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ANALYSIS AND MODELING OF THE USER-PERCEIVED LEVEL OF SERVICE FOR FOOT OVER BRIDGE STAIRWAYS INSIDE INTERCITY RAILWAY STATIONS

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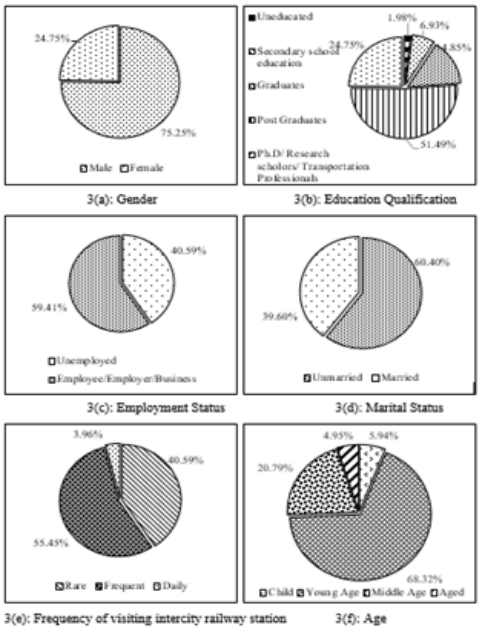
Graphical abstract



Abstract

Rail transportation being the economic means of transportation, the majority of pedestrians rely on them in countries like India. Unlike metro stations, in intercity railway stations exists a wide degree of heterogeneity in pedestrian traffic. Pedestrians walking speed on stairways depends on various factors grouped under pedestrian, infrastructure, and environmental characteristics. Understating pedestrian perception of quality of service on existing facilities provides the planners to incorporate pedestrian bothered factors for comfortable access in the design. In this research work, pedestrian perceived level of service on six different stairways in intercity railway stations was analyzed. The questionnaire survey was adopted to understand the individual pedestrian perception towards the level of service on each stairway. Pedestrian characteristics such as age, education qualification, preference of usage between stairway and escalator, and stairway characteristics such as width, inclination, and side friction significantly affect individual's perception of the serviceability of a stairway. A regression model was also developed by considering the significant factors affecting the pedestrian's perceived level of service of the stairway. Results of this study help in evaluating a stairway facility and arrive at better planning, design, and management to increase its efficiency. This study also helps in making design policies and guidelines for new stairways for better accessibility.

Keywords: Level of service, pedestrian, railway station, stairways

1.0 INTRODUCTION

In India, rail mode transportation is the economic and relatively fast means of public transportation in comparison to road transport. Railway stations are nodal points for the rail network. These are well embedded in urban geography such that the development rose around the railway station. With the increased passenger demand and limited land available, these railway stations are to be well managed, planned, and designed for future needs. The lack of land in the old, established and highly developed urban areas limits the construction of grade-seperated facilities [1]. Railway station infrastructures are to be well analyzed to come up with design policies. Level changing facilities provide pedestrian access among platforms to alight and board trains are confined walking environments,

unlike sidewalks and walkways. It provides common access for leisure, and hurrying people traveling for various needs and trip purposes. Hence pedestrian traffic heterogeneity, environmental characteristics, and infrastructure characteristics lead to conflicts, bottlenecks for smooth pedestrian flow on these facilities. Stairways are a typical foot-over bridge (FOB) infrastructure element where pedestrians make vertical movements. Identifying issues such as speed, volume and density of pedestrians are necessary to control the traffic flow and delay, and can lead to better design of facilities associated with pedestrians [2].

Understanding the level of service (LOS) of existing facilities in perception to user aids in identifying the significant factors affecting the performance and to developing better design standards for renovating the existing and construction of new stairways which are more user's friendly. Engineers have used traditional quantitative techniques to assess the LOS over the decades. To draw an essence, pedestrian level of service (PLOS) is area and region-specific. They are found to be affected by infrastructure, traffic, environmental, social, and pedestrian physical characteristics. LOS standards for pedestrian facilities are mostly defined for sidewalks, walkways, crosswalks, mid-blocks, and intersections. Few studies derived LOS for stairways and walkways in metro/suburban terminals where most of them are commuters and dominated by a certain age group [3]. Limited studies on pedestrian level changing facilities, in particular stairways, LOS in intercity railway terminals is observed mainly in India. Studies are mostly confined to understanding macroscopic pedestrian flow characteristic behavior on stairways. Hence authors found scope in evaluating the stairway facility of the FOB to access various platforms and development models to predict the same.

