Modeling the Level of Service of Passenger Walking in Transport Terminals

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Abstract: This study evaluates the fundamental characteristics of passenger walking in the context of a major railways station in Sri Lanka. Despite lot of studies being performed on characteristics of pedestrian walking, there exists a research need for understanding the impact of regional conditions on the fundamental parameters and to translate them into LOS standards. Level of Service of passenger walking is an important factor to consider when planning and designing any transport terminal. However, LOS standards used for sizing circulation corridors have not been updated for a long time. Furthermore, existing design guides blindly use LOS standards that are originally based on studies done in western countries. Therefore, the characteristics of the passenger flow in walkway of a transport terminal were identified and modeled using fundamental diagrams and traffic stream models. Further, LOS measurements and passenger characteristics were developed for the Sri Lankan context and compared with the existing standards.

Keywords: Fundamental Diagrams, Level of Service, Flow characteristics, Walkways, Passenger Characteristics

1. INTRODUCTION

The passenger terminal is a very significant component in any transportation network. They perform as a center of movements between passengers and freight while becoming an origin, destination, or transit point in the local, regional, or interregional transport network (Raicu et al., 2010). The main objective of a terminal is to facilitate modal interchange and provide a better transport service according to the demands of the passengers while providing safety, comfort, and convenience to the passengers (Oprea et al., 2016). Walking is one of the primary activities any passenger needs to perform in order to circulate within the terminal as they transit from one mode to another.

Walking is a fundamental and customary mode of movement in the society, and it connects people with all the other transport modes. In a passenger terminal, to access the processes such as ticketing, security, access to the platform, cafeteria etc. passengers must walk from one point to another through the terminal. In large transport terminals circulation corridors often become bottlenecks due to the sharp demand peaks that occur particularly with peak arrival banks. In contrast to other public facilities such as hospitals and shopping malls, pedestrians using transport terminals tend to walk faster and directed between specific points within the facility. Pedestrians, in a transport terminal is always cautious about the schedule of service operation, either to catch a departure or to connect with a transfer to get to the ultimate destination. Thus, any undue delays within the circulation component makes the passengers feel uncomfortable leaving a negative impression about the overall terminal service quality. Circulation or walking is considered as one of the primary service quality indicators in the context of airports, where have used total waking time and distance as an overall service quality measure for airports. Circulation elements of transport terminals serves dual purpose in normal operations and emergency conditions. Under normal operations they need to accommodate the peak demands under acceptable level of service. Under emergency situations, circulation elements need to provide safe emergency egress to the occupants (Vanumu et al., 2017). Therefore, proper designing of facilities for passenger walking have to be dealt with paramount importance.

However, the congestion in the passenger terminal provides a negative phenomenon for passenger dynamics and it prevents the passengers from having efficient movements. Therefore, it also causes delays while increasing travel time. Further, since congestion leads to potential collisions among passengers, they must make a strenuous effort to walk through the terminal during congested periods. Also, less personal space between the passengers may promote the spread of airborne viruses such as COVID-19 within transport terminals leading to conditions uncomfortable for the passengers. Less personal space under conditions of congestion also leads to concerns of personal security such as pickpocketing. Poor level of service perception of passengers at terminal facilities can also affect their mode choice decisions.

Further, modeling and understanding passenger movements are very complex than vehicular movements due to the ability of passengers to move in both longitudinal and lateral to the moving direction. Currently there is no accepted level of service standard defined for sizing circulation elements of transit terminals. Many planning and design exercises of transit terminals try to use either rules of thumb or standards that are not specifically developed for such facilities. One popular source for level of service standards in pedestrian facilities is the Highway capacity manual (HCM) published by the Transportation Research Board. HCM presents LOS standards for walkways and stairs which are applicable for terminal facilities. However, the published results are based on a study by Fruin. J in1971. However, when considering the passenger walking, from the past studies it can be identified that key characteristics of walking are highly dependent on aspects such as cultural, type of passenger facility, purpose of travel, age category etc. There are plenty of studies that address problems such as modeling pedestrian walking characteristics under various conditions including regional differences, facility types, difference in gender, age category, etc. However, attempts to convert them into level of service standards are extremely limited. LOS standard gives a logical basis for incorporating the walking characteristics to planning and design exercises. Thus, it is important to study the walking characteristics in the local context and develop LOS standards suitable for such conditions.

Therefore, this study focuses on estimating key pedestrian flow characteristics and developing a set of LOS standards in the context of a major transit terminal in a South Asian country and determine the gap between similar results from other regions of the world. Furthermore, this study investigates the influence of pedestrian characteristics such as age, gender and amount of luggage carried on walking.

This paper is organized as follows. The section 2 is consisting of the literature review and the section 3 is consist of the methodology. Results and discussion are explained under section 4 while the section 5 contains the conclusion of this research.

