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Research Article

Escalator Level of Service (ELOS) Criteria Based on Flow Characteristics on Escalators and in Approach Area

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Abstract

Escalators are an integral part of multi-level public buildings. The researchers have studied the flow characteristics on the escalators, but the guidelines to evaluate pedestrian flow conditions at escalators are missing. This paper proposes the Level of Service (LOS) criteria to assess the flow conditions on and around the escalators. A study was conducted at Delhi Metro stations in India. Arrival flow data and passengers' flow at escalators are recorded, and arrival density, passenger walking speed towards an escalator, and flow data are extracted. Considering that the theoretical capacity on escalators is never reached, the reference capacity as proposed in the literature is used to estimate flow (v) to (reference) capacity (C_f) ratio. Analysis indicated that the percentage of pedestrians walking on escalators varied between 3.78% and 8.45%; reference capacity varied between 81 and 178 ped/m/min; and the walking speed of pedestrians towards the escalator varied between 1.92 m/s and 0.10 m/s. This indicated the effect of density and flow condition. The maximum density in the approach area is estimated as 3.2 ped/m^2. The LOS of the selected escalators based on different criteria indicated that the selected escalators generally operated at either LOS-C or LOS-D. Criteria for planning or implementation of a new facility are also recommended. This would help the professionals and planners in taking an informed decision regarding infrastructural improvements in public buildings.

1 Introduction

Modern transportation systems like Metro Rail, Light Rail Transit, Regional Rail, Bus Rapid Transit, Commuter Suburban Rail, Long-distance train, etc., provide intracity and intercity connectivity. Considering the higher cost and availability of land in urban areas, the stations are usually constructed either underground or elevated. The connectivity between floors is ensured through stairs, ramps, escalators, or elevators. Escalators are moveable stairs operated using rollers to transfer passengers between floors at a specified speed. Compared to different level change facilities, passengers prefer escalators as their use requires minimal physical effort in scaling the level difference. Lazi and Mustafa (2015) in their route choice behavior study at escalators and stairways in Malaysia, reported that almost 60% more pedestrians used escalators compared to stairways. They also stated that, except for safety, the use of escalators is more comfortable and convenient for passengers carrying luggage or children.

Apart from the multilevel shopping malls, the installation of escalators became mandatory at metro stations, which carry a high commuter load. Metro systems in India were initiated by the Ministry of Urban Development (now Ministry of Housing and Urban Affairs) under the National Urban Transport Policy (Ministry of Housing and Urban Affairs, 2006). As in 2025, with an operational length of 945 km (17 metro systems), 45 lines across cities, and 761 metro stations, India operates the third-longest metro network in the world (Urban rail transit in India, 2025). In fact, Delhi Metro's daily ridership crossed 7 million (PIB, 2024), indicating the passenger load that a metro system may be carrying in different cities. The increase in ridership puts pressure on passenger handling facilities, including escalators, which experience congestion during peak periods. This brings in a research question – *when should the service providers or practitioners, or authorities, decide to augment the existing facilities?* Certainly, the decision would be made based on flow characteristics on and around the pedestrian facilities (here, escalators), the passenger handling capacity of the facility (escalators), and the alternate facilities available at the site for movement between floors.

The performance of the pedestrian facilities can be assessed through the concept of *LOS*. LOS is a quantitative or qualitative assessment of the operational condition of a facility. Measurement may be based on flow characteristics or on users' perception. The governing guidelines related to pedestrian facilities, like National Academies of Sciences, Engineering, and Medicine (2022), INDO-HCM (2017), and IRC-103 (2022) mention LOS criteria for pedestrian facilities like footpaths, crosswalks, sidewalks, and foot over-bridges. However, none of these guidelines provides LOS criteria for escalators. In fact, the guidelines on the planning and design of escalators like British Standards Institution (2004), Bureau of Indian Standards (2016), and European Committee for Standardization (2017) are also silent in this respect. The examination of the literature indicates that there are studies on flow characteristics at escalators installed in different categories of public buildings. These studies touch upon the theoretical capacity and field capacity of escalators and mention that the theoretical capacity is never attained in the field. This means that no such situation arises when it can be inferred that another escalator needs to be installed in the building (owing to vacancy on steps).

However, the condition prevailing in the developing countries with a large population load is different. High pedestrian volume at level change facilities causes discomfort and delays. Even under most congested conditions, there may be a vacancy on a step of the escalator that practically cannot be eliminated. Citing this shortcoming, this research work considers the reference capacity (Kahali & Rastogi, 2021b) instead of theoretical capacity and develops the LOS criteria for escalators based on the flow characteristics on and around the escalators. The flow on the escalator governs the operational conditions, and the flow in the approach area of the escalator evaluates the escalator system. The proposed criteria would be helpful for practitioners in the assessment of flow conditions and needs related to infrastructure improvement.

The discussion has been oriented as follows: An overview of the research related to flow and capacity of escalators is presented, followed by research on LOS for other pedestrian facilities.

Based on the insights, a data collection methodology is presented. Then flow characteristics on and around escalators are estimated. To develop LOS criteria, clustering techniques are used. Finally, conclusions are drawn, and recommendations are presented.

The associated literature is presented and discussed in the next section.

2 Flow characteristics on pedestrian facilities

Initially, the studies related to escalators are discussed. It is followed by studies on LOS criteria for pedestrian facilities. These are presented in successive sub-sections.

2.1 Studies on escalators

Flow characteristics on escalators in terms of count intervals, passenger flows, and capacity are discussed successively in the following sub-sections.

Count interval for extraction and flow characteristics

Various studies related to count intervals are highlighted in Table 1.

Table 1. Studies on data extraction count interval and flow characteristics on escalators.

Author (s)	Country	Count Interval	Escalator Speed	Passenger flow	Location
(Mayo, 1966)	UK	60 sec	0.75 m/s	Maximum flow rate = 5500 ped/hour	Metro station
(Al-sharif, 1996)	UK	30 sec	0.75 m/s	Maximum passenger flow on seven escalators (ped/min), varying between 86 and 140	Metro station
(Lam & Cheung, 2000)	China	60 sec	0.75 m/s	Ascending and Descending escalators (ped/min), LU & MTR = 120; KCR = 118	Railway station
(Nai et al., 2012)	China	20 sec	0.61 m/s	Maximum = 135 ped/min (ascending and descending escalators)	L-shaped interchan ge station
(Bodendorf et al., 2014)	Germany	120 sec, 90 sec, 60 sec, 30 sec, and 10 sec	0.50 m/s	Railway station (ped/min) Upwards = 103.77, Downwards =107.72 shopping malls (ped/min) Both directions = 91.50	Railway stations, shopping centers
(Shankar et al., 2016)	India	60 sec	0.5 m/s	30-40 ped/min	Railway station
(Patra et al., 2017)	India	30 sec	-	38 ped/min	Railway station
(Kahali & Rastogi, 2021b)	India	10 sec	0.65 m/s	Morning flow (ped/min) on nine escalators varies between 31.85 and 77.68. Evening flow (ped/min varies between 36.5 and 61.67	Metro station
(Kahali & Rastogi, 2021c)	India	24 sec	0.65 m/s	Morning flow (ped/min.), four escalators, varies between 33.08 and 99.183. Evening flow (ped/min), varies between 35.15 and 155.67	Metro station
(Kahali & Rastogi, 2021a)	India	30 sec	0.65 m/s	Flow/escalator (ped/min), six escalators, varies between 69.58 and 119	Metro station

LU = London Underground; MTR =Mass Transit Railway; KCR = Kowloon-Canton Railway

The data highlights that the escalators operate at a speed of 0.50 to 0.75 m/s at stations across countries. The count interval varies from 10 seconds to more than 60 seconds and is contextual in nature. In general, 1-minute counts are used for the analysis across studies. A lower count interval is used if the prediction of instantaneous peaks in the flow needs to be examined. This becomes important at metro stations where the flow builds momentarily and then subsides based on train arrival and departure frequency. Therefore, the count interval should be selected judiciously based on the operational flow attributes to be studied and the location of installation.

Capacity estimation at escalators

The design guidelines state that the escalator's capacity is affected by its speed, step width, and step occupancy. Different manuals or guidelines have reported the theoretical capacity as 150 ped/min, 195 ped/min, and 225 ped/min for escalator speeds of 0.50 m/s, 0.65 m/s, and 0.75 m/s, respectively (British Standards Institution, 2004; OTIS, 2012; Bureau of Indian Standards, 2016; European Committee for Standardization, 2017; Schindler, 2020). Attributes like passengers' eagerness, previous experience of using the facility, alertness, and ease of use also affect the capacity (O'Neill, 1974). Mayo (1966) categorized the factors influencing capacity as controllable (like escalator speed, ticket gates, and geometry of approach) and uncontrollable (like the total flow of passengers, walk-stand ratio, and distance of the escalator from the alighting or boarding point). (Fruin, 1987) has done interesting work in the field of escalators. The study explained the phenomenon of empty steps and stated that 100% pedestrian occupancy is never achieved in the field because pedestrians maintain some buffer space when they are on an escalator. Due to this, theoretical capacity is never achieved in the field. Davis and Dutta (2002) reported that the access from either side of the escalator also affects its capacity. Considering Stand-Walk etiquette, the right-side opening showed potential to increase the capacity on the standing side by 1.7 ped/min, whereas the left-side opening might have the potential to increase the capacity on the walking side by 4 ped/min.

