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Pedestrian Flows at Escalators – Arriving at Count Interval for Design Flow Estimation

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Selection of a count interval to extract flow data on pedestrian facilities seems to be governed by the operational environment of the facility and context of the study. Based on the flow condition, which may be intermittent, uniform, or periodic, the count interval has been found varying between 1 minute and 5 minutes. For instantaneous peaks, it is reduced to even 10s. The selection of a count interval will impact the flow values and subsequently the design requirements and operational efficiency. Present study, in this light, focusses on escalators located at metro rail stations. The study region is Delhi, India. Based on the analysis, the count interval for data extraction is recommended as 24 seconds, which is expected to result in a flow that does not cause unnecessary increase in facility size and keep it usable for most of the time. The absolute design flow value may be considered between 140–148 ped/m/min, which is the 5th highest rank order peak flow. The results are expected to optimize the resources, both for data collection and size of a facility.

Keywords: data extraction time interval, design flow; capacity, escalator, flows, peak flow, pedestrian.

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1. Introduction

Various pedestrian facilities are discussed in Highway Capacity Manual (HCM 2010) which emphasises flows, the characteristics of queuing area in front of the facilities, pedestrian zones, and their operational and planning criteria in the form of level-of-service (LOS). Mechanical pedestrian facility like escalators and simple floor connectivity like ramps are missing in the manual. Use of an escalator is advantageous as it moves the pedestrians between floors without using human energy. These mechanical systems can move in either direction with varying operational speed, which is decided as per the land use and pedestrian load. The convenience of its use and efficiency of moving pedestrians between floors makes escalators an essential part of today's public building design. Public buildings may be terminals of transportation systems, shopping malls, locations of tourist attractions, hospitals, etc. Alternatively, vertical elevators are provided at such locations, especially for people with different abilities. But they have lower pedestrian carrying capacity per unit time as compared to the escalators. Escalators are usually operated in either of the two ways, standing mode (all pedestrians standing) or stand-walk (one side used for standing and other side for walking pedestrians) mode. These operational modes and speed have implication on pedestrian handling capacity. Capacity is defined as the number of persons moved across a reference line or through a uniform section in unit time. This unit time in the case of pedestrian related studies is taken in minutes.

The selection of this time interval is quite important as the flow characteristics are extracted using it. The primary flow characteristics like flow, density and speed, and micro-characteristics like pedestrian space and gaps (lateral and longitudinal) are important attributes in the analysis and design of pedestrian facilities and circulation areas (HCM 2010). These characteristics also assist in the performance analysis and assessment of improvements. Nowadays, the flow data is usually captured through a camera and the information is extracted later in the office. At this time, the selection of a longer period may cause camouflaging of peak flows that may occur due to the characteristics of the flow generator. On the other side if the extraction period is taken too small then it will result in capturing of instantaneous peaks. The life of these instantaneous peaks may be quite small or reasonably long which may depend upon the pedestrian activity and land use in that area. With longer extraction interval the flow data may relate to average values and with quite smaller extraction interval it will give peak flow. This indicates that the data extraction time interval is an important influencing decision which may affect the measurements of desired flow attributes. In the case of vehicular traffic such decisions are well defined and documented. Hourly flows are used in the analysis of vehicular flows, which are either extracted for one full hour (peak/off-peak) or for a part of it (15 minute or 5 minutes, extrapolated to one hour to get equivalent hourly flow) (Roess et *al.*, 2011).

There is a difference when it comes to pedestrian related studies. The body size of the pedestrians is quite small as compared to the vehicles. That causes increase in the pedestrian density per unit area. Under high flow conditions even the pedestrians may not maintain the comfortable spaces (distances) among themselves. Reduction in longitudinal and lateral spaces among pedestrians will result in high flow values. But measuring flows over full one hour may not be required. With a walking sped of 1.2 m/s, roughly 72 pedestrians may cross the reference line in a minute under uniform flow conditions. In hourly flow this amounts to around 4400 pedestrians. This is not possible with vehicular flows in a 3.5 m wide lane where it amounts to around 1200 vehicles per hour. Therefore, it is wise that pedestrian flows can be extracted for smaller durations and then can be extrapolated to get equivalent hourly flows. Now, arises the question – what shall be the data extraction interval? Different extraction periods, from as low as 10s to 1 or 5 minutes and as high as one hour have been used by the researchers. Though it may be contextual but has not been enumerated clearly in the literature. Smaller extraction count intervals will certainly capture instantaneous peak but its conversion to hourly flow may result in a non-feasible flow value. E.g., say in 5s extraction period 30 pedestrians may cross a reference line in one meter width which means 360 pedestrians in one minute. In the case of escalators with operational speed of 0.65 m/s, 120 pedestrians may be carried per minute. Use of all these values may result is overdesign of the facilities and will also be a burden on economy. All this discussion makes the posed question quite important. This work examines the question and arrives at a data extraction interval which may be equally useful for both, peak flow, and average flow estimation.

Literature has been reviewed in this regard and discussed in the following section.

2. Literature Review

The representativeness of the count interval for extracting the flow attribute value is tried by few researchers. Jianhong and Xiaohong (2011) conducted study to arrive at an optimal measurement interval for pedestrian traffic flow modelling on a level passageway, ascending and descending stairway, and two-way stairway. Using 5s as the basic incremental time unit the count interval was increased up to 60s to examine the impact of different count intervals on pedestrian flows. 30s interval was recommended for use on all the facilities. Nai *et al.* (2012) considered 20s as data extraction period to arrive at the capacity of the facility. Das *et al.* (2016) too examined various data extraction count intervals (15s, 30s and 60s) and observed that count interval higher than 15s results in less skewed data and higher interval results in missing data. They also reported 30s as data extraction interval to get average or optimal flow values. A comparative overview of count interval used by different researchers in different contexts is given in Table 1. In general, 1 min has been used by different researchers as data extraction count interval. It provides 60 data points in a recorded video of 1 hr. Lower count intervals less than 1 min are usually used in South-Eastern Asian countries, China, and India. All these countries have high pedestrian flows which remains for a longer period. This results in the extraction of average flows as compared to instantaneous flows if data extraction count interval is 1 min or more. To capture the peaks in the flow, lower count periods have been used in these countries. In general, the pedestrian facilities at railway stations are studied using count interval of 1 min, whereas lower count interval of say 15s to 30s is used at metro stations. Further lower count interval is used on pedestrian facilities located inside other type of public buildings. Pedestrian flows at railway stations are generally steady or uniform and does not fluctuate too often or attain peak values instantaneously. In such conditions pedestrian flow extraction in an interval of 1 min has been found satisfactory to arrive at a flow that can be used for the design of a facility. In case of metro stations, the pedestrian flow builds instantaneously and at short periods due to higher frequency of operation.

Although many researchers have conducted studies on different pedestrian facilities (Refer Table 1) but only few studies exist in the case of escalators. Majority of the studies are from developed countries, which looks logical as use of escalators started there. It has been adopted later in developing countries like India at specific locations or in buildings of importance. The approach in recent years has changed in developing countries also and these facilities are felt to be an important part of public buildings or locations having significant pedestrian flows. Table 2 presents different data extraction count intervals used in different studies related to escalators. Here again it can be noted that most of the researchers have used 1 min for data extraction on escalators located at long distance train railway stations. Lower count interval has been used by researchers from Europe and China. These studies pertain to metro stations as well as railway stations.