Researchers across the globe made attempts to study, develop and apply LOS standards to various facilities like walkways, crosswalks, and sidewalks for different land use conditions and identified factors affecting them. Sidewalk and walkway LOS standards are affected by various roadway, vehicular and non-motorized traffic characteristics [4-6]. Comparison of LOS standards developed for walkway facilities in Bangkok, Thailand with the United States showed that the space occupancy of pedestrians in Bangkok is lower while flows are high for a LOS [7]. LOS standards for pedestrian walkways in Bhubaneswar and Rourkela, Odisha state, India from inventory and speed data using affinity propagation showed proportionately lower values in comparison to HCM [8]. Conjoint analysis is used to estimate the total utility value of an entire facility comprising walkways and crosswalks based on width and separation, obstructions, flow rates, and bicycle events [9]. The effective width of the facility available is almost two times more than that of the pedestrian flow on LOS for sidewalks [10]. Pedestrian perceived LOS for sidewalks [11] and crosswalks [12] are developed in China and India respectively are affected by both quantitative and qualitative factors.

Studies on stairway LOS are limited. LOS criteria for stairways are developed based on average flow volume and area occupancy like vehicle traffic LOS [13]. Few researchers worked to evaluate facilities in mass transit terminals and suburban rail terminals. Studies showed space has significant importance in evaluating the LOS of walkways and stairways at terminals [14, 15]. LOS threshold values for undivided stairways considering pedestrian space, flow rate, speed, and the volume-to-capacity ratio by using clustering analysis at Mumbai mass transit rail station, India are developed [16]. The pedestrians in Shanghai need more space on stairways than that in TCQSM at a given LOS [17]. Studies on pedestrian flow behavior resulted that the mean walking speed of pedestrians is greater on level passageway than that of on stairways in railway stations [18-23]. Hence, these are to be well designed for pedestrians to ease to ascend and descend with limited effort and fast evacuation considering various personal attributes like age, gender, luggage, trip purpose, etc.

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 study, an attempt is made to understand the pedestrian's perception of stairways of different characteristics to assess their LOS. A regression model was also developed by considering the significant factors affecting the pedestrian's perceived level of service of the stairway. The model has been validated using a different data set.

2.0 METHODOLOGY

For the present study, six stairways with different infrastructural characteristics which are located in three important intercity railway stations, Secunderabad (S), Warangal (W), and Vijayawada (V), of India, are selected. Table 1 shows the dimensional description of stairways in the selected intercity railway stations. Figure 1 shows the snapshots of stairways.

Table 1 Dimensional description of Stairways

Description	Sst	Wst	Vst1	Vst2	Vst3	Vst4
Width of the stairway (m)	3.50	2.40	3.60	2.00	2.00	3.50
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	32^0	34^0	30^0	30^0	30^0	34^0

Note: Sst- Secunderabad Stairway; Wst- Warangal Stairway; Vst1- Vijayawada Stairway 1; Vst2 Vijayawada Stairway 2; Vst3 Vijayawada Stairway 3; Vst4- Vijayawada Stairway 4.

1 (a) Sst 1 (b) Wst

1 (c) Vst1 1 (d) Vst2

1 (e) Vst3 1 (f) Vst4

Figure 1 Snapshots of stairways

Table 2 Observed pedestrian flow characteristics on stairways

Description	Sst	Wst	Vst1	Vst2	Vst3	Vst4
Width (m)	3.50	2.40	3.60	2.00	2.00	3.50
Max Flow (ped/m/min)	32	43	25	16	27	21
Critical density (ped/m^2)	1.21	2.36	1.01	0.62	1.35	0.72
Jam density (ped/m^2)	3.10	4.01	2.08	1.03	2.57	1.37
Space available (m^2/ped)	0.83	0.57	1.18	1.85	1.03	1.46
Mean Ascending speed (m/min)	40.74	45.84	33.82	37.43	34.41	35.65
Mean descending speed (m/min)	43.56	41.52	35.78	34.56	34.10	44.85
Mean Speed (m/min)	42.15	43.68	34.80	35.20	34.26	40.25
Free-flow speed (m/min)	49.98	49.62	38.51	40.69	37.12	45.32
Critical speed (m/min)	24.60	24.00	19.95	20.98	19.34	23.65

