Collective Dynamics

A review of pedestrian flow characteristics and level of service over different pedestrian facilities

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Abstract Present paper reviewed the past studies on pedestrian flow characteristics (such as speed, flow, density, space, free-flow speed and jam density) and development of Pedestrian Level of Service (PLOS) for various pedestrian facilities (i.e., sidewalk, walkway, crosswalk, grade separated, stairways and escalators. Fundamental relationships (between speed and density) were observed over different facilities and were found to be significantly different. The fundamental relationships for sidewalk facility predicted the range of free flow speeds to be $65-85$ m/min and jam densities to be $3.5-5.3$ ped/m^2. The minimum and maximum pedestrian speeds over sidewalk facility in different countries observed were 52 m/min and 98 m/min respectively, with a mean speed of 79 m/min. The male pedestrians walked at $4-9$ m/min higher speed in comparison to their female counterparts; while the older pedestrians walked at $15-20$ m/min lower speed than the younger ones over the various types of crosswalk facilities. Similarly, speed-density relationships for ascending and descending stairways showed that the difference between the two directions varied between $4-12$ m/min, and that the speed was significantly higher in case of descending direction. Moreover, the jam densities for stairways were also observed to be lower in case of descending direction, as the pedestrians generally maintain higher gap (than in ascending direction) with other pedestrians in front to avoid pushing and the risk of falling down. The flow characteristics were significantly influenced by the type of facility, width, age, gender and location of the study. Primarily factors such as physique (height), culture (dress), attractions (presence of hawkers located along sidewalks), friction (due to parked vehicles), purpose of walking trip and environmental conditions were the main reasons for pedestrians of countries such as Saudi Arabia, Iraq, Bangladesh, Indonesia and Sri-Lanka to walk significantly slower than the counterparts pedestrians in the USA, UK or Canada.

The review conducted on the PLOS mainly looked into the type of survey conducted (qualitative vs. quantitative), LOS parameters and the various software/models used in development of LOS. Researchers from the USA and Japan preferably used both qualitative and quantitative approaches in defining LOS over sidewalks; while in India, China and Malaysia qualitative method was highly preferred. Pedestrian volume, safety, surface, obstruction and width were observed as essential parameters for qualitative survey while density, flow rate, pedestrian speed and width were used in quantitative survey for sidewalks. In developing the PLOS over sidewalk facility; Conjoint analysis, Landis method, HCM method, affinity propagation cluster algorithm and Gainesville method were preferred by various researchers. Studies conducted over crosswalk facility measured space, flow rate, vehicle volume and delay as the most significant factors in developing LOS based on quantitative technique; while vehicle speed, pedestrian volume and traffic control were mostly used for LOS development using qualitative technique.

Keywords Pedestrian · flow characteristics · fundamental diagrams · level of service · sidewalk · crosswalk · stairway · grade separated

1 Introduction

The most effective and efficient mode of transportation for short trips is 'walking', and as each journey starts or ends with a walking trip; every person is a 'pedestrian' at some point in a day. Pedestrians being the most vulnerable road users are known for their wide choice of freedom while choosing a particular walking pattern which makes them far more divergent from motorized users. In comparison to vehicular movements, the pedestrians continuously interact with each other and their surrounding environment, which constantly changes their walking characteristic and direction. The different abilities of the pedestrians which make them far more complex and significantly different from the vehicular traffic are: the ability to cross another stream of pedestrians, walk in the opposing direction of a major flow, maneuver easily without major conflicts as well as move in uni-, bi- and multi-directions. The flow of pedestrians, similar to vehicular traffic does not follow proper lane discipline under low flow condition. Only at high flow levels, lane formation, lane squeezing and leader-follower relationships are some of the phenomena which are observed. The different types of pedestrian facilities available to pedestrians are shown below in Fig. 1 (Highway Capacity Manual, HCM 2010 [1]). Among the different facilities, pedestrian flow characteristics over exclusive facilities (sidewalk, walkway, crosswalk, underpass, overpass, stairway and escalator) and non-exclusive facilities (carriageway, bottleneck, queuing area and angled corridors) were studied in the present study.

Pedestrian flow characteristics are macroscopic characteristics for aggregated pedestrian groups. The flow characteristics (such as speed, flow, density, space, free-flow speed

Figure 1 Pedestrian Facility Types (Source: Exhibit 3.14, HCM 2010 [1])

and jam density) are location based phenomenon and thus different researchers try to address them locally. The study of the flow characteristics and relationship between basic flow parameters over different types of pedestrian facilities are extremely important as they allow the designers and engineers to have a consolidated approach towards the planning and designing of urban areas. Moreover, pedestrian flow characteristics under congested and uncongested conditions are pretty often explained elaborately through fundamental diagrams (i.e. the relationship between speed-flow-density). Thus, development of proper fundamental diagrams helps in estimating capacity and designing facility infrastructure as well.

The level of service (LOS) is a term closely related to the capacity; where capacity tries to give a quantitative measure, LOS provides a qualitative measure regarding measures of effectiveness (MOE). MOE which may change with the type of facility, are the key measurable parameters (such as speed, flow, density, delay, etc.) which indicate the quality of service. LOS helps in relating traffic service quality to a given flow rate and is a term which designates a range of operating conditions on a particular type of facility. LOS A defines excellent service (i.e., a free flow speed at low density), while LOS F defines very poor service (i.e., congested condition with high jam density). Defining LOS not only helps in understanding the existing pedestrian facilities but also helps in developing new facilities. Figure 2 shows the pedestrian level of service under different flow levels as per HCM 2010 [1]. LOS concept on one side tries to address a wide range of operating conditions, while on the other side the limitations on data collection and the availability make it impractical to treat a full range of operational parameters for every type of facility [2]. The LOS models can be developed by measuring the different flow parameters using either quantitative survey technique or qualitative survey technique or both.

Evaluating pedestrian flow characteristics is the basis for developing LOS models for a particular facility. Depending on the different characteristics available, LOS models predict the most significant parameters which could have an impact on the movement of pedestrians. Previously, [3] reviewed the pedestrian flow characteristics over four different facilities (i.e. walkways, crosswalks, stairways and terminals) in urban areas chronologically from 1958 to 2013. Their main aim was to understand the different types of relationships which were developed between the macroscopic flow parameters. The study was limited to a presentation on different fundamental relationships between speed-flow-density only. The study lacked proper presentation of the host of various parameters which could affect the pedestrian behaviour over the facilities for different countries. Another review study presented by [4] was limited to study of the pedestrian level of service for crosswalk and sidewalk facilities in developing countries only. Recently, [5] reviewed the past studies related to fundamental diagrams for the basic pedestrian flow characteristics using different approaches.

As the pedestrian characteristics vary significantly over different facilities, the motive of the present study was to list the various pedestrian flow characteristics (along with basic fundamental diagrams) considered by different researchers to study/model the pedestrian behavior and also shortlist the flow parameters used for the development of the level of service for different types of pedestrian facilities. The scope of the review work was limited to facility-wise (i.e., sidewalk, walkway, crosswalk, grade separated facilities, stairways and escalators, exclusive and non-exclusive) identification of the most significant factors which could affect pedestrian movement over different facilities. Also, level of service based studies were categorised based on the type of survey conducted (quantitative or qualitative) for the different facilities mentioned.

The following sections consist of the studies which were conducted on various facilities based on pedestrian flow characteristics and the factors which affect the level of service development for different types of facilities. Moreover general observations along with critical assessment were also made in the subsequent sections and salient conclusions were drawn as well.

2 Studies conducted on various facilities based on pedestrian flow characteristics

To have an integrated approach towards the traffic planning of urban areas, a detailed study of pedestrian flow characteristics (such as speed (u), flow (q), density (k), space (s), free flow speed (u_f) and jam density (k_j)) and their relationships are important. The pedestrian flow characteristics are mainly defined by basic parameters, such as speed, flow, density and space, and the relationship between such flow parameters. A linear function was developed by [6], to describe speed-density relation for vehicular traffic, based on which many pedestrian flow models were developed (refer Fig. 3).

Fundamental diagram is the basic relationship which characterizes the movement of

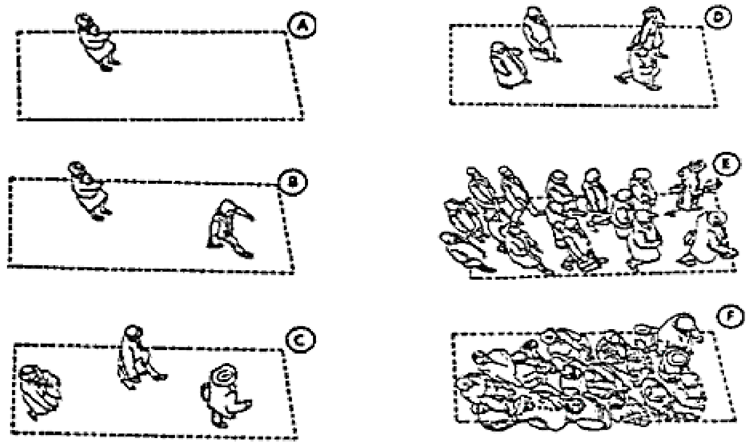

Figure 2 Pedestrian Level of Service (Source: Exhibit 3.14, HCM 2010 [1])

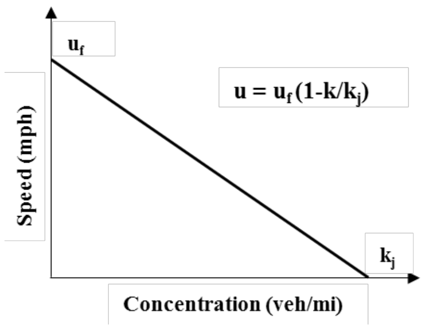

Figure 3 Greenshields model (1935) [6]

the pedestrians using the facilities. These fundamental diagrams (i.e. the relationship between speed-flow-density) elaborately explain the pedestrian flow characteristics under different congestion levels. Some of the benefits of establishing proper fundamental diagrams are deriving the capacity and level of service values, evaluating the pedestrian flow models (microscopic and macroscopic) and developing dynamic simulation models. The vast variations observed in fundamental diagrams based on similar pedestrian flow characteristics, encourages the researchers to study them with even more closer precision.

The study by [7] referred to empirical findings of other researchers, where fundamental diagrams of pedestrian flow characteristics were plotted for different types of infrastructures and under different flow compositions, (refer Fig. 4) and which exhibited significant variations in jam density and capacity. Similarly, [8] showed the variation of pedestrian flow characteristics for uni- or bi-directional flow movement (refer Fig. 5). It could be observed from Fig. 5 that for density (ρ) $> 1.0\ m^{-2}$, the fundamental diagram of uni-directional flow was above those of bi-directional flow. Moreover, the fundamental dia-

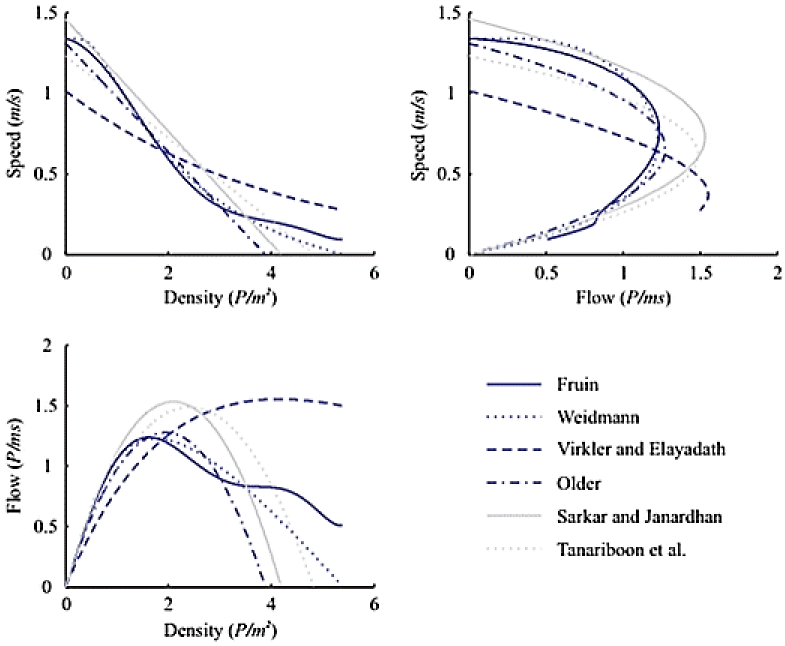

Figure 4 Fundamental diagrams of pedestrian flow characteristics (Daamen et al. [7])

grams also showed clear differences in maximum flow values of 2 $(ms)^{-1}$ and 1.5 $(ms)^{-1}$ for uni- and bi-direction movement respectively.

The Fig. 4 and 5 indicated that it was critical to study the basic pedestrian flow characteristics over various facilities under different situations to properly develop the fundamental diagrams.

