Chapter 5
Pedestrian Flow Characteristics Over Different Facilities: Findings and Way Forward

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5.1 Introduction

Walking or traveling on foot is the most efficient and effective mode of transportation. In India, as per IRC: 103 (Guidelines for Pedestrian Facilities 2012), short trips of 2 km are covered on foot daily. The 'pedestrians' or 'persons who travel on foot' form the most vulnerable road user group. To travel from one location to the other, pedestrians use different facilities like sidewalks, walkways, crosswalks, stairways, underpasses, overpasses, etc. These facilities are there to minimize the interaction between the pedestrians and the motorized traffic, and thus provide a safe and comfortable travel on foot. However, in India, post the new millennium, significant importance was given to vehicular traffic and thus curbing of pedestrian infrastructures began. This impels pedestrians to start using the carriageways and thus come in direct contact with vehicular traffic. Moreover, even the locations where proper sidewalks are available, they are either occupied by unauthorized vendors or parked vehicles, which again forces pedestrians to use the main carriageway.

A common method of segregating pedestrian-vehicular movement is through at-grade facilities (in the form of signalized/unsignalized crosswalks) or grade-separated facilities (in the form of overpasses/underpasses). However, past studies (Herms 1972; Koepsell et al. 2002) have shown that providing signalized crosswalks may sometimes be hazardous, as vehicles tend to drive even during their red phase. Provision of grade-separated facilities even does not ensure proper utilization of the facilities, due to poor maintenance, absence of proper security measures, and elevators/escalators. These situations lead to pedestrians crossing at grade using illegal median openings and thus coming in direct contact with the motorized traffic (Golakiya et al. 2019).

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The movement of the pedestrians is defined by different pedestrian flow characteristics like macroscopic/fundamental (speed, flow, density, and area module/space) or microscopic (demographic, cultural, and physique) characteristics. The relationships between these macroscopic parameters help in predicting the free-flow speed, jam density, and maximum flow rate/capacity. The development of fundamental diagrams form the basis for developing level of service (LOS) models for different pedestrian facilities and thus the prediction of the capacity of the facilities. Predicting the LOS helps in understanding the existing condition of the facilities, and thus improving them to enhance the walking comfort to the pedestrians. As the pedestrian flow characteristics vary across different countries, it is of utmost importance to conduct a detailed study for setting up the guidelines under the Indian context.

The flow characteristics can vary across different regions or countries, as well as across different pedestrian facilities. Therefore, it is extremely important to understand that the walking behavior of pedestrians is different across at-grade facilities (sidewalk, walkway, and crosswalk) and grade-separated facilities (overpass, underpasses, and stairways). US-HCM (2010) and Indo-HCM (2018) define the pedestrian facilities into nine different types: sidewalks, walkways, pedestrian zones, queuing area, crosswalk (marked and unmarked), underpasses (subways), overpasses (foot over bridges: FOBs and skywalks), stairways, and shared pedestrian-bicycle paths (refer to Fig. 5.1). Before any data collection and analysis, one needs to identify the type of pedestrian facility which is appropriate for the required study.

Post identification of the facility, it is essential to collect authentic data to understand the behavior of pedestrians, and thus develop macroscopic/microscopic models as well as predict the LOS. Across the globe, different researchers used various data collection techniques (videography, questionnaire, controlled experiments, and manual counting) to come up with practical and feasible solutions based on the actual field conditions. It is crucial to understand the importance and necessity of collecting data using the appropriate data collection technique. As different data collection techniques have their own set of challenges and limitations, selection of the appropriate technique needs to be identified first before proceeding with it.