2. LITERATURE REVIEW

Passenger walking is a very common activity that can be seen in every transport terminal. Walking is the basic means of circulation within the facility. Many factors affect to the passenger walking behavior including physical environment of the facility as well as the personal characteristics of the pedestrian themselves. The architectural design of the facility defines the type of physical environment provided for walking (Vanumu et al., 2017). Corridors are the most common and simple design elements that can be identified in almost every transport terminal. There can be both unidirectional and bidirectional passenger flows in corridors. Also, according to the studies, the maximum pedestrian flow of the corridor is proportional to the width of the corridor (Vanumu et al., 2017). Apart from that, there are higher flows in the straight corridors compared to the other elements such as bottlenecks (Zhang & Seyfried, 2013). So, this concept is mainly used when developing emergency exits. Further, when considering corridors /walkways two different types of corridors can be identified according to the observations. One type can be known as fixed corridors that can be identified clearly with the boundaries. But, when there are no boundaries in the corridors the effective walking width of the corridor is reduced due to surrounding activities such as restaurants, stores, and restrooms. So, this corridor type also can be observed in transport terminals. Also, to study the flow and speed of the passengers in the corridors Fundamental diagrams can be used and the length of the corridor does not affect these diagrams (Chattaraj et al., 2009). Apart from the design parameters such as effective width and length of the corridor, ease of way finding greatly affects passenger walking in transport terminals. The influence of wayfinding is significant in large terminals and with higher proportion of unfamiliar passengers. Relatively smaller transit terminals tend to provide intuitive way finding with simple layout and maximizing direct line of sight with key nodes in the terminal facility.

Table 1 shows a comparison of walking speed as revealed by several past studies on the subject. The comparison includes average speed, free flow speed and walking speed at capacity within a corridor section. We can observe that all the studies have adopted video recording as the means of data collection. Based on the past evidence available, there is no strong support to claim that there is a significant difference in average walking speed among different regions. However, there is a tendency to observe slower walking speeds at terminals facilities (indoors) than outdoor walkways. While most of the studies have collected empirical data, few have used experimental setups for data collection. Experimental approach has the advantage of being able to create different conditions such as bidirectional, crossflow, merging, bottlenecks, etc. in order to test the influence on walking behavior. It can be very difficult to observe a wide range of flow conditions in actual terminal operation.

Behavioral changes of the passengers can happen in the transport terminals not only due to the design elements but also from the individual characteristics of the passengers. Speed and flow of the passenger is affected by personal attributes such as gender, age category, physical body dimensions, number of baggage, group behavior, trip purpose, etc. (Shah et al., 2013).

Table 1. Comparison of pedestrian walking speeds

Research	Average Walking Speed	Free flow walking speed (m/min)	Walking speed at capacity (m/min)	Country	Data collection and extraction	Experimental/ Empirical
(Cheung & Lam, 1998)		68.56	18.93	Hong Kong Metro Station	Video recording	Empirical
(Yordphol, Siang, & Division, 1986)		73.9		Singapore sidewalks	Video recording	Empirical
(Young, 1999)		62.2 SD – 28.1		San Francisco International Airport and Cleveland Hopkins International Airport.	Video recording	Empirical
(Silva, da Cunha, & da Silva, 2014)	78 SD - 15			Portugal footways	Video recording	Empirical
(Kong, Kong, Survey, & England, 2000)	73.99	78.69	30.94	Hong Kong Railway Stations Outdoor Walkways	Video recording	Empirical
(Kong et al., 2000)	54.89	58.95	38.75	Hong Kong Railway Stations Indoor Walkways	Video recording	Empirical
(Chattaraj, Seyfried, & Chakroborty, 2009)		Free flow 76.2 SD – 9.6		India	Video recording	Experimental
		74.4 SD – 9		German	Video recording	Experimental
(Ramli et al., 2017)	81.6			Malaysia MRT Bus Station	Video recording	Empirical
(Hoogendoorn & Daamen, 2006)	79.8 SD – 9.6	93 SD – 12.6		Netherland	Video recording	Experimental
(Tanaboriboon & Guyano, 1991)	72.94 SD – 7.77			Bangkok CBD Area Walkways	Video recording	Experimental
(Das, Parida, & Katiyar, 2015)	73.48 SD – 8.16			India Sidewalks	Video recording	Empirical
(Laxman et al., 2010)		80		India Sidewalks	Video recording	Empirical

Apart from that environmental factors such as temperature and seasonal changes also can affect the differences in passenger behavior. The impact of passenger characteristics on the walking speed of different walkways can be identified as follows from the previous studies as shown in Table 2. Based on previous research findings we can clearly see that male average walking speed is higher than female walking speed. Similarly, the age and amount of luggage is found to be influencing the walking speed of pedestrians as follows regardless of their region. Middle aged passengers have a considerably higher walking speed than the Old and Young aged passengers. Apart from that heavy baggage carriers have less walking speeds than the light baggage carriers. Further, passengers have less walking speed values when they tend to walk in groups rather than walking individually.

Table 2. Comparison of the impact of passenger characteristics

Research	Passenger Speed (m/min)										Location
	Gender		Age			Baggage		Group Size			
	Male	Female	Old	Middle	Young	Heavy	Light	2	3	4	
(Yordphol et al., 1986)	79	69	54	76	74						Singapore Walkway
(Saad & Marwa, 2014)	33.78	35.84	20	43.09							Baghdad Streets in commercial zone
(Sarsam & Abdulameer, 2015)	25.8	20.6	M/F – 20	M - 30.9 F- 24.3							Baghdad Erbil CBD area
(Abustan, 2013)			M – 68.04 F – 62.4	M – 82.8 F – 72	M/F – 63.6						Malaysia Walkway
(Tanaboriboon & Guyano, 1991)	76.44	70.21	49.54	72.94	74.05						Thailand Bangkok CBD
(Young, 1999)	84.4	77				78.7	82.4				US, California - Airport terminal
(Laxman et al., 2010)	78	70.1	66.9	79	74.7	81.2	73.1				India Sidewalks
(Silva et al., 2014)	78.6	72	57	73.32	72			70.8			Portugal Footways