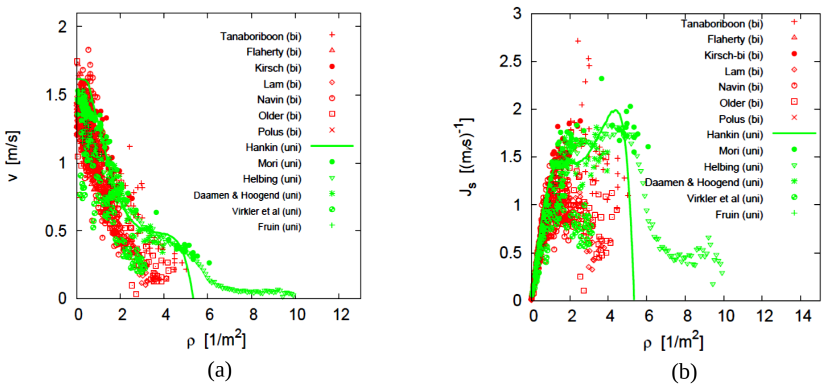

Figure 5 Fundamental diagrams (a) density-velocity and (b) density-specific flow of uni- and bi-directional movement from different studies (Source: Zhang and Seyfried [8])

The following sub-section provides an insight into the studies of pedestrian flow characteristics conducted by researchers over different pedestrian facilities such as sidewalks, walkways, stairways and escalators, crosswalks (unsignalised, signalised and mid-block), grade separated (underpass and overpass) and multiple (wide-sidewalk, precinct, indoor and outdoor walkways, etc.) facilities.

2.1 Sidewalk facility

A sidewalk or footpath is a raised path along road side which is separated from vehicular traffic by a kerb, do not allow bicycles or other users, accommodate the highest volume of pedestrians, have a width between 1.5 to 5 m and may have slight changes in grade also.

Studies on sidewalks/footpaths/footways have been conducted since early times by [9–29] based on speed, flow and density parameters for bi-directional movement of pedestrians. These studies mainly focussed on developing basic fundamental relationships. Single regime along with linear speed-density relationships were observed in majority of the studies. The above studies revealed that the mean speed for pedestrians from Saudi Arabia, Sri-Lanka and China were lower than for pedestrians in the UK and USA. The reason for such lower speed was mainly due to the socio-economic traits, characteristics of walking trip, environmental conditions and land-use patterns [30].

Recently, [31–45] also observed uni-directional as well as bi-directional movement of pedestrians on sidewalks and tried to measure space, free flow speed and jam density along with the other fundamental parameters such as speed, flow and density. Linear along with logarithmic and exponential speed-density relationships were observed; while single regime approach was highly preferred in developing a speed-density relationship. Factors such as gradient, weather, privacy, age and gender were mostly seen to affect walking speeds.

In India, [46–54] conducted studies on bi-directional movement of pedestrians on sidewalk facilities and measured the basic flow parameters (speed, flow, density, space, free flow speed and jam density). Different relationships between speed-density were plotted, and various types of regimes were also defined. The studies from India showed that the flow characteristics were highly affected by age, gender, width and the location of the facility.

In comparison to India, the researchers in other countries found factors such as gradient, weather, temperature, physical and cultural differences to be highly significant in affecting walking characteristic of the pedestrians.

Fig. 6 shows the fundamental speed-density relationship for different sidewalk facilities reported by various researchers. It could be observed from Fig. 6 that FFS ranged between $65-85\ m/min$ in most of the cases. In case of the study by [42], the FFS was reasonably low ($52\ m/min$) at Erbil (Iraq) which was due to the attire worn by the pedestrians in Iraq. Further, in the studies by [35] at Bangladesh and [41] at Baghdad (Iraq), lower pedestrian speeds were observed, and identical trends of speed-density relationships were also observed at both places. In Baghdad, the higher FFS in comparison to Erbil was mainly due to the western clothing worn by the pedestrians in Baghdad in comparison to the traditional attire worn in Erbil. Moreover, the jam density in the different studies ranged between $3.5-5.3\ ped/m^2$. The higher jam density was observed in studies conducted at Bangladesh and Iraq due to limited field data points, which were mostly in low density range.

Tab. 1 shows the mean walking speed of pedestrians over sidewalks for different countries and it further gives an insight into how mean walking speed varies over the sidewalk facility for different countries.

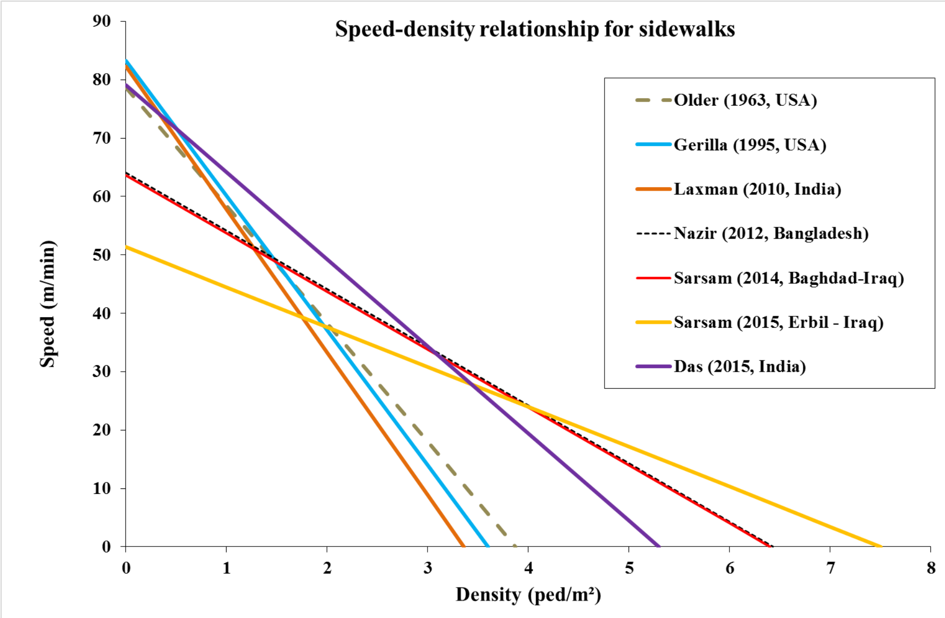

Figure 6 Speed-density relationships for sidewalks reported in different studies

Author	Location	Mean speed (m/min)	Author	Location	Mean speed (m/min)
Oeding (1963) [9]	Germany	90	Brahmbhatt (2015) [52]	India	78
Older (1968) [10]	UK	79	Sukhadia (2016) [53]	India	65
O'Flaherty (1972) [15]	UK	79	Koushki (1988) [22]	Saudi Arabia	65
Hoel (1968) [11]	USA	88	Morrall (1991) [24]	Sri-Lanka	75
Navin (1969) [12]	USA	98	Morrall (1991) [24]	Canada	84
Sleight (1972) [14]	USA	82	Koushki 1993) [23]	Kuwait	71
Roddin (1981) [19]	USA	96	Yu (1993) [26]	China	76
Murata (1978) [55]	Japan	73	Knoflacher (1995) [28]	Austria	97
Kamino (1980) [18]	Japan	69-94	Gerilla (1995) [27]	Philippines	83
Henderson (1971) [13]	Australia	87	Poei (1995) [56]	Indonesia	52
Kamino (1980) [18]	France	88	Sarsam (2013, 2014, 2015) [40–42]	Iraq	30-74
Polus (1983) [20]	Israel	79	Daamen (2005) [7]	Netherlands	85
Gupta (1986) [57]	India	72	Finnis (2008) [33]	New Zealand	88
Victor (1989) [47]	India	72	Nazir (2012) [35]	Bangladesh	52
Arasan (1994) [48]	India	74	Rahman (2012) [37]	Bangladesh	69
Laxman (2010) [49]	India	84	Tipakornkiat (2012) [36]	Thailand	74
Das (2015) [51]	India	72			

Table 1 Mean walking speed (m/min) of pedestrians over sidewalks

In correspondence with Tab. 1, Fig. 7 below represents the variation of mean walking speed among pedestrians from different countries based on age, gender and presence or absence of luggage. It could be seen that pedestrians from New Zealand or Canada had a significantly higher mean walking speed in comparison to the pedestrians from India, Iraq, Sri Lanka or Bangladesh. The main difference in speed between Canadian and Sri Lankan pedestrians was due to physique (height), culture (dress and privacy) and attractions (presence of hawkers located along sidewalks); which significantly affected the

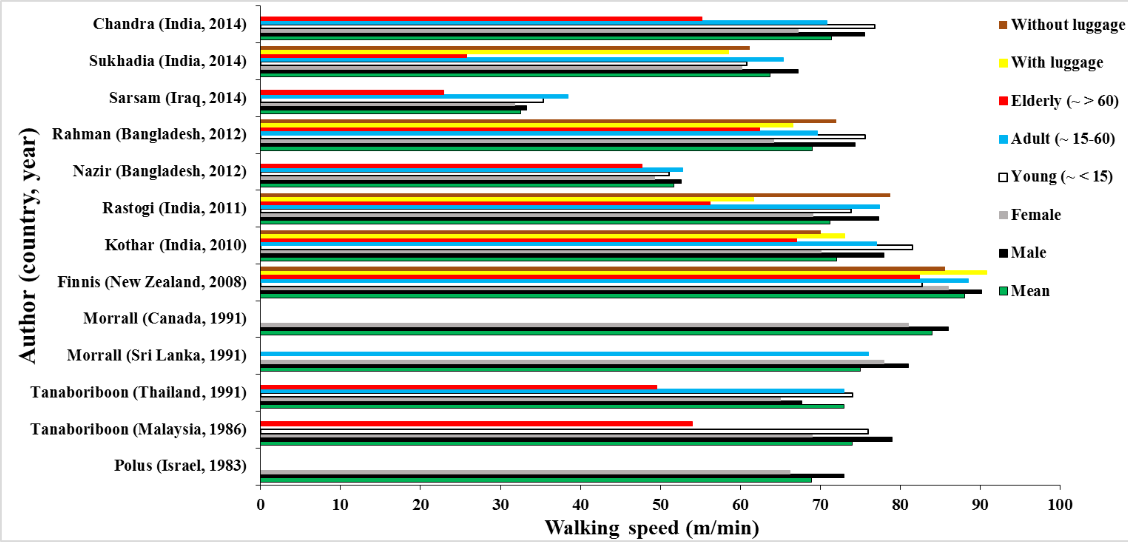

Figure 7 Variation of walking speed of different pedestrian categories over sidewalk facility

movement of the pedestrians [24]. The lower mean walking speed of different category of pedestrians in Iraq [39–42] was due to the Arabic style clothing across all gender and age categories. In Bangladesh [35], the lower walking speed was observed due to the high friction induced by parked vehicles, i.e., characteristic of location had a significant impact on the walking speed. As expected, female pedestrians and pedestrians with luggage, were observed to have lower walking speed that the male pedestrians and the pedestrians without luggage respectively in all the studies.

Tab. 2 shows a comparative study which describes the various studies conducted on different types of facilities based on location, direction of pedestrian flow (uni- and bi-), parameters which were measured (speed, flow, density, space, free flow speed and jam density), type of regime (single, two and multi) and the type of speed-density relationship (linear, logarithmic, exponential and polynomial) best fitted. The table gives an insight into the studies which were conducted on the different facilities based on the various flow parameters. The authors who had studied similar pedestrian flow parameters for the similar facilities were clubbed into the same group.

From Tab. 2, it could be observed that in case of sidewalks, even though some studies were focussed on capturing uni-directional pedestrian movement, most of the studies were conducted for bi-directional movement. Moreover, speed, flow and density were the most key parameters which were measured in all the studies; while space and free flow speed were also measured by some researchers. The parameters were preferably modelled using single regime approach. The linear speed and density relationship were mostly developed in all the studies, while some studies proposed logarithmic or exponential relationship to better fit the relationship. Also, most of the studies on the sidewalk were conducted in countries like India, Bangladesh and Iran; while some researchers in the UK, USA and Germany also studied the facility.

2.2 Walkway facility

The walkway is a pedestrian facility which is located far away from the vicinity of motorized traffic and is located in recreational or shopping areas where pedestrians can move around freely, without the intrusion of motorized vehicles. The walkway is different from the sidewalk as it is unraised and wider than sidewalks, with complete segregation from motorized traffic.