Table 1. Data Extraction Count Interval used in Different Studies

Researcher (year), country	Data collection Location	Count interval used
Facility Type: Stairway		
Fruin (1987), United States	-	1 min
Lam and Cheung (2000), Hong Kong	Railway station	1 min
Shah *et al.* (2013, 2016), India	Railway station	1 min
Sala *et al.* (2017), India	Railway station	1 min
Patra *et al.* (2017), India	Railway station	1 min
Chen *et al.* (2010), China	Metro station	30s
Xiang *et al.* (2011), Singapore	MTR stations	30s
Ya *et al.* (2007), China	Metro station	20s
Ye *et al.* (2008), China	Metro station	15s
Yang *et al.* (2012), China	Institute building	10s
Yang *et al.* (2012), China	Institute building	5s
Jianhong and Xiaohong (2011), China	Metro station	5s to 60s with 5s interval
Facility Type: Passageway		
Sarkar and Janardhan (2001), India	Intermodal transfer terminal	2 min
Lam and Cheung (2000), Hong Kong	Railway station	1 min
Sala *et al.* (2017), India	Railway station	1 min
Patra *et al.* (2017), India	Railway station	1 min
Daly *et al.* (1991), United Kingdom	Underground station	1 min
Sarkar and Janardhan (2001), India	Intermodal transfer terminal	30s
Chen *et al.* (2010), China	Metro station	30s
Ye *et al.* (2008), China	Metro station	15s
Jianhong and Xiaohong (2011), China	Metro station	5s to 60s with 5s interval
Facility Type: Sidewalk, walkway, precinct, corridor, crosswalk		
Das *et al.* (2016), India	Around Railway station	1 min
Lam and Cheung (2000), Hong Kong	Railway station	1 min
Al-Masaeid *et al.* (1993), Jordan	CBD Area	1 min
Lam *et al.* (2002, 2003), Hong Kong	Urban areas with and without the Light Rail Transit (LRT)	1 min
Laxman *et al.* (2010), India	Medium-sized city, Metropolitan city	1 min
Rastogi *et al.* (2013), India	Different Cities	1 min
Das *et al.* (2016), India	Around Railway station	30s
Ya *et al.* (2007), China	Metro station	20s
Das *et al.* (2016), India	Around Railway station	15s
Fang *et al.* (2008), China	Railway station	2s
Facility Type: On-Street		
Turvey *et al.* (1987), UK	City centres	5min to 40 min with interval of 5 min

Now the discussion can be focused on pedestrian facilities (escalators) installed at train stations. In case of railway stations, the flow keeps building as per the arrival/departure schedule of the long-distance trains. The minimum stoppage of a long-distance train at an intermediate station is 2 min and can be as high as 30 min at a major/junction station. Usually, pedestrians reach platform before time and orient themselves with respect to the boarding coach. The flow of alighted pedestrians at minor stations remains scanty and builds slowly at a major station. This maintains for a reasonable time. But the behaviour is quite different on escalators at metro stations. Here, time of boarding a transit is important for commuters. Knowing departure schedules these commuters optimise the wait time. Considering the increasing flows of pedestrians during office periods and quite short stoppage time of a train at a platform, these commuters remain in hurry. This causes instantaneous flows rather than uniform flows. Same happens to the alighted commuters. They also rush towards the escalators to get out of the system with least delay. Thus, escalators remain in use for a smaller period at a given point. In all such cases longer time interval for data extraction will not help in getting the peak flow estimates. Rather, longer period of data extraction will result in average flows.

Table 2. Data Extraction Count Interval used in Different Studies on Escalators

Researcher (year), country	Location	Count interval used
Weidmann (1993), Germany	_	1 min
Lam and Cheung (2000), Hong Kong	Railway station	1 min
Bodendorf *et al.* (2014), Germany	Railway station	1 min
Sala and Ravishankar (2016), India	Railway station	1 min
Sala *et al.* (2017), India	Railway station	1 min
Patra *et al.* (2017), India	Railway station	1 min
Al-Sharif (1996), United Kingdom	_	30s
Xiang *et al.* (2011), Singapore	MTR stations	30s
Bodendorf *et al.* (2014), Germany	Railway station	30s
Nai *et al.* (2012), China	Metro station	20s
Bodendorf *et al.* (2014), Germany	Railway station	10s, 90s, 120s

Looking at the variability with respect to the selection of time interval for data extraction, an optimal time interval for data extraction on escalators is proposed in this study which may be suitable for both average and peak flow estimation.

The study area and its characteristics are now discussed in the following section.

3. Study Location

The increase in the urban commuters has prompted the government in India to come up with a policy to implement mass or rapid transport systems in all Class-1 cities with population 0.20 million or above. Some of the cities in population range 4 million and above have implemented metro system to efficiently cater the commuters. Since inception, the intermediate and terminal stations of metro are found busy with commuters throughout the day, specifically during morning and evening hours, when work and education trips are high. The metro stations are operationally different from long distance train railway stations. These differences are in terms of pedestrian volume, speed and frequency of train, pedestrian carrying capacity of coaches, mechanisation and digitisation of ticketing and security system, advanced signalling systems and embedment of pedestrian information systems. Train at metro station arrives 5 to 10 min before departure at a terminal station and stops for less than 1 min duration at an intermediate station. Metro trains run at a frequency of 3 to 10 mins. These time periods govern the psychology of the commuters and other users. Pedestrian arrival rate during peak periods remain quite high and pattern varies every 3 to 10 mins with the change in the mix of pedestrians. This impacts the pedestrian flow rate on the escalators at metro stations, which varies from very high to negligible flow at different times.

Considering the above-mentioned points, Delhi Metro Rail (DMR) network was selected for this study. DMR had 926.1 million ridership in the year 2018 and had an average daily ridership of 4.7 million pedestrians in 2019. It has a network length of 389 km in 2021. The system caters to Delhi National Capital Region which includes Delhi, New Delhi and adjoining towns and cities (presently within 50 km distance). Delhi Transport Corporation (DTC) buses provide access support along with DMRC mini-buses, paratransit, and mobility on demand services. Permission was sought from DMR Corporation to carry out the study. Permission was given for three stations which catered heavy pedestrian flows, as all of them were transfer stations between two or more metro lines or between metro and Inter-State Bus Terminus. The stations are:

a. Central Secretariat Metro station (CSM): This is an underground transfer station for violet and yellow line. Both the lines are at same level. The land uses around are government offices, secretariat building, parliament house (government decision making seat) and central bus terminal of Delhi Transport Corporation. Hence, the pedestrian flow at this station is primarily government employees. It has four tracks. The pedestrian flow condition at this station is shown in Figure 1 'a'.

b. Rajiv Chowk Metro Station (RCM): This is an underground transfer station between yellow line (at lower level) and blue line (at upper level). It is in the heart of the city and has commercial, shopping, eating and recreational areas all around it. This is one of the busiest stations in the network. It has four tracks. The pedestrian flow at this station is quite high as shown in 'b' of Figure 1.

c. Kashmiri Gate Metro Station (KGM): It provides interchange between yellow (lowest underground level), red (on highest upper level), and violet line (parallel underground level). This is the busiest and largest metro station in the network. It has six tracks, and it is the only three-line interchange station in India. The station also caters to Inter-State Bus Terminus as well as the old Kashmiri gate area of Delhi. The pedestrian flow condition at two out of 35 escalators is shown in Figure 1 'c' and 'd'.

Yellow line connects North and South Delhi and passes through the central area of the city. In south, it goes up to Gurugram city in Haryana state. It is the busiest metro line. Blue line connects East and West Delhi, and it also passes through the central area. It connects adjoining Noida and Ghaziabad city area. Violet line provides connectivity in the south part and red line provides connectivity in the north part of the city. Selection of metro stations on these lines helped in capturing the pedestrian flows related to wider area.