The field capacity of escalators as reported by different researchers is presented in Table 2.

Table 2. Field capacity of escalators as reported by different researchers

Author (s)	Field capacity, ped/min	Escalator Speed (m/s)	Country	Location	Purpose
(Al-sharif, 1996)	Maximum = 124; Effective = 134; Actual = 94	0.75 m/s	UK	Metro station	Escalators handling capacity
(Lam & Cheung, 2000)	Ascending and descending both LU = 120; MTR = 120; KCR = 118	0.75 m/s	Hong Kong	Metro station	Speed flow relationship for walking facilities
(Davis & Dutta, 2002)	120	0.73 m/s	UK	Metro station	Escalator capacity
(Nai et al., 2012)	Maximum = 135 (ascending and descending escalators)	-	China	Metro station	Optimization of walking facilities
(Bodendorf et al., 2014)	Railway station Upwards = 104, Downwards =108 Shopping malls Both directions = 92	0.50 m/s	Germany	Railway station	Capacity of escalators
(Costescu et al., 2015)	100	0.65 m/s	Bucharest	Metro station	Capacity of escalators
(Shankar et al., 2016)	30 - 40	0.50 m/s	India	Railway station	Escalator capacity
(Patra et al., 2017)	38	-	India	Railway station	Flow characteristics

LU = London Underground; MTR =Mass Transit Railway; KCR = Kowloon-Canton Railway

Comparing the data given in Table 2, it can be observed that in none of the studies, the field capacity reaches the theoretical capacity.

Another aspect that affects capacity positively is passengers walking on the escalator. Considering this aspect, a constant walking factor of 0.7 was proposed by (Al-sharif, 1996). He considered 50% utilization on the standing side and 33% utilization on the walking side. The walking factor was used to estimate the enhanced capacity (effective capacity). The field capacity of the escalator was reported as 42% of the theoretical capacity, which increased to 60% if walking is considered. This study also concluded that the theoretical capacity is not achieved due to human ellipse size, which is bigger than the effective step dimension of escalators.

A study by Kahali and Rastogi (2021b) reported that the percentage of pedestrians walking on escalators is quite small. This may be due to higher passenger load on escalators in developing countries. The authors proposed a concept of reference capacity to deal with the issue of uncertainty, i.e., when to augment the escalators in a public building, as field capacity never reaches the theoretical capacity. The step occupancy and walking factor (ratio of practical capacity without considering walking speed of pedestrians to practical capacity considering walking speed of pedestrians) are estimated in a range of 0.80-1.70 and 0.70-0.74, respectively, for Indian conditions. The step occupancy during morning peak hours is found to be higher compared to evening peak hours.

The capacity estimation formulations proposed by researchers are presented in Table 3.

Table 3. Formulations proposed by researchers for the estimation of escalator capacity

Author(s)	Country	Capacity Estimation
(Mayo, 1966)	England	Capacity (max.) {ped/min} = 1.329 E_s - 0.0055 $E_s{}^2$ - 0.875h + 0.0112q + 0.0075h*E_s - 11.20 Capacity (mean) {ped/min} = 1.553 E_s - 0.0059 Es^2 - 0.265h + 0.0163v + 0.032h* E_s - 68.33 E_s = escalator speed (ft/min), h = vertical rise (feet), v = passenger flow (ped/hr)
(Costescu et al., 2015)	Romania	C_S (ped/min) =S_s*P_S; C_w (ped/min) = S_w*P_w C_S = capacity on standing side, C_w = capacity on walking side, S_s = Number of steps/min = E_s/d, E_s = Speed of the escalator (39 m/min), d = depth of the escalator (0.4 m), P_S = Proportion of step used while walking (0.5), S_w = Number of steps/min = (E_s+E_v)/d, E_v = speed of pedestrians walking on the escalators, P_w = 0.33
(Kahali & Rastogi, 2021b	India	Without walking speed: C = (E_s*n*O_s) + (E_s*n*O_w) With walking speed: C = E_s*n*O_s + ((E_s+ P_s) *n*O_w) E_s = escalators' speed (m/min), n = number of steps (in unit length), O_s = step occupancy on standing side, O_w = step occupancy on walking side

2.2 *Level of service approaches*

LOS criteria for different pedestrian facilities, except escalators, are presented in National Academies of Sciences, Engineering, and Medicine (2022) and INDO-HCM (2017). These are presented in Table 4. National Academies of Sciences, Engineering, and Medicine (2022) discusses LOS criteria for walkways and stairways, whereas INDO-HCM (2017) discusses LOS criteria for footpaths, sidewalks, stairways, and foot-over bridges. The criteria are based on flow characteristics. The characteristics used by different researchers in their studies on various pedestrian facilities are presented in Table 5, and approaches used for LOS estimation are given in Table 6.

Operational characteristics, pedestrian personnel characteristics, traffic characteristics, roadway characteristics, land use characteristics, and accessibility characteristics are the broad categories that influence LOS on pedestrian facilities. Pedestrian delay is an important attribute and the most employed attribute for defining LOS for crosswalk facilities. The pedestrian volume, traffic volume, flow rate, safety, traffic control, gender, age, walking speed, turning vehicles, crossing distance, convenience, crosswalk width, traffic conflicts, pedestrian behavior, and space are some of the common attributes used for crosswalks. Density, space, speed, gender, age, v/c ratio, security, comfort, environmental factors, safety, convenience, and accessibility are the attributes used for sidewalks. Width of the footpath, security, continuity, space, safety, system coherence, v/c ratio, comfort, flow rate, attractiveness, speed, and convenience are used for walkways. Space, volume, frequency rate, congestion, speed, waiting time, travelled distance, v/c ratio, and presence of escalators are considered for stairways.

Regarding the approaches used by the researchers to arrive at LOS criteria, many have used either quantitative or qualitative analysis, but very few have used both. Point system, cluster analysis, and regression analysis are the most employed methods.

Considering the factors considered by different researchers, it is decided to use pedestrian flow on the escalators, the flow in the approach area of the escalators being converted into density, and the speed of the pedestrians while they walk towards the escalators. As already mentioned, instead of the theoretical capacity, reference capacity (as suggested in the literature) is used to arrive at a measure of 'volume to capacity'. The data collection effort related to these requirements is now discussed in the next section.

Table 4. LOS criteria for various pedestrian facilities as given in guidelines

INDO-HCM (2017)						National Academies of Sciences, Engineering, and Medicine (2022)					
Footpaths (ped/min/m)						Average flow criteria for walkways				Platoon adjusted criteria for walkways	
LOS	**Commercial**	**Institutional**	**Terminal**	**Recreational**	**Residential**	**Average space (ft2/ped)**	**Flow rate (ped/min/ft)**	**Average speed (ft/s)**	**v/C ratio**	**Average space (ft2/ped)**	**Flow rate (ped/min/ft)**
A	≤13	≤13	≤15	≤12	≤16	>60	≤5	>4.25	≤0.21	>530	≤0.5
B	>13-19	>13-19	>15-26	>12-20	>16-23	>40-60	>5-7	>4.17-4.25	>0.21-0.31	>90-530	>0.5-3
C	>19-30	>19-27	>26-32	>20-32	>23-34	>24-40	>7-10	>4.00-4.17	>0.31-0.44	>40-90	>3-6
D	>30-47	>27-36	>32-68	>32-54	>34-47	>15-24	>10-15	>3.75-4.00	>0.44-0.65	>23-40	>6-11
E	>41-69	36-42	>68-78	>54-91	>47-59	>8-15	>15-23	>2.50-3.75	>0.65-1.00	>11-23	>11-18
F	Variable	Variable	Variable	Variable	Variable	≤8	Variable	≤2.50	Variable	≤11	>18

Stairways							Foot over bridge			Crosswalks
INDO-HCM (2017)				National Academies of Sciences, Engineering, and Medicine (2022)			INDO-HCM (2017)			
LOS	**Flow (ped/min/m)**	**Speed (m/min)**	**Space (m^2/ped)**	**Average space (ft^2/ped)**	**Flow rates (ped/min/ft)**	**v/c ratio**	**Flow (ped/min/m)**	**Speed (m/min)**	**Space (m^2/ped)**	**Pedestrian delay (sec)**
A	≤10	≥42.6	≥2.5	>20	≤5	≤0.33	≤12	≥56.78	≥4.89	≤5
B	>10-22	>37.2-42.6	>1.50-2.5	>17-20	>5-6	>0.33-0.41	>12-17	>55.03-56.78	>3.3-4.9	5—10
C	>22-46	>31.2-37.2	>0.75-1.50	>12-17	>6-8	>0.41-0.53	>17-27	>51.08-55.03	>1.9-3.3	11—25
D	>46-55	>28.2-31.2	>0.50-0.75	>8-12	>8-11	>0.53-0.73	>27-38	>45.65-51.08	>1.2-1.9	26—45
E	>55-70	>24.2-28.2	>0.40-0.50	>5-8	>11-15	>0.73-1.00	>38-52	>30.91-45.65	>0.6-1.2	46—80
F	variable	-	-	≤5	variable	Variable	Variable	<30.91	<0.6	>80

