to Statistical Package for Social Science (SPSS) software with predicting variables, pedestrian characteristics: age, gender, education, employment, marital status, frequency of visiting railway station, trip characteristics: morning time, evening time, infrastructure characteristics: width, inclination and flow characteristics: flow, density, speed, Side friction on stairway due to waiting/sitting pedestrians. The categorical variables- presence of side friction due to waiting pedestrians on stairways, female pedestrians, education qualification being post graduate and higher, unemployed, married, evening time usage, daily visitor to intercity railway station and age greater than 30 years are assigned 0 and others assigned 1. The dependent variable is the pedestrian perceived choice between stairway and escalator with binary values 0 and 1 respectively. Frequency distribution of perceived choices showed 32.6% choose stairway and 67.4% choose escalator to ascend. Classification cutoff is set to default value 0.5. Of the 564 responses, 70% are used for model generation and the 30% unselected are used for validation.

Forward stepwise method is selected. It starts with model that does not include any variable. In the next step, variable with highest score statistic and whose significance value less than 0.05 is added to the model. The steps continue until all significant variables are added to the model thus leaving the insignificant variable with significance value greater than 0.05. Thus a sequence of models are developed and the variables with p-value less than 0.05 are included. The final model includes age, gender, education qualification, employment status, marital status, frequency of visiting intercity railway station (familiarity), stairway inclination, and time of day.

A Binary logit model is developed to predict the respondent's perception of choice between stairway and escalator in a given condition. When the coefficient of a variable is positive, it defines that the probability of choosing escalator increases. And in converse if the coefficient is negative, the probability of individual's choice towards escalator decreases. The coefficient of a variable defines the change in logit of the probability associated for a unit change in significant variable when the other significant variables are held constant.

Table 7.4 Pedestrian perceived choice model result between stairway and escalator

Variable	Coefficient	Sig.	Exp(Coefficient)
Age (A)	1.039	0.013	2.825
Gender (G)	1.012	0.001	2.750
Educational Qualification (Q)	1.510	0.000	4.528
Employment (E)	-0.773	0.003	0.461
Marital status (M)	-1.845	0.000	0.158
Frequency of visiting (F)	1.650	0.014	5.208
Inclination (I)	-0.276	0.000	0.759
Time	0.578	0.020	1.783
Constant	-4.851	0.001	1812.877

*Sig: Significance value; Exp: Exponential

From the table 7.4, it is observed that the pedestrian characteristics has greater influence in choice making between stairway and escalator. It is evident that respondent's with characteristics of younger age, male, under graduate, unemployed, married, rare visitors tend to use escalator to that of stairway. They tend to use escalator in morning time more than that of evening as they are much active and board escalator with much ease. The maximum likelihood of a pedestrian choosing escalator in ascending directing inside an intercity railway station is given by the following equation 5.

$$\ln\left(\frac{P_E}{1-P_E}\right) = -4.851 + 1.039 * A + 1.012 * G + 1.510 * Q - 0.773 * E - 1.845 * M + 1.650 * F - 0.276 * I + 0.578 * T \quad (5)$$

The Hosmer-Lemeshow statistics for the test of model fit showed chi-square of 3.772 and significance value of 0.877 (>0.05) indicating a good fit adequately fits the data. Classification of choice generated from the model developed showed correct prediction of 72.4% from the 402 responses. Unselected 162 samples are used for validation and the validation results showed correct predictions of 64.8 %. Figure 7.3 shows the change in deviation of predictions verses predicted probabilities. The curve extending from the lower left to the upper right corresponds to responses in which choice stairway with value 0. Curve extending from lower right to upper left corresponds to the responses with escalator as choice with value 1. It shows that the respondents' choice of stairway are poorly predicted in comparison to escalator choosing respondents. This may be due to the dynamics in decision making which is instantaneous prevailing to the flow conditions at the real conditions. Various other factors may affect the individual's choice of using stairway which includes luggage carrying, queue, waiting pedestrians, time pressure which are not considered for the present study. Cox & Snell R square and Nagelkerke R square are 0.170 and 0.238 respectively.

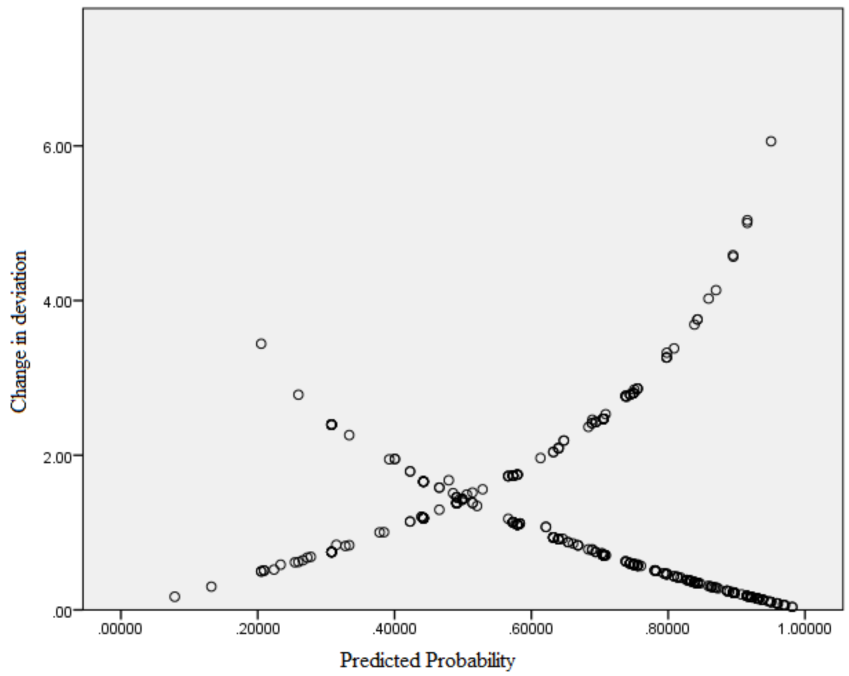


Figure 7.3 Predicted Probability variation with change in Deviation

7.4 Discussion

Younger pedestrians being aggressive and active in comparison to middle aged and elders, mounts the escalator with ease. Female pedestrians feel difficult in ascending escalator with their personal attributes. Hence they are less likely to use escalator than male pedestrians. Employed pedestrians and pedestrians with education qualification graduate and higher are less likely to use escalator due to the time pressure and hence may likely use stairway to exit faster. Pedestrians of rare trip makers and married opted to use escalator. This may be because rare trip makers and married pedestrians in intercity railway stations carry considerable luggage and hence may tend to use escalator. Also the escalator use in morning time is more than the evening time and this may due to the pedestrians being active and mounts the escalator with much ease.

From the results, it can be concluded that pedestrian and infrastructure characteristics have significant effect on the pedestrian perception in making choice between stairway and escalator. Infrastructure planning, design, and management play a major role in pedestrian accessibility, disperse efficiency and evacuation of the railway station. Pedestrian usage of stairways can be increased with proper provisions of signage boards and control of friction due to waiting pedestrians on stairways. The pedestrian safety can be increased by providing edge strips for each step, lighting facility. Adequate railing facility on edges of staircase helps for proper support to aged pedestrians. Provision of central rail for higher width stairways helps in regulated directional flow and also aids as hand support. Awareness programs on health benefits of walking aids in significant usage of stairways. Educating programs on using of escalators increases the easiness and safety of pedestrians

7.5 Summary

In this chapter, an attempt is made to replicate pedestrian perception in choice making between vertical facilities stairway and escalator to ascend foot over bridge inside an intercity railway station. Increase in demand, heterogeneity in pedestrian trip purpose, age, gender, luggage, and familiarity in the usage of various facilities significantly affects the pedestrian behavior. Moreover, infrastructure characteristics such as width, inclination with horizontal effects individual’s effort involved to ascend for a given flow characteristics. These pedestrian characteristics, stairway characteristics and flow characteristics effects individuals choice making in selecting vertical infrastructure to ascend foot over bridge. The developed Binary logit model helps in understanding the pedestrian perceived choice between stairway and escalator. Individual’s age, gender, education qualification, employment status, marital status, frequency of visiting intercity railway station (familiarity), time (morning/evening), inclination of stairway with horizontal are found to be statistically significant and influence the choice making between stairway and escalator. The results of the study help in assessing the relative proportion of shift to escalator use from existing facility and aids in decision making at the planning level, designing and managing facilities more efficiently.

In the next chapter, the summary of the research work is presented and the conclusions are drawn. The limitations of the study and the scope for further work is presented.

CHAPTER 8

SUMMARY AND CONCLUSIONS

8.1 Summary

Pedestrian flow data was collected by video-graphic method on passageways, stairways and escalators of foot over bridges in intercity railway stations. Pedestrians are classified on the characteristics of age: kids<15, young 15-30, middle age 30-60 and aged >60 years, gender: male, female, and luggage: walking with luggage and walking without luggage. Pedestrian flow-density-space are analyzed for each facility and the mean walking speeds, maximum flow and optimal density are determined. The pedestrian flow characteristics variation on level passageway to vertical stairway movement are analyzed. Observed flow characteristics are compared with those of studies across globe in metro stations, sub urban railway stations to understand the pedestrian behaviour in intercity railway stations. Statistical tests were conducted to observe the pedestrian speed variation with width of the facility. The speed variation of different pedestrian classes with width of facility are studied from the statistical tests. The speed variations with width of different class of pedestrians are analyzed and width effect is studied.

Pedestrian level of service thresholds were developed for the stairway and passageway of foot over bridge in intercity railway stations. The level of service thresholds are compared with those of the standards developed for the other transit stations. The results showed that the thresholds vary with functionality of transit station.

A binary logit model is developed to replicate pedestrian perception in choice making between vertical facilities stairway and escalator to ascend foot over bridge inside an intercity railway station. The stated preferences between stairway and escalator from respondents is collected from a questionnaire survey. Pedestrian characteristics, stairway characteristics and flow characteristics are considered as the independent variables to replicate the pedestrian perception of stairway and escalator use.

8.2 Conclusions

The following conclusions are drawn from the present study

1. The maximum flow and mean walking speed variation on stairway to passageway are 36.50% and 42.80% respectively. This is due to the higher effort involved in traversing inclined surface than horizontal level.
2. The optimal density on stairway are higher (1.36 times) than on passageway. This implies that the pedestrian have more tolerance to personal space on stairway than on passageway.
3. The maximum flow on escalators is lower in comparison to escalator in metro and other countries and is due to the pedestrians being rare visitors, unfamiliarity in usage of escalator and inability to access with the luggage.
4. On stairways of width 2.0m to 3.5m, for density less than 1ped/m^2, significant difference exists in pedestrian descending speeds with higher walking speed on wider stairway. The mean pedestrian descending walking speeds on 2.0m and 3.5m stairways are 34.33m/min and 37.90m/min respectively. However width has no influence on pedestrians ascending walking speed as it involves more effort and the effort increases with increase in rate of pacing and pedestrian attributes luggage and age.
5. Pedestrian LOS thresholds are developed for passageway and stairway in intercity railway stations. The pedestrian space required for each LOS is higher than those required by the LOS thresholds for metro stations and suburban railway stations.
6. The minimum space occupancy at capacity on passageway and stairway are 0.73m^2/ped and 0.57m^2/ped respectively with pedestrians being more tolerant to invaded spaces on stairway than on passageway.
7. Binary logit model is developed to replicate the pedestrian perception in choice making between stairway and escalator to ascend a passageway. Choice is influenced by the pedestrian characteristics: age, gender, educational qualification, employment status, marital status, frequency of visiting intercity railway station and facility characteristics: inclination.

8.3 Limitations of the study

1. Pedestrian flow characteristics determined are irrespective of flow ratio.
2. Pedestrian flow characteristics studied are under normal conditions.
3. Pedestrian choice behavior are from the stated preferences and questionnaire survey which does not include the actual behaviour caused by the influence of trip purpose, time, luggage, environment, physical and psychological state of pedestrian.
4. The layout influence and the effect of platform a passageway/stairway serves is not considered.
5. Escalators have provision to ascend the foot over bridge and hence the study limits to pedestrian behavior on escalators in ascending direction only.

8.4 Scope for further research

1. Pedestrian flow characteristics under various flow ratios and at capacity ranges can be studied on stairway and passageways.
2. Pedestrian trip characteristics, environmental characteristics and Luggage effect on pedestrian choice behaviour is to be studied further.
3. A further study on revealed preference of stair/escalator usage is to be studied to understand the effect of waiting time, flow characteristics, layout of vertical facility.