Passenger walking is also affected by the different flow types in the terminals. Mainly these flow types are identified according to the direction of passenger flow. Therefore, three different flow types can be identified, such as unidirectional flow, bidirectional flow, and cross flow. Further, there can be multidirectional flow as well in the transit areas but, this type of flow pattern can be very complicated to model. In unidirectional passenger flow, all the passengers walk in the same direction**.** Therefore, the average walking speeds of the passengers are higher than the other flow conditions due to fewer disturbances to the major walking direction (Daamen, 2004). In bidirectional passenger flow, passengers walk in both directions. Therefore, according to the flow ratio, two flows can be identified as major and minor flows. Also, the effective capacity and the speed of the flows are affected by the flow ratios (Cheung & Lam, 1998). But the free flow speed of the passengers does not vary with this ratio (Lam et al., 2003). Fruin (1971) found, for instance, that a significant difference exists in the behavior of pedestrians between one-directional and two-directional traffic, when the main flow of the latter is much bigger than that of the secondary flow. In this situation, pedestrians in the main traffic flow occupy the entire walking path space and leave the free clearance space between them to the pedestrians in the secondary traffic flow.

2.1 Fundamental Flow Equation and Diagrams

Fundamentally, characteristics of the pedestrian traffic streams can be identified according to the macroscopic and microscopic approaches. The main modeling elements of the passenger flow is the fundamental relationship between the macroscopic variables such as flow, speed, and density.

Determining functional forms to mathematically model the fundamental relationships is important for estimating important flow parameters such as free flow speed and corridor capacity. Several previous studies have used fundamental equations developed for vehicular flow to model the pedestrian flow fundamental relationships (Sarsam & Abdulameer, 2015), (Das et al., 2015). According to (May, 1990) units and numerical values are the only difference that exists between vehicles and passengers when it comes to modeling the phenomenon of flow.

Fundamental relationship between flow, speed and density is given by Equation-1.

$$\mathbf{V}(\boldsymbol{ped}) = \boldsymbol{S}(\boldsymbol{ped}) \times \mathbf{D}(\boldsymbol{ped}) \tag{1}$$

Where,
V_{ped} = unit flow rate (ped/min/m)
S_{ped} = pedestrian speed (m/min)
D_{ped} = pedestrian density (ped/m^2)

Further by considering this fundamental relationship between the speed, flow, and density another basic relationship can be developed between the space per pedestrian with the flow of the passengers.

$$\boldsymbol{Vped} = \boldsymbol{Sped} \,/\, \mathbf{M} \tag{2}$$

Where,
V_{ped} = unit flow rate (ped/min/m)
S_{ped} = pedestrian speed (m/min)
M = pedestrian space (m^2/ped)

(Hcm & Results, 2000)

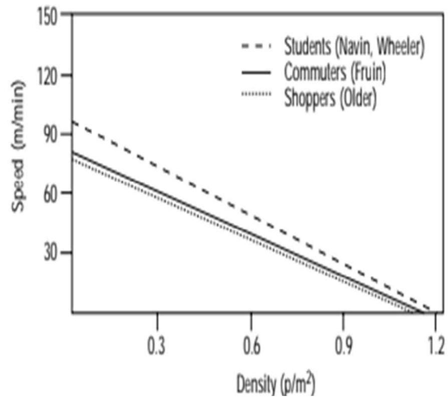

Figure 1. Pedestrian speed-density

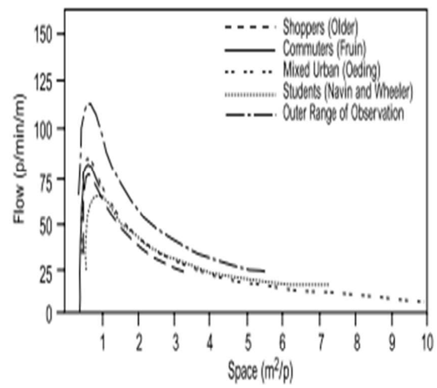

Figure 2. Pedestrian flow-space

(Hcm & Results, 2000)

When designing the infrastructure facilities these diagrams can be used to identify the needed capacity. Also, previous studies show that there is a large variation in the fundamental diagrams according to the design elements and flow characteristics (Vanumu et al., 2017). Though the fundamental diagrams are mainly developed for the macroscopic variables of the flow microscopic variables such as passenger characteristics (age, gender, purpose, baggage, clothing style, etc.) creates a considerable impact to the shape of the fundamental diagrams (Laxman et al., 2010).