Earliest studies on walkways were conducted by [21, 58–61] who studied the uni- as well as the bi-directional movement of pedestrians over such facilities. Basic flow parameters were measured, and linear as well as exponential speed-density relationships were proposed. Moreover, single and dual regime approaches were also used. It was observed by [21] that the walking speeds of Singaporean pedestrians (74 m/min) were lower in comparison to studies conducted on American pedestrians (where pedestrian speed ranged between $79-88$ m/min). Moreover, a higher flow rate (89 $ped/min/m$) was observed in Singapore in comparison to flow rate of USA (81 $ped/min/m$) and the UK (78 $ped/min/m$), and this was mainly due to smaller physique and lesser space requirement. In a study by [58], it was observed that walking speed was affected by height when pedestrians were below 62 of age; while height and age both had significant impact on pedestrians aged above 62 years over walkways. In China, [60] observed that male pedestrians (75 m/min) had a higher walking speed than their female counterparts (70 m/min). It could be observed that pedestrians from China or Singapore walked at a lower speed and had higher maximum flow rate than the pedestrians from the UK or USA. Moreover, significant variations in walking speed were observed with change in age and gender as well.

Later, [62–65] mainly focused on measuring speed, flow and density parameters over walkways. They also observed that linear and exponential relationships best fitted the speed-density equation. The study by [62] visualised that despite studying the interaction among isolated pedestrians, it could be seen that more than 70% pedestrians moved in groups of two pedestrians or more and that group size affected overall walking speeds in France. In Bangladesh, [63] observed that free-flow walking speed of pedestrians was 67 m/min on walkways, and that it was considerably lower than the other countries and this was mainly due to their attire. The study conducted by [65], captured pedestrian movement over a walkway in the Netherlands and observed that variability in flow decreased with increase in density. The study also showed that typical group walking patterns were generated due to social interactions.

Fig. 8, shows the fundamental speed-density relationship for different walkway facilities reported in literature. It could be observed that the FFS ranged between $73-87$ m/min in most of the studies. In the study by [59], the warm weather played a significant role and forced the pedestrians to walk at a lower FFS in this region. In most of the studies, researchers tried to explain the observed speed-density relationship through linear relationship, however, in studies by [60, 71, 74], the exponential relationships between speed-density were also explored. The exponential relationships between speed-density lead to unrealistic jam densities.

Early studies by [21, 58, 60] showed that factors such as age, physique and gender

<table>
<tr><th rowspan="2">Type of facility</th><th rowspan="2">Author (Year)</th><th rowspan="2">Location</th><th colspan="2">Direction of flow</th><th colspan="6">Parameters Measured</th><th colspan="3">Type of Regime</th><th colspan="4">Type of Speed-Density Equation</th></tr>
<tr><th>Uni-Directional</th><th>Bi-Directional</th><th>Speed</th><th>Flow</th><th>Density</th><th>Space</th><th>Free Flow Speed</th><th>Jam Density</th><th>Single</th><th>Two</th><th>Multi</th><th>Linear</th><th>Logarithmic</th><th>Exponential</th><th>Polynomial</th></tr>
<tr><td rowspan="22">Sidewalk/Footpath/Footway</td><td>Oeding (1963) [9]</td><td>Germany</td><td rowspan="9">✓</td><td rowspan="9">✓</td><td rowspan="9">✓</td><td rowspan="9">✓</td><td rowspan="9">✓</td><td rowspan="9">✓</td><td rowspan="9">✓</td><td rowspan="9">✓</td><td rowspan="9">✓</td><td rowspan="9"></td><td rowspan="9"></td><td rowspan="9">✓</td><td rowspan="9"></td><td rowspan="9"></td><td rowspan="9"></td></tr>
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<tr><td>Das et al.(2015) [51]</td><td>India</td></tr>
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<tr><td>Sarsam and Abdulameer (2015) [66]</td><td>Iraq</td><td rowspan="2"></td><td rowspan="2">✓</td><td rowspan="2">✓</td><td rowspan="2">✓</td><td rowspan="2">✓</td><td rowspan="2"></td><td rowspan="2">✓</td><td rowspan="2"></td><td rowspan="2">✓</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2">✓</td><td rowspan="2"></td><td rowspan="2"></td><td rowspan="2"></td></tr>
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<tr><td>Rungta and Sharma (2016) [54]</td><td>India</td></tr>
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<tr><td>Weidmann (1993) [71]</td><td>Switzerland</td><td>✓</td><td></td><td></td><td>✓</td><td></td><td>✓</td><td></td></tr>
<tr><td>Sarkar and Janardhan (2001) [72]</td><td>India</td><td>✓</td><td></td><td>✓</td><td>✓</td><td></td><td></td><td></td></tr>
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<tr><td>Fujiyama and Tyler (2004) [79]</td><td>UK</td><td></td><td>✓</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="3">Stairway and/or escalator</td><td>Daly et al. (1991) [69]</td><td>UK</td><td rowspan="3">✓</td><td rowspan="3">✓</td><td rowspan="3">✓</td><td rowspan="3">✓</td><td rowspan="3">✓</td><td rowspan="3">✓</td><td rowspan="3">✓</td><td rowspan="3">✓</td><td>✓</td><td></td><td></td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td>Lam et al. (2000) [80]</td><td>China</td><td>✓</td><td></td><td></td><td>✓</td><td></td><td></td><td></td></tr>
<tr><td>Lee (2005) [81]</td><td>Netherlands</td><td></td><td>✓</td><td></td><td>✓</td><td></td><td></td><td></td></tr>
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Table 2 Pedestrian flow characteristics on different types of facilities

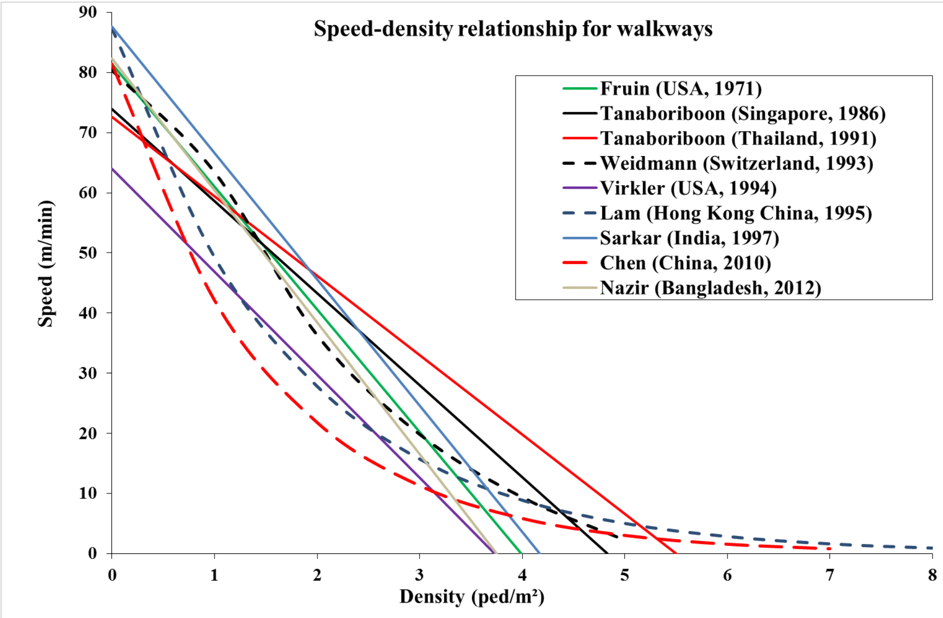

Figure 8 Speed-density relationships for walkways reported in different studies

played a significant role on pedestrian walking speed, while later [63, 65] observed that attire and group walking pattern were found to be major contributing factors which affected pedestrian movement over walkways.

From Tab. 2 based on the pedestrian flow characteristics, it was observed that most of the studies over walkway facility were conducted for both uni- as well as bi-directional flow in countries like the USA, UK, France and Netherlands; while few studies had also been conducted in Singapore and Bangladesh. Speed and flow were the basic parameters which were measured for most of the studies; and exponential as well linear speed-density relationships were developed for such studies.

2.3 Stairway and escalator facility

Stairways and escalators are the facilities which allow vertical movement and are used to ascend or descend, to and from grade separated facilities (i.e., overpasses and underpasses). As per [68], “locomotion on stairways is restricted because of the need to overcome gravity in ascent and to safely control it in descent”. Whereas, stairways allow easy movement only for a particular group of pedestrians (e.g. young male and adult male) for whom ascending or descending is relatively easy; escalators, on the other hand provide a more easy accessibility and comfort to a wider range of pedestrians (e.g. elderly, children and female). Only properly designed stairways (with low riser height and low gradient) allow easy access for all groups of pedestrians.

Studies on stairways were conducted earlier by [68–71] using uni-directional flow and the basic flow parameters were measured. Single regime approach with the linear speed-density relationship was preferably used in such studies. Field and experimental studies carried out were mainly focussed on gender, speed and age. In a metro station in London, [69] surveyed stairways and found that 35 m/min and 40 m/min were the ascending and descending speeds. In Thailand, [70] conducted quantitative surveys, and observed that the Thai pedestrians had slower ascending speed (by 4 m/min) and slower descending speed (by 8 m/min), in comparison to the study conducted in the USA by [68]. The reason for such an observation was the difference in the riser height (by about 0.05 m).

Fig. 9, shows the fundamental relationships between speed-density for ascending and descending stairways at different locations conducted by various researchers. The speed difference observed between ascending and descending stairways varied between $4-12$ m/min. It could also be observed that the reported pedestrians FFS varied widely for ascending ($27-54$ m/min) as well as descending ($34-65$ m/min) cases in different studies. As the speed over stairways greatly depend on various parameters (like riser and tread dimensions, width and direction of flow), which varies significantly from one study location to other; this could be the major contributor behind the wide spread of FFS. In China, [80] observed higher walking speed due to physical property of the stairways as the selected stairways had lower step-rise height and easier maneuverability. Similarly, in Malaysia, [64] observed the lower speed due to the higher density and unavailability of space to overtake the pedestrians in front. Moreover, in majority of the cases, it could be observed that the ascending and descending speed curves intersect each other, and the jam density of descending maneuver was lower than the ascending maneuver. Such possibilities arises as while ascending, pedestrians maintain lesser gaps in between which lead to higher jam densities in ascending maneuver. In the descending maneuver, the pedestrians maintain higher gaps (i.e. lower jam density) to avoid pushing the pedestrians in front and reduce the probability of falling down. Further, the descending maneuver requires less effort than the ascending one, which results in higher walking speed than in ascending cases.

The studies by [64, 73, 74, 77, 79–83] over stairways were conducted for both unidirectional and bi-directional movements. It was observed by [80], that the free flow speed at stairway in a metro station in Hong Kong (China) for ascending and descending speeds were 51 and 56 m/min respectively. The higher speed was mainly due to low riser dimension (15 cm) and lower stairway inclination (26°). In the UK, [79] figured out that other than gradient, factors such as age, height and weight did not provide correct information on walking speed over stairways; while in 2011 the same group of researchers [82] observed that it was gradient alone which could affect the walking speed and not the obesity of a pedestrian. Similarly, [73], noticed that for a pedestrian to walk freely in China, space required was 0.6 m^2/ped. Another study by [77], found that in China, movement over stairway was significantly different in comparison to the horizontal movement due to the dimension of the staircase. In the USA, [83] observed that during evacuation from stairways of a six-storey building, the speed variation was between $4-32$ m/min depending on the stairway dimension. It could be seen that the relationship between walking speed and physical characteristics, along with stair-gradient were the major factors which were studied by various researchers.

Similar studies over stairways were conducted in India by [72,75,76,78] at inter modal transfer terminals and train stations. All basic flow parameters were measured, and the

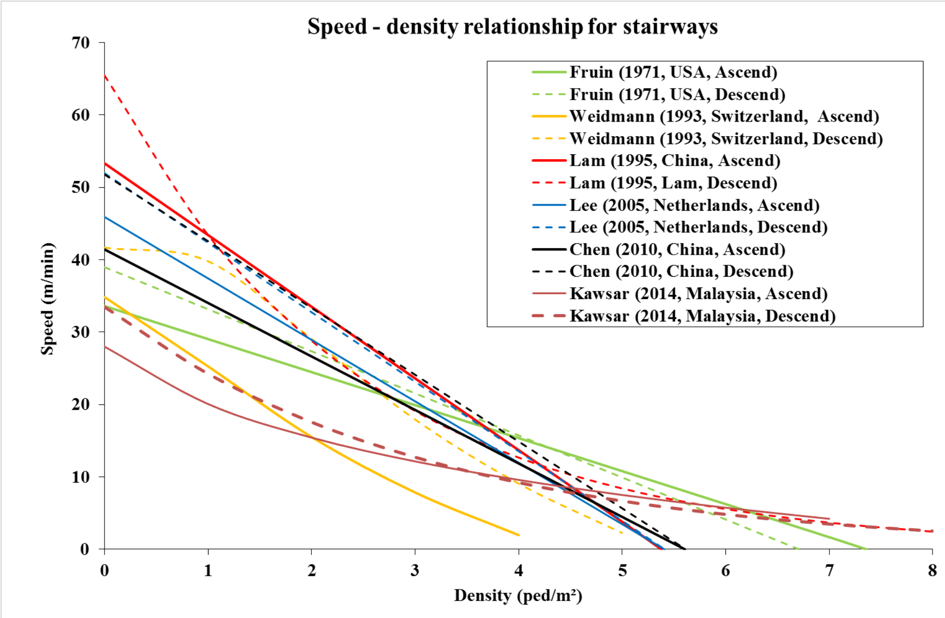

Figure 9 Speed-density relationships for ascending and descending stairways reported in different studies

different regime approaches were defined. The study by [76] found that average speed for ascending was 28 m/min during the afternoon time, while it was $17-25$ m/min during the evening. Similarly the descending speed ranged between $30-32$ m/min during the afternoon to $20-29$ m/min during the evening. Again, [78] found that stairway width and direction of movement were important factors which affected pedestrian movement over stairways at railways stations in India. The studies in India were mainly focussed on the influence of directional distribution, width of the stairway and purpose of the trip on pedestrian flow characteristics. It could also be observed that in comparison to Chinese pedestrians, the Indian pedestrians had lower speeds while ascending or descending stairways.