A Video recording camera is mounted at a suitable location to capture the pedestrians' movement on the stairways in the study locations. The recording is collected for three hours. From the playback videos, pedestrian flow characteristics-flow, density, and speed are obtained. Pedestrians crossing a reference line per minute are counted, and flow is calculated as the volume of pedestrians per minute per meter. An average number of pedestrians in an area bounded by two reference lines and side railings on the stairway is counted, and density (Ped/m^2) is determined for each minute. Speed is calculated as a ratio of the distance between two reference lines and the time to cross the two reference lines by a pedestrian. Average walking speed is determined as an average of pedestrians speeds calculated for each minute. Thus the flow- density- speed is determined for each stairway for each minute. Pedestrian flow characteristics observed on the stairways are tabulated in Table 2. Stairway widths in the present study vary from 2.00 m to 3.60 m with an inclination in a range of 30^0-34^0. Mean speed is in the range of 34.26 to 43.68 m/min.

The main objective of the study is to evaluate the stairway in perception to the user. Hence to evaluate the stairways, from the video recorded data, an excerpt of one minute is cropped for each stairway. Table 3 shows the observed flow characteristics of the corresponding excerpt of the stairways. The level of service for the excerpts is taken from the TCQSM [24] and HCM [25] concerning both flow and space. There is a discrepancy in the ranges and threshold values of standards defined by both TCQSM and HCM. This is because of the variation in pedestrian characteristics, heterogeneity in pedestrian traffic composition, and functionality of transit stations. Hence there is a need for revising the LOS standards to suit intercity railway stations.

Table 3 Pedestrian flow characteristics of one-minute excerpt for the questionnaire survey on observed stairways

Description	Sst	Wst	Vst1	Vst2	Vst3	Vst4
Flow (ped/m/min)	20	16	21	16	22	18
density (ped/m²)	0.70	0.55	0.50	0.53	1.05	0.719
Space available (m²/ped)	1.41	1.80	1.98	1.86	0.95	1.39
Mean Speed (m/min)	42.77	31.78	44.91	31.70	23.03	27.11
LOS (As per TCQSM Part-7) (WRT Flow)	B	B	B	B	B	B
LOS (As per TCQSM Part-7) (WRT Space)	B	B	A	B	C	C
LOS (As per HCM 2010) (WRT Flow)	B	B	B	B	C	B
LOS (As per HCM 2010) (WRT Space)	C	B	A	B	D	C

2.1 Questionnaire Survey Method

The questionnaire survey method is adopted to evaluate the stairways in the user perception. An individual is shown an excerpt of a stairway and provided with the stairway characteristics- width, step-rise, step-foot, inclination and flow characteristics- flow, speed, density on that particular stairway. Respondent's age, gender, educational qualification, employment status, marital status, and frequency of visiting intercity railway station are collected from the respondent. Respondent is requested to evaluate the stairway with one value from 1 (excellent), 2 (very good), 3 (good), 4 (average), 5 (bad), 6 (worst) considering the provided details. Figure 2 shows the distribution of LOS perceived by respondents for each stairway.

A total of 606 responses are collected from a questionnaire survey. An overview of the respondent's characteristic distribution is shown in Figure 3. Of the respondents 24.75% are female, 39.60% are married. The frequency of visiting the railway station gives the respondents association with familiarity in using various facilities in the intercity railway station. Familiarity distribution in the present study included 40.59% rare visitors and 55.45% frequent visitors. Employed respondents contributed to 59.41% of responses. Respondent's choice distributions and perceived level of services of each stairway are shown in Table 4.