APPENDIX-A

Table A.1 Statistical t-test results for comparison of male pedestrians walking speeds on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	180	180	61.41	72.79	37.65	51.55	-8.082	1.967
SC_{P1}- WL_{P}	180	170	61.41	68.15	37.65	250.45	-5.734	1.965
SC_{P1}- BZA_{P1}	180	177	61.41	60.05	37.65	155.30	1.041	1.967
SC_{P1}- BZA_{P2}	180	156	61.41	77.91	37.65	351.01	-9.394	1.969
SC_{P1}- BZA_{P3}	180	130	61.41	75.36	37.65	301.65	-7.854	1.971
SC_{P1}- BZA_{P4}	180	133	61.41	76.33	37.65	455.10	-7.229	1.972
SC_{P2}- WL_{P}	180	170	72.79	68.15	51.55	250.45	3.055	1.966
SC_{P2}- BZA_{P1}	180	177	72.79	60.05	51.55	155.30	8.959	1.967
SC_{P2}- BZA_{P2}	180	156	72.79	77.91	51.55	351.01	-2.782	1.968
SC_{P2}- BZA_{P3}	180	130	72.79	75.36	51.55	301.65	-1.383	1.970
SC_{P2}- BZA_{P4}	180	133	72.79	76.33	51.55	455.10	-1.656	1.971
WL_{P}- BZA_{P1}	177	156	68.15	60.05	155.30	351.01	-10.104	1.969
WL_{P}- BZA_{P2}	177	130	68.15	77.91	155.30	301.65	-8.565	1.971
WL_{P}- BZA_{P3}	177	133	68.15	75.36	155.30	455.10	-7.852	1.972
WL_{P}- BZA_{P4}	156	130	68.15	76.33	351.01	301.65	1.193	1.968
BZA_{P1}- BZA_{P2}	156	133	60.05	77.91	351.01	455.10	0.667	1.969
BZA_{P1}- BZA_{P3}	130	133	60.05	75.36	301.65	455.10	-0.402	1.969
BZA_{P1}- BZA_{P4}	170	177	60.05	76.33	250.45	155.30	5.446	1.967
BZA_{P2}- BZA_{P3}	170	156	77.91	75.36	250.45	351.01	-5.160	1.968
BZA_{P2}- BZA_{P4}	170	130	77.91	76.33	250.45	301.65	-3.776	1.969
BZA_{P3}- BZA_{P4}	170	133	75.36	76.33	250.45	455.10	-3.752	1.970

Table A.2 Statistical t-test results for comparison of female pedestrians walking speeds on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	146	104	49.43	59.65	67.95	40.35	-5.532	1.970
SC_{P1}- WL_{P}	146	162	49.43	63.97	67.95	211.68	-9.059	1.969
SC_{P1}- BZA_{P1}	146	177	49.43	54.94	67.95	141.12	-3.378	1.969
SC_{P1}- BZA_{P2}	146	95	49.43	63.45	67.95	310.74	-6.189	1.972
SC_{P1}- BZA_{P3}	146	118	49.43	60.62	67.95	140.18	-6.408	1.969
SC_{P1}- BZA_{P4}	146	108	49.43	54.93	67.95	216.77	-2.797	1.970
SC_{P2}- WL_{P}	104	162	59.65	63.97	40.35	211.68	-2.868	1.972
SC_{P2}- BZA_{P1}	104	177	59.65	54.94	40.35	141.12	3.075	1.972
SC_{P2}- BZA_{P2}	104	95	59.65	63.45	40.35	310.74	-1.731	1.974
SC_{P2}- BZA_{P3}	104	118	59.65	60.62	40.35	140.18	-0.586	1.971
SC_{P2}- BZA_{P4}	104	108	59.65	54.93	40.35	216.77	2.501	1.971
WL_{P}- BZA_{P1}	162	177	63.67	54.94	211.68	141.12	6.249	1.967
WL_{P}- BZA_{P2}	162	95	63.67	63.45	211.68	310.74	0.104	1.975
WL_{P}- BZA_{P3}	162	118	63.67	60.62	211.68	140.18	1.993	1.969
WL_{P}- BZA_{P4}	162	108	63.67	54.93	211.68	216.77	4.914	1.971
BZA_{P1}- BZA_{P2}	177	95	54.94	63.45	141.12	310.74	-4.221	1.977
BZA_{P1}- BZA_{P3}	177	118	54.94	60.62	141.12	140.18	-4.033	1.969
BZA_{P1}- BZA_{P4}	177	108	54.94	54.93	141.12	216.77	0.004	1.972
BZA_{P2}- BZA_{P3}	95	118	63.45	60.62	310.74	140.18	1.341	1.975
BZA_{P2}- BZA_{P4}	95	108	63.45	54.93	310.74	216.77	3.708	1.973
BZA_{P3}- BZA_{P4}	118	108	60.62	54.93	140.18	216.77	3.182	1.972

Table A.3 Statistical t-test results for comparison of young male pedestrians walking speeds on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	162	180	72.83	82.70	289.50	326.81	-2.600	1.967
SC_{P1}- WL_{P}	162	270	72.83	72.46	289.50	381.91	0.127	1.971
SC_{P1}- BZA_{P1}	162	177	72.83	72.24	289.50	1411.21	0.153	1.967
SC_{P1}- BZA_{P2}	162	76	72.83	85.88	289.50	2578.17	-2.036	1.982
SC_{P1}- BZA_{P3}	162	130	72.83	89.60	289.50	1741.87	-3.699	1.970
SC_{P1}- BZA_{P4}	162	133	72.83	89.47	289.50	1736.45	-3.701	1.969
SC_{P2}- WL_{P}	180	270	82.70	72.46	326.81	381.91	3.477	1.970
SC_{P2}- BZA_{P1}	180	177	82.70	72.24	326.81	1411.21	2.681	1.967
SC_{P2}- BZA_{P2}	180	76	82.70	85.88	326.81	2578.17	-0.495	1.982
SC_{P2}- BZA_{P3}	180	130	82.70	89.60	326.81	1741.87	-1.517	1.969
SC_{P2}- BZA_{P4}	180	133	82.70	89.47	326.81	1736.45	-1.501	1.969
WL_{P}- BZA_{P1}	270	177	72.46	72.24	381.91	1411.21	0.073	1.970
WL_{P}- BZA_{P2}	270	76	72.46	85.88	381.91	2578.17	-2.257	1.990
WL_{P}- BZA_{P3}	270	130	72.46	89.60	381.91	1741.87	-4.453	1.975
WL_{P}- BZA_{P4}	270	133	72.46	89.47	381.91	1736.45	-4.471	1.975
BZA_{P1}- BZA_{P2}	177	76	72.24	85.88	1411.21	2578.17	-2.107	1.981
BZA_{P1}- BZA_{P3}	177	130	72.24	89.60	1411.21	1741.87	-3.755	1.969
BZA_{P1}- BZA_{P4}	177	133	72.24	89.47	1411.21	1736.45	-3.757	1.969
BZA_{P2}- BZA_{P3}	76	130	85.88	89.60	2578.17	1741.87	-0.541	1.978
BZA_{P2}- BZA_{P4}	76	133	85.88	89.47	2578.17	1736.45	-0.524	1.978
BZA_{P3}- BZA_{P4}	130	133	89.60	89.47	1741.87	1736.45	0.025	1.969

Table A.4 Statistical t-test results for comparison of young female pedestrians walking speeds on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	14	73	56.35	65.33	116.35	75.92	-1.469	2.120
SC_{P1}- WL_P	14	156	56.35	65.40	116.35	298.08	-1.526	2.131
SC_{P1}- BZA_{P1}	14	74	56.35	57.85	116.35	236.63	-0.249	2.120
SC_{P1}- BZA_{P2}	14	26	56.35	82.88	116.35	319.09	-3.932	2.069
SC_{P1}- BZA_{P3}	14	37	56.35	68.83	116.35	333.48	-1.920	2.086
SC_{P1}- BZA_{P4}	14	36	56.35	66.12	116.35	484.34	-1.430	2.064
SC_{P2}- WL_P	73	156	65.33	65.40	75.92	298.08	-0.028	1.977
SC_{P2}- BZA_{P1}	73	74	65.33	57.85	75.92	236.63	2.758	1.977
SC_{P2}- BZA_{P2}	73	26	65.33	82.88	75.92	319.09	-4.328	2.017
SC_{P2}- BZA_{P3}	73	37	65.33	68.83	75.92	333.48	-0.964	1.995
SC_{P2}- BZA_{P4}	73	36	65.33	66.12	75.92	484.34	-0.188	2.002
WL_P- BZA_{P1}	156	74	65.40	57.85	298.08	236.63	3.340	1.975
WL_P- BZA_{P2}	156	26	65.40	82.88	298.08	319.09	-4.640	2.035
WL_P- BZA_{P3}	156	37	65.40	68.83	298.08	333.48	-1.037	2.007
WL_P- BZA_{P4}	156	36	65.40	66.12	298.08	484.34	-0.183	2.014
BZA_{P1}- BZA_{P2}	74	26	57.85	82.88	236.63	319.09	-6.363	2.023
BZA_{P1}- BZA_{P3}	74	37	57.85	68.83	236.63	333.48	-3.142	1.999
BZA_{P1}- BZA_{P4}	74	36	57.85	66.12	236.63	484.34	-2.026	2.007
BZA_{P2}- BZA_{P3}	26	37	82.88	68.83	319.09	333.48	3.045	2.004
BZA_{P2}- BZA_{P4}	26	36	82.88	66.12	319.09	484.34	3.304	2.001
BZA_{P3}- BZA_{P4}	37	36	68.83	66.12	333.48	484.34	0.572	1.995

Table A.5 Statistical t-test results for comparison of middle aged male pedestrians walking speeds on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	180	180	56.17	67.36	68.15	81.36	-6.139	1.967
SC_{P1}- WL_{P}	180	294	56.17	67.94	68.15	283.13	-7.479	1.966
SC_{P1}- BZA_{P1}	180	176	56.17	56.26	68.15	315.43	-0.050	1.967
SC_{P1}- BZA_{P2}	180	155	56.17	75.91	68.15	858.77	-7.433	1.970
SC_{P1}- BZA_{P3}	180	121	56.17	68.87	68.15	425.42	-5.663	1.971
SC_{P1}- BZA_{P4}	180	122	56.17	71.74	68.15	381.97	-7.224	1.970
SC_{P2}- WL_{P}	180	294	67.36	67.94	81.36	283.13	-0.349	1.967
SC_{P2}- BZA_{P1}	180	176	67.36	56.26	81.36	315.43	5.927	1.967
SC_{P2}- BZA_{P2}	180	155	67.36	75.91	81.36	858.77	-3.155	1.970
SC_{P2}- BZA_{P3}	180	121	67.36	68.87	81.36	425.42	-0.655	1.970
SC_{P2}- BZA_{P4}	180	122	67.36	71.74	81.36	381.97	-1.971	1.970
WL_{P}- BZA_{P1}	294	176	67.94	56.26	283.13	315.43	7.158	1.967
WL_{P}- BZA_{P2}	294	155	67.94	75.91	283.13	858.77	-3.126	1.971
WL_{P}- BZA_{P3}	294	121	67.94	68.87	283.13	425.42	-0.440	1.973
WL_{P}- BZA_{P4}	294	122	67.94	71.74	283.13	381.97	-1.877	1.972
BZA_{P1}- BZA_{P2}	176	155	56.26	75.91	315.43	858.77	-7.304	1.970
BZA_{P1}- BZA_{P3}	176	121	56.26	68.87	315.43	425.42	-5.523	1.970
BZA_{P1}- BZA_{P4}	176	122	56.26	71.74	315.43	381.97	-7.043	1.970
BZA_{P2}- BZA_{P3}	155	121	75.91	68.87	858.77	425.42	2.340	1.969
BZA_{P2}- BZA_{P4}	155	122	75.91	71.74	858.77	381.97	1.417	1.969
BZA_{P3}- BZA_{P4}	121	122	68.87	71.74	381.97	381.97	-1.113	1.970

Table A.6 Statistical t-test results for comparison of middle aged female pedestrians walking speeds on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	115	89	48.36	59.87	36.60	72.54	-5.407	1.976
SC_{P1}- WL_{P}	115	219	48.36	63.14	36.60	248.79	-9.524	1.968
SC_{P1}- BZA_{P1}	115	177	48.36	57.25	36.60	338.83	-4.980	1.968
SC_{P1}- BZA_{P2}	115	94	48.36	63.48	36.60	1252.77	-3.957	1.982
SC_{P1}- BZA_{P3}	115	118	48.36	60.27	36.60	229.87	-6.636	1.971
SC_{P1}- BZA_{P4}	115	108	48.36	55.11	36.60	540.50	-2.695	1.975
SC_{P2}- WL_{P}	89	219	59.87	63.14	72.54	248.79	-1.560	1.976
SC_{P2}- BZA_{P1}	89	177	59.87	57.25	72.54	338.83	1.152	1.973
SC_{P2}- BZA_{P2}	89	94	59.87	63.48	72.54	1252.77	-0.886	1.978
SC_{P2}- BZA_{P3}	89	118	59.87	60.27	72.54	229.87	-0.175	1.973
SC_{P2}- BZA_{P4}	89	108	59.87	55.11	72.54	540.50	1.656	1.972
WL_{P}- BZA_{P1}	219	177	63.14	57.25	248.79	338.83	3.373	1.967
WL_{P}- BZA_{P2}	219	94	63.14	63.48	248.79	1252.77	-0.089	1.982
WL_{P}- BZA_{P3}	219	118	63.14	60.27	248.79	229.87	1.635	1.970
WL_{P}- BZA_{P4}	219	108	63.14	55.11	248.79	540.50	3.241	1.975
BZA_{P1}- BZA_{P2}	177	94	57.25	63.48	338.83	1252.77	-1.596	1.980
BZA_{P1}- BZA_{P3}	177	118	57.25	60.27	338.83	229.87	-1.537	1.968
BZA_{P1}- BZA_{P4}	177	108	57.25	55.11	338.83	540.50	0.813	1.973
BZA_{P2}- BZA_{P3}	94	118	63.48	60.27	1252.77	229.87	0.821	1.980
BZA_{P2}- BZA_{P4}	94	108	63.48	55.11	1252.77	540.50	1.955	1.975
BZA_{P3}- BZA_{P4}	118	108	60.27	55.11	229.87	540.50	1.957	1.973