Once the data has been collected from the field, the subsequent important part is the extraction of data using manual, semi-automatic, or fully automatic techniques. Among the different techniques, the manual technique is quite time-consuming, however, it captures most of the essential microscopic pedestrian flow characteristics. On the other hand, to extract pedestrian trajectory data, the fully automatic technique can be used. While using the appropriate data extraction technique, one needs to carefully extract the essential information, which can help in the development of macroscopic and microscopic models for the facility. Dynamic modeling (Henderson 1971; Helbing 1991; Pauls 1995; Hughes 2002; Colombo et al. 2012), continuous modeling (Helbing and Molnár 1995; Lakoba et al. 2005; Parisi and Dorso 2007; Zhou et al. 2020), and discrete modeling (Blue et al. 1997; Fukui and Ishibashi 1999; Lämmel and Flötteröd 2015; Burstedde et al. 2001; Guo and Huang 2008; Ruiz and Hernández 2018) form the three primary modeling approaches for estimating pedestrian walking behavior over different facilities and across different geometries.
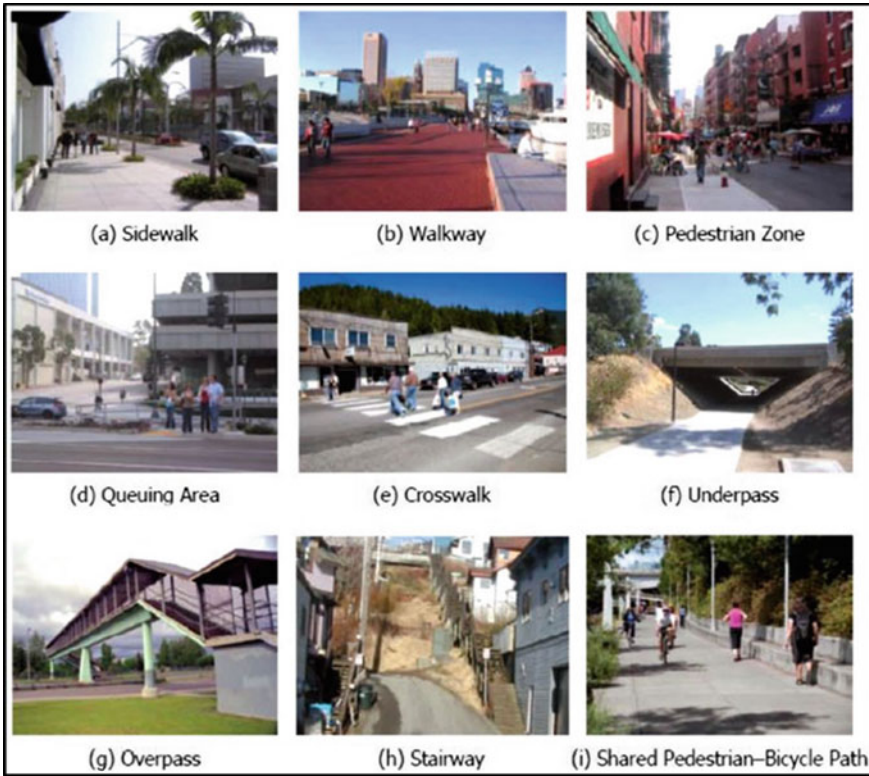
Fig. 5.1 Types of pedestrian facilities (*Source* Exhibit 3.14, US-HCM (2010))

The dynamic modeling approach is more of a macroscopic modeling approach, whereas continuous and discrete modeling approaches are microscopic in nature.

The current chapter presents the types of pedestrian facilities, different pedestrian flow characteristics, methods of field data collection, microscopic/macroscopic modeling approaches, pedestrian level of service, application of soft computing approaches in pedestrian studies, and the way forward.

5.2 Types of Pedestrian Facilities (At-Grade and Grade-Separated)

In India, the most common type of pedestrian facilities are at-grade (sidewalk, walkway, and crosswalk) and grade-separated (FOB, skywalk, underpass, and stairway). Figure 5.1 shows the different pedestrian facilities as per US-HCM (2010).

Table 5.1 shows the description of the different at-grade or grade-separated pedestrian facilities available for either crossing or through movement of pedestrians.