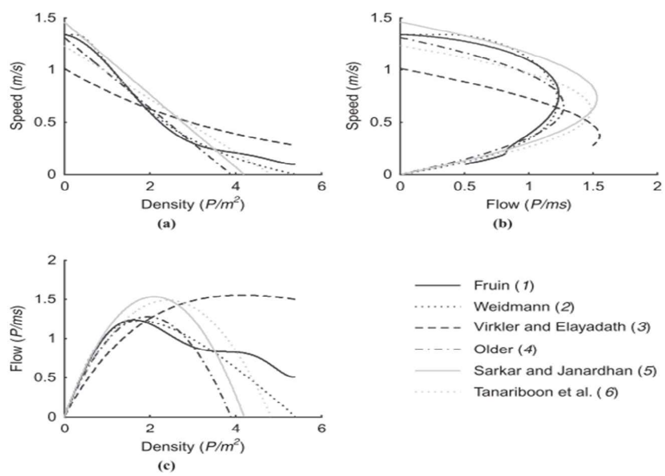

Figure 3. Fundamental diagrams in Literature (Daamen et al., 2005)

2.2 Level of Service

Passenger comfort is very important and essential when using public transportation. When it comes to pedestrian walking, ability to walk with the preferred speed, freedom to move, ability to manure without any speed changes, ability to bypass the slow-moving passengers, and ability to walk to the opposite direction of the main flow, etc. will determine the level of comfort (Ramli et al., 2017). Further, the Level of service (LOS) of service areas such as (ticketing areas checking areas and baggage areas) can be measured based on queue lengths. LOS was originally used to define level of congestion in vehicle traffic flow for determining highway capacity. Later this concept was introduced to airport passenger terminal design for defining capacity at key processing elements with regards to passenger processing, LOS referred to the level of comfort experienced by the passengers in terms of delay and level of crowding.

A number of studies have defined service levels for pedestrians based on the ranges of average area occupancy for a single pedestrian. Fruin (1971) defined six levels of service, in a similar manner to levels of service definition for vehicular traffic (Table 3). Further, Fruin (1971) found that the ease of maneuvering or comfort of walking influenced by the size of the average area available to each single pedestrian in traffic flow and that they differ according to environmental attributes and characteristics of physical facilities. Pushkarev and Zupan (1975) offer a similar level of service definitions, including low densities (above 5 m2 per pedestrian) which are beyond the range investigated by Fruin. Pushkarev and Zupan defined a number of levels of service for walking, beginning with open flow and unimpeded flow, to dense flow and jammed flow.

Definition - "The Level of Service concept is a way to ensure that considerations of demand, processing rates, and service quality are taken into account when defining service levels." (Airport Development Reference Manual, 10th ed.)

Table 3: LOS Standards of walkways by Fruin (Hcm & Results, 2000)

Level of Service	Average pedestrian occupancy (m^2/ped)	Average Flow Volume (ped/min/m)
A	>5.6	≤ 16
B	3.7 – 5.6	16 – 23
C	2.2 – 3.7	23 – 33
D	1.4 – 2.2	33 – 49
E	0.75 – 1.4	49 – 75
F	≤ 0.75	Varies

2.3 Traffic Flow Streams

The fundamental equation of vehicular flow has been used to develop many traffic streams models. Many researchers have developed various traffic stream models to understand the relationships between the flow, speed, and density parameters. Mainly these relationships have been used to design the optimum capacities for the roads while understanding the current limitations. Though these models are initially developed for the vehicular flow these relationships of the models can be applied to pedestrian flow as well since the characteristics of the fundamental flow equation are similar to the pedestrian flow characteristics as explained above. According to the earlier studies, the relationship of Greenshield's model has been commonly used to identify the relationships in passenger flows (Sarsam & Abdulameer, 2015), (Das et al., 2015) while the Underwood model also can be identified in very few studies (Das et al., 2015). Later, though some researchers have developed some deterministic fundamental passenger traffic flows, they also represent the basic relationship of these traffic stream models (DiNenno, 2002) shows the characteristics of Greenshield model and (Rastogi et al., 2013) shows the characteristics of Underwood model. Therefore, few traffic streams models as in table 4 are considered to identify the best-fitted model for the passenger flow in this research.

Table 4. Traffic stream models

Traffic Stream Model	Equation	Eq. No.	Parameters
Greenshields' model (Greenshields, 1935)	$\mathbf{V = V\mathit{f} - [\frac{V\mathit{f}}{K\mathit{j}}]K}$	(3)	V = Speed (km/h) Vf = Speed at '0' density (km/h) Kj = Jam or maximum density (veh/km) K = Density (veh/km) Vc = Speed at capacity (km/h) Kc = Density at capacity (veh/m) n = Real number
Greenberg's Model (Greenberg, 1959)	$\mathbf{V = V\mathit{c} \ln [\frac{K\mathit{j}}{K}]}$	(4)	
Underwood's Model (Underwood, 1961)	$\mathbf{V = V\mathit{f}\, e^{-(\frac{K}{Kc})}}$	(5)	
Pipe-Munjal's Model (Pipes, 1967)	$\mathbf{V = V\mathit{f}(1 - (K/Kj)^{n}}$	(6)	
Drake's Model (Drake, 1967)	$\mathbf{V = V\mathit{f}.e^{-0.5(\frac{K}{Kc})^2}}$	(7)	
Maximum Capacity Method (Li & Laurence, 2015)	$\mathbf{C\mathit{i} = max(f\mathit{i,t})}$ **For all t = 1,2,3…….m**	(8)	Ci = Capacity of location i (maximum flow rate) (p/min/m) fi,t = Observed flow rate in time interval t (p/min/m) t = Time interval (eg: - 4-min time period) m = Number of time intervals considered
Van-Arde Model (Li & Laurence, 2015)	$\mathbf{C\mathit{i} = \frac{U\mathit{i}}{C1 + \frac{C2}{U\mathit{f,i} - U\mathit{i}} + C3}}$	(9)	Ci = Estimated capacity for location i (p/min/m) Ui = Space mean speed (m/min) for location i Uf,i = Free flow speed (m/min) for location i C1, C2, C3 = Headway constant coefficients