Table A.7 Statistical t-test results for comparison of Aged male pedestrians walking speeds on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	51	85	46.31	57.62	55.48	88.05	-3.881	1.979
SC_{P1}- WL_{P}	51	127	46.31	60.34	55.48	418.11	-5.140	1.980
SC_{P1}- BZA_{P1}	51	86	46.31	51.08	55.48	274.15	-1.734	1.981
SC_{P1}- BZA_{P2}	51	15	46.31	45.44	55.48	346.22	0.166	2.086
SC_{P1}- BZA_{P3}	51	59	46.31	56.67	55.48	363.30	-3.196	1.982
SC_{P1}- BZA_{P4}	51	86	46.31	56.77	55.48	332.30	-3.647	1.980
SC_{P2}- WL_{P}	85	127	57.62	60.34	88.05	418.11	-1.008	1.973
SC_{P2}- BZA_{P1}	85	86	57.62	51.08	88.05	274.15	2.419	1.974
SC_{P2}- BZA_{P2}	85	15	57.62	45.44	88.05	346.22	2.335	2.093
SC_{P2}- BZA_{P3}	85	59	57.62	56.67	88.05	363.30	0.296	1.979
SC_{P2}- BZA_{P4}	85	86	57.62	56.77	88.05	332.30	0.303	1.974
WL_{P}- BZA_{P1}	127	86	60.34	51.08	418.11	274.15	3.696	1.972
WL_{P}- BZA_{P2}	127	15	60.34	45.44	418.11	346.22	2.911	2.101
WL_{P}- BZA_{P3}	127	59	60.34	56.67	418.11	363.30	1.205	1.980
WL_{P}- BZA_{P4}	127	86	60.34	56.77	418.11	332.30	1.354	1.972
BZA_{P1}- BZA_{P2}	86	15	51.08	45.44	274.15	346.22	1.099	2.101
BZA_{P1}- BZA_{P3}	86	59	51.08	56.67	274.15	363.30	-1.831	1.981
BZA_{P1}- BZA_{P4}	86	86	51.08	56.77	274.15	332.30	-2.144	1.974
BZA_{P2}- BZA_{P3}	15	59	45.44	56.67	346.22	363.30	-2.077	2.074
BZA_{P2}- BZA_{P4}	15	86	45.44	56.77	346.22	332.30	-2.182	2.093
BZA_{P3}- BZA_{P4}	59	86	56.67	56.77	363.30	332.30	-0.030	1.980

Table A.8 Statistical t-test results for comparison of Aged female pedestrians walking speeds on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	23	58	34.04	52.07	38.68	77.73	-5.185	2.002
SC_{P1}- WL_{P}	23	53	34.04	59.30	38.68	261.94	-7.394	2.005
SC_{P1}- BZA_{P1}	23	59	34.04	46.35	38.68	241.88	-3.740	2.009
SC_{P1}- BZA_{P2}	23	10	34.04	40.73	38.68	134.84	-1.487	2.101
SC_{P1}- BZA_{P3}	23	36	34.04	42.91	38.68	259.00	-2.376	2.004
SC_{P1}- BZA_{P4}	23	51	34.04	40.80	38.68	191.42	-2.088	2.012
SC_{P2}- WL_{P}	58	53	52.07	59.30	77.73	261.94	-2.253	1.982
SC_{P2}- BZA_{P1}	58	59	52.07	46.35	77.73	241.88	1.860	1.981
SC_{P2}- BZA_{P2}	58	10	52.07	40.73	77.73	134.84	2.613	2.110
SC_{P2}- BZA_{P3}	58	36	52.07	42.91	77.73	259.00	2.586	1.990
SC_{P2}- BZA_{P4}	58	51	52.07	40.80	77.73	191.42	3.732	1.983
WL_{P}- BZA_{P1}	53	59	59.30	46.35	261.94	241.88	4.307	1.982
WL_{P}- BZA_{P2}	53	10	59.30	40.73	261.94	134.84	4.326	2.120
WL_{P}- BZA_{P3}	53	36	59.30	42.91	261.94	259.00	4.706	1.992
WL_{P}- BZA_{P4}	53	51	59.30	40.80	261.94	191.42	6.273	1.984
BZA_{P1}- BZA_{P2}	59	10	46.35	40.73	241.88	134.84	1.340	2.131
BZA_{P1}- BZA_{P3}	59	36	46.35	42.91	241.88	259.00	1.024	1.993
BZA_{P1}- BZA_{P4}	59	51	46.35	40.80	241.88	191.42	1.979	1.982
BZA_{P2}- BZA_{P3}	10	36	40.73	42.91	134.84	259.00	-0.479	2.086
BZA_{P2}- BZA_{P4}	10	51	40.73	40.80	134.84	191.42	-0.018	2.131
BZA_{P3}- BZA_{P4}	36	51	42.91	40.80	259.00	191.42	0.636	1.995

Table A.9 Statistical t-test results for comparison of walking speeds of male pedestrians walking without luggage on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	173	180	58.01	74.21	108.61	213.64	-6.011	1.967
SC_{P1}- WL_P	173	317	58.01	72.05	108.61	315.69	-7.549	1.968
SC_{P1}- BZA_{P1}	173	177	58.01	57.71	108.61	462.70	0.137	1.967
SC_{P1}- BZA_{P2}	173	156	58.01	85.52	108.61	1947.01	-7.104	1.971
SC_{P1}- BZA_{P3}	173	119	58.01	70.77	108.61	554.68	-4.764	1.970
SC_{P1}- BZA_{P4}	173	113	58.01	76.03	108.61	729.25	-6.017	1.972
SC_{P2}- WL_P	180	317	74.21	72.05	213.64	315.69	0.903	1.969
SC_{P2}- BZA_{P1}	180	177	74.21	57.71	213.64	462.70	6.083	1.967
SC_{P2}- BZA_{P2}	180	156	74.21	85.52	213.64	1947.01	-2.725	1.969
SC_{P2}- BZA_{P3}	180	119	74.21	70.77	213.64	554.68	1.121	1.968
SC_{P2}- BZA_{P4}	180	113	74.21	76.03	213.64	729.25	-0.544	1.969
WL_P- BZA_{P1}	317	177	72.05	57.71	315.69	1947.01	7.604	1.968
WL_P- BZA_{P2}	317	156	72.05	85.52	315.69	1947.01	-3.675	1.973
WL_P- BZA_{P3}	317	119	72.05	70.77	315.69	554.68	0.541	1.974
WL_P- BZA_{P4}	317	113	72.05	76.03	315.69	729.25	-1.461	1.976
BZA_{P1}- BZA_{P2}	177	156	57.71	85.52	462.70	1947.01	-7.159	1.971
BZA_{P1}- BZA_{P3}	177	119	57.71	70.77	462.70	554.68	-4.845	1.970
BZA_{P1}- BZA_{P4}	177	113	57.71	76.03	462.70	729.25	-6.085	1.972
BZA_{P2}- BZA_{P3}	156	119	85.52	70.77	1947.01	554.68	3.562	1.970
BZA_{P2}- BZA_{P4}	156	113	85.52	76.03	1947.01	729.25	2.181	1.969
BZA_{P3}- BZA_{P4}	119	113	70.77	76.03	554.68	729.25	-1.577	1.971

Table A.10 Statistical t-test results for comparison of walking speeds of female pedestrians walking without luggage on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	146	104	49.75	58.87	97.50	90.12	-3.684	1.970
SC_{P1}- WL_P	146	224	49.75	66.38	97.50	239.24	-8.601	1.969
SC_{P1}- BZA_{P1}	146	177	49.75	52.48	97.50	273.41	-1.332	1.968
SC_{P1}- BZA_{P2}	146	95	49.75	66.76	97.50	1395.74	-4.083	1.979
SC_{P1}- BZA_{P3}	146	118	49.75	60.17	97.50	385.81	-4.276	1.969
SC_{P1}- BZA_{P4}	146	102	49.75	57.85	97.50	676.48	-2.657	1.973
SC_{P2}- WL_P	104	224	58.87	66.38	90.12	239.24	-3.525	1.974
SC_{P2}- BZA_{P1}	104	177	58.87	52.48	90.12	273.41	2.855	1.972
SC_{P2}- BZA_{P2}	104	95	58.87	66.76	90.12	1395.74	-1.851	1.977
SC_{P2}- BZA_{P3}	104	118	58.87	60.17	90.12	385.81	-0.500	1.971
SC_{P2}- BZA_{P4}	104	102	58.87	57.85	90.12	676.48	0.322	1.973
WL_P- BZA_{P1}	224	177	66.38	52.48	239.24	273.41	8.598	1.966
WL_P- BZA_{P2}	224	95	66.38	66.76	239.24	1395.74	-0.096	1.982
WL_P- BZA_{P3}	224	118	66.38	60.17	239.24	385.81	2.982	1.972
WL_P- BZA_{P4}	224	102	66.38	57.85	239.24	676.48	3.074	1.978
BZA_{P1}- BZA_{P2}	177	95	52.48	66.76	273.41	1395.74	-3.544	1.981
BZA_{P1}- BZA_{P3}	177	118	52.48	60.17	273.41	385.81	-3.504	1.971
BZA_{P1}- BZA_{P4}	177	102	52.48	57.85	273.41	676.48	-1.877	1.976
BZA_{P2}- BZA_{P3}	95	118	66.76	60.17	1395.74	385.81	1.555	1.978
BZA_{P2}- BZA_{P4}	95	102	66.76	57.85	1395.74	676.48	1.930	1.974
BZA_{P3}- BZA_{P4}	118	102	60.17	57.85	385.81	676.48	0.737	1.973

Table A.11 Statistical t-test results for comparison of walking speeds of male pedestrians carrying luggage on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	149	143	60.11	67.53	97.80	109.31	-3.113	1.968
SC_{P1}- WL_{P}	149	142	60.11	65.56	97.80	285.58	-2.531	1.968
SC_{P1}- BZA_{P1}	149	176	60.11	57.25	97.80	392.71	1.296	1.968
SC_{P1}- BZA_{P2}	149	96	60.11	60.57	97.80	397.93	-0.180	1.972
SC_{P1}- BZA_{P3}	149	118	60.11	72.54	97.80	409.94	-5.033	1.970
SC_{P1}- BZA_{P4}	149	94	60.11	60.36	97.80	377.15	-0.099	1.972
SC_{P2}- WL_{P}	143	142	67.53	65.56	109.31	285.58	0.876	1.969
SC_{P2}- BZA_{P1}	143	176	67.53	57.25	109.31	392.71	4.469	1.968
SC_{P2}- BZA_{P2}	143	96	67.53	60.57	109.31	397.93	2.592	1.971
SC_{P2}- BZA_{P3}	143	118	67.53	72.54	109.31	409.94	-1.959	1.969
SC_{P2}- BZA_{P4}	143	94	67.53	60.36	109.31	377.15	2.696	1.971
WL_{P}- BZA_{P1}	142	176	65.56	57.25	285.58	392.71	4.033	1.968
WL_{P}- BZA_{P2}	142	96	65.56	60.57	285.58	397.93	2.009	1.973
WL_{P}- BZA_{P3}	142	118	65.56	72.54	285.58	409.94	-2.980	1.970
WL_{P}- BZA_{P4}	142	94	65.56	60.36	285.58	377.15	2.117	1.973
BZA_{P1}- BZA_{P2}	176	96	57.25	60.57	392.71	397.93	-1.316	1.972
BZA_{P1}- BZA_{P3}	176	118	57.25	72.54	392.71	409.94	-6.399	1.970
BZA_{P1}- BZA_{P4}	176	94	57.25	60.36	392.71	377.15	-1.245	1.972
BZA_{P2}- BZA_{P3}	96	118	60.57	72.54	397.93	409.94	-4.334	1.972
BZA_{P2}- BZA_{P4}	96	94	60.57	60.36	397.93	377.15	0.075	1.973
BZA_{P3}- BZA_{P4}	118	94	72.54	60.36	409.94	377.15	4.450	1.972

Table A.12 Statistical t-test results for comparison of walking speeds of female pedestrians carrying luggage on passageways