Table 5.1 Definition of different pedestrian facilities under Indian scenario (as per Indo-HCM (2018))

Facility	Grade	Important descriptions
Sidewalk/footpath	At-grade	• Raised path along side of road • Separated from motorized vehicles by curbs and guardrails • Accommodate the highest volume of pedestrians • Width varies in the range 1.5–5 m
Walkway		• Located far away from vicinity of motorized traffic • It is unraised and wider than sidewalk
Crosswalk		• Provided for safe and easy crossing • Can be provided at intersections (signalized/unsignalized) or mid-blocks
Overpass (FOB and skywalk)	Grade-separated	• Elevated facilities which either allow easy and continuous crossing access (FOB) or connect one strategic location to another (skywalk) • Should be provided with ramps/elevators/escalators along with stairways
Underpass (subway)		• Underground facilities which allow safe dispersal from one side of the road to another
Stairway/escalators elevator		• These are facilities which provide vertical connectivity between grade-separated and at-grade facilities

5.3 Parameters Related to Pedestrian Flow Characteristics and Infrastructure Geometry

5.3.1 Parameters Related to Pedestrian Flow Characteristics

The pedestrian walking behavior over various facilities is dependent on different macroscopic and microscopic factors. The macroscopic parameters are related to the speed, flow, density, space, and the relationship among these parameters. The macroscopic parameters are extracted using the videography data collection technique. The developed relationships between the different macroscopic factors help in developing fundamental diagrams (FD)/fundamental relationships between the parameters which can be useful for predicting the free-flow speed (FFS), jam density (K_j), maximum flow rate (capacity), and level of service estimation of the facility. The different macroscopic factors along with the fundamental diagrams are discussed as follows:

Pedestrian flow: This represents the number of pedestrians crossing a particular section of a facility over a specified time (ped/min). However, while analyzing one

generally uses the term flow rate, i.e., the flow over the effective width considered (ped/min/m) as one generally tends to compare or combine different locations together.

Pedestrian speed: The walking speed of the pedestrian refers to the time taken to cross a particular trap length (i.e., distance between two sections) over a specified time. It is represented as m/s. However, while developing fundamental diagrams, m/s is converted to m/min.

Pedestrian density: The density refers to the average number of pedestrians over a defined walkway or queuing area. The factor is generally represented as ped/m^2. The minimum density is generally observed at free-flow speed, i.e., when pedestrians are able to choose their walking speed over different facilities. However, at jam density condition the walking speed becomes zero, i.e., pedestrians come to standstill.

Pedestrian space: The area module or walking space is defined as the average area required by the pedestrian to pass through a particular facility. Space is considered as the inverse of density, i.e., in m^2/ped. Indo-HCM (2018) suggests a minimum area of 0.18m^2 and 0.26m^2 for pedestrians without and with luggage, respectively. The space is an important parameter for defining LOS.

Fundamental diagrams: The fundamental diagrams represent the relationships between different macroscopic pedestrian flow characteristics. The development of such diagrams help in estimating the capacity and the LOS of the facility. Across different studies, the authors preferred to use either linear or exponential speed–density relationships. Table 5.2 shows the different studies conducted over various facilities and the observed/adopted speed–density relationships.

Figure 5.2a–c shows the different speed–density relationships established for sidewalks, walkways, and stairways.