Earlier studies show that the age and gender were the only factors which affected the pedestrian movement over stairways, but later dimension of the stairway (riser dimension and stairway inclination) was seen to play a significant part in determining the movement characteristics over the stairways. It could also be seen that most of the studies were conducted either in China, UK or USA, where factors such as the free flow speed, space required and gradient were found to be most suitable in describing pedestrian movements. In India, [76, 78] stated that width of stairway, trip purpose and direction of movement were important factors which contributed to the pedestrian walking characteristics.

Studies over escalators were conducted by [69, 80, 81]. At a metro station in London (UK), [69] found that the ascending and descending escalator speeds were 50.4 m/min and 60 m/min respectively. In a similar study in Hong Kong (China) metro station, [80] observed that the speeds in the ascending and descending directions were 53.4 m/min and 63 m/min respectively. Irrespective of having similar escalator capacity of 120 $ped/m/min$, the slightly higher speed in both the directions in Hong Kong (in comparison to London) was due to the escalator dimension and the degree of inclination. In a public transport terminal in the Netherlands, [81] studied escalators and reported the maximum flow in ascending and descending directions were 40 $ped/m/min$ and 56 $ped/m/min$, which were much lower than the observations made by [69, 80]. The lower capacities were observed, as the fundamental model was developed based on the limited observed data of lower flow condition. However, the reported speed over escalators in ascending and descending directions were 49.2 m/min and 52.8 m/min, which were comparable to the previous studies.

The findings from Tab. 2 indicated that other than very early studies by [68, 69, 71] which considered both uni- as well as bi-directional movement; most of the recent studies by [73,76,78,79,81,82] were done on the bi-directional movement of pedestrians over the stairways. Speed and flow were the preliminary parameters which were measured in all the studies. Moreover, single regime approach was mostly preferred while a few studies also used two or multi regime approaches.

2.4 Crosswalk and crossing facility

Crosswalks are the at-grade facilities which are provided for easy and safe dispersal of pedestrians from one side of the road to the other. These crosswalks/ crossings can be located either at intersections or at midblocks with either presence of signals or can be unsignalised with/ without zebra crossings. Crosswalks are more critical than sidewalks due to greater pedestrian interaction with vehicular traffic, as pedestrians generally tend to cross the road at signalised and unsignalised intersections or at mid blocks sections. At signalised intersections, pedestrians have a pedestrian green signal time during which they have to cross, while the pedestrians have to wait during the pedestrian red time. At uncontrolled/ unsignalised intersections or midblock crossings, no pedestrian signals are provided and pedestrians might have to wait for a longer time to cross depending on the pedestrian gap acceptance behaviour. If the waiting time increases beyond a certain threshold, then the tendency of taking risk while crossing illegally increased significantly.

Early studies on crosswalk and crossing had been carried out by [15, 84–88] for bi-directional pedestrian movement, and speed was the only parameter measured. The study by [87] found that illegal signalised crossings were nearly $30-45\%$ at different locations in China and was a significant reason for pedestrians being killed regularly, yet pedestrians were more interested in crossing at grade instead of using the over or under passes. Later, [89–98] measured both speed and flow parameters for crosswalks. In a crosswalk study, [90] reported that male pedestrians had 1.35 times shorter waiting time than female pedestrians to cross from one side of the road to the refuge. In a before-after study in Ireland by [91], it was observed that before timers were installed, 65% pedestrians started crossing when it was pedestrian green phase or amber phase; while after the installation of timers the crossing percentage rose to 76%, due to the safety aspect. In Malaysia a study by [94] found the waiting time to range between $7-23$ s depending on whether vehicles were moving alone or in a platoon; while in China, [97] observed that the average waiting time ranged between $6-8$ seconds. In a similar study in China conducted by [98], it was observed that average delay was 34 s, which was nearly half of red time of

77 s. In Canada, [96] observed that crossing speed of pedestrians also varied from season to season. Parameters such as pedestrian volume, group size and stopping times and their effect on crossing speed were well explored in China and Malaysia. It could be seen that average crossing speed for Chinese or Malaysian pedestrian was between $78-91$ m/min and those in the USA or Canada was 80 m/min.

Recently, [99–104] performed studies on signalised and unsignalised crosswalks for estimating speed parameter for bi-directional pedestrian movement. In Egypt, [102] attempted to study accepted gap size, and it was seen that with rolling gap, the gap size was 2.76s; while without rolling gap it was 5.22s, which proved that pedestrians in Egypt had a higher risk taking tendency. In Hungary, [104] observed that average waiting time at pedestrian crossings was 5.1 s. The opposing pedestrian flow, speed of the incoming vehicle, frequency of attempts and rolling gap significantly affected the behaviour of pedestrians and how they chose gaps to cross. Moreover, cautiousness was found to be more amongst elderly and female pedestrians while crossing.

Similar studies in India studies were conducted by [50, 105–109] over crosswalk and mid-block crossings respectively, and gap acceptance behaviour was mainly measured under mixed traffic condition. The study by [105] observed the average accepted gaps to cross intersections were 4.75 s, 3.35 s and 3.50 s by elderly, middle-aged and young pedestrians; while in 2014 the same authors [106] used Artificial Neural Network (ANN) technique to predict gap acceptance behaviour under different mixed traffic conditions. In another study, [108] observed that 45.1% of the pedestrians utilised crosswalks, while average waiting time was 24.7 s. The before-after study by [109] showed that 4.65s and 7.07s were the average waiting times, before and after the installation of a signal. The decrease in walking speed was mainly due to one stage crossing which was available after signal installation, and thus pedestrians moved at a slower speed due to enhanced safety. Rolling gap, driver yielding behaviour and frequency of attempts played major role in uncontrolled road crossing behaviour. Moreover, ANN technique was frequently used to model gap acceptance behaviour under mixed traffic conditions. It could also be seen that pedestrian delay and utilisation of crossings increased with age, while conflicts decreased with age. Moreover, the installation of signals also had a significant impact on the walking speeds of the pedestrians.

Fig. 10, shows the variation of pedestrian walking speed observed at signalized crosswalks, unsignalized crosswalks and midblock crosswalks.

From Fig. 10, in the study by [107] in India, the pedestrians were observed to take higher risks while crossing and thus the mean speed was higher in comparison to other studies. Similarly, in the case of study by [103] in Iran, the attire contributed towards the lower pedestrian crossing speeds at unsignalized crosswalks. Overall, the female pedestrians had a lower walking speed (by $4-9$ m/min) than their male counterparts. Also, younger pedestrians had greater walking speed (by $10-20$ m/min) than the elderly pedestrians in most of the studies.

Earliest studies by [84, 85, 88, 89, 94] mainly focussed on age and gender as primary factors which affected crossing speed of pedestrians, while later [97, 98] observed waiting time, season and delay to be important factors affecting the crossing speed. Recently [102, 104, 105, 108, 109], observed that accepted gap size and opposing flow were major

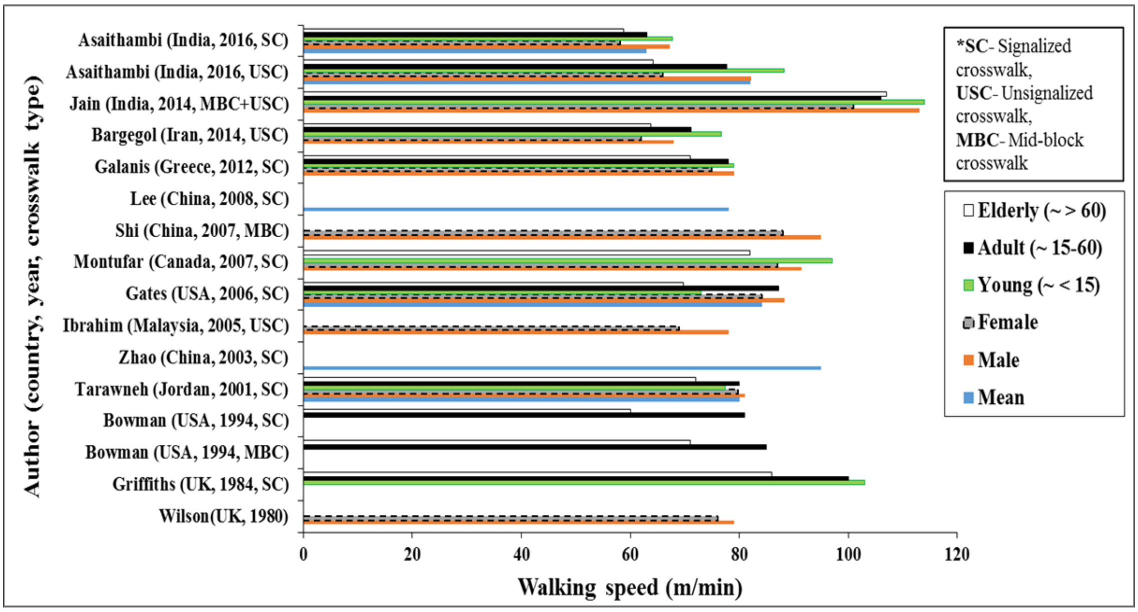

Figure 10 Variation of walking speed for different pedestrian categories over crosswalk facilities

factors which significantly affected the crossing speed. In India, many studies were conducted by various researchers over crosswalk facility, where they primarily focussed on gap acceptance and waiting time.

2.5 Grade separated facilities

Grade separated pedestrian facilities are the facilities which are constructed to have complete segregation of pedestrian and vehicular interaction. The grade separated facilities are constructed in urban situations where pedestrian crossing signals may cause congestion or accident. The facilities allow reduction in pedestrian crash at locations where there is a high chance of interaction between the pedestrians and the vehicular traffic. The grade separated facilities are primarily of two types, underpass (i.e. subway) and overpass (i.e. foot-over bridge and skywalk).

A subway or underpass is an underground pedestrian facility which allows both pedestrians and cyclists to reach to the other side of the road safely. The main benefit of providing a subway is that pedestrians tend to use it more than an elevated facility (like a foot-over bridge or skywalks), as in a subway the pedestrians need to go down first and then climb up. This psychological tendency to avoid stairways arrives when a pedestrian has to use an elevated facility. The main problem with a subway is that if it is not properly maintained and safety along with security is not ensured, then it may be misused in many ways.

A skywalk system as defined by [110] is “a network of elevated interconnecting pedestrian walkways, which consists of bridges over streets, second-storey corridors usually with shops and services within buildings, and activity hubs”. In India, skywalks are elevated pedestrian facilities which connect major heavy-concentration commercial areas with targeted destinations and range from a few hundred metres to few kilometres. These skywalks ensure safe and efficient dispersal of pedestrians from highly congested areas to strategic locations as well as allow pedestrians to travel long distances without worrying about interaction with vehicular traffic and vendors (who occupy the sidewalks), along with reduction of consumption of intoxicated and polluted air.

Similarly, a foot over bridge (FOB) is an elevated pedestrian facility which allows easy and continuous access of crossing from one side of the road to the other without any interaction with vehicular traffic. These foot over bridges should have stairs on both sides of the road; with ramp, escalator or elevator on one or both sides to improve the usability. Moreover, high flow of vehicles, the presence of minor while crossing at grade, safety and connectivity are some of the major issues which encourage pedestrians to use the particular elevated pedestrian facility.