Passageways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_{P1}- SC_{P2}	31	78	43.72	58.50	30.34	65.76	-5.471	1.990
SC_{P1}- WL_{P}	31	127	43.72	61.94	30.34	259.50	-7.464	1.997
SC_{P1}- BZA_{P1}	31	79	43.72	51.94	30.34	204.54	-3.221	1.994
SC_{P1}- BZA_{P2}	31	31	43.72	56.03	30.34	264.14	-3.490	2.006
SC_{P1}- BZA_{P3}	31	59	43.72	58.30	30.34	321.63	-4.763	1.988
SC_{P1}- BZA_{P4}	31	81	43.72	46.37	30.34	282.59	-0.972	1.989
SC_{P2}- WL_{P}	78	127	58.50	61.94	65.76	259.50	-1.482	1.975
SC_{P2}- BZA_{P1}	78	79	58.50	51.94	65.76	204.54	2.685	1.976
SC_{P2}- BZA_{P2}	78	31	58.50	56.03	65.76	264.14	0.065	1.980
SC_{P2}- BZA_{P3}	78	59	58.50	58.30	65.76	321.63	-11.581	1.992
SC_{P2}- BZA_{P4}	78	81	58.50	46.37	65.76	282.59	4.629	1.975
WL_{P}- BZA_{P1}	127	79	61.94	51.94	259.50	204.54	4.649	1.973
WL_{P}- BZA_{P2}	127	31	61.94	56.03	259.50	264.14	1.819	2.014
WL_{P}- BZA_{P3}	127	59	61.94	58.30	259.50	321.63	1.330	1.983
WL_{P}- BZA_{P4}	127	81	61.94	46.37	259.50	282.59	6.622	1.974
BZA_{P1}- BZA_{P2}	79	31	51.94	56.03	204.54	264.14	-1.228	2.010
BZA_{P1}- BZA_{P3}	79	59	51.94	58.30	204.54	321.63	-2.245	1.982
BZA_{P1}- BZA_{P4}	79	81	51.94	46.37	204.54	282.59	2.259	1.975
BZA_{P2}- BZA_{P3}	31	59	56.03	58.30	264.14	321.63	-0.607	1.996
BZA_{P2}- BZA_{P4}	31	81	56.03	46.37	264.14	282.59	2.789	2.003
BZA_{P3}- BZA_{P4}	59	81	58.30	46.37	321.63	282.59	3.991	1.980

APPENDIX-B

Table B.1 Statistical t-test results for comparison of male pedestrians walking speeds on Stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	349	218	45.38	47.53	162.23	252.68	-1.683	1.966
SC_S –BZA_{S1}	349	1661	45.38	36.64	162.23	280.84	10.983	1.964
SC_S -BZA_{S2}	349	550	45.38	36.61	162.23	293.69	8.780	1.963
SC_S -BZA_{S3}	349	1108	45.38	34.87	162.23	229.86	12.826	1.963
SC_S -BZA_{S4}	349	1829	45.38	41.89	162.23	607.70	3.913	1.963
WL_S - BZA_{S1}	218	1661	47.53	36.64	252.68	280.84	9.449	1.968
WL_S - BZA_{S2}	218	550	47.53	36.61	252.68	293.69	8.392	1.966
WL_S - BZA_{S3}	218	1108	47.53	34.87	252.68	229.86	10.831	1.968
WL_S - BZA_{S4}	218	1829	47.53	41.89	252.68	607.70	4.617	1.967
BZA_{S1}- BZA_{S2}	1661	550	36.64	36.61	280.84	293.69	0.037	1.963
BZA_{S1}- BZA_{S3}	1661	1108	36.64	34.87	280.84	229.86	2.887	1.961
BZA_{S1}- BZA_{S4}	1661	1829	36.64	41.89	280.84	607.70	-7.416	1.961
BZA_{S2}- BZA_{S3}	550	1108	36.61	34.87	293.69	229.86	2.022	1.962
BZA_{S2}- BZA_{S4}	550	1829	36.61	41.89	293.69	607.70	-5.675	1.962
BZA_{S3}- BZA_{S4}	1108	1829	34.87	41.89	229.86	607.70	-9.560	1.961

Table B.2 Statistical t-test results for comparison of female pedestrians walking speeds on Stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	299	185	35.61	38.45	78.70	114.75	-3.023	1.967
SC_S –BZA_{S1}	299	487	35.61	30.26	78.70	129.37	7.356	1.963
SC_S -BZA_{S2}	299	229	35.61	33.79	78.70	381.70	1.309	1.968
SC_S -BZA_{S3}	299	419	35.61	28.25	78.70	92.71	10.562	1.964
SC_S -BZA_{S4}	299	478	35.61	31.41	78.70	456.57	3.805	1.963
WL_S - BZA_{S1}	185	487	38.45	30.26	114.75	129.37	8.702	1.967
WL_S - BZA_{S2}	185	229	38.45	33.79	114.75	381.70	3.081	1.966
WL_S - BZA_{S3}	185	419	38.45	28.25	114.75	92.71	11.111	1.967
WL_S - BZA_{S4}	185	478	38.45	31.41	114.75	456.57	5.610	1.964
BZA_{S1}- BZA_{S2}	487	229	30.26	33.79	129.37	381.70	-2.540	1.968
BZA_{S1}- BZA_{S3}	487	419	30.26	28.25	129.37	92.71	2.869	1.963
BZA_{S1}- BZA_{S4}	487	478	30.26	31.41	129.37	456.57	-1.040	1.963
BZA_{S2}- BZA_{S3}	229	419	33.79	28.25	381.70	92.71	4.027	1.968
BZA_{S2}- BZA_{S4}	229	478	33.79	31.41	381.70	456.57	1.471	1.965
BZA_{S3}- BZA_{S4}	419	478	28.25	31.41	92.71	456.57	-2.905	1.963

Table B.3 Statistical t-test results for comparison of young male pedestrians walking speeds on Stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	333	182	52.21	54.66	426.61	542.19	-1.184	1.967
SC_S –BZA_{S1}	333	473	52.21	43.16	426.61	423.47	6.134	1.963
SC_S -BZA_{S2}	333	147	52.21	43.11	426.61	420.43	4.472	1.968
SC_S -BZA_{S3}	333	295	52.21	39.69	426.61	271.12	8.442	1.964
SC_S -BZA_{S4}	333	619	52.21	49.77	426.61	667.79	1.588	1.963
WL_S - BZA_{S1}	182	473	54.66	43.16	542.19	423.47	5.839	1.968
WL_S - BZA_{S2}	182	147	54.66	43.11	542.19	420.43	4.778	1.967
WL_S - BZA_{S3}	182	295	54.66	39.69	542.19	271.12	7.580	1.968
WL_S - BZA_{S4}	182	619	54.66	49.77	542.19	667.79	2.424	1.967
BZA_{S1}- BZA_{S2}	473	147	43.16	43.11	423.47	420.43	0.027	1.970
BZA_{S1}- BZA_{S3}	473	295	43.16	39.69	423.47	271.12	2.578	1.963
BZA_{S1}- BZA_{S4}	473	619	43.16	49.77	423.47	667.79	-4.705	1.962
BZA_{S2}- BZA_{S3}	147	295	43.11	39.69	420.43	271.12	1.760	1.970
BZA_{S2}- BZA_{S4}	147	619	43.11	49.77	420.43	667.79	-3.357	1.969
BZA_{S3}- BZA_{S4}	295	619	39.69	49.77	271.12	667.79	-7.134	1.963

Table B.4 Statistical t-test results for comparison of young female pedestrians walking speeds on Stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	210	111	39.61	43.88	119.25	172.55	-2.926	1.972
SC_S –BZA_{S1}	210	110	39.61	32.84	119.25	70.88	6.149	1.969
SC_S -BZA_{S2}	210	56	39.61	36.93	119.25	101.36	1.738	1.986
SC_S -BZA_{S3}	210	74	39.61	34.10	119.25	144.48	3.472	1.980
SC_S -BZA_{S4}	210	89	39.61	38.80	119.25	180.97	0.502	1.977
WL_S - BZA_{S1}	111	110	43.88	32.84	172.55	70.88	7.441	1.973
WL_S - BZA_{S2}	111	56	43.88	36.93	172.55	101.36	3.785	1.977
WL_S - BZA_{S3}	111	74	43.88	34.10	172.55	144.48	5.220	1.974
WL_S - BZA_{S4}	111	89	43.88	38.80	172.55	180.97	2.678	1.973
BZA_{S1}- BZA_{S2}	110	56	32.84	36.93	70.88	101.36	-2.611	1.985
BZA_{S1}- BZA_{S3}	110	74	32.84	34.10	70.88	144.48	-0.781	1.980
BZA_{S1}- BZA_{S4}	110	89	32.84	38.80	70.88	180.97	-3.643	1.977
BZA_{S2}- BZA_{S3}	56	74	36.93	34.10	101.36	144.48	1.460	1.979
BZA_{S2}- BZA_{S4}	56	89	36.93	38.80	101.36	180.97	-0.954	1.977
BZA_{S3}- BZA_{S4}	74	89	34.10	38.80	144.48	180.97	-2.356	1.975

Table B.5 Statistical t-test results for comparison of middle aged male pedestrians walking speeds on Stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	315	180	41.12	44.66	183.28	236.98	-2.565	1.967
SC_S –BZA_{S1}	315	985	41.12	35.00	183.28	215.96	6.836	1.964
SC_S -BZA_{S2}	315	370	41.12	34.51	183.28	213.83	6.139	1.963
SC_S -BZA_{S3}	315	660	41.12	33.86	183.28	188.92	7.793	1.964
SC_S -BZA_{S4}	315	1003	41.12	39.02	183.28	607.65	1.929	1.962
WL_S - BZA_{S1}	180	985	44.66	35.00	236.98	215.96	7.789	1.970
WL_S - BZA_{S2}	180	370	44.66	34.51	236.98	213.83	7.371	1.967
WL_S - BZA_{S3}	180	660	44.66	33.86	236.98	188.92	8.527	1.969
WL_S - BZA_{S4}	180	1003	44.66	39.02	236.98	607.65	4.065	1.966
BZA_{S1}- BZA_{S2}	985	370	35.00	34.51	215.96	213.83	0.552	1.964
BZA_{S1}- BZA_{S3}	985	660	35.00	33.86	215.96	188.92	1.606	1.962
BZA_{S1}- BZA_{S4}	985	1003	35.00	39.02	215.96	607.65	-4.422	1.961
BZA_{S2}- BZA_{S3}	370	660	34.51	33.86	213.83	188.92	0.698	1.963
BZA_{S2}- BZA_{S4}	370	1003	34.51	39.02	213.83	607.65	-4.145	1.962
BZA_{S3}- BZA_{S4}	660	1003	33.86	39.02	188.92	607.65	-5.462	1.961

Table B.6 Statistical t-test results for comparison of middle aged female pedestrians walking speeds on Stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	220	153	34.67	36.03	84.55	130.04	-1.225	1.968
SC_S –BZA_{S1}	220	274	34.67	30.95	84.55	160.28	3.784	1.965
SC_S -BZA_{S2}	220	165	34.67	31.41	84.55	216.38	2.503	1.969
SC_S -BZA_{S3}	220	250	34.67	28.05	84.55	49.60	8.682	1.966
SC_S -BZA_{S4}	220	277	34.67	31.25	84.55	637.99	2.089	1.967
WL_S - BZA_{S1}	153	274	36.03	30.95	130.04	160.28	4.247	1.967
WL_S - BZA_{S2}	153	165	36.03	31.41	130.04	216.38	3.143	1.968
WL_S - BZA_{S3}	153	250	36.03	28.05	130.04	49.60	7.802	1.971
WL_S - BZA_{S4}	153	277	36.03	31.25	130.04	637.99	2.695	1.966
BZA_{S1}- BZA_{S2}	274	165	30.95	31.41	160.28	216.38	-0.338	1.968
BZA_{S1}- BZA_{S3}	274	250	30.95	28.05	160.28	49.60	3.279	1.965
BZA_{S1}- BZA_{S4}	274	277	30.95	31.25	160.28	637.99	-0.177	1.966
BZA_{S2}- BZA_{S3}	165	250	31.41	28.05	216.38	49.60	2.741	1.971
BZA_{S2}- BZA_{S4}	165	277	31.41	31.25	216.38	637.99	0.087	1.965
BZA_{S3}- BZA_{S4}	250	277	28.05	31.25	49.60	637.99	-2.025	1.967

Table B.7 Statistical t-test results for comparison of aged male pedestrians walking speeds on Stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	183	75	34.22	32.52	114.62	109.12	1.177	1.977
SC_S –BZA_{S1}	183	154	34.22	27.65	114.62	77.14	6.184	1.967
SC_S -BZA_{S2}	183	74	34.22	27.46	114.62	110.61	4.640	1.977
SC_S -BZA_{S3}	183	116	34.22	26.51	114.62	210.74	4.932	1.972
SC_S -BZA_{S4}	183	168	34.22	30.80	114.62	85.43	3.207	1.967
WL_S - BZA_{S1}	75	154	32.52	27.65	109.12	77.14	3.481	1.979
WL_S - BZA_{S2}	75	74	32.52	27.46	109.12	110.61	2.946	1.976
WL_S - BZA_{S3}	75	116	32.52	26.51	109.12	210.74	3.323	1.973
WL_S - BZA_{S4}	75	168	32.52	30.80	109.12	85.43	1.226	1.979
BZA_{S1}- BZA_{S2}	154	74	27.65	27.46	77.14	110.61	0.136	1.979
BZA_{S1}- BZA_{S3}	154	116	27.65	26.51	77.14	210.74	0.750	1.973
BZA_{S1}- BZA_{S4}	154	168	27.65	30.80	77.14	85.43	-3.135	1.967
BZA_{S2}- BZA_{S3}	74	116	27.46	26.51	110.61	210.74	0.522	1.973
BZA_{S2}- BZA_{S4}	74	168	27.46	30.80	110.61	85.43	-2.361	1.979
BZA_{S3}- BZA_{S4}	116	168	26.51	30.80	210.74	85.43	-2.814	1.973