Apart from the macroscopic factors, understanding the microscopic factors helps in the development of models for the prediction of walking speeds over different facilities. These microscopic factors help in the identification of the relevant factors which affect the walking behavior over the different facilities. Some of the definitions of such factors are discussed as follows:

Age: The age of the pedestrian plays a significant role in determining the walking speed over different facilities. In general, the age is divided into 3 categories:

Table 5.2 Developed relationships across different facilities

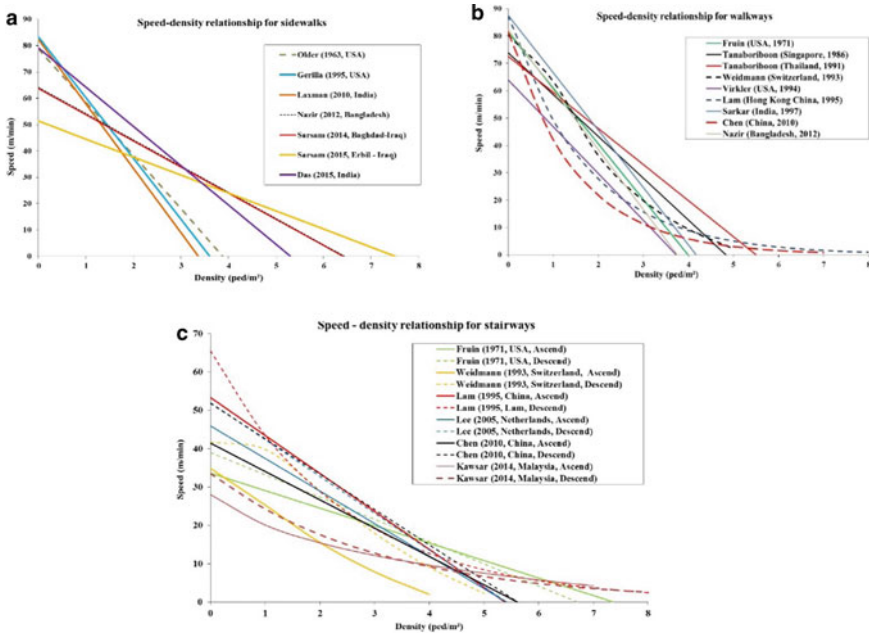| Facility	Authors	Speed–density relationship
Sidewalk/walkway	Oeding (1963), Older (n.d), Navin and Wheeler (n.d.), Bargegol and Gilani (2015), Rungta and Sharma (2016)	Linear/exponential
Stairway/FOB	Fruin (1971), Daly et al. (1991), Weidmann (1993), Shah et al. (2017a), Indo-HCM (2018)	Linear

Fig. 5.2 Speed–density relationships for sidewalk, walkway, and stairway facilities (*Source* Banerjee et al. (2018))

<18 years, 18–55 years, and >55 years. However, dividing the age into 4 or 5 categories gives a better representation of the actual age category which affects the speed. Studies across different facilities (sidewalks, crosswalks, and stairways) reported that young pedestrians (<18 years) walk faster than the middle-aged (18–55 years) and older (>55 years) pedestrians (Fruin 1987; Montufar et al. 2007; Patra et al. 2017; Shah et al. 2017b).

Gender: Gender plays a crucial role while defining the walking speed of the pedestrians over different facilities. In general, male pedestrians are observed to walk at a higher speed than females by 7.7 m/min, 7 m/min, 6.6 m/min, 5.6 m/min, and 7.6 m/min across sidewalk, walkway, crosswalk, ascending stairway, and descending stairway (Polus et al. 1983; Chandra et al. 2014; Siddharth and Vedagiri 2018; Gore et al. 2020).

Luggage: The size and weight of the luggage plays an important role in the walking speed, especially when pedestrians are traversing slopes/stairways. The luggage generally considered across different studies are trolleys, side bags, backpacks, carrying children, etc. Previous studies reported that depending on the type and grade of the facility, walking with luggage reduced the walking speed by 3–15% (Shah et al. 2017b; Morrall et al. 1991; Laxman et al. 2010).

Use of handheld devices: The use of mobile phone/handheld devices tends to distract the pedestrians and thus influence their walking speeds. The reduction of walking speed while using the phone, texting, and calling were 3 m/min, 1.2 m/min, and 15.6 m/min (New York Pedestrian Study 2006; Krasovsky et al. 2017; Reynolds 1999).