Operational characteristics of the selected escalators at these stations are given in Table 3. Physical and operational features of the selected escalators are given below:

1. Width of escalator : 1000 mm
2. Depth of step on escalator : 400 mm
3. Angle of inclination of escalator : 30°
4. Speed of Escalator : 0.65 m/s

(a) (b)

(c) (d)

Figure 1. Selected Escalators at Metro Stations: (a) CSM Station; (b) RCM Station; (c) and (d) KGM Station

It can be noticed that flow during evening time is higher compared to morning period across all the metro stations, except RCM station. The pedestrian flow at CSM station is the lowest. During morning time, it varied from 1985 to 3767 ped/m/hr, whereas, during evening period it varied from 2109 to 3550 ped/m/h.

Next section now discusses the data collection and extraction of flow characteristics.

Table 3. Operational Characteristics of Selected Escalators

Sl. No.	**Station Name**	**Operational condition**	**Presence of other facility alongside**	**Morning flow (pass/m/hr)**	**Evening flow (pass/m/hr)**
1	CSM Station	One up moving	Yes (one undivided staircase)	1985	2109
2	RCM Station	Three parallel up moving	No	11302	9340
3	KGM Station (Site-1)	One up moving	Yes (one undivided staircase)	3382	3496
4	KGM Station (Site-2)	One up and one down moving	Yes (one undivided staircase)	5951	7100

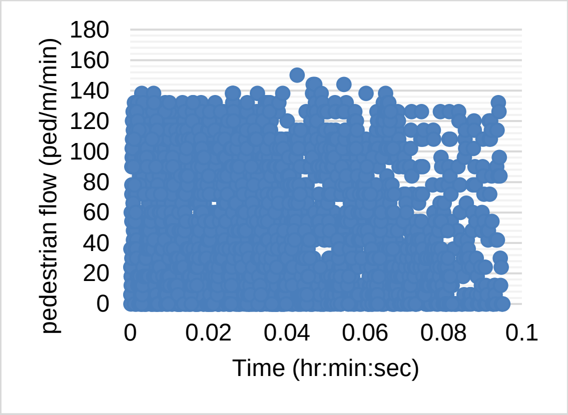
4. Data Collection and Extraction

Considering high pedestrian flows, accumulation in front of escalators, walking by some pedestrians on escalators, possibility of missing a pedestrian, etc. it was found difficult to collect the pedestrian flow data using manual method. Hence, videographic method was adopted to collect the data. Camera were installed to capture flow from both the sides of an escalator. Data were recorded in the month of July 2016, during 8:00 am to 10:00 am and 4:00 pm to 6:00 pm. These covered morning and evening peaks. The data were usable as the aim of this study was to arrive at the optimal count interval for data extraction rather than examining the pedestrian flow conditions on the escalators. The data, in fact, can also be used to estimate the actual practical capacity of the escalator which is a maximum flow value under given operational environment. Another terminology used is theoretical capacity, which is independent of flow data as it depends upon the escalator step size, operational speed, and usage etiquette. This is the ideal pedestrian handling capacity which is difficult to achieve in the field.

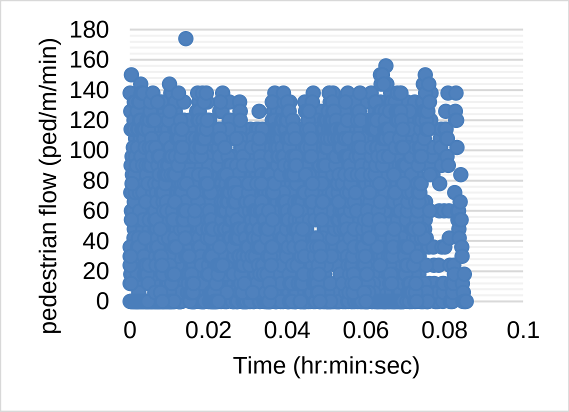
The recorded video was played on a monitor in the office. Flow data were extracted using 25 frames per second rate. 10s was considered as minimum count interval to extract the data. This allowed capturing of instantaneous peak flows (Buchmueller and Weidmann 2006; Bodendorf et al., 2014). Combination of successive count intervals allowed to get average flows and peak flows during varying time intervals. This helped in examining the effect of data extraction count intervals (in multiple of 10s up to 60s and with a gap of 1 min up to 5 min) on the extracted mean and peak pedestrian flows. To extract the pedestrian flow per unit width in a unit time period a trap is marked on the escalator. Pedestrian flow is measured by counting the total number of pedestrians passing the trap section during each 10s interval. As width of the escalator is 1000 mm the flow itself became per meter. Pedestrian flow in ped/10s was converted to ped/min to make it uniform across the different count intervals. This was done using multiplication factors, say 6 for 10s flow, 3 for two successive 10s flows (= 20s flow), 0.5 for 2 min flow and 0.2 for 5 min flow. Then the peak and average flows are calculated for each interval. Average flow for specific count intervals was calculated by summing average flows for number of those specific count intervals and then dividing the sum by total numbers. As the width of escalator step was 1000 mm, the pedestrian flow was estimated as ped/m/min.

The variation in pedestrian flow with respect to different extraction count intervals is plotted and shown in Figure 2. Morning and evening flows are examined separately. The plots are made using combined data from all the study locations (escalators) so that variability is accounted for before arriving at a decision regarding optimal count interval for data extraction. It can be noticed that with an increment in time, the data points and peak pedestrian flow decreased. The order is: **F_{10sec} > F_{20sec} > F_{30sec} > F_{1min} > F_{5min}**. The estimated values are in line with the findings of Bodendorf *et al.* (2014). They also reported highest flow on the escalator at a railway station during data extraction count interval of 10s.

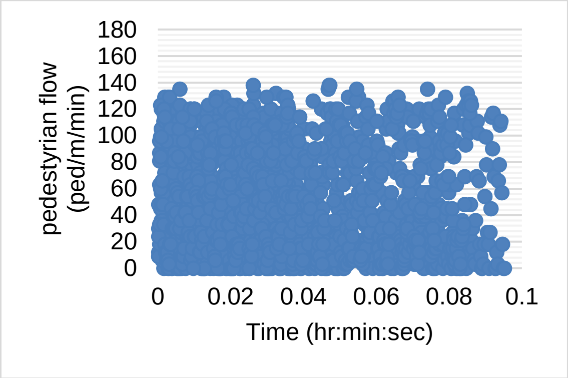
The next section now examines whether the data extraction count interval more than 10s can be used to arrive at a design flow value for escalators or not. Here, design flow is considered as the pedestrian flow lower than the theoretical capacity, the use of which would result in the reasonable size or operational plan of the facility.