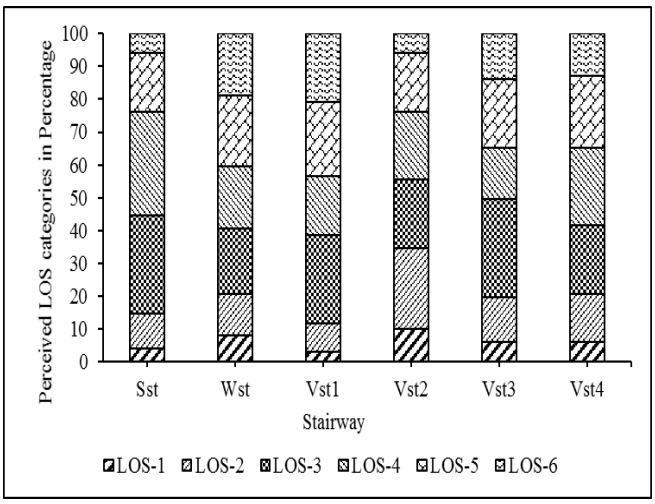


Figure 2 Pedestrian perceived LOS distribution of stairways

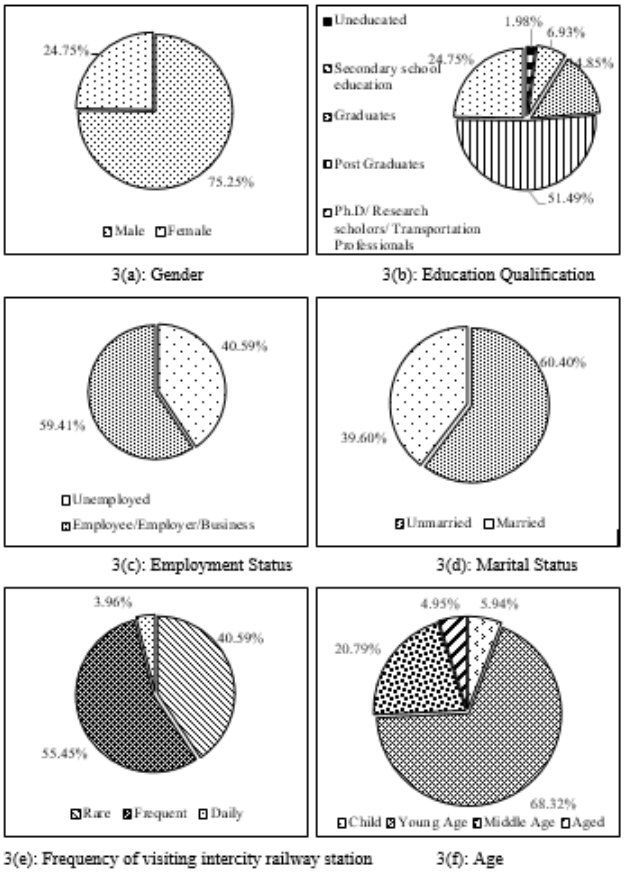


Figure 3 An overview of respondent's characteristic distribution

The average LOS of each stairway is determined from the weighted average of pedestrian-perceived LOS. From Table 5, pedestrians perceive better LOS for stairways without side friction caused by waiting for pedestrians on stairway steps. A comparison of average LOS and the pedestrian perceived choice implies pedestrians' tendency towards stairway use increases with better LOS. Also, the pedestrian perceived LOS of stairways with greater width is

better than that of stairways with lower widths. Stairway with inclination ranging 30^0-34^0 perceived better LOS in comparison to 300 inclination. This is because lower values of inclination involve an increase in inclined length while higher values need more effort to traverse.

Table 4 Pedestrian perceived choice and LOS distribution on observed stairways

Pedestrian Perceived LOS	Vst1	Vst2	Vst3	Vst4	Wst	Sst
LOS 1	4	8	3	10	6	6
LOS 2	11	13	9	25	14	15
LOS 3	30	20	27	21	30	21
LOS 4	32	19	18	21	16	24
LOS 5	18	22	23	18	21	22
LOS 6	6	19	21	6	14	13
Average LOS	3.7	3.9	4.1	3.3	3.7	3.8
Side friction due to waiting pedestrians	No	Yes	Yes	No	No	Yes
% choosing Stairway	23.76	31.68	23.76	55.45	33.66	38.61
% choosing Escalator	76.24	68.32	76.24	44.55	66.34	61.39

3.0 RESULTS AND DISCUSSION

Responses are segregated with respect to demographic characteristics and the average LOS for each category are shown in Table 5. Age is classified as a child (<15 years), young (15- 30 years), middle-aged (30- 60 years), and aged (>60 years).