Group size/group formation: The size and formation of groups tend to impact the walking speed of the pedestrians while using different pedestrian facilities. When a pedestrian walks alone in comparison to walking in a group of 2 or more pedestrians, their walking speed is impacted. Previous studies reported that while walking in groups, pedestrians tend to engage in talking or observe the surroundings more. This leads to a reduction in walking speed by 12–20% (Laxman et al. 2010; New York Pedestrian Study 2006; Reynolds 1999; Al-Masaeid et al. 1993; Rastogi et al. 2011; Vanumu et al. 2017).

Disability: In general, while studying pedestrian walking behavior, one may have the tendency to overlook specially abled/disabled pedestrians. However, they form an integral part of the pedestrian network and their inclusion/exclusion can affect the overall walking speed of the system. Previous researchers (Clark-Carter et al. 1986; Wrigbt et al. 1999; Arango and Montufar 2008; Sharifi et al. 2016) reported that under complex environments, the walking ability of pedestrians with special-ability decreased.

Direction of movement: The direction of movement (i.e., whether a pedestrian is ascending/descending stairways or walking in a major/minor direction of flow) impacts the overall walking speed. The studies conducted by previous researchers (Daly et al. 1991; Lee and Lam 2006; Alhajyaseen et al. 2011) reported that if a pedestrian was walking in the minor flow direction or was ascending stairways, then their walking speeds significantly decreased.

The speed and flow rate were the most common macroscopic factors, while gender, age, and luggage were the commonly used microscopic factors considered across different studies in the past. However, in order to estimate the pedestrian flow characteristics, it is essential to estimate the density (macroscopic factor) along with the mobile use, group size, movement direction, and disability (microscopic factors) as these factors significantly affect the walking behavior of the pedestrians.

5.3.2 Parameters Related to Infrastructure/Geometry

Apart from different pedestrian flow characteristics, there are infrastructure/geometry-related factors, which can influence the walking behavior of the pedestrians. These factors are related to the physical characteristics as well as user characteristics [IRC-103 (Guidelines for Pedestrian Facilities 2012)]. Physical characteristics are the factors which the pedestrians observe while using the facility and which can affect their walking behavior/choice. On the other hand, the user

Table 5.3 Description of different physical and user characteristics which influence pedestrian behavior

Characteristics	Description
Physical characteristics	
Surface	It indicates whether there are any cracks or bumps to comfortable walking
Width	It defines the walkable width of the facility which can accommodate enough pedestrians for comfortable travel
Obstructions	The presence of garbage bins, trees, electric poles, and hoardings can obstruct the travel path of the pedestrians
Encroachments	The encroachments are generally in the form of vendors/beggars/standing pedestrians which reduce the overall walkable width of the facility
Potential for vehicular conflict	To segregate the pedestrians (using the at-grade) facilities from the vehicular traffic, guardrails and raised facilities can be helpful
Continuity	For disabled and old pedestrians, the continuity of a particular walkway helps in easy traversing
User characteristics	
Safety and Security	Safety is generally ensured by segregating pedestrians from vehicular traffic by guard rails/raised walkways. The security is ensured through proper street lighting, police patrolling, and installation of CCTV cameras
Comfort	Comfort is generally measured through the proper shade, provision of chairs/benches, and washrooms
Walk Environment	The surroundings (i.e., whether clean and free from stinks) provide a pleasant travel experience

characteristics are the factors which the pedestrians perceive while using a particular facility, and they can influence their choice toward using a particular facility. Table 5.3 shows the different physical and user characteristics which impact walking behavior.

The past studies reported that among different physical and user characteristics, the most common factors used by different researchers were width, surface, safety and security, and comfort level of the facility (Banerjee et al. 2018). However, considering the other factors mentioned in Table 5.3 would be beneficial to the development of better infrastructures for pedestrians.