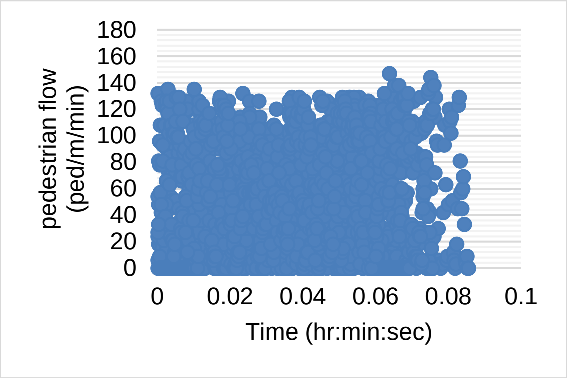
(a) Morning 10s extraction



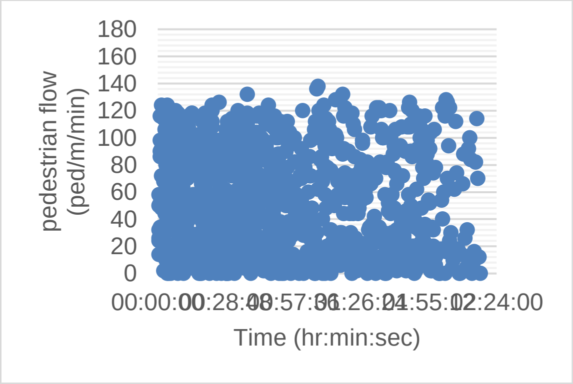
(b) Evening 10s extraction



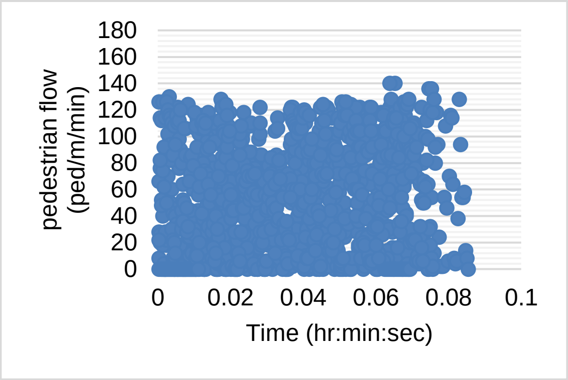
(c) Morning 20s extraction



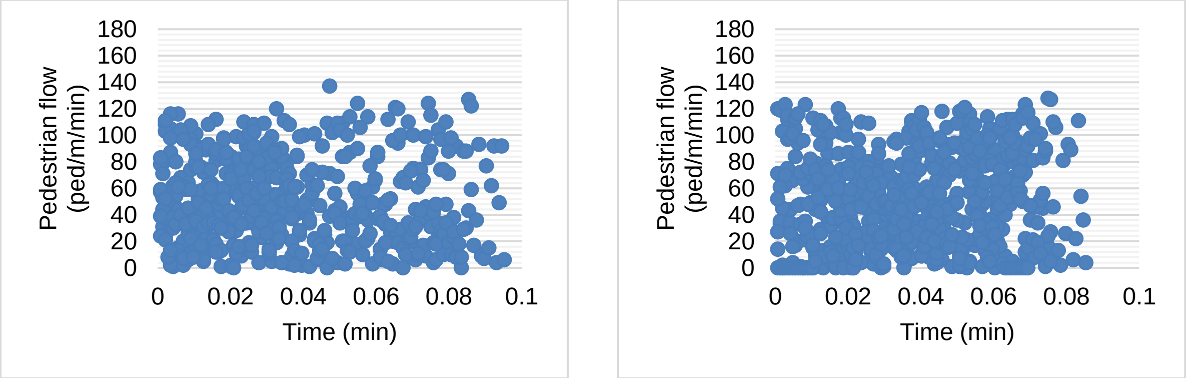
(d) Evening 20s extraction



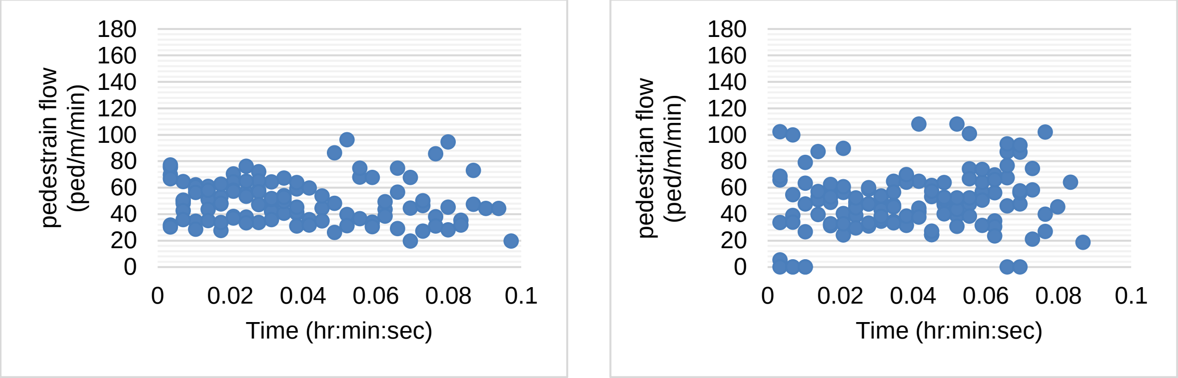
(e) Morning 30s extraction



(f) Evening 30s extraction



(g) Morning 1 min extraction (h) Evening 1min extraction



(i) Morning 5 min extraction (j) Evening 5 min extraction

Figure 2. Variation in Pedestrian Flow for Different Data Extraction Count Intervals

5. Analysing Data Extraction Count Interval

Pedestrian flows with respect to different data extraction count intervals were extracted and then simple statistical measurements like standard deviation (SD), coefficient of variation (COV), standard error of mean (SE) and mean of pedestrian flow for different data extraction intervals were calculated. These are given in Table 4 and plotted in Figure 3.

It can be noted that the average flow estimated across varying count intervals remains the same, but the peak flow varies and reduces with an increase in the count interval used for estimating pedestrians' flow. It is expected that lowest time interval will be able to capture the instantaneous peak occurring in the flow. This is specific to the metro stations where the pedestrian flow builds or subsides on pedestrian facilities with the arrival and departure time of the train. As the count interval increases, the highest peaks occurring for a smaller time will get missed and the peak flows will start reducing in magnitude. It is further expected that with a time headway of 3 to 10 min in the arrival/departure of trains at metro stations, the pedestrian flow will maintain during the peak periods and hence, the average flows are expected to remain as such. If the data is analysed beyond peak flow periods, then the average flows are also expected to reduce.

Further, though the average flow across count intervals remained uniform, but its statistical values varied a lot. Coefficient of Variation (COV) of different data extraction count intervals indicates higher values for smaller count intervals. It is to be noted that higher COV value shows high variability with respect to the mean. In the case of lower count intervals, it is obvious that very high flows may be observed. Metro station escalators attain its highest flow for few seconds depending upon the arrival of the train and after that, it works under free-flow condition. So high variability is expected to occur for smaller duration of time. In contrast, extraction count interval above 1 min shows lesser variability but with high standard error of mean. The exponential peak flows at lower data extraction count intervals are due to instantaneous building of flows at escalators in metro stations for smaller time periods.

Table 4. Pedestrian Flows with respect to Data Extraction Count Periods

Sl. No.	**Data extraction count interval**	**Average pedestrian flow**		**Peak pedestrian flow**		**Standard deviation - average flow (p/m/min)**	**COV**	**SE (Mean)**
		p/m/min	**p/m/hr**	**p/m/min**	**p/m/hr**			
Morning Data								
1	10 sec	50.31	3019	150	9000	39.99	0.79	0.70
2	20 sec	50.29	3017	141	8460	37.94	0.75	0.94
3	30 sec	50.26	3016	138	8280	36.59	0.73	1.11
4	40 sec	50.24	3014	136.5	8190	34.63	0.69	1.22
5	50 sec	50.24	3014	136.8	8208	32.94	0.66	1.29
6	1 min	50.2	3012	132	7920	31.45	0.63	1.35
7	2 min	50.06	3004	125	7500	22.9	0.46	1.39
8	3 min	50.2	3012	116	6960	18.48	0.37	1.37
9	4 min	49.99	2999	110	6600	17.32	0.35	1.51
10	5 min	49.99	2999	96	5760	16.01	0.32	1.54
Evening Data								
1	10 sec	49.92	2995	174	10440	42.72	0.86	0.69
2	20 sec	49.93	2996	150	9000	40.99	0.82	0.93
3	30 sec	49.93	2996	140	8400	39.56	0.79	1.1
4	40 sec	49.93	2996	133.5	8010	38.31	0.77	1.23
5	50 sec	49.96	2998	130.8	7848	37.05	0.74	1.34
6	1 min	49.93	2996	128	7680	35.62	0.71	1.41
7	2 min	49.93	2996	127.5	7650	29.77	0.6	1.66
8	3 min	49.93	2996	119.33	7160	25.22	0.51	1.72
9	4 min	50.05	3003	115	6900	24.29	0.49	1.92
10	5 min	50.05	3003	110.2	6612	22.32	0.45	1.97