Table 5. Attributes used in LOS determination on various pedestrian facilities

Type of a Facility	Attributes Considered	Author(s), Year, Country
Walkways	Continuity, safety, system coherence, security, comfort, attractiveness, convenience, level of congestion, space, flow rate, speed, V/c ratio, and lateral and longitudinal gap between pedestrians	(Sarkar, 1993), Italy, Germany; (Sarkar, 2003), India; (Gacutan & Tan, 2012), Philippines; (Sahani & Bhuyan, 2013), India; (Shah et al., 2016), China
Crosswalks	Width of median, vehicular flow, non-motorised flow, pedestrian flow, delay, speed limits, crosswalk width, crossing length, zebra crossing provision, stop line marking, crossing orientation, bollards at crossing, raised medians, road signage, skid resistance, drainage, curb ramp, tactile paving, illumination, parking prohibition, conflicts, and pedestrian delay	(Baltes & Chu, 2002), U.S.; (Muraleetharan et al., 2005), Japan; (Sahani & Bhuyan, 2019), India; (Ahmed et al., 2021), Malaysia
Signalized Crosswalks	Crossing time, traffic volume, delay, median width, pedestrian flow, area occupancy, walking speed, signal spacing, turning movements, cycle length, and presence of pedestrian signal	(Lee et al., 2005), China; (Marisamynathan & Vedagiri, 2019), India; (Tallam & Lakshmana Rao, 2020), India
Sidewalks	Lane width, width of separation, sidewalk width, speed of vehicle, roadway width, surface condition, number of obstructions, pedestrian flow, safety, security, comfort, convenience, size of platoon, maintenance, and aesthetic	(Kim, Choi, Kim & Tay, 2013), South Korea; (Daniel et al., 2016), Malaysia; (Sahani et al., 2017), India; (Wibowo & Nurhalima, 2018), Indonesia; Sahani & Bhuyan, 2020), India; (Al-Mukaram & Musa, 2020), Iraq
Stairways	Environmental factors, lighting and clear visibility, flow conflict, congestion level, information signs, presence of escalator, density, flow, walking speed, escalator speed, space, v/C ratio, pedestrian volume, occupancy, waiting time, and distance travelled	(Lee et al., 2003), China; (Cheung & Lam, 1998), China; (Shah et al., 2016), India; (Hu et al., 2019), China
Overpass	Pedestrian density, pedestrian speed, delay, pedestrian flow rate, personal safety, sanitation, comfort, security, convenience, maintenance, location, walking distance, public awareness, attractiveness, and trip purpose	(Kim & Kang, 2013), South Korea; (Bandara & Hewawasam, 2020), Sri-Lanka

Table 6. LOS estimation approaches used by researchers.

Analysis method	Facility	Author(s), Year, Country
Qualitative Analysis	Walkways	(Sarkar, 1993), Italy, Germany; (Gacutan & Tan, 2012), Philippines
	Stairways	(Cheung & Lam, 1998), China
Quantitative analysis	Walkways	(Sarkar, 2003), India; (Shan et al., 2016), China
	Stairways	(Lee et al., 2003), China
	Overpass	(Kim & Kang, 2013), South Korea
Regression analysis variants (Stepwise, Ridge, Pearson, Multiple)	Crosswalks – midblock, signalized	(Muraleetharan et al., 2005), Japan; (Baltes & Chu, 2002), USA; (Lee et al., 2005), China; (Nagraj & Vedagiri, 2013), India; (Sahani & Bhuyan, 2019), India
	Sidewalks	(Petritsch et al., 2006), USA; (Kim, Choi & Kim, 2013), South Korea; (Daniel et al., 2016), Malaysia; (Rastogi et al., 2014), India
	Overpass	(Panda & Chattaraj, 2023), India
Clustering-Affinity propagation clustering and K-means	Walkways	(Sahani & Bhuyan, 2013), India
	Stairways	(Shah et al., 2016), India
	Signalized crosswalks	(Tallam & Lakshmana Rao, 2020), India
	Overpass	(Panda & Chattaraj, 2023), India
Point system	Walkways	(Asadi-Shekari et al., 2013), Malaysia; (Asadi-Shekari et al., 2014), Malaysia
	Crosswalks	(Ahmed et al., 2021), Malaysia
HCM-based, Trip quality method, and Gainesville Australian PLOS method	Walkways	(Karataş, 2015), Turkey
	Sidewalks	(Wibowo & Nurhalima, 2018), Indonesia
Factor Analysis, Regression Analysis, Clustering	Sidewalks	(Sahani et al., 2017), India
Fuzzy linear regression and clustering	Signalized crosswalks	(Marisamynathan and Vedagiri, 2019), India
Simulation in building-EXODUS software	Stairways	(Hu et al., 2019), China
Statistical analysis and Content analysis,	Overpass	(Bandara & Hewawasam, 2020), Sri Lanka

3 Selection of study area and data collection

Delhi Metro is selected for data collection. It is the busiest and largest metro system in India. Currently, it has 12 metro lines with different color codes. The total network length is 393km (including the Rapid Metro Gurugram and Noida-Greater Noida Aqua line) with 288 stations. Apart from transfers between different metro lines, it has interchanges with the Noida Metro and Rapid Metro Gurgaon. The Delhi metro has ground-level, underground, and elevated stations. Smart technologies are deployed for ticketing and recharging, like smart cards, tourist cards, and QR code-based ticketing (Delhi Metro Rail Corporation, 2025).

Following transfer stations, which cater to high flows of passengers during peak hours, are selected for the data collection. Permission was taken from DMRC, the controlling authority.

1. Sarai-Kale Khan - Nizamuddin Metro Station (HNMS): This station lies on the pink line and has two platforms and tracks. This station is near Nizamuddin railway station (long distance). Escalator No. 3 was selected for the data collection, which connects the concourse area to the floor (Ground level) above.
2. Haus Khas Metro Station (HKMS): It is an interchange between the yellow line and the magenta line. It is an underground station, having four tracks and four platforms. Escalator No. 2A was selected for the data collection, which connects the platform area with the floor above.
3. Dilli-Haat Metro Station (DHMS): It is an interchange between the yellow line and the pink line. It is an underground station, having four platforms and four tracks with three levels. Escalator No. 2 was selected for data collection, which connects the concourse area (level 1) with the floor above.

The area around these escalators had space to fix a camera at an elevated position. This helped in the effective capture of pedestrian flows. All escalators run with the same characteristics, namely, step width 1000 mm, depth of step 400 mm, angle of inclination 30˚, and speed 0.65 m/s. They operate in an upward direction, connecting the platform or concourse with the floor above, which leads to entry/exit from the station. Data was recorded during morning peak hours (09.00 to 11.00 am) and evening peak hours (06.00 to 08.00 pm) in February 2023. All the escalators have adjacent stairways, which are divided for directional movements. The condition of pedestrian movement on selected escalators is shown in Figure 1 (a, b, and c).

a) Escalator No. 3 (HNMS) *b) Escalator No. 2A (HKMS)* *c) Escalator No. 2 (DHMS)*

Figure 1. Pedestrian movement on an escalator at different metro stations

4 Conceptual framework

Three approaches are used for developing the LOS criteria for escalators, namely, v/*reference capacity* ratio, density in the approach area, and pedestrian walking speed towards the escalator. The flow pattern on escalators at metro stations is usually governed by the arrival and departure schedule of the metro trains and the location and directional operation of escalators. The alighted passengers walk towards the escalators at a higher walking speed to avoid possible congestion at the escalator. As the flow builds, the passengers walk at a platoon speed. This process continues till the flow starts subsiding. During the platoon flow long queue forms in front of the escalator. Walking speed during this period becomes quite low. Even during the peak period, a few locations on the escalator steps remain vacant. This means the escalator does not reach its theoretical capacity (i.e., operating with two pedestrians per step). The evaluation of pedestrian flow with respect to the capacity allows to examine the service condition of the escalator. This simulates with volume to reference capacity ratio analysis and allows categorisation of LOS.

Between the successive arrival and departure of metro trains, the flow remains low, and the arrival pattern of the pedestrians at the escalator becomes random. Service condition during the lean period remains good but starts deteriorating with the building of flow. Building a flow in front of the escalator provides two possibilities for the evaluation of the system. One is the estimation of pedestrian density in front of the escalator (considering a specified area), and the other is the estimation of walking speed towards the escalator, which reduces as the flow builds. The variation in the approaching walking speed varies from an independent speed (high during the arrival of initial pedestrians) to a dependent speed (platoon speed, wherein each pedestrian follows the other to reach the escalator). The pedestrian density and approach speed can be categorized to arrive at the LOS criteria for the service area of the escalator. The combined approaches can evaluate the escalator both as a facility and a system.

Now, these approaches are discussed in detail.