5.4   Data Collection Techniques

Researchers across the globe use quantitative (videography technique), qualitative (questionnaire/perception survey), controlled (experimental), manual counting, and

semi-manual data collection techniques. The initial studies on pedestrian behavior used manual counters and tally mark sheets to calculate the pedestrian flow. However, the major issue with such a technique was that it is quite labor-intensive which limits the extracted amount of data.

Subsequently, majority of the past studies used either videography or questionnaire techniques for data collection, and some even used both the techniques. Table 5.4 discusses the pros and cons of the different data collection techniques for pedestrian walking behavior study.

Table 5.4 shows that across different grade and at-grade facilities, commonly extracted parameters for qualitative survey were demographics (age, gender, and luggage), safety, and width (Parida and Parida 2008; Bivina et al. 2018; Rankavat and Tiwari 2020; Banerjee et al. 2020; Banerjee and Maurya 2020). Similarly, in the case of videography data collection, apart from demographics other common parameters extracted were flow rate, speed, density, and space (Shah et al. 2017b; Marisamynathan and Lakshmi 2016; Sahani and Bhuyan 2017; Patra et al. 2020).

Controlled experiments were also set up to study pedestrian behavior under different geometric conditions. Mostly, these studies were conducted to understand the walking behavior of pedestrians under different types of geometries like bottlenecks, corridors, etc. These studies explored to understand the impact of flow direction, pedestrian–pedestrian interactions, and flow characteristics (Daamen and Hoogendoorn 2003; Helbing et al. 2007; Seyfried et al. 2009; Chattaraj et al. 2009).

Apart from the videography/questionnaire/controlled data collection techniques, recently a semi-manual data collection technique has been developed by Banerjee et al. (Banerjee et al. 2021). To study the pedestrian path/trajectory, top-down videos are essential, however, getting top-down videos (to capture trajectory data over facilities) is difficult where shade is available at low heights. In the semi-manual method, the camera can be placed on a tripod stand with a frontal camera angle (similar to the CCTV), and data can be extracted using a vanishing point method [as developed by Fung et al. (2003)]. Even from high vantage points, it could be difficult to mark the foot of each pedestrian (especially at moderate to high densities) to get the position coordinates of the pedestrians. Thus, this method tries to mark the head of the pedestrians (considering the appropriate elevation corrections) and converts the video image coordinates to real-world coordinates. Apart from pedestrian coordinates, this technique can also provide body dimensions, trajectories, gaps maintained by pedestrians, and other microscopic features. Figure 5.3 shows the snapshot of the semi-manual technique.

5.5 Level of Service (LOS)

The level of service is defined as the "quantitative stratification of a performance measure that represents the quality of service, measured on an A-F scale, with LOS A representing the best-operating conditions from the traveler's perspective and LOS F the worst (US-HCM 2010)". The performance of a facility under the existing

Table 5.4 Data collection technique and crucial parameters considered

Type of data collection	Description	Special cautions to be considered	Limitations	Advantages	Facility	Parameters considered for study
Questionnaire/qualitative/perception survey	In interviewer-administered questionnaire survey, the respondents are randomly selected and those willing to undergo entire survey are interviewed	1. The sample size per location needs to be estimated 2. Hoardings should be set up to capture the view of the pedestrians and significance of the study	1. Respondent rate is low (especially during peak hours) 2. Enumerators should be well trained	1. Perception under current existing conditions can be reported 2. Future required improvements can be detected	At-grade (sidewalk/walkway/crosswalk)	Demographics (age, gender, luggage), surface, comfort, accessibility, safety, security, obstruction, width, and actual and perceived risks
					Grade-separated (overpass/underpass)	Demographics, height of facility, length of facility, walkable width, safety, security, illumination, comfort, walk environment, slope, and surface

(continued)

Table 5.4 (continued)