Studies on subways or tunnels were conducted by [111–115] to understand whether pedestrians preferred to use underground or elevated facilities. In the study by [111], it was observed that the pedestrian movement over the level subway, upward stairs and downward stairs in a terminal station in the United Kingdom were 97, 48 and 59 m/min respectively, which indicated that a bottleneck might be formed due to huge differences in speed. In China, [112], collected data on pedestrian characteristics from underground transfer hubs, and observed that the walking speed over passageway, upward stairways and downward stairways were 80, 43 and 54 m/min respectively. Using, expert opinion survey and using Analytical Hierarchy Process (AHP), [113] in Bangladesh tried to understand the preference of pedestrians in using overpass, at-grade or underpass facility. It could be seen that in comparison to the other two types of facilities, the overpass was highly preferable due to better safety and security. Similarly in Jordan, [114] collected data over overpasses and tunnels, and tried to develop regression prediction models. It could be concluded that even though bridges were safer than tunnels, yet pedestrians preferred to use tunnels due to discomfort, waste of time and high stairs in using the bridges. In Bangladesh, [115] observed that the factors such as insufficient security, time consumption, poor entrance and presence of hawkers encouraged 71% pedestrians to use underpasses instead of overpasses.

Skywalk systems were studied by [110, 116–119] to understand pedestrian movement and strategies were suggested for improving such facility using either quantitative or qualitative survey or both types of survey methods. In Des Moines (Iowa), [116] identified the factors that affected pedestrian movement over skywalk facility and proposed a method for estimating pedestrian traffic. In the USA, [117] observed pedestrian movement over skywalk systems based on land-use variables and volume to estimate pedestrian trips. The study by [110], emphasized on the usability of skywalk systems in the USA by presenting the problems and improving the prospect of such facilities. In Taiwan, [119] conducted a qualitative survey to suggest future recommendations on how to improve skywalk systems.

Earlier, [120–122] studied foot over bridges (FOBs) and the factors which influenced the usability of such facilities. The study by [120], observed that if a pedestrian found a direct route with less or equal time to cross, the tendency was to cross at grade without using the overpass, even though this increased their taking risk probability. In England, [121] by using statistical methods tried to figure out the stepping frequency and walking speed (81 m/min) over foot bridges. Similarly, [122] found that in Turkey, use or non-use of foot bridge was a habit and not a coincidental behaviour, and suggestions were made to increase usability by setting up escalators to improve convenience.

Recently, in Malaysia, [123] used linear regression analysis to analyse factors which lead to low utilization of foot bridges and observed that presence of fence, the direction of flow, median existence, vehicle volume and the distance to the facility, had a significant impact on the utility of such facilities. Similarly, in another study in Malaysia, [124] studied the effect of structure and street characteristics to use footbridges and found that other than high volume of vehicular traffic, vehicular speed did not have a strong impact on the usability of foot bridges. Moreover, the angle of stairs, smaller width, good paved surface, the existence of fence and presence of traffic light impacted the usability or non-usability of the bridges. In China, [125] developed a binary logit model to identify factors affecting the preference of overpass usage and found that gender, age, career, educational level, license, detour wishes, detour distance and crossing time had significant impact over the choice of the pedestrians. The study by [126] in Thailand, used logistic regression analysis and found that number of pedestrians, proximity to bus stop and self-experience of accident influenced the use of the pedestrian bridges in urban and sub-urban locations. In Turkey, [127] studied the crossing time and speed with distance and time gap perception for safe road crossing within 25 m of overpass locations and found that age, speed of approaching vehicle, gender, group size and tendency to save time were significant factors in crossing at grade. A study by [128] tried to compare the usability of a foot over bridge in comparison to the at-grade crossing at Indonesia, and found that only 51% used the bridge and this indicated that the usability needed to be improved to attract more pedestrians. In Bangladesh, [129] conducted qualitative survey over foot over bridges and found that factors such as time of travel, height of the bridge, presence of hawkers and security contributed towards pedestrians being reluctant to use such facilities. The study by [130] in Pakistan, used questionnaire survey technique to understand the perception of pedestrians on the usage of bridges; and found that awareness, safety and security were primary concerns which prevented pedestrians from using the bridges. In Malaysia, [131], used relative importance index method to rank the most important factors affecting the usability of foot bridges, and found that existence of escalator and safety awareness were extremely important.

Studies were conducted in India by [57, 132, 133] using volume count, qualitative survey or VISSIM software to assess the feasibility of providing skywalk systems. The studies concluded that it was better to construct such facilities than signalised crosswalks or to improve sidewalks, as travel time would decrease considerably and safety would also get enhanced along with smoother vehicular traffic movement. Similarly, [134] tried to study the effect of overpasses and underpasses on pedestrian perception, using different factors such as safety, convenience, lighting, maintenance and security.

It could be seen that even though overpasses were safer, yet pedestrians preferred to use at-grade crossing facilities due to the high stairs and extra time required. Similarly, in case of skywalks, most of the studies were focussed on how to improve the facility. In case of FOBs, most of the studies had been conducted in Malaysia, China and Turkey using different statistical tests to improve the usability of such facilities. Moreover, suggestions were also made like setting up escalators, building fences, figuring out proper locations, improving security and designing appropriately with low rise stairs to increase the accessibility of the foot bridges.

2.6 Multiple (exclusive and non-exclusive) facilities

In some of the studies, multiple type of facilities (i.e. exclusive and non-exclusive facilities) were investigated together instead of a single exclusive facility. Exclusive pedestrian facilities included sidewalks, stairways, crosswalks, walkways, etc., while non-exclusive pedestrian facilities included carriageway, bottleneck, queuing area, etc. Study of multiple facilities were done as researchers were interested to know not only how pedestrians moved over sidewalks, but also over wide sidewalk, precinct and carriageway facilities; which would instead provide information about the effect of width and other related factors on the walking speed of the pedestrians.

Studies on exclusive and non-exclusive pedestrian facilities like sidewalk, stairway, crosswalk, indoor and outdoor walkways, were conducted by [27,60,70,80,135] and they tried to measure all the flow parameters in bi-directional flow. The study by [70] observed that in Thailand, the average walking speed over the sidewalk, ascending stairways, descending stairways and signalised crosswalks were 73 m/min, $28-34$ m/min, $35-37$ m/min and 77 m/min respectively. In China, [80] found that the crossing speed of pedestrians over signalised crosswalk ranged between $81-87$ m/min, while over walkway the range was $47-78$ m/min. In Pakistan, [135] observed that pedestrians were running while crossing and some even tried to cross even when approaching vehicles were at 2s headways. It could be observed that linear, as well as exponential speed-density relationship were used for the different facilities. The most important observation from these studies was that pedestrian flow characteristics over such facilities were site- and region-specific. Moreover, the studies also suggested that country wise local design standards for pedestrians was extremely important.

Recently, [64, 136, 137] tried to study uni- and bi-directional movement of pedestrians over stairways, crosswalk, level passageway, bottleneck, queuing area and different angles (right angle and oblique angle). It was observed by [64] that average free flow speed over level walkways, upwards stairways and downward stairways were 85 m/min, 30 m/min and 33 m/min respectively in Malaysia. In the USA under controlled experiments, [136] found that free flow speed for passageway, oblique angle, right angle, bottleneck, queuing area and stairway were 61, 64, 60, 66, 73 and 37 m/min respectively. Some interesting relationships like an exponential relationship for the upward stairway and logarithmic relationship for downward stairway were reported as well. Similarly, a parabolic relationship was found to be the best fit for bottleneck and queuing areas.

In India, [49, 51, 138–142] studied movement of pedestrians over sidewalk, carriageway, wide-sidewalk, precinct, stairway, walkway and crosswalk. It was found by [49] that free flow speed for all the different types of locations was 84 m/min up to a density of 3.6 ped/m^2. Moreover, [139] also observed that the mean walking speed of pedestrians over sidewalks, wide-sidewalks and precincts were 71, 69 and 64 m/min respectively, which meant that with an increase in the width of the facility, the speed decreased. Also, with the increase in width of the pedestrian facility, weaving and the interaction with neighbouring person increased which resulted in a reduction of their speed. In 2013, [140] observed that free flow speed was highest on sidewalks (95 m/min), while it was lowest over precincts (80 m/min). Two behavioural effects namely squeezing effect (at the centre) and follow the predecessor (at the sides) were observed under heavy bi-directional flow. Presence of bi-directional flow and bottleneck were observed to affect the free flow speed, maximum flow and space available significantly. It was concluded that due to the limitations of heavy pedestrian flows and width of facility, pedestrians in India walked slower, but given proper facility, the pedestrians could have comparable walking speeds as in the USA, UK or China. Study over the sidewalk, wide-sidewalk, precinct and carriageway was also made by [141], where the observed mean speed over the different facilities were 75, 82, 58 and 74 m/min respectively. In 2014, [142] had made similar studies over sidewalks, wide-sidewalks, carriageways and crossings; and observed mean walking and crossing speeds over such facilities as 70, 64, 70 and 75 m/min respectively. A study on pedestrian movement was made by [51] over sidewalk and carriageway facilities, and it was observed to be 72 and 75 m/min over the two facilities respectively. Moreover, for the same study the flow ranged between 17 to 18 $ped/min/m$ for such facilities. In the above studies, basic parameters were measured, and single, dual, as well as multi-regime approaches were used. Different speed-density relationships such as linear and exponential relationship for the sidewalk, and exponential relationship for crosswalk and carriageway were observed. The pedestrian flow characteristics were found to be affected by the type of facility and location of such facilities. Free flow speed over sidewalk and carriageway was found to be higher than for China or Singapore, but lower than Germany. It could also be perceived that pedestrian flow characteristics changed depending on the type of facility, width, gender and location. The general walking speed over crosswalks/crossings was more than on sidewalks by $4-6$ m/min due to the safety aspect involved by crossing the roads. Also, width of facility was observed to play a significant role in determining the walking speed of the pedestrians, as lower walking speed was observed over precinct and wide-sidewalks in comparison to sidewalks.

From this section, it could be observed that significant studies on multiple pedestrian facilities was carried out in India; while some studies were also conducted in China, Bangladesh and the USA. The studies mainly focussed on calculating the average walking speed over different exclusive and non-exclusive facilities and different relationships which could best fit were developed as well. Factors such as the type of facility, location, width, gender and age were observed to have the most significant impact on the walking characteristics of the pedestrians.

3 Studies conducted on Pedestrian Level of Service (PLOS) for different facilities

The level of service (LOS) as per Highway Capacity Manual (HCM) 2010 is explained as “a quantitative stratification of a performance measure or measures that represent the quality of service, measured on an A-F scale, with LOS A representing the best-operating conditions from the traveller’s perspective and LOS F the worst”.

LOS evaluates the performance of a facility and the need to redesign it. Several studies were conducted in developing LOS for different types of facilities by various researchers across the globe. The different studies either used quantitative or qualitative methods for conducting the survey and it was observed that a combination of both the studies could reflect the actual field conditions. Various factors such as flow rate, area module, speed, adjacent land use, obstruction, volume, safety, surface, width, etc. were used in developing the LOS for different types of facilities.

The following sub-section provides an overview of the studies which were conducted over different pedestrian facilities such as sidewalks, walkways, stairways, crosswalks and multiple facilities by various researchers in order to develop LOS for such facilities based on either quantitative or qualitative survey.

3.1 Sidewalk facility

Earliest studies on LOS over sidewalk facility using quantitative survey technique was done by [20] in Israel; and [29, 143] in Japan, respectively. They used density as the common parameter for defining LOS, while space and width were also used as secondary factors.

Later, [32, 144–147] used geometric and traffic conditions for estimating LOS in the USA, UK and Denmark. Width, pedestrian volume and obstruction/ friction were the most common parameters which were measured quantitatively and used by all authors in defining the LOS. Conjoint analysis was used by [144], where each segment was evaluated and appropriate utility values for each level were added to form a weighted score. In the UK, [32] observed that steep gradient and age affected walking speed, while gender had no effect in determining walking speed.

Recently, [34, 148–150] used various parameters such as flow, sidewalk variables, side friction and width for explaining LOS for the facility. SFStreet SIModel 1.0 was used by [148] in order to analyse how sidewalk design affected the LOS, and it was recommended that design and traffic calming measures needed to be incorporated to make the streets more walkable. In Greece, [34] used traffic, geometry and pedestrian movement as parameters to evaluate LOS. Different approaches such as trip quality, Landis method, conjoint analysis method, HCM method, Gainesville method and behavioural theory-based approaches were used by researchers for developing LOS using the various parameters.

In order to develop LOS, [151–157] used qualitative survey on sidewalks. The factors which were considered for predicting LOS were width, obstruction, flow rate, space and volume (of pedestrians, bicycles and motor vehicles). The factors defined were weighed by relative importance, and thus LOS was defined. In the USA, [151] proposed nine evaluation measures which could help in generating a list of specific improvements which were needed at precise locations. Conjoint analysis technique was used by [153] in Japan to evaluate pedestrians LOS based on different attributes. In China, [157] used step-wise regression analysis based on pedestrians' subjective perception, quality of road physical factors and traffic operations to determine LOS.