Table B.8 Statistical t-test results for comparison of aged female pedestrians walking speeds on Stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	101	31	26.41	26.28	70.28	80.32	0.072	2.012
SC_S –BZA_{S1}	101	81	26.41	24.29	70.28	71.13	1.692	1.974
SC_S -BZA_{S2}	101	36	26.41	20.92	70.28	51.36	3.772	1.993
SC_S -BZA_{S3}	101	69	26.41	21.17	70.28	98.48	3.599	1.978
SC_S -BZA_{S4}	101	81	26.41	22.51	70.28	74.82	3.069	1.974
WL_S - BZA_{S1}	31	81	26.28	24.29	80.32	71.13	1.070	2.007
WL_S - BZA_{S2}	31	36	26.28	20.92	80.32	51.36	2.676	2.002
WL_S - BZA_{S3}	31	69	26.28	21.17	80.32	98.48	2.551	1.998
WL_S - BZA_{S4}	31	81	26.28	22.51	80.32	74.82	2.014	2.006
BZA_{S1}- BZA_{S2}	81	36	24.29	20.92	71.13	51.36	2.221	1.991
BZA_{S1}- BZA_{S3}	81	69	24.29	21.17	71.13	98.48	2.055	1.978
BZA_{S1}- BZA_{S4}	81	81	24.29	22.51	71.13	74.82	1.328	1.975
BZA_{S2}- BZA_{S3}	36	69	20.92	21.17	51.36	98.48	-0.149	1.986
BZA_{S2}- BZA_{S4}	36	81	20.92	22.51	51.36	74.82	-1.036	1.990
BZA_{S3}- BZA_{S4}	69	81	21.17	22.51	98.48	74.82	-0.873	1.978

Table B.9 Statistical t-test results for comparison of walking speeds of male pedestrians walking without luggage on stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	334	205	50.62	51.82	356.95	474.17	-0.652	1.966
SC_S –BZA_{S1}	334	1298	50.62	37.65	356.95	284.94	11.430	1.965
SC_S -BZA_{S2}	334	437	50.62	37.56	356.95	344.62	9.587	1.963
SC_S -BZA_{S3}	334	810	50.62	35.62	356.95	274.24	12.651	1.964
SC_S -BZA_{S4}	334	1201	50.62	44.18	356.95	809.83	4.884	1.963
WL_S - BZA_{S1}	205	1298	51.82	37.65	474.17	284.94	8.905	1.970
WL_S - BZA_{S2}	205	437	51.82	37.56	474.17	344.62	8.100	1.967
WL_S - BZA_{S3}	205	810	51.82	35.62	474.17	274.24	9.953	1.969
WL_S - BZA_{S4}	205	1201	51.82	44.18	474.17	809.83	4.425	1.967
BZA_{S1}- BZA_{S2}	1298	437	37.65	37.56	284.94	344.62	0.092	1.963
BZA_{S1}- BZA_{S3}	1298	810	37.65	35.62	284.94	274.24	2.725	1.961
BZA_{S1}- BZA_{S4}	1298	1201	37.65	44.18	284.94	809.83	-6.901	1.961
BZA_{S2}- BZA_{S3}	437	810	37.56	35.62	344.62	274.24	1.830	1.963
BZA_{S2}- BZA_{S4}	437	1201	37.56	44.18	344.62	809.83	-5.471	1.962
BZA_{S3}- BZA_{S4}	810	1201	35.62	44.18	274.24	809.83	-8.505	1.961

Table B.10 Statistical t-test results for comparison of walking speeds of female pedestrians walking without luggage on stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	231	144	38.99	42.46	92.61	138.50	-2.974	1.969
SC_S –BZA_{S1}	231	370	38.99	30.93	92.61	152.71	8.941	1.964
SC_S -BZA_{S2}	231	166	38.99	32.91	92.61	257.08	4.352	1.970
SC_S -BZA_{S3}	231	309	38.99	28.42	92.61	96.72	12.510	1.965
SC_S -BZA_{S4}	231	294	38.99	31.75	92.61	161.78	7.424	1.965
WL_S - BZA_{S1}	144	370	42.46	30.93	138.50	152.71	9.840	1.969
WL_S - BZA_{S2}	144	166	42.46	32.91	138.50	257.08	6.027	1.968
WL_S - BZA_{S3}	144	309	42.46	28.42	138.50	96.72	12.437	1.970
WL_S - BZA_{S4}	144	294	42.46	31.75	138.50	161.78	8.711	1.968
BZA_{S1}- BZA_{S2}	370	166	30.93	32.91	152.71	257.08	-1.419	1.969
BZA_{S1}- BZA_{S3}	370	309	30.93	28.42	152.71	96.72	2.941	1.963
BZA_{S1}- BZA_{S4}	370	294	30.93	31.75	152.71	161.78	-0.840	1.964
BZA_{S2}- BZA_{S3}	166	309	32.91	28.42	257.08	96.72	3.293	1.970
BZA_{S2}- BZA_{S4}	166	294	32.91	31.75	257.08	161.78	0.803	1.968
BZA_{S3}- BZA_{S4}	309	294	28.42	31.75	96.72	161.78	-3.584	1.964

Table B.11 Statistical t-test results for comparison of walking speeds of male pedestrians carrying luggage on Stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	281	102	41.31	42.96	182.16	162.08	-1.103	1.973
SC_S –BZA_{S1}	281	363	41.31	33.02	182.16	250.14	7.166	1.964
SC_S -BZA_{S2}	281	167	41.31	31.57	182.16	104.86	8.618	1.966
SC_S -BZA_{S3}	281	298	41.31	32.84	182.16	104.07	8.485	1.965
SC_S -BZA_{S4}	281	628	41.31	37.52	182.16	192.71	3.876	1.964
WL_S - BZA_{S1}	102	363	42.96	33.02	162.08	250.14	6.584	1.972
WL_S - BZA_{S2}	102	167	42.96	31.57	162.08	104.86	7.647	1.973
WL_S - BZA_{S3}	102	298	42.96	32.84	162.08	104.07	7.273	1.976
WL_S - BZA_{S4}	102	628	42.96	37.52	162.08	192.71	3.950	1.977
BZA_{S1}- BZA_{S2}	363	167	33.02	31.57	250.14	104.86	1.261	1.965
BZA_{S1}- BZA_{S3}	363	298	33.02	32.84	250.14	104.07	0.183	1.964
BZA_{S1}- BZA_{S4}	363	628	33.02	37.52	250.14	192.71	-4.509	1.963
BZA_{S2}- BZA_{S3}	167	298	31.57	32.84	104.86	104.07	-1.275	1.967
BZA_{S2}- BZA_{S4}	167	628	31.57	37.52	104.86	192.71	-6.151	1.967
BZA_{S3}- BZA_{S4}	298	628	32.84	37.52	104.07	192.71	-5.786	1.963

Table B.12 Statistical t-test results for comparison of walking speeds of female pedestrians carrying luggage on stairways

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	209	80	34.08	34.73	79.77	105.90	-0.495	1.979
SC_S –BZA_{S1}	209	117	34.08	28.14	79.77	50.29	6.598	1.968
SC_S -BZA_{S2}	209	102	34.08	29.01	79.77	69.91	4.907	1.971
SC_S -BZA_{S3}	209	110	34.08	27.79	79.77	81.94	5.931	1.971
SC_S -BZA_{S4}	209	184	34.08	30.85	79.77	930.54	1.385	1.971
WL_S - BZA_{S1}	80	117	34.73	28.14	105.90	50.29	4.976	1.979
WL_S - BZA_{S2}	80	102	34.73	29.01	105.90	69.91	4.032	1.976
WL_S - BZA_{S3}	80	110	34.73	27.79	105.90	81.94	4.826	1.975
WL_S - BZA_{S4}	80	184	34.73	30.85	105.90	930.54	1.534	1.969
BZA_{S1}- BZA_{S2}	117	102	28.14	29.01	50.29	69.91	-0.828	1.972
BZA_{S1}- BZA_{S3}	117	110	28.14	27.79	50.29	81.94	0.324	1.972
BZA_{S1}- BZA_{S4}	117	184	28.14	30.85	50.29	930.54	-1.159	1.971
BZA_{S2}- BZA_{S3}	102	110	29.01	27.79	69.91	81.94	1.026	1.971
BZA_{S2}- BZA_{S4}	102	184	29.01	30.85	69.91	930.54	-0.768	1.970
BZA_{S3}- BZA_{S4}	110	184	27.79	30.85	81.94	930.54	-1.273	1.970

APPENDIX-C

Table C.1 Statistical t-test results for comparison of pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	174	114	40.74	45.98	131.71	130.87	-3.802	1.970
SC_S –BZA_{S1}	174	181	40.74	33.79	131.71	107.19	5.983	1.967
SC_S -BZA_{S2}	174	100	40.74	37.43	131.71	312.19	1.678	1.976
SC_S -BZA_{S3}	174	118	40.74	34.41	131.71	223.57	3.883	1.971
SC_S -BZA_{S4}	174	163	40.74	35.66	131.71	149.14	3.926	1.967
WL_S - BZA_{S1}	114	181	45.98	33.79	130.87	107.19	9.246	1.971
WL_S - BZA_{S2}	114	100	45.98	37.43	130.87	312.19	4.139	1.974
WL_S - BZA_{S3}	114	118	45.98	34.41	130.87	223.57	6.634	1.971
WL_S - BZA_{S4}	114	163	45.98	35.66	130.87	149.14	7.188	1.969
BZA_{S1}- BZA_{S2}	181	100	33.79	37.43	107.19	312.19	-1.892	1.977
BZA_{S1}- BZA_{S3}	181	118	33.79	34.41	107.19	223.57	-0.397	1.973
BZA_{S1}- BZA_{S4}	181	163	33.79	35.66	107.19	149.14	-1.526	1.967
BZA_{S2}- BZA_{S3}	100	118	37.43	34.41	312.19	223.57	1.348	1.972
BZA_{S2}- BZA_{S4}	100	163	37.43	35.66	312.19	149.14	0.882	1.975
BZA_{S3}- BZA_{S4}	118	163	34.41	35.66	223.57	149.14	-0.744	1.971

Table C.2 Statistical t-test results for comparison of male pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	172	112	43.70	49.07	208.99	192.19	-3.136	1.970
SC_S –BZA_{S1}	172	977	43.70	35.38	208.99	331.56	6.675	1.969
SC_S -BZA_{S2}	172	132	43.70	37.02	208.99	487.73	3.016	1.971
SC_S -BZA_{S3}	172	449	43.70	34.56	208.99	318.61	6.591	1.966
SC_S -BZA_{S4}	172	826	43.70	36.24	208.99	333.17	5.863	1.968
WL_S - BZA_{S1}	112	977	49.07	35.38	192.19	331.56	9.550	1.975
WL_S - BZA_{S2}	112	132	49.07	37.02	192.19	487.73	5.182	1.971
WL_S - BZA_{S3}	112	449	49.07	34.56	192.19	318.61	9.318	1.971
WL_S - BZA_{S4}	112	826	49.07	36.24	192.19	333.17	8.812	1.974
BZA_{S1}- BZA_{S2}	977	132	35.38	37.02	331.56	487.73	-0.816	1.975
BZA_{S1}- BZA_{S3}	977	449	35.38	34.56	331.56	318.61	0.802	1.963
BZA_{S1}- BZA_{S4}	977	826	35.38	36.24	331.56	333.17	-1.001	1.961
BZA_{S2}- BZA_{S3}	132	449	37.02	34.56	487.73	318.61	1.172	1.973
BZA_{S2}- BZA_{S4}	132	826	37.02	36.24	487.73	333.17	0.383	1.975
BZA_{S3}- BZA_{S4}	449	826	34.56	36.24	318.61	333.17	-1.596	1.962

Table C.3 Statistical t-test results for comparison of female pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	131	93	33.45	41.46	84.54	146.33	-5.379	1.975
SC_S –BZA_{S1}	131	344	33.45	30.39	84.54	152.06	2.932	1.968
SC_S -BZA_{S2}	131	48	33.45	35.28	84.54	515.47	-0.544	2.006
SC_S -BZA_{S3}	131	202	33.45	27.67	84.54	67.05	5.850	1.969
SC_S -BZA_{S4}	131	274	33.45	27.70	84.54	644.74	3.322	1.966
WL_S - BZA_{S1}	93	344	41.46	30.39	146.33	152.06	7.797	1.976
WL_S - BZA_{S2}	93	48	41.46	35.28	146.33	515.47	1.761	2.000
WL_S - BZA_{S3}	93	202	41.46	27.67	146.33	67.05	9.994	1.978
WL_S - BZA_{S4}	93	274	41.46	27.70	146.33	644.74	6.946	1.967
BZA_{S1}- BZA_{S2}	344	48	30.39	35.28	152.06	515.47	-1.463	2.008
BZA_{S1}- BZA_{S3}	344	202	30.39	27.67	152.06	67.05	3.099	1.964
BZA_{S1}- BZA_{S4}	344	274	30.39	27.70	152.06	644.74	1.612	1.966
BZA_{S2}- BZA_{S3}	48	202	35.28	27.67	515.47	67.05	2.289	2.009
BZA_{S2}- BZA_{S4}	48	274	35.28	27.70	515.47	644.74	2.097	1.995
BZA_{S3}- BZA_{S4}	202	274	27.67	27.70	67.05	644.74	-0.019	1.967