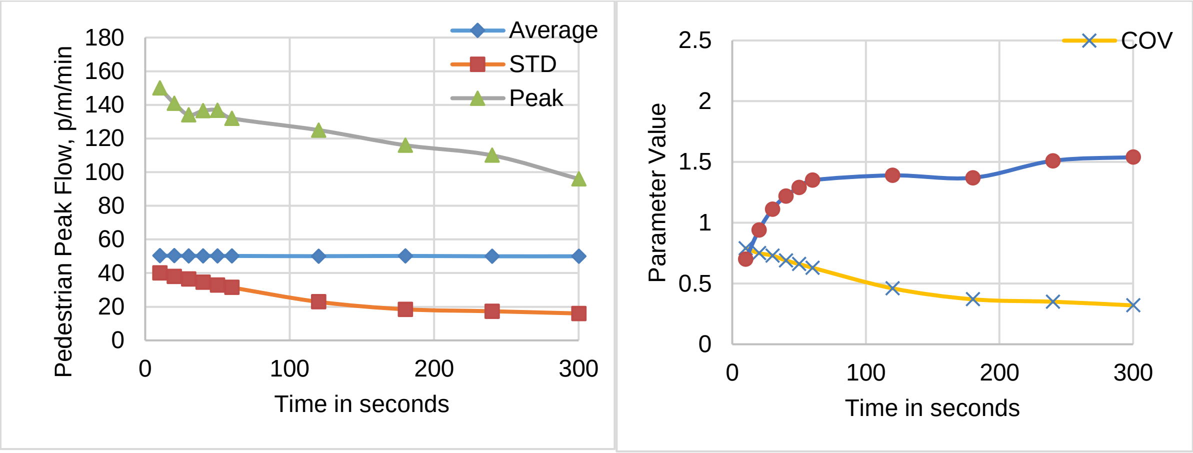
Further examination of the variation in the statistical parameters indicate that the variation reduces a lot after data extraction count interval of 1 min. ***This provides first limiting condition regarding the data extraction time.*** This is in line with the practice used by most of the researchers (Refer Table 1 and 2). It is envisaged that this count interval will result in an average flow and will miss the instantaneous peak. If escalator is designed based on average flow, then there will be periods when actual flows will be much higher than that and may decrease the performance of the escalator. In order to arrive at the possible count interval satisfying average and peak flow estimation, the following procedure was used:

a) 10s peak flow values (successive) were placed in increasing order. These were categorised and peak flow frequency per category was recorded.

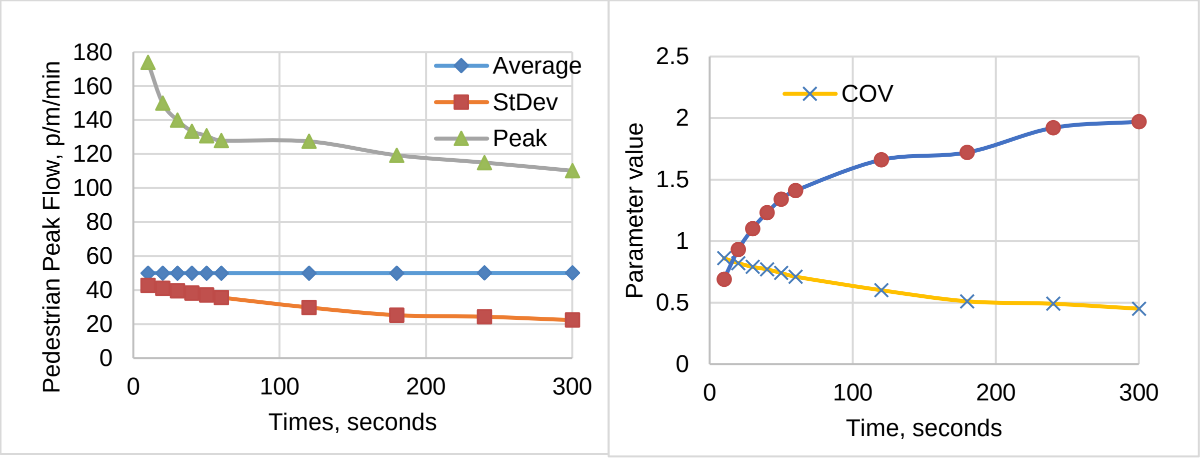
b) Above categorised information was used to plot cumulative frequency distribution and 98th percentile value was noted.

c) A relationship was developed between peak flows and data extraction count interval.

d) Count interval corresponding to the 98th percentile flow value was noted. This is considered as the optimal count interval for data extraction.



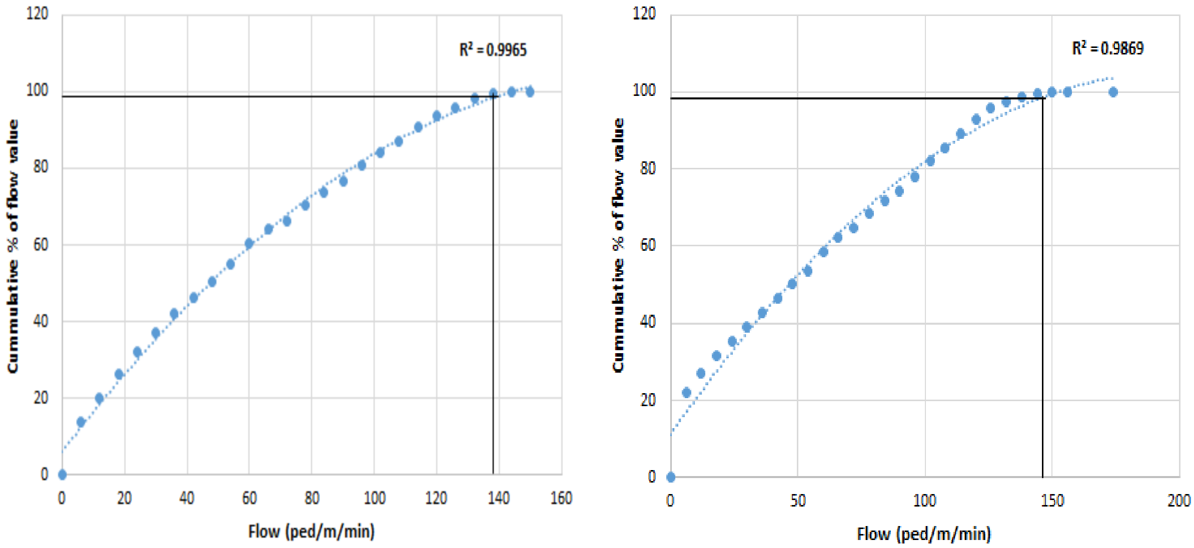
(a) *Morning period*



(b) *Evening period*

Figure 3. Variation in Statistical Flow Attributes and Parameters up to 300s

Cumulative distribution for both morning and evening peak flows are shown in Figure 4. 98th percentile peak flow was observed as 138 ped/m/min for morning and 147 ped/m/min for evening. The relationship between peak flow and count interval used for data extraction were examined using different distributions and based on their goodness-of-fit, exponential curve for morning and power curve for evening data was found to be the best (Refer Table 5 and Figure 5). Data extraction count interval corresponding to the 98th percentile peak flows for morning and evening period was noted from the plots as 40s and 20s, respectively. This indicated that the analysis of pedestrian flows on escalators can be done using 20s peak flow (highest value) or 40s peak flow (lower value). ***This became the second limiting condition regarding the most optimal data extraction count interval.***