3. METHODOLOGY

After carrying out a few pilot visits and observations in different transport terminals a field survey was carried out at Maradana Railway Station to identify the passenger flow and its characteristics. Maradana Railway station is the main operational rail hub in Sri Lanka. Also, it is one of the primary rail gateways to Colombo, which is the commercial capital of Sri Lanka. Therefore, it is served by many commuter and inter-city trains each day. Due to these aspects, a large amount of crowd travel through this terminal each day. Due to the continuing pandemic situation, there is less than usual passenger volume utilizing public transit. The specific location for data collection was chosen by conducting preliminary observations in order to make sure it is possible to observe flow conditions within the range of free flow to congested flow. Maradana railway stations consists of 10 platforms, connected by a foot bridge to the main building with entrance lobby and ticketing. A section along the foot bridge was selected for the data collection as passengers from all the platforms converge towards this corridor.

3.1 Data Collection

The field survey was carried out on a normal weekday at Maradana Railway Station for 12 hours starting from 6 am – 6 pm. It covers all the peak periods of the day (Morning Peak, Mid-day Peak, Evening Peak). The data was collected in a 5.5m length of the corridor. Total passenger counts were taken for 2-minute time duration. Time to traverse a fixed distance was measured for randomly selected passengers within the time duration. Sampling technique was random selection, and the sampling rate was 10 passengers per minute. In addition to the above variables, directional split (flow ratio), and the passenger characteristics (age, gender, baggage, and group size) were collected. Though most of the previous studies were done by using video recordings, this study employed a method of onsite data collection by observations. Even though video recording yields better resolution of data, most major transport terminals do not allow access to video record for research purposes. Thus, this research is an attempt to estimate fundamental pedestrian flow models using data collected with onsite observations.
When considering about the passenger groups such as disabled persons we need to consider their impact to the walking speeds. But in Sri Lanka most of the railways are not developed according to a user-friendly manner to the disabled persons. As an example, there are so many issues such as the entry corridors for the platforms are only accessible through the stairs and the level of the platform and the train is not aligned with each other and etc. Therefore, in our research this factor is not considered since the impact of this factor towards the passenger flow is negligible due to the very low usage of these walkways by the disabled persons. If we need to consider that impact as well need to do the data collection in an experimental setting while considering about the composition of the passenger group.

Figure 4. Data collection location and passenger walking behavior

3.2 Determination of fundamental flow equations

Fundamental traffic flow equations model the relationship between flow rate (Vped) and traffic density (Dped). Pedestrian flowrate is given by equation 3 below.

$$Vped = \frac{2minute\ flow}{2 \times corridor\ width} \tag{3}$$

Using Equation-1 flow density D_{ped} is given by the following equation.

$$D_{ped} = \frac{V_{ped}}{S_{ped}} \tag{4}$$

Average pedestrian speed (S_{ped}) is estimated by taking the space mean speed of the sampled pedestrians. Then the estimated values of V_{ped} and D_{ped} are fitted to the traffic stream models by using the least Squared Regression method. Model with the Least Sum of Squared Errors (SSE) was selected as the best fit model. Though there are several other methods such as Mean Absolute Error and the Mean Squared Error, in this research Least Sum of Squared Error was the best method available to check the goodness of fit test because we have compared different models by using the same number of data points.

3.2 Determination of the Level of Service Values

LOS of the walkway in the terminal is determined based on the space that can be allocated for a passenger. Therefore, the relationship between the flow (p/min/m) and space (m^2/p) is required. Therefore, the flow-space relationship (2) was used which was developed based on the fundamental flow equation. LOS standard published in the Highway capacity manual based on Fruin (1971) study consists for both space per pedestrian and the corresponding flowrate under each LOS category. LOS categories were identified based on the flowrate values given by the HCM LOS standards. New LOS standards for area per pedestrian was estimated using the best fit flow-density model determined using empirical data. New LOS standards for space per pedestrian was compare with the corresponding values of the HCM standards in order to determine significant deviations.

4. RESULTS AND DISCUSSION

4.1 Fitted Model Analysis

According to the extracted speed and density values, traffic stream models were fitted to the data as follows.

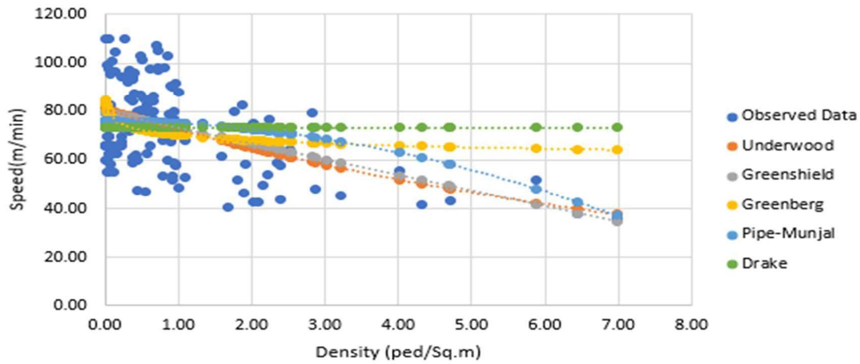

Figure 5. Fitted traffic stream models (Speed-Density)

Table 5. Curve fitting results

Traffic Stream Model	SSE Value	R-Squared Value
Greenshields' Model	36326.150	0.223
Greenberg's Model	43401.694	0.072
Underwood's Model	**36265.062**	**0.224**
Pipe-Munjal's Model	39258.745	0.160
Drake's Model	46823.224	0.001

According to the above curve fitting Underwood Model (5) was the best-fitted model and according to the data below fitted equations were derived.

$$V = 80.69e^{-\left(\frac{K}{9.15}\right)} \quad (5)$$

$$Q = V.9.15(\ln V - \ln 80.69) \quad (6)$$

$$Q = K80.69e^{-\left(\frac{K}{9.15}\right)} \quad (7)$$

According to the derived equation (5), the free flow speed of the passengers was 80.69 m/min. It is comparatively a higher value than some Asian countries such as Hong Kong and Singapore according to the previous studies. Also by comparing to previous work, this free flow speed value is in a similar range with the free flow speed values of India.