Table C.4 Statistical t-test results for comparison of young male pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	157	94	51.17	56.42	594.81	432.91	-1.813	1.971
SC_S –BZA_{S1}	157	267	51.17	41.04	594.81	504.30	4.251	1.968
SC_S -BZA_{S2}	157	30	51.17	49.32	594.81	1112.94	0.289	2.030
SC_S -BZA_{S3}	157	126	51.17	39.37	594.81	393.75	4.488	1.968
SC_S -BZA_{S4}	157	288	51.17	44.80	594.81	695.58	2.557	1.967
WL_S - BZA_{S1}	94	267	56.42	41.04	432.91	504.30	6.036	1.974
WL_S - BZA_{S2}	94	30	56.42	49.32	432.91	1112.94	1.100	2.028
WL_S - BZA_{S3}	94	126	56.42	39.37	432.91	393.75	6.134	1.972
WL_S - BZA_{S4}	94	288	56.42	44.80	432.91	695.58	4.386	1.972
BZA_{S1}- BZA_{S2}	267	30	41.04	49.32	504.30	1112.94	-1.326	2.037
BZA_{S1}- BZA_{S3}	267	126	41.04	39.37	504.30	393.75	0.747	1.969
BZA_{S1}- BZA_{S4}	267	288	41.04	44.80	504.30	695.58	-1.813	1.964
BZA_{S2}- BZA_{S3}	30	126	49.32	39.37	1112.94	393.75	1.569	2.032
BZA_{S2}- BZA_{S4}	30	288	49.32	44.80	1112.94	695.58	0.719	2.035
BZA_{S3}- BZA_{S4}	126	288	39.37	44.80	393.75	695.58	-2.309	1.968

Table C.5 Statistical t-test results for comparison of young female pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	71	64	37.66	48.06	164.50	186.41	-4.548	1.979
SC_S –BZA_{S1}	71	74	37.66	31.44	164.50	69.89	3.446	1.980
SC_S -BZA_{S2}	71	7	37.66	41.48	164.50	90.52	-0.979	2.306
SC_S -BZA_{S3}	71	30	37.66	32.21	164.50	90.25	2.361	1.993
SC_S -BZA_{S4}	71	36	37.66	33.24	164.50	122.43	1.849	1.990
WL_S - BZA_{S1}	64	74	48.06	31.44	186.41	69.89	8.464	1.984
WL_S - BZA_{S2}	64	7	48.06	41.48	186.41	90.52	1.653	2.262
WL_S - BZA_{S3}	64	30	48.06	32.21	186.41	90.25	6.514	1.991
WL_S - BZA_{S4}	64	36	48.06	33.24	186.41	122.43	5.899	1.988
BZA_{S1}- BZA_{S2}	74	7	31.44	41.48	69.89	90.52	-2.696	2.365
BZA_{S1}- BZA_{S3}	74	30	31.44	32.21	69.89	90.25	-0.389	2.011
BZA_{S1}- BZA_{S4}	74	36	31.44	33.24	69.89	122.43	-0.865	2.004
BZA_{S2}- BZA_{S3}	7	30	41.48	32.21	90.52	90.25	2.322	2.262
BZA_{S2}- BZA_{S4}	7	36	41.48	33.24	90.52	122.43	2.039	2.262
BZA_{S3}- BZA_{S4}	30	36	32.21	33.24	90.25	122.43	-0.407	1.998

Table C.6 Statistical t-test results for comparison of middle aged male pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	145	95	39.63	44.71	232.51	200.16	-2.638	1.971
SC_S –BZA_{S1}	145	582	39.63	33.93	232.51	278.71	3.950	1.970
SC_S -BZA_{S2}	145	84	39.63	34.33	232.51	246.93	2.484	1.974
SC_S -BZA_{S3}	145	260	39.63	33.96	232.51	315.04	3.380	1.967
SC_S -BZA_{S4}	145	434	39.63	32.36	232.51	82.01	5.427	1.973
WL_S - BZA_{S1}	95	582	44.71	33.93	200.16	278.71	6.705	1.977
WL_S - BZA_{S2}	95	84	44.71	34.33	200.16	246.93	4.618	1.974
WL_S - BZA_{S3}	95	260	44.71	33.96	200.16	315.04	5.902	1.971
WL_S - BZA_{S4}	95	434	44.71	32.36	200.16	82.01	8.148	1.982
BZA_{S1}- BZA_{S2}	582	84	33.93	34.33	278.71	246.93	-0.220	1.981
BZA_{S1}- BZA_{S3}	582	260	33.93	33.96	278.71	315.04	-0.022	1.965
BZA_{S1}- BZA_{S4}	582	434	33.93	32.36	278.71	82.01	1.915	1.963
BZA_{S2}- BZA_{S3}	84	260	34.33	33.96	246.93	315.04	0.185	1.975
BZA_{S2}- BZA_{S4}	84	434	34.33	32.36	246.93	82.01	1.115	1.986
BZA_{S3}- BZA_{S4}	260	434	33.96	32.36	315.04	82.01	1.347	1.967

Table C.7 Statistical t-test results for comparison of middle aged female pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	82	75	32.39	37.03	81.96	178.51	-2.524	1.979
SC_S –BZA_{S1}	82	194	32.39	31.62	81.96	207.47	0.536	1.970
SC_S -BZA_{S2}	82	34	32.39	34.35	81.96	679.55	-0.426	2.028
SC_S -BZA_{S3}	82	135	32.39	27.97	81.96	44.90	3.836	1.978
SC_S -BZA_{S4}	82	169	32.39	28.46	81.96	973.84	1.512	1.971
WL_S - BZA_{S1}	75	194	37.03	31.62	178.51	207.47	2.913	1.977
WL_S - BZA_{S2}	75	34	37.03	34.35	178.51	679.55	0.568	2.020
WL_S - BZA_{S3}	75	135	37.03	27.97	178.51	44.90	5.506	1.985
WL_S - BZA_{S4}	75	169	37.03	28.46	178.51	973.84	3.004	1.970
BZA_{S1}- BZA_{S2}	194	34	31.62	34.35	207.47	679.55	-0.593	2.026
BZA_{S1}- BZA_{S3}	194	135	31.62	27.97	207.47	44.90	3.089	1.968
BZA_{S1}- BZA_{S4}	194	169	31.62	28.46	207.47	973.84	1.210	1.970
BZA_{S2}- BZA_{S3}	34	135	34.35	27.97	679.55	44.90	1.415	2.032
BZA_{S2}- BZA_{S4}	34	169	34.35	28.46	679.55	973.84	1.159	2.004
BZA_{S3}- BZA_{S4}	135	169	27.97	28.46	44.90	973.84	-0.201	1.973

Table C.8 Statistical t-test results for comparison of aged male pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	84	23	31.81	31.76	103.79	141.65	0.018	2.040
SC_S –BZA_{S1}	84	86	31.81	27.76	103.79	80.98	2.746	1.975
SC_S -BZA_{S2}	84	15	31.81	24.15	103.79	97.77	2.752	2.086
SC_S -BZA_{S3}	84	51	31.81	26.02	103.79	70.05	3.585	1.980
SC_S -BZA_{S4}	84	82	31.81	27.75	103.79	58.44	2.907	1.975
WL_S - BZA_{S1}	23	86	31.76	27.76	141.65	80.98	1.503	2.045
WL_S - BZA_{S2}	23	15	31.76	24.15	141.65	97.77	2.139	2.032
WL_S - BZA_{S3}	23	51	31.76	26.02	141.65	70.05	2.093	2.037
WL_S - BZA_{S4}	23	82	31.76	27.75	141.65	58.44	1.530	2.052
BZA_{S1}- BZA_{S2}	86	15	27.76	24.15	80.98	97.77	1.322	2.101
BZA_{S1}- BZA_{S3}	86	51	27.76	26.02	80.98	70.05	1.143	1.982
BZA_{S1}- BZA_{S4}	86	82	27.76	27.75	80.98	58.44	0.004	1.975
BZA_{S2}- BZA_{S3}	15	51	24.15	26.02	97.77	70.05	-0.666	2.086
BZA_{S2}- BZA_{S4}	15	82	24.15	27.75	97.77	58.44	-1.340	2.110
BZA_{S3}- BZA_{S4}	51	82	26.02	27.75	70.05	58.44	-1.200	1.984

Table C.9 Statistical t-test results for comparison of aged female pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	54	5	25.36	22.16	52.86	60.85	0.883	2.571
SC_S –BZA_{S1}	54	59	25.36	25.19	52.86	71.44	0.115	1.982
SC_S -BZA_{S2}	54	4	25.36	24.85	52.86	26.29	0.186	2.776
SC_S -BZA_{S3}	54	28	25.36	19.74	52.86	58.39	3.213	2.007
SC_S -BZA_{S4}	54	51	25.36	20.52	52.86	48.38	3.490	1.983
WL_S - BZA_{S1}	5	59	22.16	25.19	60.85	71.44	-0.829	2.571
WL_S - BZA_{S2}	5	4	22.16	24.85	60.85	26.29	-0.622	2.365
WL_S - BZA_{S3}	5	28	22.16	19.74	60.85	58.39	0.641	2.571
WL_S - BZA_{S4}	5	51	22.16	20.52	60.85	48.38	0.454	2.571
BZA_{S1}- BZA_{S2}	59	4	25.19	24.85	71.44	26.29	0.122	2.776
BZA_{S1}- BZA_{S3}	59	28	25.19	19.74	71.44	58.39	3.004	2.002
BZA_{S1}- BZA_{S4}	59	51	25.19	20.52	71.44	48.38	3.181	1.982
BZA_{S2}- BZA_{S3}	4	28	24.85	19.74	26.29	58.39	1.738	2.571
BZA_{S2}- BZA_{S4}	4	51	24.85	20.52	26.29	48.38	1.581	2.776
BZA_{S3}- BZA_{S4}	28	51	19.74	20.52	58.39	48.38	-0.447	2.008

Table C.10 Statistical t-test results for comparison of walking speeds of male pedestrians walking without luggage on stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	158	106	48.08	52.69	403.36	279.82	-2.022	1.969
SC_S –BZA_{S1}	158	758	48.08	36.69	403.36	320.66	6.603	1.971
SC_S -BZA_{S2}	158	97	48.08	40.27	403.36	590.86	2.660	1.974
SC_S -BZA_{S3}	158	340	48.08	35.30	403.36	387.70	6.651	1.968
SC_S -BZA_{S4}	158	536	48.08	38.86	403.36	444.25	5.015	1.969
WL_S - BZA_{S1}	106	758	52.69	36.69	279.82	320.66	9.142	1.977
WL_S - BZA_{S2}	106	97	52.69	40.27	279.82	590.86	4.206	1.974
WL_S - BZA_{S3}	106	340	52.69	35.30	279.82	387.70	8.944	1.972
WL_S - BZA_{S4}	106	536	52.69	38.86	279.82	444.25	7.426	1.973
BZA_{S1}- BZA_{S2}	758	97	36.69	40.27	320.66	590.86	-1.399	1.982
BZA_{S1}- BZA_{S3}	758	340	36.69	35.30	320.66	387.70	1.112	1.964
BZA_{S1}- BZA_{S4}	758	536	36.69	38.86	320.66	444.25	-1.939	1.962
BZA_{S2}- BZA_{S3}	97	340	40.27	35.30	590.86	387.70	1.845	1.978
BZA_{S2}- BZA_{S4}	97	536	40.27	38.86	590.86	444.25	0.533	1.979
BZA_{S3}- BZA_{S4}	340	536	35.30	38.86	387.70	444.25	-2.536	1.963

Table C.11 Statistical t-test results for comparison of walking speeds of female pedestrians walking without luggage on stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	86	83	37.38	45.50	106.67	173.05	-4.452	1.975
SC_S –BZA_{S1}	86	265	37.38	31.04	106.67	177.89	4.585	1.973
SC_S -BZA_{S2}	86	34	37.38	37.91	106.67	683.33	-0.115	2.026
SC_S -BZA_{S3}	86	151	37.38	28.14	106.67	67.40	7.115	1.976
SC_S -BZA_{S4}	86	166	37.38	27.65	106.67	100.41	7.162	1.974
WL_S - BZA_{S1}	83	265	45.50	31.04	173.05	177.89	8.708	1.977
WL_S - BZA_{S2}	83	34	45.50	37.91	173.05	683.33	1.611	2.021
WL_S - BZA_{S3}	83	151	45.50	28.14	173.05	67.40	10.910	1.980
WL_S - BZA_{S4}	83	166	45.50	27.65	173.05	100.41	10.882	1.978
BZA_{S1}- BZA_{S2}	265	34	31.04	37.91	177.89	683.33	-1.507	2.030
BZA_{S1}- BZA_{S3}	265	151	31.04	28.14	177.89	67.40	2.744	1.966
BZA_{S1}- BZA_{S4}	265	166	31.04	27.65	177.89	100.41	3.000	1.966
BZA_{S2}- BZA_{S3}	34	151	37.91	28.14	683.33	67.40	2.155	2.032
BZA_{S2}- BZA_{S4}	34	166	37.91	27.65	683.33	100.41	2.255	2.030
BZA_{S3}- BZA_{S4}	151	166	28.14	27.65	67.40	100.41	0.477	1.968