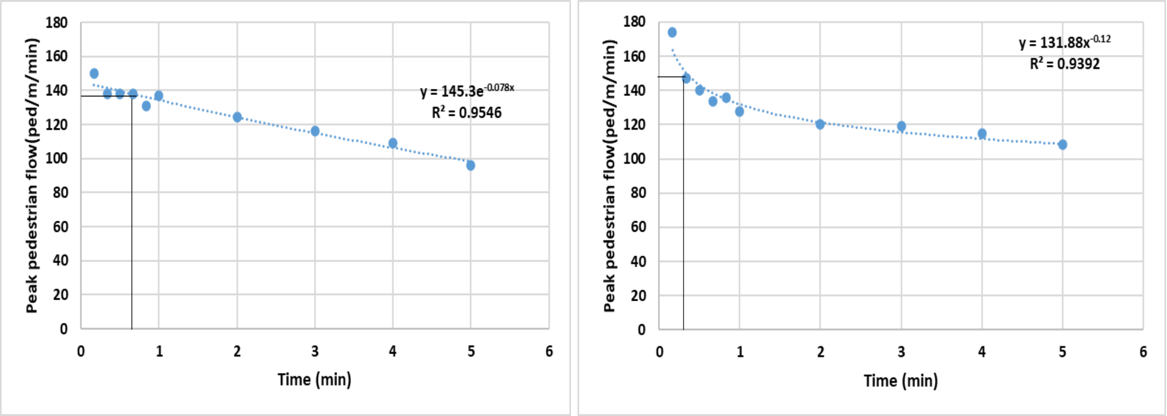


(a) *Morning period* (b) *Evening period*

Figure 4. Cumulative Plot of Peak Flow Frequencies and 98th Percentile Value

Table 5. Curve Fitting Between Extraction Time and Peak Pedestrian Flow

Morning		**Evening**	
Fitted Plot	R^2 **Value**	**Fitted Plot**	R^2 **Value**
Exponential	0.9546	Power	0.9392
Polynomial	0.9545	Logarithmic	0.9139
Linear	0.9538	Polynomial	0.7749
Logarithmic	0.8872	Exponential	0.7212
Power	0.8555	Linear	0.6522



(a) *Morning period* (b) *Evening period*

Figure 5. Variation in Peak Pedestrian Flow with Data Extraction Count Interval

Further, analysis was done to examine if any count interval between 20s and 40s can be used for data extraction. This was done through hypothesis testing. Peak flows observed during 20s-, 30s- and 40s-time interval were compared. The hypothesis was:

Null Hypothesis: The difference in mean of peak flow values for two count intervals is zero.

Alternate Hypothesis: Their difference is not zero.

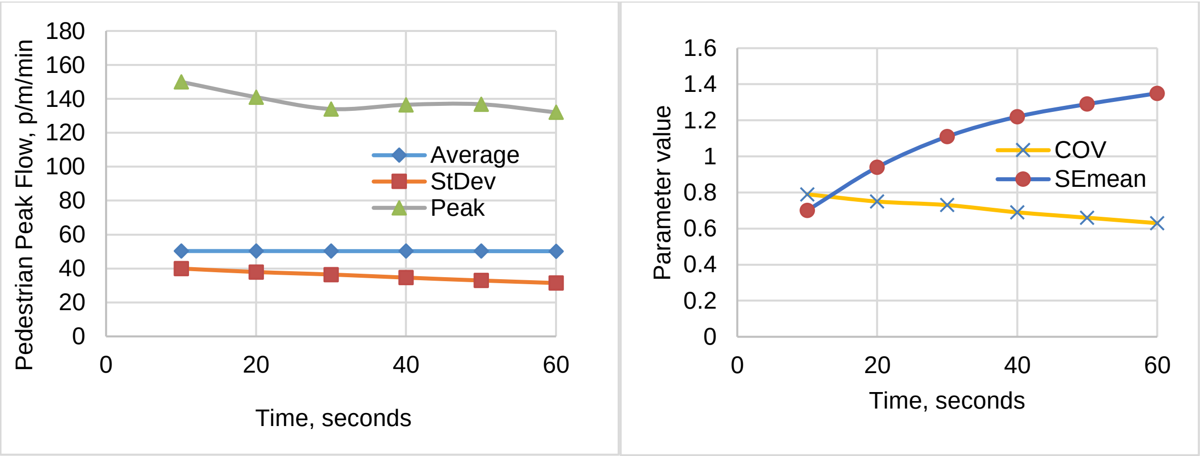
$$H_o: \mu_1 - \mu_2 = 0 \qquad H_a: \mu_1 - \mu_2 \neq 0 \tag{1}$$

The results are presented in Table 6.

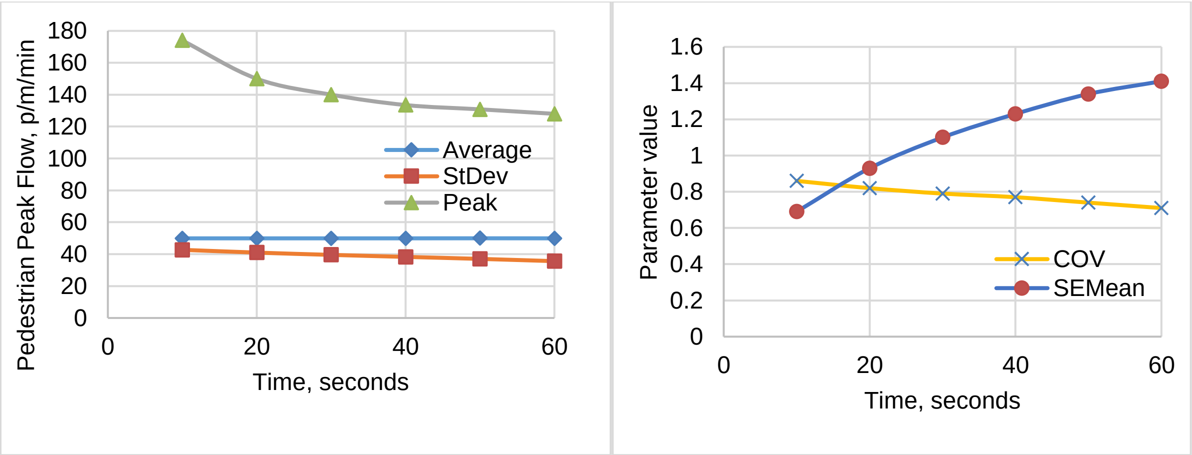
Table 6. Statistical Examination of 20s, 30s and 40s Peak Pedestrian Flows

Comparison	$Z_{observed}$	$Z_{critical}$	P – Value	Risk to reject N.H	Decision
20s vs. 30s					
Morning	-13.172	1.960	<0.0001	0.01%	Rejected
Evening	-13.165	1.960	<0.0001	0.01%	Rejected
20s vs. 40s					
Morning	-19.225	1.960	<0.0001	0.01%	Rejected
Evening	-18.986	1.960	<0.0001	0.01%	Rejected
30s vs. 40s					
Morning	-8.518	1.960	<0.0001	0.01%	Rejected
Evening	-8.413	1.960	<0.0001	0.01%	Rejected

The rejection of the null hypothesis indicated that the peak flows during different count intervals are statistically different and hence, any count interval between 20s and 40s cannot be considered. For further examination, the variation in peak flows and statistical parameters across 10s to 60s interval were used. These variations are shown in Figure 6.