Type of data collection	Description	Special cautions to be considered	Limitations	Advantages	Facility	Parameters considered for study
Videography/quantitative survey	It is the most primitive method of data collection where pedestrian movement is captured using cameras set up at high vantage points	1. Camera needs to be set up at high vantage point 2. The trap length and total width need to be measured 3. Duration of data collection should be well planned in advance	1. Positioning of camera can impact the data collected 2. The enumerators need to be trained in the functioning of the camera	1. Permanent record available 2. Macroscopic and microscopic factors can be extracted	At-grade (sidewalk/walkway/crosswalk)	Demographics, flow rate, speed, density, area module/space, width, vehicle volume, obstruction, v/c ratio, pedestrian volume, number of lanes, and delay
					Grade-separated (overpass/underpass)	Demographics, group size, use of handheld devices, travel direction, speed, flow rate, density, space, geometric dimensions, direction of movement, and travel time

(continued)

Table 5.4 (continued)

Type of data collection	Description	Special cautions to be considered	Limitations	Advantages	Facility	Parameters considered for study
Controlled experiments	Locations where field data collection is difficult, researchers develop experimental set up to study pedestrian walking behavior	1. The sample size needs to be predefined 2. The pedestrians participating in the experiment need to be well aware of the study	1. Actual walking behavior available from the field may not be captured 2. The sample size may be restricted	1. With a small sample size of 20–100 pedestrians, the study can be conducted 2. Different geometries (bottlenecks and corridors) can be set up	Bottleneck (wide, narrow), corridor (straight, ring shaped, circular, angled)	Flow under normal and panic situations, step length and frequency, speed, and characteristics

Fig. 5.3 Snapshot of developed semi-manual technique (*Source* Banerjee et al. (2021))

conditions and subsequent need for its redesigning depends on the LOS of the facility. LOS of a facility can be defined by different ranges (4–6) for either qualitative method (using perception) or quantitative method (by videography) or a combination of both. The development of LOS helps in understanding the current situation and thus improving the facilities in the near future. Table 5.5 shows the different studies related to LOS which have been conducted using both techniques.

Table 5.5 Studies related to quantitative and qualitative LOS development

Data collection technique adopted	Facility studied	Author	Measures of effectiveness
Qualitative/Perception survey	Sidewalk/Walkway/Stairway	Sarkar (2003), Marisamynathan and Lakshmi (2018), Parvathi (2018), Bivina and Parida (2019)	Perception score
Quantitative/videography		Fruin (Fruin 1971), Polus et al. (1983), Sahani and Bhuyan (2017), Rastogi et al. (2014)	Flow rate, density, speed, space, v/c ratio
Quantitative and Qualitative	Sidewalk/Stairways/FOB	IRC-103 (2012), US-HCM (2010), Indo-HCM (2018)	**Quantitative**: Flow rate, space **Qualitative**: Perception score

5.6 Modeling Approaches Related to Pedestrian Studies

The movement of pedestrians is generally modeled using a dynamic approach, continuous approach, or discrete approach. The dynamic approach deals with pedestrian behavior at the macroscopic level, while continuous and discrete models deal with pedestrian motion at the microscopic level.

5.6.1 Dynamic Approach

It is a macroscopic modeling approach based on Navier–Stokes or Boltzmann equations, and which considers the pedestrians as gas or fluid. Henderson (1971) used the Navier–Stokes equation to predict the motion of pedestrians. Thereafter, Helbing (1991) improved Henderson's equation to develop a fluid dynamic model based on the gas kinetic theory of the Boltzmann constant. Further, Pauls (1995), Hughes (2002), and Colombo et al. (2012) used fluid dynamics to predict the walking behavior of pedestrians. The main drawback of dynamic modeling is that pedestrian interaction at the individual level is not available.