Table C.12 Statistical t-test results for comparison of walking speeds of male pedestrians carrying luggage on stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	121	43	39.71	46.18	260.70	218.82	-2.402	1.990
SC_S –BZA_{S1}	121	219	39.71	30.84	260.70	344.21	4.598	1.969
SC_S -BZA_{S2}	121	35	39.71	28.02	260.70	97.52	5.260	1.986
SC_S -BZA_{S3}	121	109	39.71	32.24	260.70	97.53	4.280	1.972
SC_S -BZA_{S4}	121	290	39.71	31.40	260.70	92.46	5.284	1.975
WL_S - BZA_{S1}	43	219	46.18	30.84	218.82	344.21	5.944	1.994
WL_S - BZA_{S2}	43	35	46.18	28.02	218.82	97.52	6.470	1.993
WL_S - BZA_{S3}	43	109	46.18	32.24	218.82	97.53	5.698	2.002
WL_S - BZA_{S4}	43	290	46.18	31.40	218.82	92.46	6.354	2.012
BZA_{S1}- BZA_{S2}	219	35	30.84	28.02	344.21	97.52	1.349	1.990
BZA_{S1}- BZA_{S3}	219	109	30.84	32.24	344.21	97.53	-0.892	1.967
BZA_{S1}- BZA_{S4}	219	290	30.84	31.40	344.21	92.46	-0.410	1.968
BZA_{S2}- BZA_{S3}	35	109	28.02	32.24	97.52	97.53	-2.198	2.002
BZA_{S2}- BZA_{S4}	35	290	28.02	31.40	97.52	92.46	-1.918	2.018
BZA_{S3}- BZA_{S4}	109	290	32.24	31.40	97.53	92.46	0.760	1.973

Table C.13 Statistical t-test results for comparison of walking speeds of female pedestrians carrying luggage on stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	80	30	32.59	33.45	94.60	145.47	-0.351	2.015
SC_S –BZA_{S1}	80	79	32.59	28.23	94.60	60.41	3.127	1.976
SC_S -BZA_{S2}	80	14	32.59	28.92	94.60	67.31	1.502	2.086
SC_S -BZA_{S3}	80	51	32.59	26.27	94.60	64.71	4.035	1.980
SC_S -BZA_{S4}	80	108	32.59	27.77	94.60	1490.15	1.245	1.979
WL_S - BZA_{S1}	30	79	33.45	28.23	145.47	60.41	2.205	2.023
WL_S - BZA_{S2}	30	14	33.45	28.92	145.47	67.31	1.460	2.028
WL_S - BZA_{S3}	30	51	33.45	26.27	145.47	64.71	2.903	2.015
WL_S - BZA_{S4}	30	108	33.45	27.77	145.47	1490.15	1.315	1.978
BZA_{S1}- BZA_{S2}	79	14	28.23	28.92	60.41	67.31	-0.291	2.110
BZA_{S1}- BZA_{S3}	79	51	28.23	26.27	60.41	64.71	1.371	1.983
BZA_{S1}- BZA_{S4}	79	108	28.23	27.77	60.41	1490.15	0.119	1.980
BZA_{S2}- BZA_{S3}	14	51	28.92	26.27	67.31	64.71	1.072	2.086
BZA_{S2}- BZA_{S4}	14	108	28.92	27.77	67.31	1490.15	0.265	1.985
BZA_{S3}- BZA_{S4}	51	108	26.27	27.77	64.71	1490.15	-0.387	1.979

APPENDIX-D

Table D.1 Statistical t-test results for comparison of pedestrians walking speeds on Stairways in descending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	177	93	43.58	41.55	76.93	153.16	1.403	1.977
SC_S –BZA_{S1}	177	170	43.58	37.90	76.93	109.69	5.464	1.967
SC_S -BZA_{S2}	177	162	43.58	34.56	76.93	84.25	9.228	1.967
SC_S -BZA_{S3}	177	141	43.58	34.10	76.93	114.74	8.486	1.969
SC_S -BZA_{S4}	177	165	43.58	45.01	76.93	173.07	-1.171	1.968
WL_S - BZA_{S1}	93	170	41.55	37.90	153.16	109.69	2.414	1.975
WL_S - BZA_{S2}	93	162	41.55	34.56	153.16	84.25	4.750	1.976
WL_S - BZA_{S3}	93	141	41.55	34.10	153.16	114.74	4.754	1.973
WL_S - BZA_{S4}	93	165	41.55	45.01	153.16	173.07	-2.102	1.972
BZA_{S1}- BZA_{S2}	170	162	37.90	34.56	109.69	84.25	3.092	1.967
BZA_{S1}- BZA_{S3}	170	141	37.90	34.10	109.69	114.74	3.149	1.968
BZA_{S1}- BZA_{S4}	170	165	37.90	45.01	109.69	173.07	-5.459	1.968
BZA_{S2}- BZA_{S3}	162	141	34.56	34.10	84.25	114.74	0.403	1.969
BZA_{S2}- BZA_{S4}	162	165	34.56	45.01	84.25	173.07	-8.337	1.968
BZA_{S3}- BZA_{S4}	141	165	34.10	45.01	114.74	173.07	-7.992	1.968

Table D.2 Statistical t-test results for comparison of male pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	177	106	47.02	45.90	112.27	313.82	0.591	1.976
SC_S –BZA_{S1}	177	684	47.02	38.44	112.27	203.27	8.890	1.967
SC_S -BZA_{S2}	177	418	47.02	36.48	112.27	233.37	9.651	1.965
SC_S -BZA_{S3}	177	659	47.02	35.08	112.27	169.67	12.644	1.967
SC_S -BZA_{S4}	177	1003	47.02	46.54	112.27	786.39	0.400	1.963
WL_S - BZA_{S1}	106	684	45.90	38.44	313.82	203.27	4.133	1.979
WL_S - BZA_{S2}	106	418	45.90	36.48	313.82	233.37	5.021	1.976
WL_S - BZA_{S3}	106	659	45.90	35.08	313.82	169.67	6.032	1.979
WL_S - BZA_{S4}	106	1003	45.90	46.54	313.82	786.39	-0.332	1.974
BZA_{S1}- BZA_{S2}	684	418	38.44	36.48	203.27	233.37	2.118	1.963
BZA_{S1}- BZA_{S3}	684	659	38.44	35.08	203.27	169.67	4.511	1.962
BZA_{S1}- BZA_{S4}	684	1003	38.44	46.54	203.27	786.39	-7.793	1.961
BZA_{S2}- BZA_{S3}	418	659	36.48	35.08	233.37	169.67	1.551	1.963
BZA_{S2}- BZA_{S4}	418	1003	36.48	46.54	233.37	786.39	-8.685	1.962
BZA_{S3}- BZA_{S4}	659	1003	35.08	46.54	169.67	786.39	-11.233	1.962

Table D.3 Statistical t-test results for comparison of female pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	168	92	37.29	35.40	68.12	65.40	1.786	1.972
SC_S –BZA_{S1}	168	143	37.29	29.93	68.12	75.33	7.620	1.968
SC_S -BZA_{S2}	168	181	37.29	33.39	68.12	348.14	2.554	1.969
SC_S -BZA_{S3}	168	217	37.29	28.80	68.12	116.39	8.743	1.966
SC_S -BZA_{S4}	168	204	37.29	36.39	68.12	162.28	0.823	1.967
WL_S - BZA_{S1}	92	143	35.40	29.93	65.40	75.33	4.917	1.972
WL_S - BZA_{S2}	92	181	35.40	33.39	65.40	348.14	1.238	1.969
WL_S - BZA_{S3}	92	217	35.40	28.80	65.40	116.39	5.908	1.971
WL_S - BZA_{S4}	92	204	35.40	36.39	65.40	162.28	-0.803	1.969
BZA_{S1}- BZA_{S2}	143	181	29.93	33.39	75.33	348.14	-2.211	1.969
BZA_{S1}- BZA_{S3}	143	217	29.93	28.80	75.33	116.39	1.094	1.967
BZA_{S1}- BZA_{S4}	143	204	29.93	36.39	75.33	162.28	-5.614	1.967
BZA_{S2}- BZA_{S3}	181	217	33.39	28.80	348.14	116.39	2.926	1.969
BZA_{S2}- BZA_{S4}	181	204	33.39	36.39	348.14	162.28	-1.816	1.968
BZA_{S3}- BZA_{S4}	217	204	28.80	36.39	116.39	162.28	-6.571	1.966

Table D.4 Statistical t-test results for comparison of young male pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	176	88	53.14	52.77	277.25	658.26	0.124	1.979
SC_S –BZA_{S1}	176	206	53.14	45.92	277.25	307.18	4.129	1.966
SC_S -BZA_{S2}	176	117	53.14	41.52	277.25	238.40	6.116	1.969
SC_S -BZA_{S3}	176	169	53.14	39.93	277.25	181.36	8.119	1.967
SC_S -BZA_{S4}	176	331	53.14	54.10	277.25	605.31	-0.518	1.965
WL_S - BZA_{S1}	88	206	52.77	45.92	658.26	307.18	2.289	1.979
WL_S - BZA_{S2}	88	117	52.77	41.52	658.26	238.40	3.647	1.978
WL_S - BZA_{S3}	88	169	52.77	39.93	658.26	181.36	4.390	1.981
WL_S - BZA_{S4}	88	331	52.77	54.10	658.26	605.31	-0.436	1.978
BZA_{S1}- BZA_{S2}	206	117	45.92	41.52	307.18	238.40	2.339	1.969
BZA_{S1}- BZA_{S3}	206	169	45.92	39.93	307.18	181.36	3.736	1.966
BZA_{S1}- BZA_{S4}	206	331	45.92	54.10	307.18	605.31	-4.493	1.964
BZA_{S2}- BZA_{S3}	117	169	41.52	39.93	238.40	181.36	0.901	1.970
BZA_{S2}- BZA_{S4}	117	331	41.52	54.10	238.40	605.31	-6.398	1.967
BZA_{S3}- BZA_{S4}	169	331	39.93	54.10	181.36	605.31	-8.318	1.965

Table D.5 Statistical t-test results for comparison of young female pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	139	47	40.61	38.18	94.21	99.71	1.455	1.991
SC_S –BZA_{S1}	139	36	40.61	35.73	94.21	62.23	3.148	1.997
SC_S -BZA_{S2}	139	49	40.61	36.28	94.21	101.38	2.610	1.989
SC_S -BZA_{S3}	139	44	40.61	35.39	94.21	180.23	2.390	2.002
SC_S -BZA_{S4}	139	53	40.61	42.58	94.21	187.89	-0.960	1.993
WL_S - BZA_{S1}	47	36	38.18	35.73	99.71	62.23	1.247	1.990
WL_S - BZA_{S2}	47	49	38.18	36.28	99.71	101.38	0.924	1.986
WL_S - BZA_{S3}	47	44	38.18	35.39	99.71	180.23	1.117	1.990
WL_S - BZA_{S4}	47	53	38.18	42.58	99.71	187.89	-1.852	1.985
BZA_{S1}- BZA_{S2}	36	49	35.73	36.28	62.23	101.38	-0.285	1.989
BZA_{S1}- BZA_{S3}	36	44	35.73	35.39	62.23	180.23	0.140	1.994
BZA_{S1}- BZA_{S4}	36	53	35.73	42.58	62.23	187.89	-2.985	1.988
BZA_{S2}- BZA_{S3}	49	44	36.28	35.39	101.38	180.23	0.360	1.990
BZA_{S2}- BZA_{S4}	49	53	36.28	42.58	101.38	187.89	-2.658	1.985
BZA_{S3}- BZA_{S4}	44	53	35.39	42.58	180.23	187.89	-2.602	1.986

Table D.6 Statistical t-test results for comparison of middle aged male pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	170	85	42.40	44.60	138.85	281.00	-1.085	1.979
SC_S –BZA_{S1}	170	403	42.40	36.56	138.85	121.70	5.519	1.968
SC_S -BZA_{S2}	170	286	42.40	34.56	138.85	204.93	6.328	1.966
SC_S -BZA_{S3}	170	400	42.40	33.80	138.85	107.52	8.251	1.968
SC_S -BZA_{S4}	170	569	42.40	44.10	138.85	949.68	-1.079	1.963
WL_S - BZA_{S1}	85	403	44.60	36.56	281.00	121.70	4.233	1.984
WL_S - BZA_{S2}	85	286	44.60	34.56	281.00	204.93	5.005	1.979
WL_S - BZA_{S3}	85	400	44.60	33.80	281.00	107.52	5.712	1.984
WL_S - BZA_{S4}	85	569	44.60	44.10	281.00	949.68	0.224	1.973
BZA_{S1}- BZA_{S2}	403	286	36.56	34.56	121.70	204.93	1.979	1.965
BZA_{S1}- BZA_{S3}	403	400	36.56	33.80	121.70	107.52	3.652	1.963
BZA_{S1}- BZA_{S4}	403	569	36.56	44.10	121.70	949.68	-5.370	1.963
BZA_{S2}- BZA_{S3}	286	400	34.56	33.80	204.93	107.52	0.767	1.965
BZA_{S2}- BZA_{S4}	286	569	34.56	44.10	204.93	949.68	-6.175	1.963
BZA_{S3}- BZA_{S4}	400	569	33.80	44.10	107.52	949.68	-7.398	1.963