Table 5 Average LOS Perceived with respect to various categories

Average LOS In Perception of		Vst1	Vst2	Vst3	Vst4	Wst	Sst
Gender	Male	3.7	3.8	4.0	3.3	3.7	3.7
	Female	3.6	4.1	4.5	3.0	3.9	4.2
Age	Child	4.0	5.2	4.8	3.7	5.3	5.3
	Young	3.5	3.6	3.9	3.0	3.4	3.6
	Middle Aged	3.5	4.0	4.2	3.4	4.0	3.3
	Aged	5.6	6.0	6.0	5.2	6.0	6.0
Education	Uneducated	6.0	6.0	6.0	5.5	6.0	6.0
	Educated	3.6	3.9	4.0	3.2	3.7	3.7
Frequency of Visiting	Rare Visitors	3.7	4.0	4.2	3.4	4.2	3.9
	Frequent Visitors	3.6	3.8	4.0	3.1	3.4	3.7
	Daily Visitors	4.3	3.8	4.5	3.25	3.0	3.5
Average LOS		3.7	3.9	4.1	3.3	3.7	3.8

Categorical respondents perceived average LOS is compared with that of average LOS obtained from the weighted average of all the responses. LOS in perception to male respondents is in comparison to that of average LOS while female respondents perceive higher value (towards lesser LOS standards). This is because female pedestrians walking speed is less in comparison to male pedestrians and they feel uncomfortable in being in a crowd. Hence they perceive the lesser quality of service in comparison to the male pedestrian for the same flow characteristics. While child and aged category pedestrian's perception of stairway LOS show extremes and are not in range to the average LOS. LOS perceived by young, and middle-aged respondents is in the range of the average LOS. However, young respondents perceive LOS as a bit lesser, and middle-aged respondents assign a better LOS than that of average LOS. And average LOS is more close to the average LOS perceived by young and middle-aged respondents. Young respondents, in general, walk faster and tend to maneuver slow-walking pedestrians. As stairways are confined paths, there usually has little chance to overtake the leading pedestrian. Hence they perceive a higher rank than that of middle-aged respondents. Similarly, LOS in perception to uneducated is also not in a comparable range to that of average LOS. An educated respondent, in general, considers all the issues with the stairway and has a greater capacity to assess the functionality of a stairway. Hence the LOS in perception to educated is in very close range to that of average LOS. Rare and frequent visitors' LOS perception is in close comparison to that of average LOS. This is because unlike metro rail users where daily commuters are in greater proportion, intercity rail users are more often rare and frequent visitors.

To understand the effect of each quantitative and qualitative variable from the questionnaire survey on LOS in perception to the user, correlation analysis is conducted. Pedestrian perceived LOS correlates with age, education, marital status, preference of usage between stairway and escalator, width, inclination, and side friction. Width has a good correlation with step rise, step foot, the inclination of the stairway with horizontal, flow, density, walking speed, and side friction. Thus width has an indirect effect on pedestrian perception towards stairway LOS. Thus it is clear that the pedestrian perceived LOS is affected by qualitative variables- age, educational qualification, marital status, preference between stairway and escalator, side friction due to waiting pedestrians and quantitative variables- width, step rise, step foot, the inclination of the stairway with horizontal, flow, density, and walking speed.

To understand the respondent's most bothered quantitative variables, in using a stairway, respondents are asked to tick (one or more) among "Rush," "Width" and "Inclination." Figure 4 shows the priorities they consider in using and evaluating the stairway. Most respondents bother about rush (Flow) on the stairway. When considered as a union of two variables, width and rush are the most considered factors in evaluating stairway and in choosing

between stairway and escalator to ascend a FOB. About 17% consider all three (width, rush, and inclination).

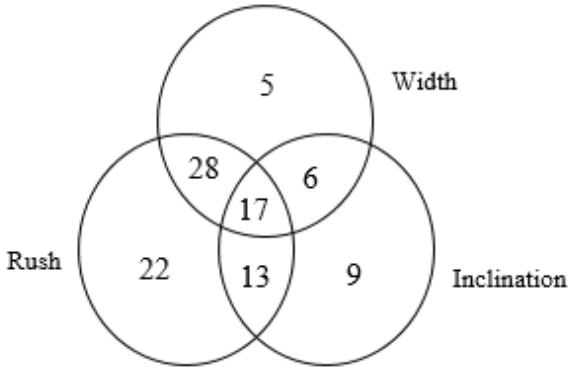


Figure 4 Percentage of respondents most bothered quantitative variable in choosing between stairway and escalator

3.1 Regression Model and Validation

Regression models will be developed to predict the value of a dependent variable based on independent variables. In the present study, LOS was considered as a dependent variable whereas age, education qualification, preference of usage between stairway and escalator, width, inclination, and side friction were considered independent variables. With the identified factors affecting pedestrian perceived LOS of the stairway in an intercity railway station, a regression equation is developed. Equation 1 is the linear regression equation predicting stairway LOS in perception to a pedestrian.

$$LOS = 0.016(A) - 0.333(Edu) + 0.909(Pre) - 0.117(W) - 0.007(Inc) + 0.240(SF) + 3.204 \quad (1)$$

Where A- Age of respondent/user in years, Edu- Highest Education Qualification, Pre- Respondent/ User preference of usage between stairway and escalator; W- Width of Stairway; Inc- Inclination of stairway with the horizontal; SF- Side friction due to pedestrians sitting/standing on stairway.