1. Volume/Reference Capacity (C_f) Ratio: In this approach, the flow of pedestrians on the escalator is calculated by marking the trap covering ten steps. Two reference lines are marked, and the count interval is set as 24 seconds, as suggested by Kahali and Rastogi (2021c). It is then converted into ped/m/min and hourly flow (ped/m/hour).
   The theoretical capacity of escalators at an operational speed (E_s = 0.65 m/s) is 195 ped/m/min. The literature suggests that the actual flow on escalators varies between 40% and 80% of the theoretical capacity in developing countries and 50% to 70% in Western countries (Kahali & Rastogi, 2021b). The use of theoretical capacity for comparison will always show that the escalator still has space to handle more passengers. But under peak conditions in developing countries, this may not be true. A solution to this condition is proposed by Kahali and Rastogi (2021b). They proposed 'reference capacity' considering actual step occupancy (O), pedestrian walking speed (Ev) on the escalators, and percentage of pedestrians walking (P_w). The reference capacity can be calculated as given in Equation 1.
   C_f = *(Practical Capacity considering walking /*S_f*)* (1)
   where, Standing factor = S_f *= (1 - percent walking)*
   The practical capacity (for the Stand-walk etiquette) is given by Equation 2. Though in India no such etiquette is followed but under normal conditions the pedestrians are observed walking on the escalators while moving in a zig-zag pattern. Considering this, the practical capacity (C_p) is calculated using equation (2).
   $$C_p = (E_s \times n \times O_s) + ((E_s + E_v) \times n \times O_w)\quad (2)$$
   where, E_s *= speed of escalators, m/min;* E_v *= walking speed of the passengers(s), m/min;* n *= number of steps in unit length;* O_s *= passenger occupancy at the standing side of an escalator;* O_w *= passenger occupancy at the walking side of an escalator.*

The use of the volume/C_f ratio allows comparison across escalators as well as allows temporal comparison. Being normalised, it is not dependent upon the influencing attributes like the width and speed of the escalator. Thus, the flow condition at the escalators can be easily compared in spatial and temporal spectrums. Use of a simple flow value for arriving at the LOS categorisation would not be an appropriate approach for escalators due to their operation at a constant speed.

2. Density in Approach Area: While observing the pedestrians who were approaching escalators, it was noticed that as the distance increases from the escalator, the width through which the pedestrians approach that escalator increases. This is due to the movement of passengers from different coaches on the train towards the location of an escalator. Geometrically, it creates a trapezoidal pattern with one side being 1 m wide and the other side varying in width with distance from the escalator entry. This is conceptualized similarly by (Al-Widyan et al., 2016) and is depicted in Figure 2. With an increase in the flow or density in front of the escalator, the width of the opposite reference line increases, but the distance between the two reference lines decreases. Considering the availability of space in front of the selected escalators and the flow patterns during congested flow conditions, the size of the trapezoid varied between 8.84 m^2 and 9.38 m^2. Based on the number of pedestrians counted in this area in 1s count interval, the density (ped/m^2) in the approach area of the escalator was calculated.

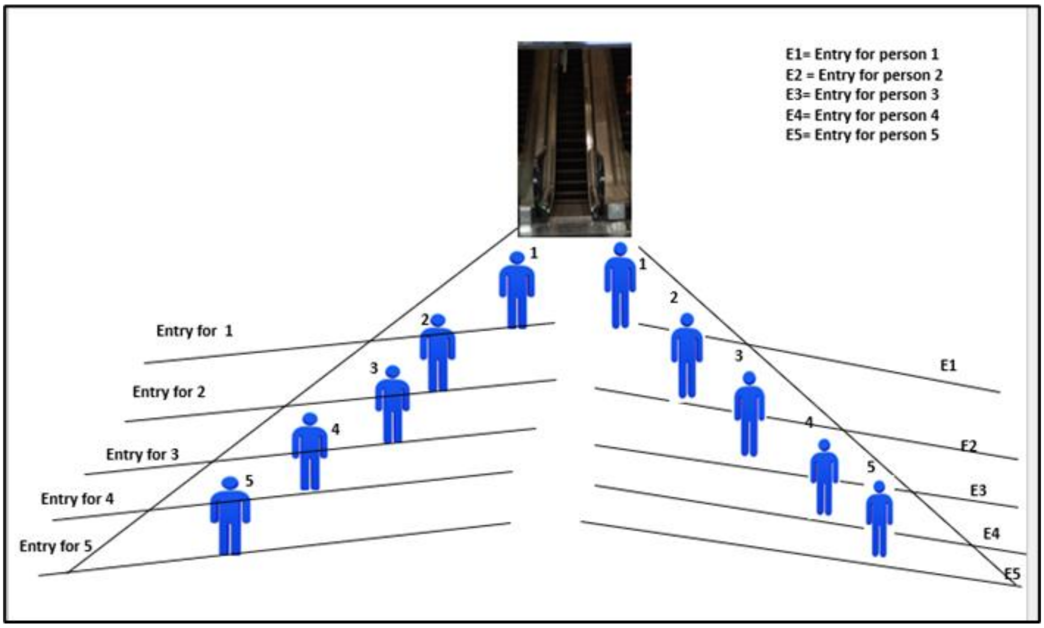


Figure 2. Arrival patterns of pedestrians in front of the escalator (Source: Author)

3. Pedestrian Walking Speed towards Escalator: The pedestrians walk towards an escalator at a certain speed, which varies from pedestrian to pedestrian and with flow. As discussed before, it can vary from individual (fast walking) during the initial period of alighting from the train to platoon speed during the later period after alighting. To calculate this speed, two reference lines are marked at a specified distance: the 1st reference line just at the entry of the escalator, and the 2nd reference line at 2.8 m to 4 m from the 1st reference line, based on the availability of space in front of the escalator. The time taken by pedestrians to cross these two lines is noted, and the speed is calculated. All pedestrians who crossed the lines are considered, irrespective of conditions like talking on cell phones, carrying baggage, or being accompanied by known people, etc. This variation in the walking speed of the pedestrians is used to arrive at the LOS categorization for escalators.

4.1 *Categorization approach*

Clustering is an unsupervised learning technique used to distinctly categorize the data. This technique creates data clusters, wherein the data within a cluster has certain homogeneity, and data across the clusters are distinct based on certain characteristics. Mainly, clustering is of two types, i.e., hierarchical and partitional. Agglomerative and divisive hierarchical clustering are the two forms of hierarchical methods. Divisive clustering can be further divided into three more groups based on similarity linkages or measures, i.e., single-linkage, complete linkage, and average linkage. The partitioning clustering can be further divided into distance-based, model-based, and density-based clustering. In hierarchical clustering, clusters are formed by iteratively dividing the patterns into a bottom-up or top-down approach, while in partitioning clustering, the 'K' clusters are formed without any hierarchical structure by optimization of some criterion function like Euclidean distance (Saxena et al., 2017). The taxonomy of clustering is given in Figure 3.

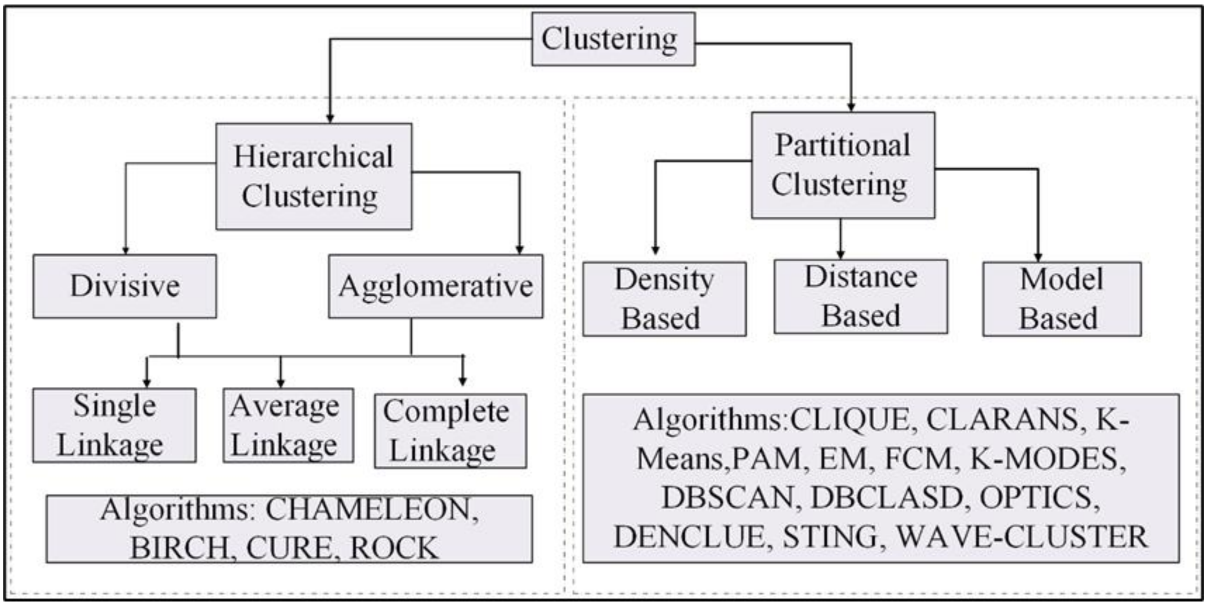


Figure 3. Taxonomy of Clustering (Saxena et al., 2017)

The K-means algorithm is a popular method for pattern recognition and data analysis (Chaudhry et al., 2023). It is a simple, well-known squared error-based partitioning clustering algorithm (Xu & Wunsch, 2005). It is used for forming homogeneous clusters of data so that the data points within the same group are similar and within other groups are dissimilar. Since it is an unsupervised algorithm, the data set is classified through the user-defined number of clusters (K) (Saxena et al., 2017). There is no universal or efficient method for finding the optimum number of clusters and identifying the initial partitions (Chaudhry et al., 2023). The elbow method, silhouette score, and gap statistics are the three methods that are used for finding the optimum number of clusters (Tallam & Lakshmana Rao, 2020).