Table D.7 Statistical t-test results for comparison of middle aged female pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	138	78	36.03	35.07	81.74	83.25	0.741	1.975
SC_S –BZA_{S1}	138	80	36.03	29.31	81.74	43.18	6.315	1.972
SC_S -BZA_{S2}	138	131	36.03	30.65	81.74	97.64	4.648	1.969
SC_S -BZA_{S3}	138	115	36.03	28.14	81.74	55.54	7.608	1.969
SC_S -BZA_{S4}	138	108	36.03	35.61	81.74	85.18	0.357	1.970
WL_S - BZA_{S1}	78	80	35.07	29.31	83.25	43.18	4.547	1.977
WL_S - BZA_{S2}	78	131	35.07	30.65	83.25	97.64	3.284	1.974
WL_S - BZA_{S3}	78	115	35.07	28.14	83.25	55.54	5.569	1.977
WL_S - BZA_{S4}	78	108	35.07	35.61	83.25	85.18	-0.392	1.974
BZA_{S1}- BZA_{S2}	80	131	29.31	30.65	43.18	97.64	-1.185	1.971
BZA_{S1}- BZA_{S3}	80	115	29.31	28.14	43.18	55.54	1.157	1.973
BZA_{S1}- BZA_{S4}	80	108	29.31	35.61	43.18	85.18	-5.465	1.973
BZA_{S2}- BZA_{S3}	131	115	30.65	28.14	97.64	55.54	2.268	1.970
BZA_{S2}- BZA_{S4}	131	108	30.65	35.61	97.64	85.18	-4.001	1.970
BZA_{S3}- BZA_{S4}	115	108	28.14	35.61	55.54	85.18	-6.623	1.972

Table D.8 Statistical t-test results for comparison of aged male pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	99	52	36.26	32.85	115.79	96.86	1.956	1.981
SC_S –BZA_{S1}	99	68	36.26	27.52	115.79	73.40	5.830	1.975
SC_S -BZA_{S2}	99	59	36.26	28.30	115.79	112.06	4.543	1.979
SC_S -BZA_{S3}	99	65	36.26	26.89	115.79	323.60	3.777	1.986
SC_S -BZA_{S4}	99	86	36.26	33.71	115.79	94.66	1.694	1.973
WL_S - BZA_{S1}	52	68	32.85	27.52	96.86	73.40	3.112	1.984
WL_S - BZA_{S2}	52	59	32.85	28.30	96.86	112.06	2.348	1.982
WL_S - BZA_{S3}	52	65	32.85	26.89	96.86	323.60	2.279	1.983
WL_S - BZA_{S4}	52	86	32.85	33.71	96.86	94.66	-0.496	1.982
BZA_{S1}- BZA_{S2}	68	59	27.52	28.30	73.40	112.06	-0.454	1.982
BZA_{S1}- BZA_{S3}	68	65	27.52	26.89	73.40	323.60	0.253	1.986
BZA_{S1}- BZA_{S4}	68	86	27.52	33.71	73.40	94.66	-4.192	1.976
BZA_{S2}- BZA_{S3}	59	65	28.30	26.89	112.06	323.60	0.537	1.983
BZA_{S2}- BZA_{S4}	59	86	28.30	33.71	112.06	94.66	-3.121	1.980
BZA_{S3}- BZA_{S4}	65	86	26.89	33.71	323.60	94.66	-2.763	1.986

Table D.9 Statistical t-test results for comparison of aged female pedestrians walking speeds on Stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	47	26	27.63	27.08	89.06	82.59	0.243	2.006
SC_S –BZA_{S1}	47	22	27.63	21.88	89.06	65.29	2.605	2.011
SC_S -BZA_{S2}	47	32	27.63	20.43	89.06	53.21	3.816	1.992
SC_S -BZA_{S3}	47	41	27.63	22.15	89.06	125.58	2.459	1.990
SC_S -BZA_{S4}	47	30	27.63	25.90	89.06	104.10	0.746	2.002
WL_S - BZA_{S1}	26	22	27.08	21.88	82.59	65.29	2.096	2.013
WL_S - BZA_{S2}	26	32	27.08	20.43	82.59	53.21	3.023	2.011
WL_S - BZA_{S3}	26	41	27.08	22.15	82.59	125.58	1.973	2.000
WL_S - BZA_{S4}	26	30	27.08	25.90	82.59	104.10	0.457	2.005
BZA_{S1}- BZA_{S2}	22	32	21.88	20.43	65.29	53.21	0.675	2.018
BZA_{S1}- BZA_{S3}	22	41	21.88	22.15	65.29	125.58	-0.109	2.003
BZA_{S1}- BZA_{S4}	22	30	21.88	25.90	65.29	104.10	-1.583	2.009
BZA_{S2}- BZA_{S3}	32	41	20.43	22.15	53.21	125.58	-0.792	1.995
BZA_{S2}- BZA_{S4}	32	30	20.43	25.90	53.21	104.10	-2.415	2.007
BZA_{S3}- BZA_{S4}	41	30	22.15	25.90	125.58	104.10	-1.467	1.997

Table D.10 Statistical t-test results for comparison of walking speeds of male pedestrians walking without luggage on stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	176	99	52.91	50.89	306.29	685.56	0.683	1.976
SC_S –BZA_{S1}	176	540	52.91	39.00	306.29	232.20	9.440	1.969
SC_S -BZA_{S2}	176	340	52.91	36.79	306.29	273.22	10.105	1.967
SC_S -BZA_{S3}	176	470	52.91	35.84	306.29	192.69	11.635	1.969
SC_S -BZA_{S4}	176	665	52.91	48.46	306.29	1064.43	2.432	1.964
WL_S - BZA_{S1}	99	540	50.89	39.00	685.56	232.20	4.387	1.982
WL_S - BZA_{S2}	99	340	50.89	36.79	685.56	273.22	5.074	1.980
WL_S - BZA_{S3}	99	470	50.89	35.84	685.56	192.69	5.557	1.982
WL_S - BZA_{S4}	99	665	50.89	48.46	685.56	1064.43	0.834	1.976
BZA_{S1}- BZA_{S2}	540	340	39.00	36.79	232.20	273.22	1.990	1.963
BZA_{S1}- BZA_{S3}	540	470	39.00	35.84	232.20	192.69	3.442	1.962
BZA_{S1}- BZA_{S4}	540	665	39.00	48.46	232.20	1064.43	-6.640	1.962
BZA_{S2}- BZA_{S3}	340	470	36.79	35.84	273.22	192.69	0.857	1.964
BZA_{S2}- BZA_{S4}	340	665	36.79	48.46	273.22	1064.43	-7.528	1.962
BZA_{S3}- BZA_{S4}	470	665	35.84	48.46	192.69	1064.43	-8.897	1.962

Table D.11 Statistical t-test results for comparison of walking speeds of female pedestrians walking without luggage on stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	145	61	39.95	38.34	82.47	63.57	1.270	1.979
SC_S –BZA_{S1}	145	105	39.95	30.64	82.47	90.15	7.788	1.971
SC_S -BZA_{S2}	145	132	39.95	31.63	82.47	143.53	6.465	1.970
SC_S -BZA_{S3}	145	158	39.95	28.69	82.47	125.20	9.648	1.968
SC_S -BZA_{S4}	145	128	39.95	37.07	82.47	192.28	2.000	1.971
WL_S - BZA_{S1}	61	105	38.34	30.64	63.57	90.15	5.580	1.977
WL_S - BZA_{S2}	61	132	38.34	31.63	63.57	143.53	4.597	1.974
WL_S - BZA_{S3}	61	158	38.34	28.69	63.57	125.20	7.121	1.976
WL_S - BZA_{S4}	61	128	38.34	37.07	63.57	192.28	0.794	1.973
BZA_{S1}- BZA_{S2}	105	132	30.64	31.63	90.15	143.53	-0.706	1.970
BZA_{S1}- BZA_{S3}	105	158	30.64	28.69	90.15	125.20	1.519	1.970
BZA_{S1}- BZA_{S4}	105	128	30.64	37.07	90.15	192.28	-4.183	1.971
BZA_{S2}- BZA_{S3}	132	158	31.63	28.69	143.53	125.20	2.141	1.969
BZA_{S2}- BZA_{S4}	132	128	31.63	37.07	143.53	192.28	-3.382	1.969
BZA_{S3}- BZA_{S4}	158	128	28.69	37.07	125.20	192.28	-5.531	1.970

Table D.12 Statistical t-test results for comparison of walking speeds of male pedestrians carrying luggage on stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	160	59	42.52	40.62	120.63	110.52	1.174	1.982
SC_S –BZA_{S1}	160	144	42.52	36.34	120.63	90.06	5.257	1.968
SC_S -BZA_{S2}	160	132	42.52	32.52	120.63	103.30	8.068	1.968
SC_S -BZA_{S3}	160	189	42.52	33.18	120.63	108.05	8.111	1.967
SC_S -BZA_{S4}	160	338	42.52	42.77	120.63	219.39	-0.215	1.966
WL_S - BZA_{S1}	59	144	40.62	36.34	110.52	90.06	2.702	1.984
WL_S - BZA_{S2}	59	132	40.62	32.52	110.52	103.30	4.970	1.982
WL_S - BZA_{S3}	59	189	40.62	33.18	110.52	108.05	4.756	1.985
WL_S - BZA_{S4}	59	338	40.62	42.77	110.52	219.39	-1.358	1.983
BZA_{S1}- BZA_{S2}	144	132	36.34	32.52	90.06	103.30	3.225	1.969
BZA_{S1}- BZA_{S3}	144	189	36.34	33.18	90.06	108.05	2.892	1.967
BZA_{S1}- BZA_{S4}	144	338	36.34	42.77	90.06	219.39	-5.694	1.966
BZA_{S2}- BZA_{S3}	132	189	32.52	33.18	103.30	108.05	-0.569	1.968
BZA_{S2}- BZA_{S4}	132	338	32.52	42.77	103.30	219.39	-8.571	1.967
BZA_{S3}- BZA_{S4}	189	338	33.18	42.77	108.05	219.39	-8.682	1.965

Table D.13 Statistical t-test results for comparison of walking speeds of female pedestrians carrying luggage on stairways in ascending direction

Stairways Compared	n_1	n_2	μ_1	μ_2	σ_1^2	σ_2^2	t-value	t-Critical
SC_S-WL_S	129	50	35.01	35.50	68.99	83.05	-0.328	1.989
SC_S –BZA_{S1}	129	38	35.01	27.96	68.99	30.26	6.112	1.986
SC_S -BZA_{S2}	129	88	35.01	29.03	68.99	71.09	5.159	1.973
SC_S -BZA_{S3}	129	59	35.01	29.10	68.99	94.44	4.045	1.984
SC_S -BZA_{S4}	129	76	35.01	35.23	68.99	111.49	-0.158	1.978
WL_S - BZA_{S1}	50	38	35.50	27.96	83.05	30.26	4.808	1.989
WL_S - BZA_{S2}	50	88	35.50	29.03	83.05	71.09	4.114	1.985
WL_S - BZA_{S3}	50	59	35.50	29.10	83.05	94.44	3.542	1.983
WL_S - BZA_{S4}	50	76	35.50	35.23	83.05	111.49	0.149	1.981
BZA_{S1}- BZA_{S2}	38	88	27.96	29.03	30.26	71.09	-0.847	1.983
BZA_{S1}- BZA_{S3}	38	59	27.96	29.10	30.26	94.44	-0.736	1.986
BZA_{S1}- BZA_{S4}	38	76	27.96	35.23	30.26	111.49	-4.835	1.981
BZA_{S2}- BZA_{S3}	88	59	29.03	29.10	71.09	94.44	-0.043	1.981
BZA_{S2}- BZA_{S4}	88	76	29.03	35.23	71.09	111.49	-4.112	1.977
BZA_{S3}- BZA_{S4}	59	76	29.10	35.23	94.44	111.49	-3.502	1.979

APPENDIX-E

Respondent Age: ________________________

Gender: ☐ Male ☐ Female

Education Qualification:

- ☐ Uneducated
- ☐ Secondary School Education
- ☐ Graduate
- ☐ Post Graduate
- ☐ Research Scholar/Ph.D/Transportation Professional and higher

Employment Status:

- ☐ Employer/Employee
- ☐ Unemployed

Marital Status:

- ☐ Unmarried
- ☐ Married

Frequency of visiting/using railway station

- ☐ Rare
- ☐ Frequent/ Daily

Preference of usage for the video exhibit

- ☐ Stair
- ☐ Escalator

What do you bother the most in making choice between stair and escalator (Check one or more options)

- ☐ Width of stairway
- ☐ Inclination of stairway
- ☐ Rush (Flow/density)

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