For validation of the developed model, a survey is conducted for a stairway in Kazipet railway station, located along Secunderabad and Vijayawada railway corridor. The width of the stairway is 2.47m inclined at 31o with horizontal, step rise 0.19 m, and step foot 0.32m. Demographic data and perception of LOS offered by the stairway are collected. A total of 214 responses are collected. Figure 5 shows the plot for predicted vs. stated LOS in perception to a pedestrian. The average LOS in perception to the users from the survey is 3.42, and the average predicted LOS in perception to a pedestrian is 4.20. In comparison to actual perceived LOS, predicted LOS has an average difference of 22.73 %. The difference in prediction is due to the survey where the respondent's perception of LOS offered by a stairway to the flow conditions they experienced influenced by the environmental and other unforeseen factors.

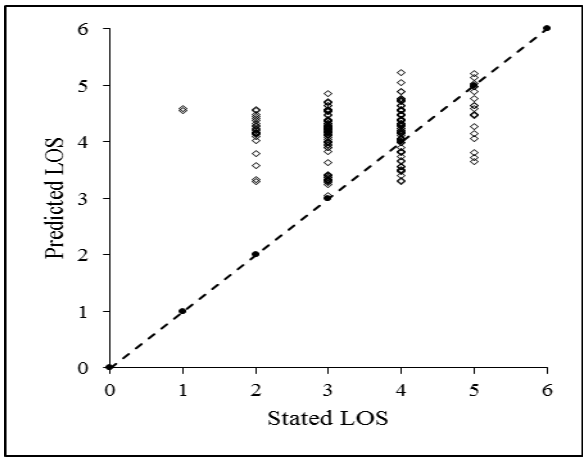


Figure 5 Predicted LOS to stated LOS in perception to pedestrian

4.0 CONCLUSION

An attempt is made to understand pedestrians' perception of stairways of different characteristics to assess their LOS. Several factors have an impact on pedestrian-perceived LOS. Pedestrian characteristics- age, education qualification, his/her preference of usage between stairway and escalator to ascend, and stairway characteristics- width, inclination, and side friction caused by waiting (sitting/standing) pedestrians on stairway significantly affect individuals perception of the serviceability of a stairway.

- Aged pedestrians feel uncomfortable and difficult to access stairways as their health and body conditions do not support them. With the increase in age, pedestrian's perception of a stairway becomes difficult.
- Pedestrian's educational qualification showed a significant effect on an individual's perception. Educated pedestrians perceive a better LOS to a stairway in comparison to uneducated pedestrians. This is because of social behavior that changes with education and employment.
- Higher width offered better LOS than lower width stairways. For given flow characteristics, on lower width stairways, pedestrians psychologically feel discomfort hence have a better perception of higher width stairways.
- Similarly, pedestrian's easiness to ascend reduces with an increase in inclination with horizontal. Hence they offer better perception towards lower inclinations.
- Also, side friction due to waiting for (sitting/standing) pedestrians on stairways

relatively reduces the effective width of a stairway and induces psychological discomfort in maneuvering pedestrians. With side friction, the pedestrian's perception of LOS offered by a stairway becomes worse.

With this, it can conclude that the LOS of a stairway in an intercity railway station is affected by an individual's age, education qualification, preference of usage between escalator and stairway. It is also affected by the width and inclination of the facility and side friction due to waiting pedestrians.

This study has some limitations, the pedestrian perception on stairways is obtained via a questionnaire survey for an excerpt of similar flow conditions on stairways with different infrastructure characteristics. A further study on an individual's perception of various flow character tics, stairway characteristics, real-time perception concerning experienced flow on stairways gives a much spread data. Group behavior, environmental conditions, time of day are to be studied which may significantly affect the perception. Despite the limitations, this research work identified the factors affecting pedestrian perception on stairways with respect to stairway characteristics in intercity railway stations. Results of this study help in evaluating a stairway facility and arrive at better planning, design, and management to increase its efficiency. This study also helps in making design policies and guidelines for new stairways for better accessibility.

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