The Elbow method is a graphical method that is used to determine the best K value. In this method, the graph plots the WCSS (Within Cluster Sum of Squares) values against different K values. *The point at which the graph bends like an elbow is considered the optimum K-value.* However, this can be considered as the method of interpretation and validation to find the optimum number of clusters in any dataset (Tallam & Lakshmana Rao, 2020).

The objective function (D) used in this algorithm is highlighted by Equation 3 (Saxena et al., 2017). The main aim is to minimize the objective function D.

$$D = \sum_{j=1}^{K} \sum_{i=1}^{n} \left| x_i{}^j - m_i \right|^2 \tag{3}$$

$\left| x_i{}^j - m_i \right|^2 = selected\ distance\ between\ a\ cluster\ centre\ and\ data\ point$

where K = number of clusters, n = number of data points in cluster j, x_i^j = i^{th} data point in cluster j

The typical steps in this algorithm are as follows:

1. The first step is to initialize the cluster centers (by user-defined K). Now, the dataset will take K distinct patterns randomly. These points represent initial centroid groups. These centroids will change with every iteration.
2. It then assigns each data point to the nearest centroid.
3. Then it updates the cluster centers as the means of the data points within the cluster.
4. It repeats 2) and 3) until the centroids stabilize and stop moving significantly.
5. Once the centroids stabilize and stop moving significantly, they converge.

Random assignment of initial centroids is the major limitation of this algorithm (Alasali & Ortakci, 2024). It requires specialized knowledge to find the optimum number of clusters (required for initialization of the algorithm) (Chaudhry et al., 2023). It depends on the user-defined number of clusters (which is unknown and if chosen wrongly, can give inaccurate results). It is sensitive to outliers (as it uses the mean as a centre) and noise (Alasali & Ortakci, 2024). The results might be subjective as it is a visual interpretation. However, the major advantage of this algorithm is that it is easy to implement on large data sets, and its computation is faster than other clustering algorithms (Xu & Wunsch, 2005).

Considering the merits and demerits of the methods, the Elbow method is used to arrive at the optimum number of clusters, and K-means clustering is used to find the ranges of the clusters. The three approaches resulted in three sets of LOS criteria for the escalator system. These are presented in the next section.

5 Flow characteristics and ELOS

The observed peak pedestrian flow for selected escalators at respective stations during morning (MP) and evening (EP) peak hours is shown in Figure 4.

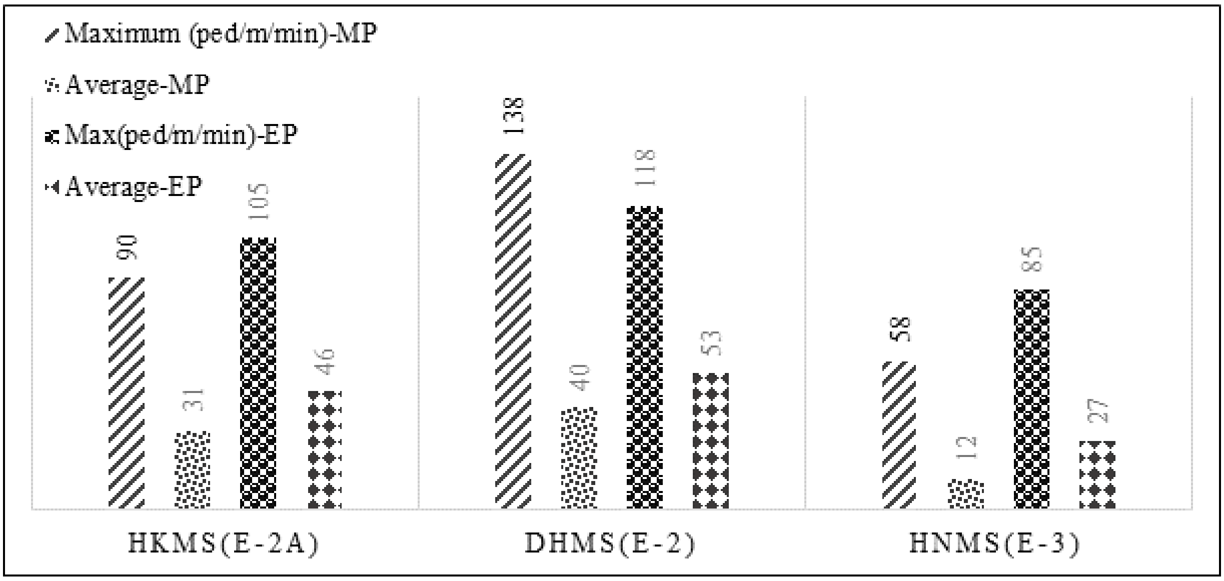


Figure 4. Peak Pedestrian flow at selected escalators at the metro station

The selected escalators at DHMS, and HNMS metro stations are single type, while that at HKMS is parallel type. Among all, the escalator at DHMS has the highest peak flow, and that at HNMS has the lowest peak flow. At HNMS, most of the time, the escalator was running empty, whereas at HKMS, the escalator catered to continuous flow. The difference in the flow pattern could be due to the location of escalators on the platform or different land use around the station. The selected escalators at HNMS and DHMS are in the concourse area, while the selected escalator at HKMS is away from the concourse area. HKMS and DHMS are the interchange stations that could also be the reason for having more peak flow than HNMS. DHMS serves busy markets like Sarojini Nagar (a very famous market) and the INA market. This is also famous for craft bazaars and food plazas. The Hazrat Nizamuddin railway station, Sarai Kale Khan Inter-State Bus Terminus are very near to HNMS, and the locality around it is also famous for street food. The entrance of HKMS is located on the outer ring road, and tourist attraction places are very near to this station. *This makes clear that flow is governed by the location of escalators on the platform, duration of the day (morning or evening), the locality, and land uses around the metro station.*

Along with flow, the walking speed, walking percentage, step occupancy, standing factor, and reference capacity for the respective escalators at metro stations during evening and morning peak hours are calculated. These are presented in Table 7. It is noted that in none of the cases, step occupancy reached 2 pedestrians (full utilization), which is highlighted by (Fruin, 1987) too. Possible reasons behind such a phenomenon can be the space required for the baggage or discomfort due to body ellipse size, or not willing to share space with an unknown person.

For Indian conditions, the standing and walking side on the escalator is not fixed. This allowed pedestrians to walk (observed mostly on their right side in this study), though their proportion is observed to be small. The walking percentage was between 3.78% and 8.45%. The average walking speed of passengers on escalators was 0.72 m/s during morning peak hours and 0.67 m/s during evening peak hours. The significant difference in speeds during evening peak hours may be attributed to passengers' tiredness as compared to morning, and the possible hurry to reach their workplace in the morning. The step occupancy is calculated by the number of steps occupied by the passengers within a trap at any instant of time on the escalators.

Table 7. Walking speed, walking percentage, step occupancy, standing factor, and reference capacity during peak hours

Station	Walking speed (m/s)		Walking percentage (%)		Step occupancy		Standing factor		Reference capacity	
	Morning	Evening	Morning	Evening	Morning	Evening	Morning	Evening	Morning	Evening
HKMS(E-2A)	0.72	0.62	6.2	6.5	1.6	1.54	0.938	0.935	178	171
DHMS(E-2)	0.58	0.62	4.32	3.78	1.6	1.4	0.957	0.962	170	147
HNMS(E-3)	0.85	0.78	8.45	7.43	0.8	0.7	0.916	0.926	95	81

HKMS= Hauz Khas metro station, DHMS= Dilli Haat metro station, HNMS= Sarai Kale Khan Nizamuddin metro station

The step occupancy is higher during morning peak hours compared to evening peak hours, as also observed by (Kahali & Rastogi, 2021b). Incorporating all these factors, O_S and O_W are calculated at respective stations.

The reference capacity is found varying between 81 and 178 ped/min, which is less than the theoretical capacity and thus can be used for evaluating the flow condition.

The maximum arrival density during morning and evening peak hours at escalators at selected metro stations is given in Table 8.

Table 8. Maximum density in the approach area of selected escalators at metro stations

Station	Morning (ped/m²)	Evening (ped/m²)
HKMS (E-2A)	1.92	3.2
DHMS (E-2)	3.15	2.5
HNMS (E-3)	0.79	1.13

Note: *Area of the trapezoid was varying from 8.84 m² to 9.38 m² (angle appx. 30°)*

Among three escalators**,** the maximum arrival density is observed at HKMS. The arrival density at HNMS is very low (0.79 ped/m² and 1.13 ped/m² during morning and evening peak, respectively). At DHMS, during morning peak hours, the arrival density reached 3.15 ped/m², indicating congested and jammed conditions. The arrival density at HKMS during evening peak hours touched 3.2 ped/m², which also indicates a tendency towards the worst condition.

For approaching speed, 200 samples each for male and female passengers during morning and evening peak hours were collected for two stations (HKMS and DHMS), thus collecting 800 samples per station. Data samples for HNMS are discarded due to homogeneity among the speeds, as most of the time the escalator was running empty. Density was also very low in the approach area at that station. A bigger sample size allowed to incorporate the influence of factors like variations in walking speed due to arrival and departure of metro trains (individual and platoon speeds), type of commuters (daily vs occasional), carrying baggage, distractions (using a cell phone or not), and gender of the pedestrian. The descriptive statistics for approaching speed are given in Table 9. An equal sample of male and female pedestrians is taken in this study to ensure the homogeneity of the data. The reason for taking male and female speed separately is to study their dynamics and realms. Usually, males and females exhibit different mobility behaviours. Thus, identifying and including these in the analyses would help in planning safer and inclusive facilities. The distinction between male and female was made based on visual appearance while extracting the data using a software.