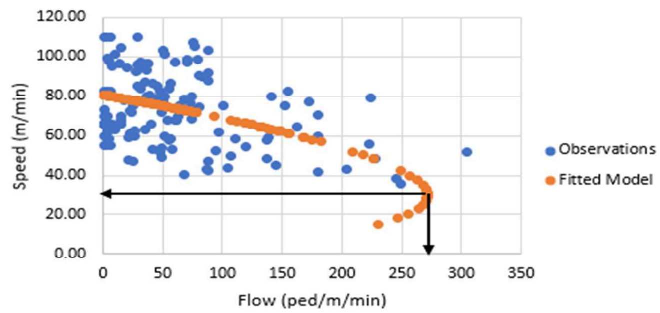

Figure 6. Fitted model data plot (speed-flow)

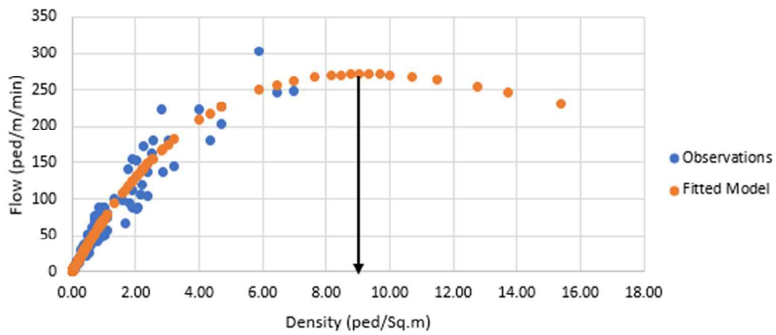

Figure 7. Fitted model data plot (flow-density)

According to the speed-flow relationship, capacity of the walkway can be estimated as 272 (ped/min/m). Also, the speed at capacity is 30 (m/min) and density at capacity can be estimated as 9 (ped/ m^2) by using Equation 6.

Further according to the flow-space relationship equations can be derived as follows for the fitted model.

$$Q = (1/S)80.69e^{-\left(\frac{1}{S9.15}\right)} \tag{8}$$

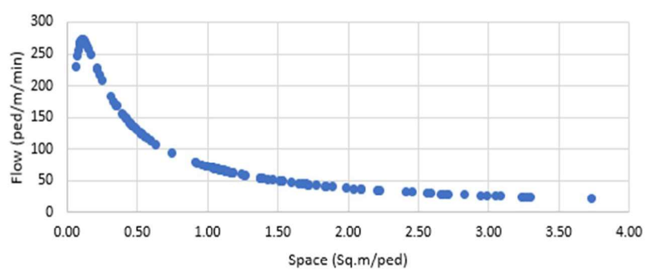

Figure 8. Fitted model data plot (flow-space)

4.2 LOS Comparison

The flow values were calculated for all the LOS categories and they were compared with existing LOS standards published in the HCM 2000. The respective speed values were also calculated for each LOS category and compared as follows.

Table 6. LOS Standards according to the study

Level of Service	Average pedestrian occupancy (m^2 /ped)	Average Flow Volume (ped/min/m) (Fruin, 1971)	Average Flow Volume (ped/min/m) from analysis	Speed (m/min) According to (Fruin, 1971)	Speed (m/min) from analysis	Significance
A	>5.6	≤ 16	≤ 14	≤ 89.6	≤ 79.157	Not significant
B	3.7 – 5.6	16 – 23	14 – 23	89.6 – 85.1	79.157 –78.276	Significant
C	2.2 – 3.7	23 – 33	23 – 39	85.1 – 72.6	78.276 –76.778	Not Significant
D	1.4 – 2.2	33 – 49	39 – 62	72.6 – 68.6	76.778–74.629	Significant
E	0.75 – 1.4	49 – 75	62 – 124	68.6– 56.25	74.629–69.746	Significant
F	≤ 0.75	Varies	Varies	Varies	Varies	

After calculating confidence intervals with a 95% of confidence level it can be identified that the LOS categories B, D, and F have a significant difference between the LOS measurements. As stated in the previous studies, Asian people do not consider their personal space than western people. Therefore, this cultural difference can be a reason for this variance. In addition to that since differences in passenger speeds also can affect these values, those factors were further analyzed.