(a) *Morning period*



(b) *Evening period*

Figure 6. Variation in Statistical Flow Attributes and Parameters up to 60s Interval

Examination of the variations indicated that the 98th percentile peak flow value during morning and evening periods (i.e., 138 ped/m/min and 147 ped/m/min respectively), relates to 24s for both the periods. This indicates that flow values related to 24s count interval shall be used for the data extraction. Further examination has been done to see if instead of 24s flow, can we use 20s or 30s flows. Hypothesis testing was now carried out for 24s flow vs 20s and 30s flows.

H_0 (Null Hypothesis): The difference between the mean of peak flow values is zero.

H_a (Alternate Hypothesis): The difference between the mean of peak flow values is different from zero.

$$H_o: \mu_1 - \mu_2 = 0 \qquad H_a: \mu_1 - \mu_2 \neq 0 \tag{2}$$

The results are presented in the Table 7.

Table 7. Statistical Examination of the 20s, 24s, and 30s Peak Pedestrian Flow

Comparison	$Z_{observed}$	$Z_{critical}$	P – Value	Result	Decision
Morning (20s vs 24s)	-4.307	1.960	< 0.0001	p-value < significance level alpha=0.05	Reject the null hypothesis
Evening (20s vs 24s)	-7.904	1.960	< 0.0001	p-value < significance level alpha=0.05	Reject the null hypothesis
Morning (24s vs 30s)	-6.001	1.960	< 0.0001	p-value < significance level alpha=0.05	Reject the null hypothesis
Evening (24s vs 30s)	-5.950	1.960	< 0.0001	p-value < significance level alpha=0.05	Reject the null hypothesis

It is observed that all these flows calculated for 20s, 24s, and 30s are significantly different at 95% confidence level. Hence, 24s flows shall be used for the extraction of flow data. Keeping in view the ease of data extraction and the time interval conducive to the hourly system, it is suggested to use 25s as the time interval for data extraction.

6. Relationship Development

Relationship between peak pedestrian flow (PPF) and the count interval of data extraction (t_{de}) were estimated as follows:

a) Morning Flow:

$$\text{PPF} = 145.3\ e^{-0.078 t_{de}} \quad (R^2 = 0.9546) \tag{3}$$

b) Evening Flow:

$$\text{PPF} = 131.88 \times t_{de}^{-0.12} \quad (R^2 = 0.9392) \tag{4}$$

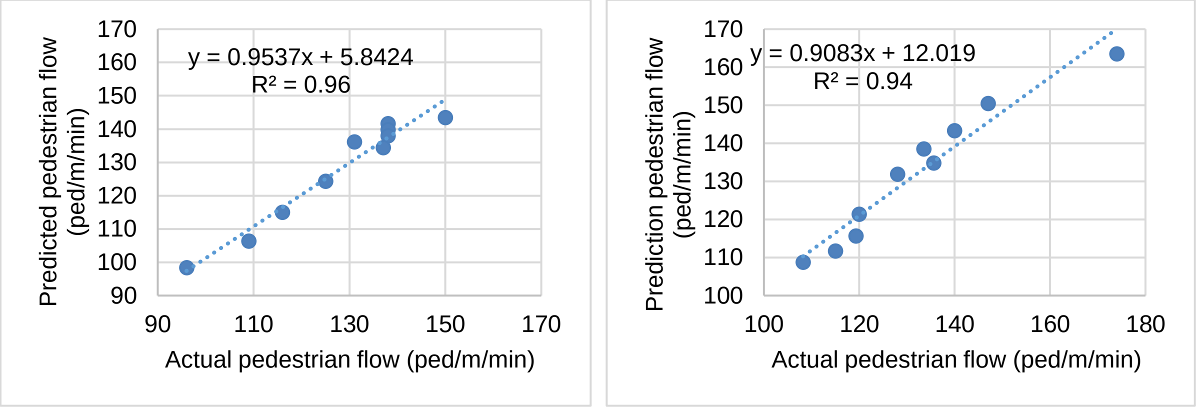
These relationships were used for an internal validation purpose. Actual pedestrian flow and predicted pedestrian flow (for a particular data extraction count interval) were plotted for morning and evening separately (Refer Figure 8). The relationship developed between actual pedestrian flow (APF) and the predicted peak pedestrian flow (PPPF) for morning and evening flow were estimated as follows:

(a) Morning Flow:

$$\text{PPPF} = 0.9537\ (\text{APF}) + 5.8424\ (R^2 = 0.96) \tag{5}$$

(b) Evening Flow:

$$\text{PPPF} = 0.9083\ (\text{APF}) + 12.019\ (R^2 = 0.94) \tag{6}$$



(a) *Morning* (b) *Evening*

Figure 7. Actual Pedestrian Flow versus Predicted Pedestrian Flow

The prediction accuracy of the above-mentioned relationships is presented in Table 8. The variation has been observed varying within ±7% for evening flows and ±4% for morning flows, which is quite low. This indicates towards good predictive power of the two models. In general, flows were underestimated by the models.

Table 8. Prediction Accuracy of PPPF - Time Model

Morning Flow Model			**Evening Flow Model**		
Actual pedestrian flow (ped/m/min)	**Predicted pedestrian flow (ped/m/min)**	**Percentage variation**	**Actual pedestrian flow (ped/m/min)**	**Predicted pedestrian flow (ped/m/min)**	**Percentage variation**
100	101	+ 1%	100	103	+ 3.0%
150	149	- 0.67%	150	148	- 1.33%
200	197	- 1.50%	200	194	- 3.00%
250	244	- 2.40%	250	239	- 4.40%
300	292	- 2.67%	300	285	- 5.00%
350	340	- 2.86%	350	330	- 5.71%
400	387	- 3.25%	400	375	- 6.25%
450	435	- 3.33%	450	421	- 4.22%
500	483	- 3.40%	500	466	- 6.80%
550	530	- 3.63%	550	512	- 6.90%

The instantaneous peak pedestrian flow based on peak flow for 25s interval can be estimated as:

$$\text{IPPF} = \text{A} * PF_{25s} \qquad (7)$$

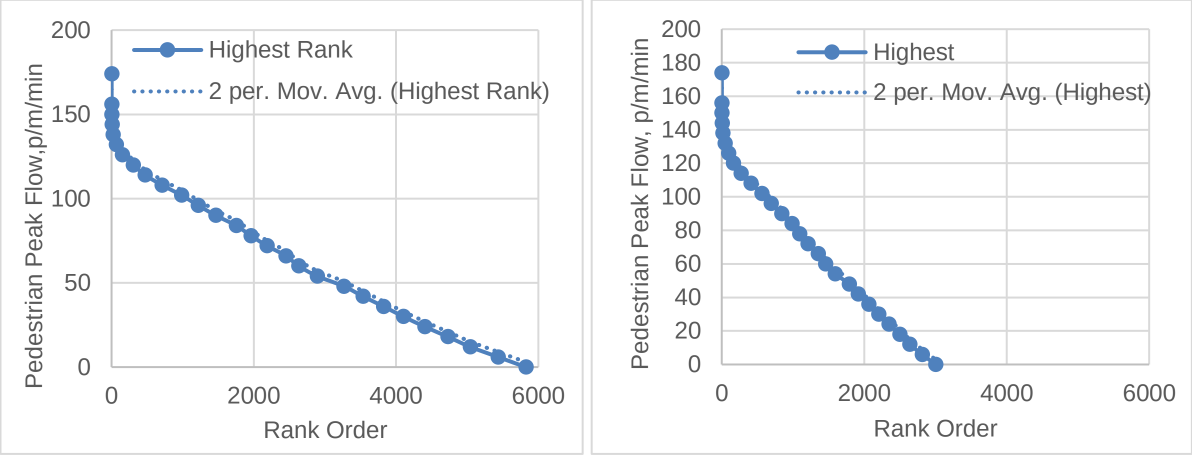
Where, IPPF = Instantaneous Peak Pedestrian Flow, ped/m/min

PF_{25s} = Peak pedestrian flow for 25s data extraction time interval, ped/m/min

A = 1.071 for morning peak and 1.18 for evening peak

Peak pedestrian flow for 25s data extraction count interval for morning and evening periods in this study was 140 ped/m/min and 148 ped/m/min, respectively. The effect of mixing of commuters travelling with different purposes during evening period is reflected in higher value of parameter 'A'.