However, the pedestrians might change their speed while getting on the escalators or to adjust to the escalator speed. The speed of the pedestrians might also vary due to the presence of any hindrances in front of the escalators or the prevailing conditions like talking on cell phones, carrying baggage, being accompanied by known people, etc. But real-time data showed that initially, the passenger wants to get on the escalators at the maximum possible speed, but as the flow builds, they walk at a platoon speed. This process continues till the flow starts subsiding (refer to section 4). These conditions will vary from escalator to escalator at different locations. In this case, the average approaching speed would allow a fair comparison over time and would be a correct representation of actual service quality.

From the data, it is observed that the average speeds of male and female pedestrians are reasonably different. The average speed of male pedestrians during morning peak hours was 0.65 m/s and was 0.60 m/s for female pedestrians. During evening peak hours, the average speeds were 0.61 m/s for male and 0.60 m/s for female pedestrians

It is also observed that the presence of stairways alongside an escalator affected the flow on the escalator. During the large queue formation in front of the escalators, the passengers started shifting from the escalator to the stairways. Sometimes, this happens due to the inconvenience faced by female pedestrians during queue formation.

Table 9. Descriptive statistics for approaching speed towards escalators

Characteristics	DHMS(E-2)		HKMS(E-2A)	
	Morning	Evening	Morning	Evening
Sample size	400	400	400	400
Minimum (m/s)	0.21	0.23	0.12	0.10
Maximum(m/s)	1.92	1.92	1.87	1.46
Median (m/s)	0.64	0.70	0.41	0.40
Average (m/s)	0.70	0.72	0.55	0.50
Standard Deviation	0.34	0.31	0.33	0.27
Characteristics	DHMS(E-2)		HKMS(E-2A)	
Sample size	800		800	
Minimum (m/s)	0.21		0.10	
Maximum (m/s)	1.92		1.87	
Median (m/s)	0.67		0.40	
Average (m/s)	0.71		0.52	
Standard Deviation	0.33		0.30	
Combined data for both stations				
Characteristics	Morning		Evening	
Sample size	800		800	
Minimum (m/s)	0.12		0.10	
Maximum (m/s)	1.92		1.92	
Median (m/s)	0.59		0.59	
Average (m/s)	0.63		0.61	
Standard Deviation	0.34		0.31	

Note: 1st Reference Line (at the entry of the escalator), 2nd Reference Line (2.8 m to 4 m from 1st reference line)

For finding the K value, the elbow method is used, and the results are shown in Figures 5, 6, and 7 for all three approaches, i.e., the v/C_f ratio, arrival density, and approaching speed, respectively. As discussed in Section 4.1, the point at which the graph takes the shape of the elbow is the optimum K-value. From Figures 5, 6, and 7, it seems that at K=4, the graph is taking the shape of the elbow, so it can be considered as the optimum K value.

However, taking K=4 results in five ELOS categories, which are different from the existing literature for pedestrian facilities and the existing guidelines (INDO-HCM 2017), National Academies of Sciences, Engineering, and Medicine (2022), as already highlighted in Table 4. Usually, six LOS ranges from LOS (A-F), where LOS A represents the highest flow condition and LOS F represents the worst flow condition, are used. Some of the studies, like Lee et al. (2003), Lee et al. (2005), and Rastogi et al. (2014) presented five LOS, whereas Hu et al. (2019) proposed three LOS ranges. This shows that LOS categorization can be done as per the requirements.

Meanwhile, Kothari & Garg (2019) suggested that the researcher has the freedom to decide which value of K yields the best results. Further suggested to repeat and compare the analysis with different K values until the best solution is reached. Considering this, the analysis for K=5 is also done, resulting in six ELOS categories (like existing guidelines). The ranges of clusters for K=4 (left diagrams “a”) and K=5 (right diagrams “b”) are shown in Figures 8, 9, and 10 with different color codes.

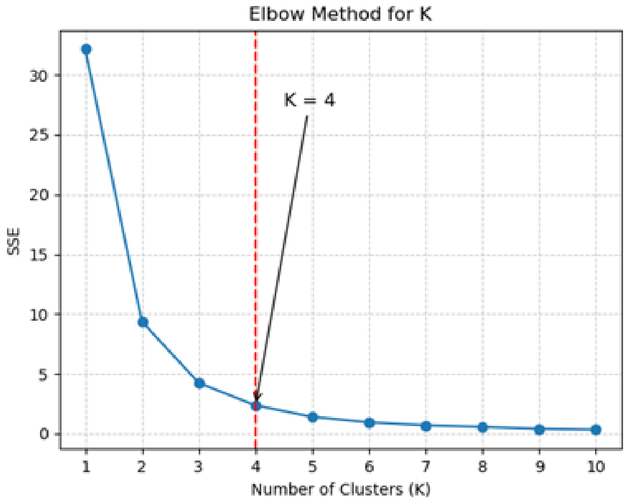


Figure 5. *Number of clusters for v/C_f approach*

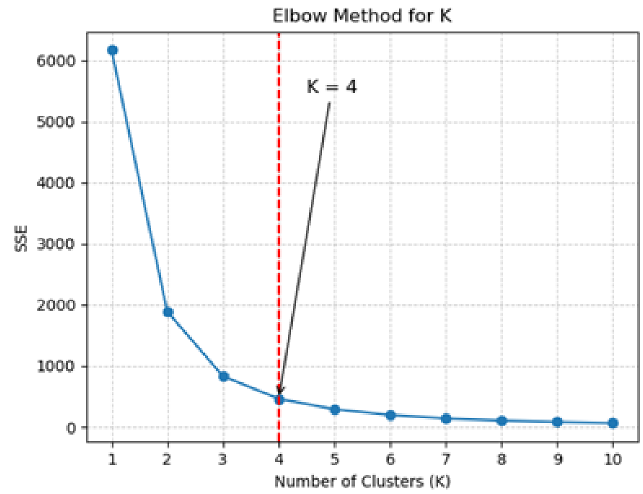


Figure 6. *Number of clusters for the arrival density approach*

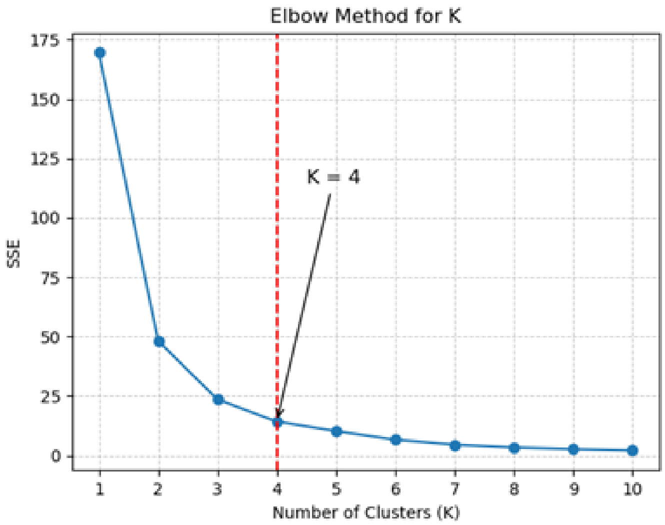
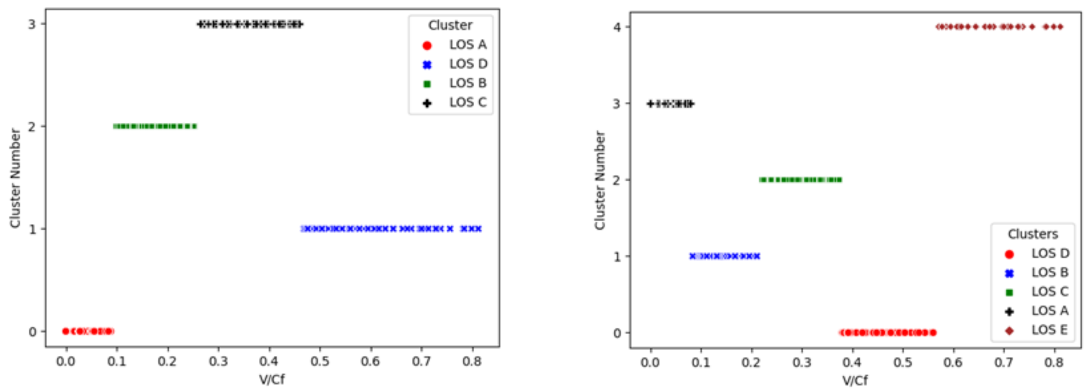
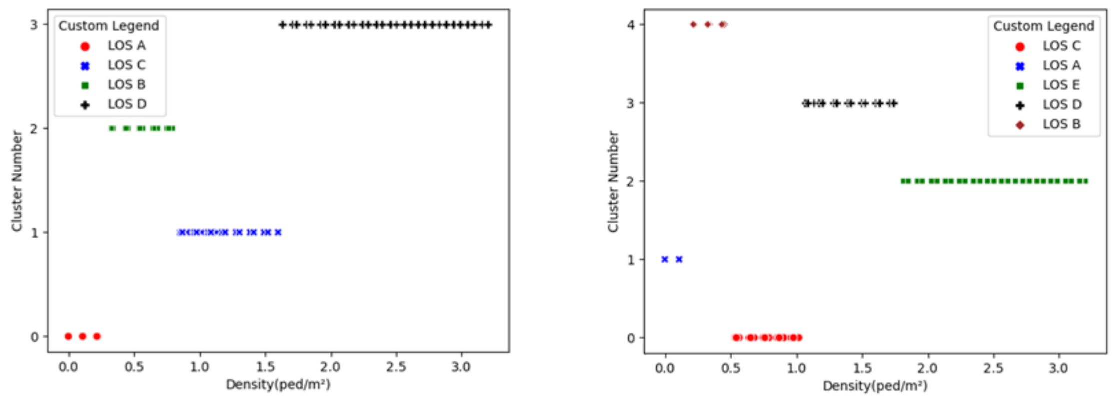