Recently, [149,158–161] defined LOS based on qualitative approach using factors such as continuity, surface, safety, obstruction, gender, age, effective width, pedestrian and vehicle volume. The correlation was established between different attributes and satisfaction levels to describe the LOS. In Malaysian commercial areas, [158] conducted a qualitative survey to understand the LOS of the facilities and it could be seen that safety and sidewalk conditions were the major factors which affected pedestrian perception. In a study in China, [159] observed that flow rate was the predominant factor which influenced the perception of the pedestrians. In Malaysia, [161], tried to analyse the satisfaction level of pedestrians based on gender and it could be seen that female pedestrians gave an overall lower satisfaction value in comparison to the male pedestrians.

In India, [162–164] used the qualitative technique to define LOS. Physical factors (such as width, surface, comfort, convenience, attractiveness) and user factors (such as safety, conflict and volume) were used in LOS development. Global walkability index (GWI) method was used in deriving walkability ratings. Ten different factors were used by [162] to estimate the overall pedestrian satisfaction level for sidewalks from different land uses. A quantitative survey technique was used by [50, 165, 166] where they used space and flow rate in defining LOS using affinity propagation (AP) cluster algorithm technique and HCM method. In a similar study, [166] used the quantitative technique to observe factors which influenced pedestrian movement over sidewalk, wide-sidewalk and precinct; and the difference in LOS was observed for the same space and speed. Similarly, [167], used both quantitative as well as qualitative survey; and factors such as sidewalk surface, width, presence of guardrail and barriers and traffic volume were considered to predict the LOS.

Tab. 3 and 4 describe the various studies conducted on different types of facilities (i.e. sidewalk, walkway, stairway and crosswalk) for the development of the pedestrian level of service (PLOS) based on quantitative and qualitative survey. For quantitative analysis, different types of parameters (i.e., density, space, flow rate, speed, width, pedestrian volume, vehicle volume, surface, obstruction/friction, delay, land use, v/c ratio) were considered; while for qualitative analysis other factors (i.e., lateral separation, vehicle speed, vehicle volume, bicycle speed, bicycle volume, safety, security, surface, obstruction, width, encroachment, comfort, convenience, conflict, crossing, accessibility, gender, age, environment and traffic control) were used. It could be observed that inclusion of both qualitative and quantitative parameters could secure the actual reflection of the existing conditions.

From Tab. 3 and 4, following observations could be made:

- In the USA and Japan, both quantitative and qualitative techniques were highly used; while in India, China and Malaysia the qualitative survey method was more preferred.

- For quantitative survey technique method, flow rate and width were the most common parameters which were measured.

- Pedestrian volume, safety and obstruction were the most common factors which were determined using qualitative survey technique.

Tab. 5 and 6 revealed that different LOS models were developed in India and China, as well as Malaysia, by various researchers over sidewalk facility using both quantitative surveying as well as qualitative surveying techniques. From Tab. 5 it could be seen that in the USA, Malaysia and India; width and traffic volume were the most common parameters which were measured. In India, apart from the above mentioned two factors, the presence of guardrail/ barrier was also measured [167, 186]. In the same work, [186] further used a percentage of vendor encroachment and percentage of on-street parking along with the average speed of vehicles to develop LOS model based on genetic programming clustering technique.

Similarly, from Tab. 6, it could be seen that pedestrian models for sidewalks were developed in China and South Korea. In these studies based on qualitative survey, width of separation (between sidewalk and vehicle lane) along with vehicle volume were the most common factors which were used in developing the model. Also, [157] incorporated bicycle traffic volume in the model as there was significant bicycle volume in the survey area.

3.2 Walkway facility

The studies by [27, 68] used quantitative as well as a qualitative study on the walkway by considering flow rate, density, speed and area module as parameters and LOS was thus proposed. The area module was used by [68] as the basis for developing the concept of level of service. The limitation of the study was that it could only provide a qualitative aspect of the design environment. Similar studies on walkway based on the qualitative survey were also conducted by [174–176] for LOS development. Factors such as comfort level, accessibility, connectivity and safety were chosen for LOS development. In the USA, [174] introduced three levels based on physical, psychological and physiological factors. Similarly in Malaysia, [176] used Pearson correlation coefficient to develop the relationship between comfort, safety, connectivity and accessibility. The study reported that pedestrians were highly influenced by physical safety of the walkways. A quantitative survey was conducted in China by [187] using macro-level indicators (i.e. frequency and proportion of sideways behaviour) and micro-level indicators (i.e. longitudinal and horizontal distances before and after interaction); and pedestrian interactive behaviour was analyzed to predict the level of service. The results of the study showed that illegal vendors, safety and security were the primary factors which affected pedestrian LOS.

In India, [50, 165] determined six ranges of pedestrian LOS for walkways by using a quantitative technique utilizing average pedestrian space, pedestrian speed, flow rate,

Type of facility	Author (Year)	Country	Density	Space	Flow Rate	Pedestrian Speed	Width	Pedestrian Volume	Vehicle Volume	Surface	Obstruction/Friction	Delay	Land use	v/c ratio
			Important parameters considered											
Sidewalk	Polus (1983) [20]	Israel	✓	✓	✓									
	Mori and Tsukaguchi (1987) [143]	Japan	✓				✓							
	Kwon et al. (1998) [29]	Japan	✓			✓								
	Sisiopiku et al. (2002) [144]	USA			✓		✓			✓				✓
	Petritsch et al. (2006) [146]	USA						✓						
	Jensen (2007) [147]	Denmark				✓	✓	✓	✓		✓			
	Sisiopiku et al. (2006) [145]	USA					✓			✓	✓	✓		
	Al-Azzawi and Raeside (2007) [32]	UK	✓		✓								✓	
	Talevska and Todorova (2012) [148]	Macedonia					✓				✓			
	Christopoulou and Latinopoulou (2012) [34]	Greece					✓							
	Kim et al. (2013) [149]	South Korea			✓	✓	✓				✓		✓	
	Tuydes-Yaman et al. (2014) [168]	Turkey					✓		✓					
	Daniel et al. (2016) [169]	Malaysia			✓	✓	✓	✓						
	Marisamynathan and Lakshmi (2016) [167]	India					✓		✓	✓	✓			
Walkway	Sahani and Bhuyan (2013, 2017) [50, 165]	India		✓	✓	✓	✓		✓					✓
	Gerilla (1995) [27]	Philippines	✓	✓	✓	✓								
Stairway	Fruin (1971) [68]	USA		✓	✓									
Crosswalk	Tanaboriboon and Guyano (1991) [70]	Thailand		✓	✓									
	Zhang and Prevedouros (2003) [170]	USA										✓		
	Hubbard et al. (2007, 2009) [171, 172]	USA							✓					
	Alhajyaseen and Nakamura (2010) [99]	Japan			✓		✓							
	Asadi-Shekari et al. (2014) [168]	Malaysia				✓								
	Rastogi et al. (2014) [166]	India		✓	✓									
	Marisamynathan and Vedagiri (2017) [173]	India						✓	✓			✓	✓	

Table 3 Pedestrian Level of Service (PLOS) on different types of facilities based on quantitative/videography survey

Type of facility	Author (Year)	Country	Important parameters considered																				
			Lateral separation	Vehicle speed	Vehicle volume	Pedestrian volume	Bicycle speed	Bicycle volume	Safety	Security	Surface	Obstruction	Width	Encroachment	Comfort	Convenience	Conflict	Crossing	Accessibility	Gender	Age	Environment	Traffic control
Sidewalk	Jaskiewicz (2000) [151]	USA									✓	✓	✓						✓				
	Landis et al. (2001) [152]	USA	✓	✓	✓	✓			✓						✓							✓	
	Muraleetharan et al. (2003) [153]	Japan										✓	✓					✓					✓
	Bian et al. (2007) [155]	China	✓	✓		✓	✓	✓				✓											
	Dandan et al. (2007) [157]	China			✓	✓		✓															
	Ferreira and Sanches (2007) [156]	Brazil									✓		✓					✓					
	Parida and Parida (2008) [162]	India				✓			✓		✓	✓	✓	✓									
	Bahari et al. (2012) [158]	Malaysia							✓		✓	✓							✓				
	Kang et al. (2013) [159]	China				✓		✓					✓										
	Kim et al. (2013) [149]	South Korea		✓		✓																	
	Gokhale and Telang (2013) [163]	India							✓						✓	✓						✓	
	Martokusumo et al. (2013) [160]	Indonesia													✓								
	Babu et al. (2016) [164]	India		✓					✓	✓							✓	✓					
	Arshad et al. (2016) [161]	Malaysia																		✓			
Walkway	Sarkar (2003) [174]	USA													✓								
	Khan (2005) [175]	Bangladesh							✓	✓					✓	✓			✓			✓	
	Zakaria and Ujang (2014) [176]	Malaysia							✓						✓				✓				
Stairway	Lee et al. (2003) [177]	China							✓								✓		✓			✓	
Crosswalk	Miller et al. (2000) [178]	USA							✓													✓	
	Baltes and Chu (2002) [179]	USA	✓	✓	✓	✓					✓	✓	✓	✓	✓		✓	✓	✓	✓			✓
	Muraleetharan et al. (2005) [180]	Japan		✓	✓	✓							✓										✓
	Petritsch et al. (2005) [181]	USA							✓								✓						✓
	Lee et al. (2005) [182]	China		✓	✓	✓																	
	Muraleetharan and Hagiwara (2007) [154]	Japan		✓														✓					✓
	Kim et al. (2011) [183]	South Korea									✓											✓	
	Saha et al. (2011) [113]	Bangladesh																		✓	✓		
	Archana and Reshma (2013) [184]	India				✓					✓		✓					✓					
	Yadav et al. (2015) [185]	India							✓						✓	✓			✓				

Table 4 Pedestrian Level of Service (PLOS) on different types of facilities based on qualitative/questionnaire survey

and volume to the capacity ratio as critical parameters. The pedestrian LOS was determined using affinity propagation (AP), self-organizing map (SOM) in ANN and Genetic Algorithm (GA)- Fuzzy clustering techniques based on HCM 2010 methodology. Wilk's Lambda was used on the three clustering methods and it was seen that GA-Fuzzy was the most suitable clustering technique.

From Tab. 3 regarding parameters considered for LOS development based on quantitative survey techniques, it was observed that space, flow rate and speed were the most common parameters which had been measured for quantitative survey. Similarly from Tab. 4, regarding parameters considered for LOS development for qualitative analysis; safety, comfort and accessibility were the most common factors which were used.

3.3 Stairway facility

In the USA, [68] studied stairway facility using quantitative method (time-lapse photography) and tried to develop LOS for six service levels. In the study, it was recommended that to make stairways more usable, factors such as lighting, tread/ riser dimension and location should be thoroughly investigated while designing the facility.

In a qualitative study in China, [177] proposed that LOS standards (except LOS A and B) were similar to the ones predicted by [68]. Lighting/ clear visibility, the presence of informatory signs and congestion level were the most prominent factors which affected pedestrian perception while using the facility. The reason for a difference at LOS A and LOS B was that pedestrians in China expected a walking area with more space.

From Tab. 3 on parameters considered for LOS development based on quantitative survey technique it could be seen that; space and flow rate were mostly considered for quantitative analysis. Similarly as per Tab. 4 on parameters considered for LOS development based on qualitative survey technique; safety, conflict, accessibility and environment were the factors measured.

3.4 Crosswalk facility

The early studies on signalised and unsignalised crosswalks were conducted by [70] based on quantitative technique. They used space and flow rate as parameters for defining LOS. Recently, [100, 168, 170, 172] also used qualitative method; and considered parameters like delay, right-turn volume, platoon size, age and direction of travel in developing LOS. Pearson correlation and stepwise multivariable regression analysis using SPSS software were used to relate the parameters. In the USA, [170] developed a methodology which could quantify potential conflict between left-turning vehicles and opposing through vehicles with pedestrians. Delay and safety index were combined in order to form a comprehensive indicator for LOS. The term compromised pedestrian crossing was used by [172] in order to understand what factors affected pedestrian crossing at a signalized intersection in the USA. In Japan, [100] developed a methodology for estimating the required crosswalk width based on the different combinations of pedestrian demand as well as pre-defined LOS.