4.3 Passenger Characteristics Analysis

Table 7: Analysis of Individual Passenger Characteristics

Category		Sample Mean Speed (m/min)	Sample Standard Deviation (m/min)	Hypothesis Test Criteria	P – value (t-test)	Mean Comparison Results Mean value (μ)
Gender	Male	95.24	55.04	Male Vs. Female	0.000	μ (Male) > μ (Female)
	Female	85.17	41.96			
Age	Old	73.66	37.44	Middle Age Vs. Old	4.904E-10	μ (Middle) > μ (Old)
	Middle	96.5	54.53	Middle Age Vs. Child	7.765E-07	μ (Middle) > μ (Child)
	Children	77.31	34.99	Old Vs. Child	0.224	μ (Child) ≤ μ (Old)
Baggage	Heavy	76.27	27.49	Light Vs. Heavy	1.360E-12	μ (Light) > μ (Heavy)
	Light	95.15	54.59			
Groups	2 members	90.54	55.61	Size 2 Vs. 3 or 4 Size	0.006	μ (2) > μ (3,4)
	3 or 4 members	78.23	41.39			
	5 or 6 members	63.8	14.24	Size 3 or 4 Vs. Size 5 or 6	0.022	μ (3,4) > μ (5,6)

According to the above results in Table 7, it can be identified that individual passenger characteristics have a significant impact on passenger walking speed and flow values. According to Table 2. Comparison of the impact of passenger characteristics, it can be identified that impact of passenger characteristics also different in walkways in commercial areas and the walkways in transport terminals. Based on the results, we can observe that gender, age, baggage and group size is significantly affecting the average walking speed of passengers. Ideally less variability in waking speeds across the corridor allows greater comfort to passengers. Fast moving pedestrians need to change direction bypass slow moving passengers, which is causing congestion and discomfort to walk. Specially for long walking distances, application of mechanically assisted devices such as moving walkways can assist elderly passengers as well as passengers carrying heavy luggage. Also, the standard deviations of all passenger categories are comparatively high according to this study.

4.4 Speed Variations

Further, under the unidirectional flow analysis (95% major flow was identified as unidirectional) Lognormal distribution was the best-fitted probability distribution for passenger walking speed and the average speed value is 72.818 m/min with a standard deviation of 19.067 m/min. According to Table 1, this average speed value is also comparatively similar to the mean walking speeds of India and Thailand. But the standard deviation of the mean speed in this study is higher than the other countries. According to the passenger characteristic analysis also it can be identified that the passenger walking speeds in this study have a higher variation rather than the other walkways. The main reason for this variation is the unordered flow of the passengers in the transport terminal and their walking and running behavior due to the time constraints. Also, due to these unpredicted behaviors, passengers cannot move with constant speeds. This variation can be clearly identified in below Figure 9 and Figure 10.

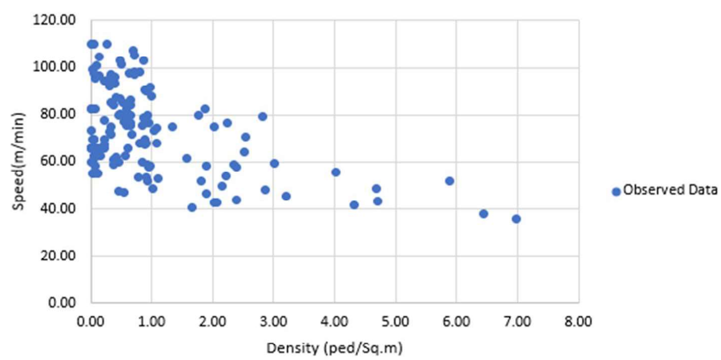

Figure 9. Scattered speed-density values in railway station

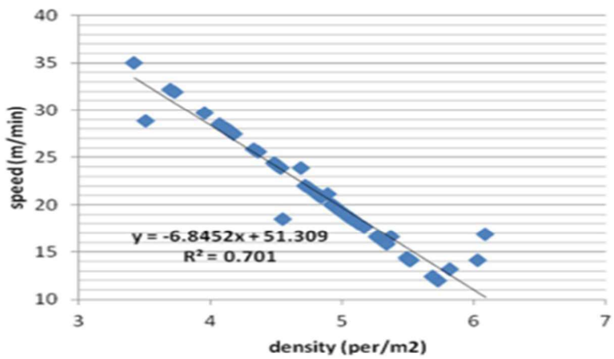

Figure 10. Ordered passenger speed-density values with on sidewalks (Sarsam & Abdulameer, 2015)

According to Figure 9 average speeds at low density values (<1ped/sqm) show a relatively high variation. Speed-density relationship, for lower densities (0-1 ped/m^2) speed does not have a significant relationship with the density. But for high densities (over 1 ped/m^2) the speed has a significant relationship with the density according to the p-values of the regression model. This density-speed variation can also be identified through the past studies. During low density conditions pedestrians choose to walk in their natural waking speeds compared to more congested conditions. Thus, depicting a relatively high variation. This is a marked deviation from more orderly flow of vehicular traffic even under low density conditions. This high variation in average speeds is also causing the low model fit statistics (R squire) observed for all the traffic flow models used to obtain flow-density relationships. This is a clear indication that traffic flow models intended for analyzing vehicular traffic could have deficiency when directly used with pedestrian traffic.

Table 8 shows a comparison of the range of the average speed values under similar density levels found in several previous studies as well as the current study. According to Table 8 it can be identified that the passenger walking speed values within a transport terminal have a higher variation given low density conditions. Results of this study also shows wider range in average speed values for low density situations. It also shows that the fundamental flow equation is not applicable to the passenger flows with high variation. Because this equation is mainly developed based on fluid approximation which was developed for uncompressible flows. But according to the observations, passenger flow cannot be considered as an uncompressible flow because the passengers can pack together and provide space for fast moving passengers according to the requirement. Therefore, specific models need to be developed for passenger flow analysis rather than using fundamental flow equation or other traffic models that were developed based on the fundamental flow equation.