Finally, 30th Highest Hourly Volume concept was used to the peak flows to rank order them from highest to the lowest observed value considering successive 10s data extraction count intervals. Plot of peak pedestrian flow values in their rank order, for morning and evening period, are shown in Figure 8.



(a) *Morning* (b) *Evening*

Figure 8. Peak Pedestrian Flows plotted as per their Rank Order

The peak flows were found reaching a zero value at the highest rank order. This is logical for escalators at metro stations. Flows on escalators are controlled by the arrival and departure of the train, which runs with minimum headway of 3 mins or more. Other influencing factor is the location of the escalator at the platform. The flow on the nearest escalator builds very fast and subsides too. So, there will be periods when there will not be any flow on the escalator. These instances will increase if headway is high, or the extraction interval is low. The plots presented in the Figure 8 shows both the actual data plot and a moving-average trend line which follows the plot. The examination of the plots indicates that the 98th percentile peak flow in both the time periods is rank ordered as 5. Therefore, 5th highest rank ordered value of the peak flows can be used for the design purpose. This is reasonably lower than the highest peak flow observed which is more than 170 ped/m/min.

7. Conclusions

Count interval for the extraction of pedestrian flow data has been used varying between 1 and 5 mins by researchers. Literature also indicates the use of less than 1 min count interval for data extraction. Higher values are used if average flows are desired, and lower values are used if peak flows are desired. It becomes tedious if both the flows are required or a decision is to be taken to design a facility. Low count interval like 10s results in very high peak flow and if the facility is designed for that flow, then the facility will remain under-utilised for most of the time. Working with average flow or flow extracted with say 1 min time interval will result in a facility that will face congestion for a longer period. The stimulus behind this study was to arrive at the optimum count interval that can be used for data extraction and satisfies estimation of peak and average flows. Pedestrian flows on escalators located at metro stations were studied. Peak and average flows were extracted for count intervals as low as 10s, and as high as 5 mins. It is suggested that 25s (against 24s) can be taken as the most optimal count interval for pedestrian flow data extraction. This will result in 144 data points in one hour recorded data. The associated peak flow will be the 98th percentile peak flow. The design flow value for the escalators is suggested as 140–148 ped/m/min. In terms of rank-ordered peak flows it can be taken as the 5th rank order value.

One aspect which need to be discussed in association with the design flow values is the pedestrian handling capacity of the escalators. Though, it is not the objective of this paper but the 98th percentile values can be examined with respect to the theoretical capacity of the escalators. Theoretical capacity of the escalator is governed by the size of the step of the escalator, operational speed of the escalator and usage etiquette (Mayo, 1966; Davis and Dutta, 2002). In line with the escalators selected in this study, the size of the step was 1000 mm wide and 400 mm deep.

Operational speeds vary between 0.50 m/s and 0.90 m/s. Here for capacity estimation, we can consider 0.65 m/s. Usage etiquette means whether the escalator is operated with all pedestrians standing (stand only) or pedestrians stand on one side and are allowed to walk on other side of the escalator (stand-walk etiquette). Considering stand only etiquette it can be assumed that two persons can stand on one step of the escalator. This operational condition will result in theoretical capacity of 195 pass/min (DIN EN 115-1:2017). As can be seen, the highest instantaneous peak flow and 98th percentile peak flows are less than the theoretical capacity. The design flow value estimated in this work is around 70-75% of the theoretical capacity. This shows that still the escalators at selected metro stations are not operating under severe pedestrian load. But the field condition, as also depicted from photographs in Figure 1, is totally opposite. It is reported that the theoretical capacity is never achieved in actual. This may be due to varying body ellipse size, comfort distance maintained by pedestrians among themselves, carrying of an object, time lag in boarding on the escalator step, etc. These cause a gap between pedestrians on a escalator. This was defined as empty-step phenomenon by Fruin (1987). The difference between the theoretical capacity and actual practical capacity needs to be studied so that a reference capacity can be estimated which is lower than the theoretical capacity but can be achieved in practical. This will help the planners in arriving at the improvement plans and easing out the heavy pedestrian load experienced by the escalators during peak periods at metro stations.

Another aspect is the effect of directional pedestrian flows on escalator capacity. Escalators may be transferring the pedestrians from entrance to the platforms or from platform to exit or between platforms, say at an interchange station. In such cases the pedestrian walking psychology and behaviour may be different. This may affect the pedestrian handling capacity of the escalators. As in this study most of the escalators were moving pedestrians in upward direction (platform to exit), such a comparison was not possible. There can also be an impact of cultural values, attire, movement discipline, etc. on the pedestrian flow characteristics which may affect the maximum flow rates or capacity of an escalator. These need to be taken up at length in a separate study.

The findings of this work related to the data extraction time interval are different than those reported by various researchers. Nai *et al.* (2012) have suggested 20s as the data extraction time interval for pedestrian flows on escalators at metro stations in China, whereas Al-Sharif (1996) and Xing *et* al. (2011) suggested to use 30s interval for extracting pedestrian flow on escalators at metro stations. In the case of escalators at railway stations, it varied from 30s to 1 min. This is true for India, Europe, and South-East Asia. Comparison with studies on other pedestrian facilities at metro stations indicate that the use of 20s to 30s as data extraction time interval is mostly being suggested in studies conducted either in China or South-east Asia (Ya et al. 2007, Chen *et* at. 2010, Xian *et* al. 2011). The facilities studied are sidewalks, passage, walkway, and stairs. Indian study in this area suggests 30s for an intermodal transfer station (Sarkar and Janardhan, 2001) and around railway station (Das *et al.* 2016). The outcome is also different compared to the recommendation given by Bodendorf *et al.* (2014) wherein 10s is suggested to get the (instantaneous) peak flow value for facility design. This paper presents an equation which can be used to estimate the instantaneous peak flow related to 10s interval using the 25s count. The optimal time interval proposed in this study can be used across all mechanised pedestrian facilities, as well as, for facilities at locations where higher fluctuations in pedestrian flows are expected. Such locations can be interchanges, transfer facilities, entry-exit facilities at transport terminals, cinema theatre, classroom complexes, attraction points for group events, connectivity between floors, etc. In the case of facilities on which the pedestrian flow builds or subsides slowly and uniformly even a longer period like 30s or 1 min can also be used for the data extraction. This can be further substantiated through a study. Another aspect is the methodology that is based on simple data statistics which can be used by any researcher if he/she wants to ascertain the values for the existing environmental condition of a facility.

The recommendations can help the researchers and practitioners to take decisions regarding data extraction time interval to arrive at the design flow values for escalators. This will assist in arriving at the capacity of the facility. This will reduce the time and manpower requirement, which may half if compared with the lowest time interval used. The information and results of this work can be an input for a simulation study which can assist in the planning of number of escalators required at a transport terminal to manage peak flows. The work can be extended to study the pedestrian motor movement and mechanics and minimising the distance and time to the location of escalators at a terminal building. As suggested by Bodendorf et *al.* (2014) also it would be a good idea to use the method to arrive at the most optimal time for data extraction at other locations, cities and countries, as pedestrian movement patterns and psychology are expected to be different across boundaries.

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