Author	Location	Facility	LOS model	Remarks
Asadi-Shekari et al. (2014) [168]	Malaysia	Campus	$PLOS = \sum_{i=1}^{27} C_i PI_i$	(a) i =indicator number, c =coefficient of pedestrian indicator, PI =pedestrian indicator score (b) $PLOS$ for campus street facilities and infrastructure introduced
Petritsch et al. (2006) [146]	USA	Sidewalk	$PLOS = a_1(\text{Xing } width/mi)$ $+a_2(vol_{15}) + C$	(a) Xing $width$ =total width of crossings at conflict locations, vol_{15} =average 15-min volume on adjacent roadway (b) Useful for developing LOS for arterials with sidewalks
Daniel et al. (2016) [169]	Johor Bahru, Malaysia	Sidewalk	$FOOT-LOS = 0.7078(FW+RW)$ $-0.2138(SD+OBS) - 0.1909\{\frac{P+V}{1000}\}^2$	FW =footpath width (meter), RW =road width ($meter$), SD =surface damage (% of area), OBS =number of obstructions (number per 100$meter$), P =pedestrian flow ($pedestrians/minute/meter$), and V =traffic volume ($vehicles/hour$).
Rastogi et al. (2014) [166]	India	Sidewalk, wide-sidewalk & precinct	$LOS_{sidewalk} = 6.065 - 0.054q$ $+0.11(w-w_o)$ $LOS_{wide-sidewalk/precinct} = 6.183 - 0.056q$ $+0.044(w-w_o)$	q =Pedestrian Flow, w =Width of sidewalk, w_o =width of obstruction
Marisamynathan and Lakshmi (2016) [167]	Chennai, India	Sidewalk	$LOS_{ped} = 3.404ln(SSC+G_{sw}+B_{sw})$ $+15.215ln(Vol_{15})17.639ln(W_{sw}) - 20.770$	SSC =sidewalk surface condition, G_{sw} =the presence of guardrails, B_{sw} =the presence of barriers, Vol_{15} =average traffic during a 15 min interval, W_{sw} =sidewalk width in m.
Sahani et al. (2017) [186]	India	Sidewalk	$PLOS = 0.808 - 1.25F_{ws}$ $+0.267lnF_{mv} + 0.0059F_{nmv} + 0.035F_{ped}$ $+0.384e^{0.0401F_{ob}} + 0.033S_p$	(a) $F_{ws} = W_{ls} + W_{ln} + W_b + W_s$, and $F_{ob} = Ob_v + Ob_l + \%VE + \%OSP$ (b) W_{ls} =Width of lateral separation, W_{ln} =Width of non-motorized vehicle lane, W_s =width of sidewalk, F_{mv} =factor for motorized vehicle volume, F_{nmv} =factor for non-motorized vehicle volume, F_{ob} =factor for total obstruction, F_{ped} =factor for pedestrian volume, F_{ws} =Factor for width separation, Ob_v =walking barrier and visual obstruction, Ob_l =No of live stocks in 15 min/100, $\%VE$ =percentage of vender encroachment, $\%OSP$ =percentage of on-street parking, S_p =average speed of vehicle (km/hr) (c) Multi-variate regression analysis was used in order to develop $PLOS$ and Genetic Programming clustering used to classify $PLOS$ values
Nagraj and Vedagiri (2013) [188]	Mumbai, India	Signalised crosswalk	Predicted $LOS = a_1 * \log(l+r) + a_2 * \log(t)$ $+a_3*(p) + a_4*(d) + constant$	l =left-turning vehicles ($PCU/15min$), r =right-turning vehicles ($PCU/15min$), t =through vehicles ($PCU/15min$), p =number of pedestrians crossing every 15 mins
Marisamynathan and Vedagiri (2017) [173]	Mumbai, India	Signalised crosswalk	$PLOS_{score} = 7.550 + 0.020 * D_{ped}$ $+0.021 * V_{traffic} + 0.033 * P(y_n)$	D_{ped} =pedestrian delay (sec), $V_{traffic}$ =traffic volume along with pedestrian crossing ($volume/crosswalk/cycle$), $P(y_n)$ =probability of interaction between pedestrians and vehicles

Table 5 Various pedestrian LOS models developed based on quantitative survey

Author	Location	Facility	LOS model	Remarks
Landis et al. (2001) [152]	Florida, USA	Collector and arterial facilities	$PedLOS = -1.2021\ln(W_{ol}+W_l$ $+f_p * \%OSP + f_b * W_b$ $+f_{sw} * W_s) + 0.253\ln(Vol_{15}/L)$ $+0.0005SPD^2 + 5.3876$	Also known as Florida Department of Transportation (FDOT)âĂŹs Pedestrian LOS Model W_{ol} =Outside lane width (ft), W_l =Shoulder or bike lane width (ft), fp =On-street parking $coefficient = 0.20$, $\%OSP$ =Percent of segment with on-street parking, f_b =Buffer area barrier $coefficient = 5.37$ for trees spaced 20 feet on center, W_b =Buffer width between edge of pavement and sidewalk (ft), f_{sw} =Sidewalk presence coefficient, W_s =Sidewalk width (ft), Vol_{15} =Average 15 min motor vehicle traffic, L =Total number of through lanes for street, SPD =Average running speed of motor vehicles (mph).
Khan (2005) [175]	Dhaka, Bangladesh	Walkway	$LOS = f(0.14 * safety$ $+0.39 * security$ $+0.2 * convenience\ and\ comfort$ $+0.12 * continuity$ $+0.002 * system\ coherence$ $+0.13 * attractiveness$	AHP used in analyzing data and summarizing qualitative result
Dandan et al. (2007) [157]	China	Sidewalk	ped $LOS = -1.43 + 0.006Q_B$ $-0.003Q_P + 0.056Q_V/Wr$ $+11.24(P - 1.17P^3)$	Q_B =bicycle traffic during a five-minute period, Q_P =pedestrian traffic during a five-minute period, Q_V =vehicle traffic during a five-minute period (pcu), P =driveway access quantity per meter, Wr =distance between sidewalk and vehicle lane (m)
Kim et al. (2013) [149]	South Korea	Sidewalk	PS $= 2.485 + 3.001\ln(W_t)$ $1.438\ln(W_b)$ $0.544\ln(W_s)$ $+0.045SPD_5$ $+0.017VOL_5$,	PS =perception of pedestrian LOS, W_t =width of lane, W_b =width of separation, W_s =sidewalk width, SPD =vehicle speed, VOL_5 =vehicle volume
Muraleetharan et al. (2005) [180]	Sapporo, Japan	Crosswalk	$PLOS = 7.842 + \sum_{i=1} 3\sum_{j=1} 3D_{ij}\delta_{ij}$ $(0.037 * p_d)(0.0031 * p_b)$	D_{ij} =Categorical score associated with jth level of the ith attribute, $\delta_{ij} = 1$ if the jth level of the ith attribute is present, p_d =Pedestrian delay in seconds, p_b =Number of pedestrian-bicycle interactions Roadway designers can determine how well an intersection would accommodate pedestrian travel
Petritsch et al. (2005) [181]	Florida, USA	Signalised crosswalk	$PLOS = a_1(RTOR + PermLefts)$ $+a_2(PerpTrafVol * PerpTrafSpeed)$ $+a_3(LanesCrossed^{0.514})$ $+a_4(\ln(PedDelay)$ $+C$	$RTOR + PermLefts$ =sum of the number of right-turn-on-red, vehicles and the number of motorists making, $PerpTrafVol * PerpTrafSpeed$ = product of the traffic volume in the outside through lane of the street being crossed and the midblock 85th percentile speed of the traffic on the street being crossed, $LanesCrossed$ =the number of lanes being crossed by the pedestrian, $PedDelay$ =average number of seconds that the pedestrian is delayed before being able to cross the intersection
Zhao et al. (2014) [189]	Anhui, China	Unsignalised crosswalk	$Ped_{LOS} = a_1 V_m{}^0.1535$ $+a_2\{\frac{L_b}{(N_m+1)^2+(N_m+1)+(N_u+1)}\} + C$	V_m =two-way motor vehicle flow, L_b =Length being crossed, N_m =number of marked crosswalks, N_u =number of unmarked crosswalks Model did not consider pedestrian safety w.r.t. gap acceptance of vehicles
Kadali and Vedagiri (2015) [190]	Mumbai, India	Mid-block crosswalk	$yLOS = -1.385 + 0.152 * LU$ $+0.368 * PPCD + 0.616 * PPCS$ $+0.053 * WOM0.369 * NOL$ $+0.023 * NOVE$	LU =Land-use type, $PPCD$ =pedestrian perceived crossing difficulty, $PPCS$ =pedestrian perceived crossing safety, WOM =width of median, NOL =number of lanes, $NOVE$ =number of vehicles encountered while crossing
Archana (2015) [191]	India	Signalised crosswalk	$P-LOS = 7.443 - 0.002PFH$ $-0.061PCT + 0.679CSR$	CSR =crosswalk surface condition rating, PCT =pedestrian crossing time (sec), PFH =pedestrian flow (ped/hr)
Yadav et al. (2015) [185]	Bhopal, India	Signalised crosswalk	$POS(\%) = 56.198 + 0.150CWM$ $+0.847CWHA - 0.040LTVSpd$ $+0.592Mt.Bhvr - 0.037RdTm$	CWM =Visibility of crosswalk marking, $CWHA$ =Crosswalk holding area, $LTVSpd$ =Average Speed of left turning vehicles on green signal for pedestrian, $Mt.Bhvr$ =Behaviour of motorist, $Rd.Tm$ =Red time for pedestrian in sec

Table 6 Various pedestrian LOS models developed based on qualitative survey

Similar studies on crosswalks using qualitative techniques were conducted by [113, 178–180]. Common parameters selected for such studies were pedestrian flow, pedestrian crossing time, crosswalk width, environment, safety, gender, age, geometric and traffic characteristics. Moreover, methods such as Analytical Hierarchy Process (AHP) and stepwise multi-variable regression analysis were used to identify parameters and develop the LOS. The mid-block crossing locations in USA were used by [179], to predict the factors which highly affected pedestrian LOS. It was reported that width of painted medians, signal spacing and turning movements were the factors which increased the level of difficulty in crossing. In a qualitative study in Bangladesh, [113] found comfort and security as the most prominent factors which influenced pedestrian road crossing behaviour.

In India, [188] developed a LOS model based on a qualitative survey technique using turning and through vehicle flow, as well as the number of pedestrians crossing every 15 minutes. In a study by [184], both quantitative as well as qualitative survey techniques were used, and the LOS model was developed using pedestrian flow, crossing time, delay, crosswalk surface condition, width and marking. In perspective of the type of land-use, [190], tried to evaluate LOS for signalised crosswalks based on pedestrian perceived safety and difficulty using both qualitative as well as quantitative survey. Similarly, [173] used both qualitative and quantitative methods to derive the parameters such as pedestrian delay, traffic volume and probability of interaction between pedestrians and vehicles at signalised crosswalks; to develop the level of service.

From Tab. 3 and 4 regarding the parameters considered in the development of LOS using quantitative and qualitative surveying techniques respectively, over crosswalk facilities, it could be seen that:

- Both quantitative and qualitative surveying techniques were highly preferred in India, Japan and the USA to develop the LOS over crosswalk facility.

- Flow rate, space and delay were the factors widely used for development of LOS based on quantitative method.

- The vehicle speed and traffic control were the most common parameters considered for qualitative LOS development.

As per Tab. 5 on the various pedestrian LOS models developed based on quantitative survey, it could be seen that the models were mostly developed in India with traffic volume and pedestrian volume parameters. Using pedestrian delay factor, [188] as well [173] tried to develop LOS for signalized crosswalks in Mumbai, India. The main difference was that [188] was focussed on modelling LOS based on the traditional Webster's delay model (based on HCM 2010); while [173] used fuzzy linear regression (FLR) in developing the LOS model.

LOS models based on qualitative surveying were developed mostly in India, while some researchers in China, Japan and the USA also tried to develop models for different types of crosswalks (refer Tab. 6). In a study area around a university in Japan, [180] used conjoint analysis to develop a LOS, which could predict the factors which contributed towards high and low LOS. Pearson correlation analysis and a stepwise regression model were used in the USA by [181] to develop the pedestrian LOS for signalised crosswalk. Similar to [181], in using Pearson correlation analysis and stepwise regression model, [189] developed a model that was mainly focussed on the pedestrians' perception of safety and convenience at unsignalised midblock crossings in China. The study conducted by [190] in India, was done for mid-block crosswalks based on ordered probit (OP) model using NLOGIT software package. In the studies over signalised crosswalks in India, [184, 185] developed LOS models by stepwise multi variable regression analysis using SPSS software. The two models varied significantly as [184] mainly focussed on developing the model based on a qualitative survey, while [185] tried to use both qualitative as well as quantitative surveying techniques to develop the model.

3.5 Multiple (exclusive and non-exclusive) facilities

Researchers like [30, 70, 128, 147, 156, 168, 183, 192–194] conducted study over multiple pedestrian facilities (such as sidewalk, stairway, crosswalk, precinct, foot over bridge and underpass) using quantitative or qualitative survey. They considered facility characteristics as well as pedestrian movement characteristics to represent LOS criteria. Parameters such as density, flow, speed, space, trip type, trip purpose, age and gender were used to develop LOS over such facilities.