Figure 7. *Number of clusters for approaching speed*



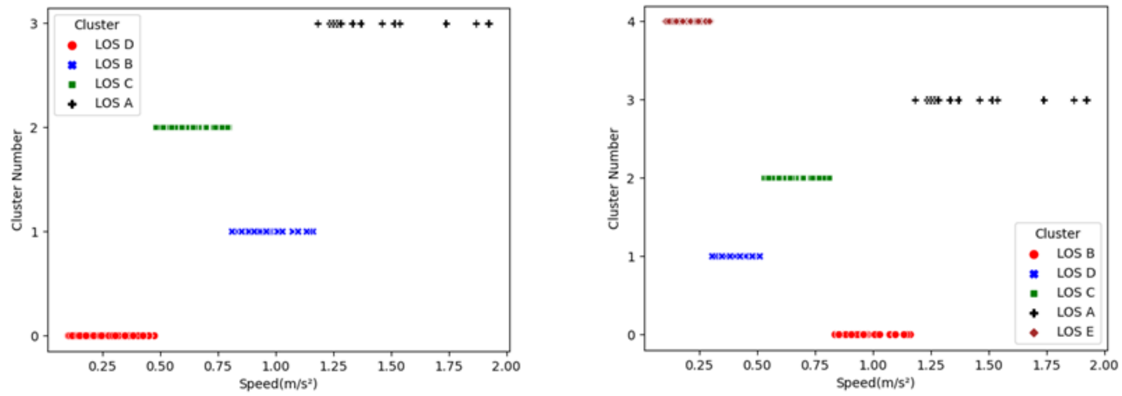
a) K = 4 b) K = 5

Figure 8. Cluster ranges for the v/C_f ratio approach



a) K = 4 b) K = 5

Figure 9. Cluster ranges for the arrival density approach



a) K = 4 b) K = 5

Figure 10. Clusters ranges for approaching speed

From Figures 8, 9, and 10 (left diagrams "a"), it can be concluded that four distinct groups are formed within their own centroids. The points within clusters are more tightly grouped, giving a balanced distribution across clusters, while in the right diagrams, slightly over-segmentation is visible, making clusters look very closely, which might be due to the overlap of some data points.

The final ELOS categorization based on each of the approaches is presented in Tables 10 and 11 for K=4 and K=5 analysis, respectively.

Table 10. ELOS based on three approaches for (K=4)

ELOS	v/C_f ratio	Arrival density (ped/m²)	Approach speed (m/s)
LOS A	Up to 0.10	Up to 0.23	Above 1.16
LOS B	Above 0.10 up to 0.25	Above 0.23 up to 0.80	Above 0.80 up to 1.16
LOS C	Above 0.25 up to 0.46	Above 0.80 up to 1.52	Above 0.48 up to 0.80
LOS D	Above 0.46 up to 0.81	Above 1.52 up to 3.20	Above 0.11 up to 0.48
LOS E	Above 0.81	Above 3.20	Below 0.11

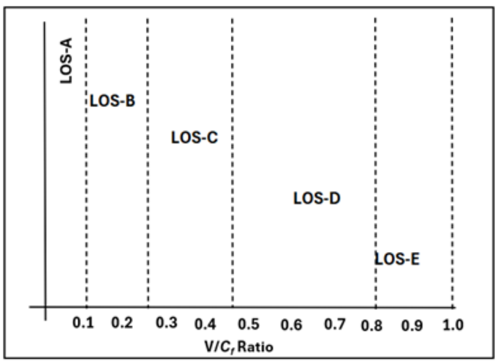
Table 11. ELOS based on three approaches for (K=5)

ELOS	v/C_f ratio	Arrival density (ped/m²)	Approach speed (m/s)
LOS A	Up to 0.080	Up to 0.11	Above 1.16
LOS B	Above 0.080-up to 0.21	Above 0.11 up to 0.45	Above 0.81 up to 1.16
LOS C	Above 0.21-up to 0.36	Above 0.45 up to 1.02	Above 0.52 up to 0.81
LOS D	Above 0.36-up to 0.55	Above 1.02 up to 1.74	Above 0.31 up to 0.52
LOS E	Above 0.55-up to 0.81	Above 1.74 up to 3.20	Above 0.11 up to 0.31
LOS F	Above 0.81	Above 3.20	Below 0.11

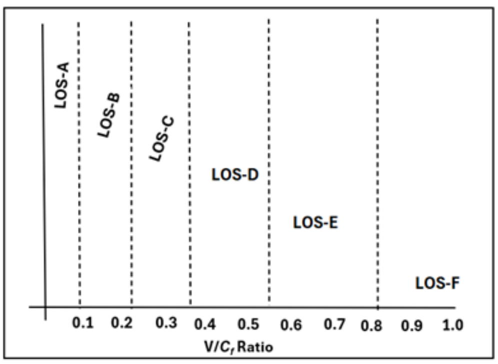
Comparing Table 10 and Table 11, it is noted that LOS categorization has broader ranges with K=4, while with K=5 the ranges are narrower. In the case of LOS categories based on v/C_f ratio and approach speed, the categorization as LOS-A, LOS-B, and lowest as either LOS-E (K=4) or LOS-F (K=5) is similar. Readjustment has happened in LOS-C, LOS-D, and LOS-E (for K=5) categories. Basically, LOS-D has additionally been created in the case of K=5. Larger variation is observed in LOS categorization based on arrival density. Readjustment has occurred in all the LOS categories, making the initial ones more stringent. To maintain the LOS-A, LOS-B, and LOS-C while using approach K=4, there shall be two, seven, and fourteen pedestrians in a 9 m² area, whereas with K=5 categorization based on arrival density, there shall be only one, four, and nine pedestrians respectively, in a 9 m² area in front of the escalator. This is not the case with the other two approaches.

Based on the respective analysis, it can be concluded that K=5 results in reasonably similar categorization (except addition of a category) when v/C_f ratio or approach speed is considered for assessment. The categorization using K=4 analysis based on arrival density looks reasonably better and less stringent in assessment. Any small day-to-day variation might lead to a change in LOS categorization without a significant change in operational performance in the analysis when K=5 is considered.

The visual representation of LOS based on the v/C_f **ratio** and arrival density is shown in Figure 11 ("a" and "b"). This is based on K=4 ("i") and K=5 ("ii") analyses.

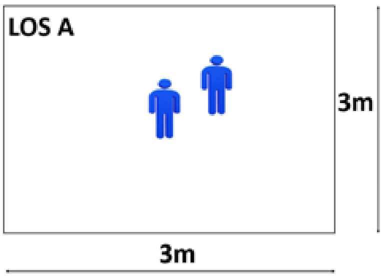


i) K=4 case

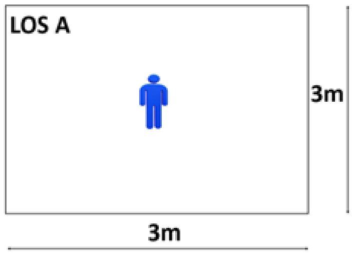


ii) K=5 case

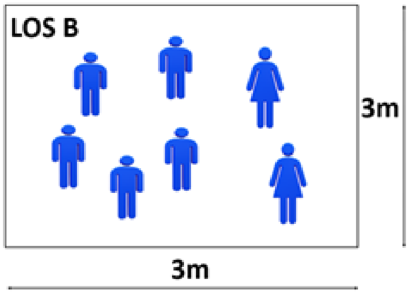
a) LOS Representation based on v/C_f ratio



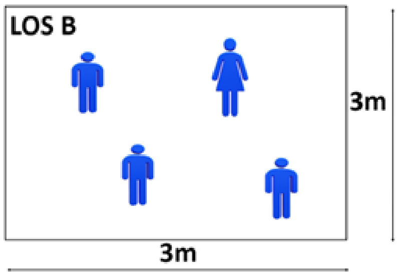
i) LOS A (K=4 case)



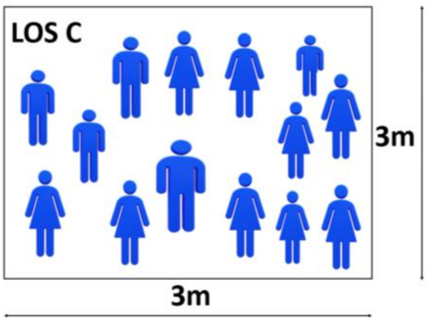
ii) LOS A (K=5 case)