Table 8. Density-Speed comparison of the pedestrian flows

Density (ped/Sq.m)	0-1	1-2	2-3	3-4	4-5	5-6	Location	Research
Speed (m/min)	84-72	72-36	36-24	-	-	-	Railway Terminal, China	(Q. Zhang, Han, & Lu, 2009)
	0-300, 0-240	0-240, 0-180	0-180, 0-120	0-120, 0-90	0-90, 0-60	0-60, 0-50	Railway Station Switzerland	(Nikolić, Bierlaire, Farooq, & de Lapparent, 2016)
	120-60	60-36	36-24	24-18	-	-	Experimental Germany	(J. Zhang & Seyfried, 2014)
	72-60	60-40	40-28	28-15	15-0	-	Walkways Singapore	(Yordphol, Siang, & Division, 1986)
	108-60	60-36	36-24	24-18	-	-	Experimental Germany	(J. Zhang, Klingsch, Schadschneider, & Seyfried, 2012)
	100-50	50-40	-	-	-	-	Sidewalk India	(Das, Parida, & Katiyar, 2015)
	90-50	-	-	-	-	-	Sidewalk India	(Laxman, Rastogi, & Chandra, 2010)
	-	-	-	35-28	28-20	20-10	Sidewalk Baghdad	(Sarsam & Abdulameer, 2015)
	110-55	90-50	80-40	75-45	60-40	55-30	This study	2020

5. CONCLUSION

According to the analysis, it was found that the LOS measurements that were developed through this study have a significant difference with the existing LOS standards especially for the lower LOS categories. According to the newly developed values, the number of passengers and speed of the passengers who use the terminal in LOS D and E are comparatively higher than the existing standards. The main reason for that can be the cultural difference between these countries because according to the previous studies Asians prefer less personal space than Europeans. Therefore, it is important in terms of sustainable passenger facility design to consider these LOS measurements in the local context rather than using the existing values that were already developed for other countries.

In this study, the average free-flow speed of the passenger in Sri Lanka is 80.69 m/min and the mean walking speed is 72.818 m/min with a standard deviation of 19.067 m/min. These speed values are comparatively more similar to the speed values of India while the standard deviation is comparatively higher than the other countries. Further, when considering the bidirectional flow minor flow has a significant impact on the major flow speed in a negative way. Therefore, it can be concluded that allowing bidirectional flows in the walkways is also another reason for congestion. Further, the mean walking speed of the minor flow is lower than the major flow, and these results justify the results of the previous studies (Cheung & Lam, 1998). Moreover, according to the speed-density analysis, it can be stated that the relationship between the speed and density for lower density values is not significant, while the relationship between speed and density for higher density values is significant. Therefore, the fundamental relationship between flow, speed, and density (Equation-1) is less accurate in low-density conditions.

Also, based on past research the passenger walking speed values of the walkways in the other commercial areas and the walkways in the transport terminals are significantly different due to the different passenger behaviors. Therefore, when planning the transport terminals specific studies need to be done by considering the passenger walking in the transport terminals. Further, different individual passenger characteristics affect the free flow walking speed in different ways. According to the observations, male, middle-aged, and light baggage passengers were rushed towards the platform than the other passenger categories. Therefore, those categories have a higher walking speed than the other categories. Also, it can be observed that the speed of the passenger categories has more variability due to the flow patterns such as walking and running. The higher standard deviation values justify these speed variations.

Further, though the previous studies mentioned that the units and the numerical values are the only difference between modeling the vehicles and passengers (May, 1990). Vehicular traffic stream models are developed for well-organized traffic flows and accordingly they do not significantly violate fluid flow approximations used in fundamental equations. But the passengers in a transport terminal walk with high variations in both direction of movement and speed, passengers have different speed levels and also there are random crossings and weaving to avoid slow moving passengers. Therefore, more ordered passenger walking behavior cannot be observed, and due to that the use of traffic stream models may result in less accurate parameter estimates. Therefore, countries that have a higher variation in the passenger walking speeds in the transport terminals need to use specific models for future analysis to get more accurate results.

Further, most of past studies were done using videography techniques for data collection. But there are transport terminals that do not allow video recordings due to security issues and privacy issues. Thus, when such techniques are not available data collection by manual observations is the only method available. Also, many researchers use experimental setups for observing pedestrian behavior due to the difficulties in identifying a wide range of flow conditions in actual transport terminal environments. But the use of empirical data to analyze passenger behavior is important since passenger behavior is also affected by their psychology and therefore the behavior pattern and the mentality of the passengers in a terminal differ from the experimental condition. This was evident in the observations made in this study where high variation of pedestrian walking speeds such as walking and running cannot be properly captured in experimental conditions.

A drawback of manual observation for data collection was the difficulty in measuring flow density onsite. Thus, flow density was estimated by using Equation-1. In order to use equation-1 it is necessary to assume that pedestrian flow behaves approximately similar to an incompressible fluid. Thus, given low density conditions, Equation-1 results in an underestimation of the true density. Furthermore, according to the observations, pedestrians regulate their walking speed and separation from others under different flow conditions. Thus, the true behavior may deviate significantly from the fluid approximation. Therefore, specific models need to be developed for passenger flow analysis rather than using fundamental flow equation or other traffic models.

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