Studies over exclusive and non-exclusive facilities (roadway corridor and segment, streets and campus) were conducted by [146, 152, 168, 195–199] using qualitative survey. They defined parameters such as lateral separation, vehicle volume and speed, type and width of facility, safety and security, flow and speed of pedestrians for defining LOS. Methods such as Gainesville Mobility Plan Prototype, SAS (version 8.1), SARTRE 4 and inferential analysis were used to develop the LOS.

Studies by [194, 200] used field survey and sensor based technology respectively for developing pedestrian LOS for transport terminals using qualitative pedestrian level of service (Q-PLOS) and traffic assignment model methods. Factors such as accessibility, safety, comfort, flow, speed and density were considered for the study.

Similar studies on exclusive and non-exclusive pedestrian facilities were also conducted in India by [49, 50, 201, 202]; using affinity propagation (AP) and cost-benefit ratio to define LOS criteria. The primary parameters (space, flow rate, speed and density) and secondary parameters (occupation and trip purpose) were preferably used.

It could be seen that most of the studies for LOS development over multiple facilities were either carried out over sidewalk or crosswalk facilities. Both qualitative and quantitative survey methods seemed to be equally preferred methods of conducting surveys to develop LOS. Some common parameters which were seen to be considered were the physical geometry of facilities (width, surface and obstruction), its location and user factors (safety, security and volume).

4 Concluding Remarks

The current paper presented a detailed review of the past studies which were conducted on various aspects of pedestrian flow characteristics and the factors used in development of pedestrian level of service (PLOS) over the various facilities. This section primarily focusses on the critical discussions on the various observations made during this literature review. Further a consolidated list of parameters used by various researchers in the study of different pedestrian facilities are presented, and research gap along the future scope are also highlighted.

4.1 Discussion

4.1.1 Pedestrian flow characteristics

The studies conducted on pedestrian flow characteristics mainly focussed on measuring the basic fundamental parameters, developing relationships between them and understanding the factors which affect pedestrian walking speed. Pedestrian flow characteristics were found to change with respect to the type of facility, width, gender and location (refer Sec. 2.6). The pedestrians from Saudi Arabia, Iraq, Bangladesh, Indonesia and Sri-Lanka walked significantly slower than the pedestrians counterparts in the USA, UK or Canada over sidewalks facilities. This reduction in speed was due to their physique (height), culture (dress), attractions (presence of hawkers located along sidewalks), friction (due to parked vehicles), purpose of walking trip and environmental conditions (diurnal temperature and weather). Across the different studies in various countries, the mean speed over sidewalk facility was observed to be 79 m/min with a standard deviation of 11.17. Moreover, the minimum and maximum pedestrian speeds observed were 52 m/min and 98 m/min respectively (refer Tab. 1). Also, the speed-density relationship for sidewalk facilities (refer Fig. 6) showed that free flow speeds ranged between $65-85$ m/min, while jam densities ranged between $3.5-5.3$ ped/m^2 respectively. Moreover, in spite of having low density range, the studies conducted in Bangladesh and Iraq, showed higher jam density due to limited data points in the studies.

For walkway facility, studies were majorly conducted in the USA, UK, France and Netherlands (refer Tab. 2) and factors such as age, physique, gender, group size and attire were found to be most significant in affecting the movement of pedestrians (refer Sec. 2.2). Most of the researchers who studied pedestrian flow characteristics over walkways, tried to explain observed speed-density relationship through linear relationships, however in a few studies, exponential relationships (which lead to unrealistic jam densities) were also explored.

Earlier studies by [68,69,71] over stairways showed that only the age and gender factors were observed to affect the pedestrian speed, but in later studies by [77–80] the dimension of the stairway (i.e. riser dimension and stairway inclination) and direction of the movement (ascending and descending) were also found to play significant role in determining the movement characteristics of pedestrian over the stairways. The fundamental diagrams over stairways (refer Fig. 9) showed that the difference in speed of ascending and descending stairways ranged between $4-12$ m/min for different countries. Moreover, depending on the dimension of the stairways (i.e. tread, riser and width), location and direction of flow, the speed over stairways in ascending and descending directions were observed to be between $27-54$ m/min and $34-65$ m/min respectively (refer Sec. 2.3). Also, in most of the cases, the ascending and descending speed-density curves intersected each other, and the jam density of descending maneuver was lower than those of the ascending ones. In ascending scenarios, the pedestrians maintained lower gaps (which lead to higher jam densities), while in case of descending the pedestrians maintained higher gaps (which lead to lower jam densities) in order to avoid pushing the pedestrians in front and reducing the probability of falling down. Moreover, the higher walking speed while descending was observed as it required lesser effort to maneuver than in the case of ascending.

Early studies revealed that age and gender were the primary factors which affected movement over crosswalk facilities [84,85,88,89,94], while later, [97,98] reported; waiting time, season and delay to be significant factors which affected the crossing speed. Recently, [102, 104, 105, 108, 109], also explored the effect of accepted gap size and opposing flow on pedestrian crossing speed. The male pedestrians were observed to walk at a speed $4-9$ m/min higher than their female counterparts; and the older pedestrians walked at a speed $10-20$ m/min lower than the younger ones over the various types of crosswalks (refer Fig. 10). The studies conducted over grade separated facilities mainly focussed on preference of pedestrians over using overpasses, underpasses or cross at-grade. Factors such as presence of escalators, security and building fences encouraged pedestrians to use the grade separated facilities in contrast to the at-grade facilities (refer Sec. 2.5).

4.1.2 Pedestrian Level of Service

The studies conducted on the pedestrian level of service mainly looked into the type of survey conducted, LOS parameters and the various software/models used to develop the LOS. Researchers in the USA and Japan preferred to use both qualitative as well as quantitative data collection techniques in defining LOS over sidewalks; while in India, China and Malaysia, qualitative method was preferred. For quantitative technique over sidewalk facility, the most common parameters chosen were density, flow rate and width; while vehicle speed, pedestrian volume, safety, obstruction and width were observed to be the most essential parameters for qualitative survey (refer Tab. 3 and 4). In developing the LOS over sidewalk facility, Conjoint analysis, Landis method, HCM method, affinity propagation cluster algorithm and Gainesville method were preferred by various researchers across different countries.

Studies conducted over walkways measured space and flow rate as the most significant factors in developing LOS based on quantitative technique; while safety, comfort and accessibility were mostly chosen for LOS development using qualitative technique (refer Tab. 3 and 4). For LOS development over stairways, space and flow rate were highly preferred for quantitative surveying; while for qualitative survey technique, safety, conflict, accessibility and environment played a major role. Moreover, lighting/clear visibility was also a prominent factor which influenced pedestrians in using the stairways.

Flow rate, space and delay were the most common parameters used for development of LOS over crosswalk facility based on quantitative technique while vehicle speed and traffic control were the preferred parameters for qualitative survey. Different modelling techniques (Webster's delay model, fuzzy linear model and stepwise multi variable regression model) were used in defining LOS for the crosswalk facilities (refer Tab. 3 and 4).

4.2 List of consolidated factors affecting the pedestrian movement significantly over different facilities

This section presents a consolidated list of factors which were considered in the past by various researchers for study of different pedestrian facilities. The list quickly provides an idea about the different factors/ parameters which could be used by the budding researchers in the related research field.

Tab. 7 presents a list of important factors which were looked into while collecting or extracting the data over the different types of facilities for the study of pedestrian flow characteristics as well as the development of level of service. The different set of factors used by various researchers were based on their requirements/ objectives, and thus various techniques were used in order to estimate such factors.

As per Tab. 7, factors such as speed, flow, density, space, jam density, age, gender and direction of movement were observed as basic parameters which should be measured for sidewalks, walkways and stairways facilities (refer Tab. 2). Apart from the above mentioned basic factors; physique (height), culture (attire and privacy), environment (weather and temperature) and location (country) were the other significant factors which affected the walking speed of the pedestrians over sidewalks and walkways (refer Sec. 2.1). Moreover, Indian researchers observed that width also played a significant role in determining the pedestrian flow characteristics over sidewalks (refer Sec. 2.6). Over stairways and escalators, apart from the basic factors mentioned; stairway dimension (width, gradient and riser height) and trip purpose also played significant role in determining the pedestrian flow characteristics (refer Sec. 2.3). Depending on the type of crosswalk location (signalised or unsignalised), factors such as age, gender, group size and season were reported to be directly related to the average waiting time, delay and accepted gap size by the pedestrians (refer Sec. 2.4). Similarly, when using grade separated facilities (underpasses or overpasses), factors such as gender, age and group size were closely linked to the perception of pedestrians towards the vehicular flow, safety, security, connectivity, stairway dimension, frictions and crossing time (refer Sec. 2.5).

Similarly, from Tab. 7, in case of development of level of service, measurement of some basic factors were needed in both approaches (quantitative and qualitative). In case of quantitative measurement, flow rate and space were the basic factors measured; while safety was the most important factor used in qualitative measurement (refer Tab. 3 and 4). In studies conducted over sidewalks, for both quantitative as well as qualitative techniques; the most significant factors were traffic volume, width and obstruction, which affected the development of LOS (refer Tab. 3, 4, 5 and 6). In case of walkways, factors such as speed and width were used in quantitative approach; while comfort and accessi-

Pedestrian flow characteristics	
Type of facility	**Most prominent factors considered in past studies**
Sidewalk	Speed, flow, density, space, free flow speed, jam density, age, gender, environmental conditions, physical and cultural differences, width, location, attire, bi-directional movement
Walkway	Speed, flow, density, space, jam density, age, gender, physical differences, attire, location, group walking pattern, bi-directional movement
Stairway and escalator	Speed, flow, density, space, free flow speed, jam density, stairway dimension (width, gradient and riser height), uni- and bi-directional movement, trip purpose, age, gender
Crosswalk	Speed,age, gender, group size, crossing location (signalised or unsignalised), average waiting time, season, delay, accepted gap size
Grade separated	Vehicular flow, safety, security, connectivity, stairway dimension, frictions, crossing time, gender, age, group size

Level of service		
Type of facility	**Most prominent factors considered in the past studies**	
	Quantitatively	**Qualitatively**
Sidewalk	Density, age, space, flow rate, obstruction/friction, width, traffic volume (refer Tab. 3 and 5)	Vehicle speed, volume (of pedestrians, bicycles and motor vehicles), safety, surface, obstruction, width (refer Tab. 4 and 6)
Walkway	Space, flow rate, speed and width (refer Tab. 3)	Safety, comfort and accessibility (refer Tab. 4)
Stairway	Space,flow rate, environment, congestion (refer Tab. 3)	Safety, comfort, accessibility and environment (refer Tab. 4)
Crosswalk	Space, flow rate, volume (vehicle and pedestrian) and delay (refer Tab. 3 and 5)	Vehicle speed, volume (vehicle and pedestrian), safety, surface, width, traffic control (refer Tab. 3 and 5)

Table 7 List of consolidated factors considered in past studies in measurement of flow characteristics and development of LOS

bility factors were used in qualitative approach of the development of LOS (refer Tab. 3 and 4). In case of stairways, environment was the common factors which played a significant role in development of LOS model (Tab. 7). Depending on the type of crosswalk and type of measurement techniques used, from Tab. 7, it could be visualised that vehicle and pedestrian volume were the most important factors which affected the pedestrian LOS. Similarly, delay and width (in case of quantitative survey); surface and traffic control (in case of qualitative survey) were the significant parameters used in the development of LOS (Tab. 3, 4, 5 and 6).

4.3 Research gap

The past research works on pedestrian flow characteristics and development of level of service for different types of pedestrian facilities were presented in detail in the current paper. Although, lots of researchers have been working since many decades on various aspects of pedestrian behaviour, yet this review study identified following research gaps which could be taken up for future research:

- Studies dealing with the effect of crosswalk position and geometry on intersection delay and capacity.

- Understanding/ evaluating the effect of the crosswalk width and unprotected/protected road crossing behaviour on pedestrian speed.

- Considering factors such as effect of friction (i.e., vendors, waiting pedestrians, etc.), physical dimension of pedestrians, climatic conditions, gradient or roughness of the facility and culture (clothing and privacy) into modelling, along with studying their effect on walking speed for the different types of facilities.

- In order to address the heterogeneity in the behaviour of different pedestrians, concept of standard pedestrian equivalency factor could be explored in detail.

- Studying the movement characteristics/ requirements of disabled persons and how to make facilities better equipped for their easy movement needs to be rigorously looked into.

- Incorporating both qualitative and quantitative measures together in the development of PLOS for providing more reliable operational and policy recommendations.

- Developing statistical models for different locations based on the road safety level and incorporating the attitude and behaviour of the road users.

- Considering detailed analysis of qualitative factors such as safety, security, comfort, convenience and attractiveness across all facilities.

- Developing highly accurate and sensitive evaluation tool which would incorporate micro-scale factors affecting pedestrian walking environment over different facilities and capture pedestrian behaviour at microscopic level.

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