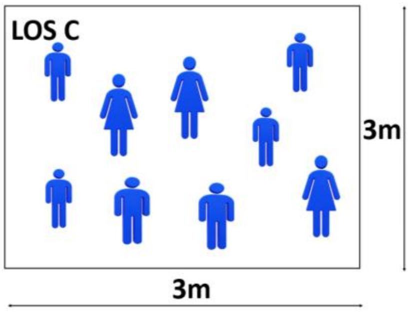
i) LOS B (K=4 case)



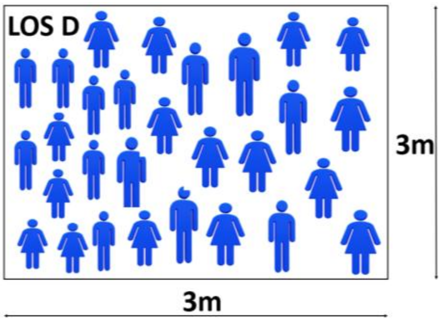
ii) LOS B (K=5 case)



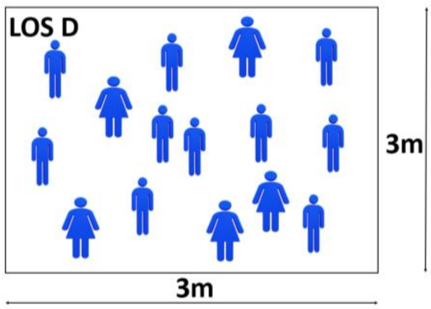
i) LOS C (K=4 case)



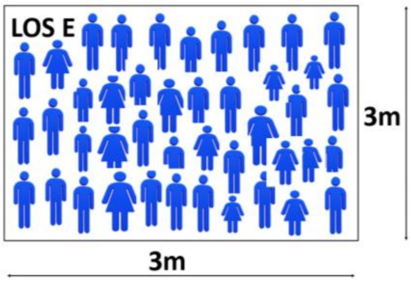
ii) LOS C (K=5 case)



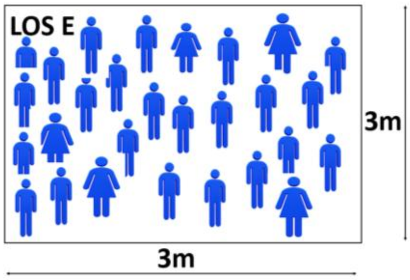
i) LOS D (K=4 case)



ii) LOS D (K=5 case)

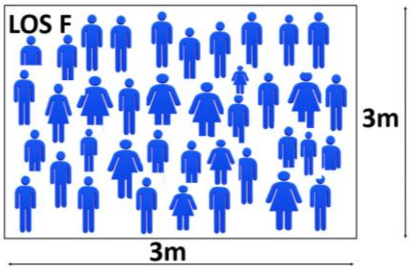


i) LOS E (K=4 case)



ii) LOS E (K=5 case)

i) LOS F (K=4 case, Not Applicable)



ii) LOS F (K=5 case)

b) LOS Representation based on arrival density

Figure 11. LOS representation based on v/C_f ratio and arrival density.

6 Conclusions and recommendations

Escalators are important pedestrian facilities designed for the smooth movement of pedestrians from one floor to another. The standards suggest that the theoretical capacity of escalators is influenced by the speed of the respective escalators. On increasing the speed, the theoretical capacity also increases, but the practical capacity starts decreasing beyond a certain speed. This happens due to the difficulty that pedestrians may face while stepping on the escalator's steps at higher speeds. Considering the possibility of a vacancy on a step, the reference capacity (which considers the practical capacity) is used in this study to calculate the v/C_f ratio. Here, one point that needs to be noted is that there will always be some escalators that may cater to high flows and some others that may experience lower flows throughout the operation time. For both cases, the theoretical capacity would be a constant value (depending on escalator operational speed), but the reference capacity would vary. In the case of escalators catering to low flows, it is not wise to rate the flow condition based on reference capacity (whose value would also be low). Considering this issue, examination of the reference capacity in (Kahali & Rastogi, 2021b) highlighted that on all escalators catering to medium to heavy flow, the reference capacity ranges between 84 percent and 93 percent of the theoretical capacity. In the present study, reference capacity varies between 87 percent and 91 percent of the theoretical capacity. In both studies, the average value comes out to be 88.4 percent, which converts to 172 ped/m/min. This is used as the base value for arriving at the LOS criteria for escalators based on the v/C_f ratio. The criteria are also developed to evaluate the escalator system based on pedestrian density in the approach area and the pedestrians' approach speed towards the escalator.

Based on the criteria being developed for the LOS of escalators, the LOS of the three escalators that are studied can be identified as given in Table 12.

Table 12. LOS of the escalators studied (considering peak values)

	LOS of escalators based on K=4			LOS of escalators based on K=5		
Escalator	Peak v/C_f ratio	Maximum Arrival density (ped/m^2)	Median Approach speed (m/s)	Peak v/C_f ratio	Maximum Arrival density (ped/m^2)	Median Approach speed (m/s)
HKMS	0.61 LOS-D	3.2 LOS-E	0.40 LOS-D	0.61 LOS-E	3.2 LOS-E	0.40 LOS-D
DHMS	0.80 LOS-D	3.15 LOS-D	0.67 LOS-C	0.80 LOS-E	3.15 LOS-E	0.67 LOS-C
HNMS	0.49 LOS-D	1.13 LOS-C	-	0.49 LOS-D	1.13 LOS-D	-

It can be observed that the escalators being studied are, in general, operating at LOS-D or lower level based on the three criteria. It is also evident that more than 50% of pedestrians approaching the escalators are experiencing platoon speed conditions, which are indicative of constrained flow conditions.

An examination of the flow during peak hour is done to check the period for which the flow condition remains constrained. The percentage time for which the flow condition remains in a LOS category is presented in Table 13. On all escalators, the flow condition remained at LOS C or lower for 19% to 55% of the time within peak hour.

Table 13. Percent time the flow remained in a LOS category based on v/C_f ratio

ELOS	HKMS		DHMS		HNMS	
	Morning	Evening	Morning	Evening	Morning	Evening
No flow period in peak hour	2%	0%	8.70%	8.70%	58.67%	51.3%
LOS A	25.85	12.00	26.28	21.90	88.52	43.83
LOS B	55.10	40.00	35.04	22.62	9.84	37.00
LOS C	18.37	37.33	25.55	27.74	1.64	17.80
LOS D	0.68	10.67	13.13	27.74	0	1.37
LOS E	0	0	0	0	0	0

The peak flow-based analysis and the assessment of actual flow conditions suggested that, instead of peak values, the average values can be considered to arrive at the flow condition. This is presented in Table 14. This indicates that the flow condition, in general, on all escalators is at LOS-C. This goes well with the assessment of actual flow being observed on the escalators.

Table 14. LOS of the escalators being studied, considering average values

	LOS of escalators based on K=4 analysis		
Escalator	v/C_f ratio	Average Arrival density (ped/m^2)	Average Approach speed (m/s)
HKMS(E-2A)	0.27 (LOS-C)	0.91 (LOS-C)	0.55 (LOS-C)
DHMS(E-2)	0.31 (LOS-C)	0.65 (LOS-B)	0.71 (LOS-C)
HNMS(E-3)	0.16 (LOS-B)	0.33 (LOS-B)	-

Now, *another question is to understand and arrive at a criterion when the escalator system needs to be enhanced* based on the flow condition. The following is recommended:

1. To start planning for a new facility: Any or a combination of:
    a. If the pedestrian flow on an escalator becomes 80 ped/m/min,
    b. If the approach speed becomes less than 70 percent of the free approach speed (i.e., 1.16 m/s at LOS-A)
    c. If the flow condition on an escalator deteriorates to LOS-C or lower for a cumulative period of 50 percent during peak hours
2. Installation of a new facility: Any or a combination of:

a. If the pedestrian flow on an escalator becomes 140 ped/m/min,
b. If the approach speed becomes less than 40 percent of the free approach speed (i.e., 1.16 m/s at LOS-A)
c. If the flow condition on an escalator deteriorates to LOS-C or lower for a cumulative period of 70 percent during peak hours

The LOS criteria developed in this work have not considered the perception of the users regarding the flow condition on the escalators. Perception-based ELOS can be developed, which will be qualitative in nature. However, controlling subjectivity would be a big issue in such an analysis. Another aspect is the impact of Stand-Walk etiquette and pedestrians carrying adolescents or toddlers or backpacks on the reference capacity and its impact on the LOS criteria developed based on the v/C_f ratio.

The proposed LOS criteria would be helpful to the service providers or professionals working with the planning and installation of escalators in public buildings. It would work as an assessment tool to take informed decisions regarding when to start planning or by when to implement the new floor change facilities for pedestrians, so that flow conditions remain within LOS-C, which would be reasonably convenient for the pedestrians.

Data/Software Access Statement

The data underlying this article will be shared on reasonable request to the corresponding author.

Author and Contributor Statement

Varsha Yadav: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing-original draft.
Rajat Rastogi: Conceptualization, Investigation, Methodology, Project Administration, Resources, Supervision, Writing-review and editing.

Use of AI

During the preparation of this work, the authors did not use AI

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Conflict Of Interest (COI)

There is no conflict of interest.

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