5.6.2 Discrete Approach

The discrete approach is portrayed by the Cellular Automata (CA) model where the behavior of individuals is defined using a discrete particle-based hopping model using a certain set of local rules. The CA approach was used by Nagel and Schreckenberg (1992) on vehicular traffic which was later adopted by Blue et al. (1997) for pedestrian motion. The developed approach could imitate the goals of the pedestrians in reality, such as avoiding conflicts and minimizing traveled distance. As per the CA model, the subject pedestrian finds its way from origin cell to destination cell using a certain set of rules. The model was further modified by Blue and Alder (1998, 1999, 2000, 2001) under normal situations for different directional flows (uni-, bi-, and multi-) using various cell sizes. Figure 5.4 shows the pedestrian movement captured using the CA model.

Later on, using the developed CA concept, researchers tried to model the pedestrians' movement for normal situations (Fukui and Ishibashi 1999; Lämmel and Flötteröd 2015) and evacuation scenarios (Burstedde et al. 2001; Guo and Huang 2008; Ruiz and Hernández 2018). The different interesting features observed at normal/evacuation scenarios were back-stepping, collective phenomenon, and oscillation at doors.

Fig. 5.4 Illustration of pedestrian movements (Blue et al. 1997)
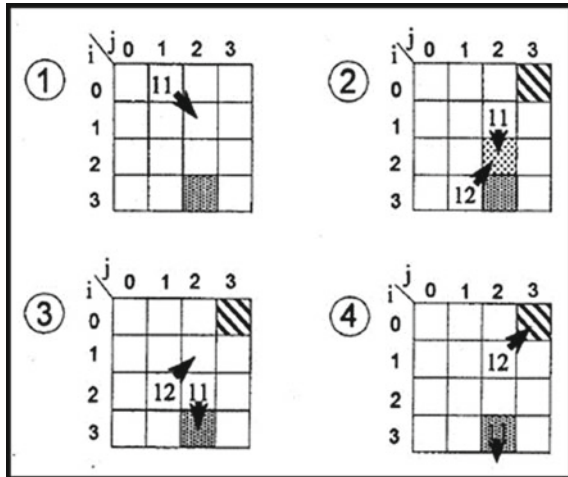
5.6.3 Continuous Approach

Based on the social fields' concept of Lewin (1951), the social force model (a continuous modeling approach) was developed to model the pedestrian movement. The first social force model was developed by Hirai and Tarui (1975) inspired by a model developed by Suzuki and Sakai (1973) based on the motion of shoals. Later, Okazaki (1979) used the magnetic force to develop a social force model. However, in order to overcome the limited computational power of the developed models, Helbing and Molnár (1995) proposed the social force model for normal situations. The model was based on three formulations:

a. Reaching destination using the shortest path.
b. A repulsive effect from other pedestrians and objects (walls).
c. An attractive effect from other pedestrians and objects (window displays).

The developed model was further modified (by adding new parameters or modifying existing parameters) by various researchers (Lakoba et al. 2005; Parisi and Dorso 2007; Zhou et al. 2020) for normal and emergency/evacuation situations. Different parameters (like memory effect, respect area, panic, self-stopping mechanism, and collision avoidance) were introduced to analyze pedestrian interactions at microscopic levels. Features such as reduction of pushing behavior, self-slow mechanism, clogging, and lane formation were observed under normal/evacuation scenarios.

Some major benefits of the social force model over the cellular automata model are:

- Gives a realistic description of pedestrian movement at a microscopic level considering pedestrian intentions, desired velocities, and pair interactions.
- Self-organizing phenomena are well portrayed.

- Flexible while considering geometry.
- Commercially available software Viswalk (2013) which has a better graphical user interface used a social force model to predict the pedestrians' movement behavior. Moreover, the developed model can also be calibrated using a genetic algorithm through the COM interface in MATLAB. In general, the Mean Absolute Percentage Error (MAPE) between the observed and simulated velocities of the pedestrian are calculated to validate the performance of the model.

5.7 Application of Soft Computing Tools in Pedestrian-Related Studies

Soft computing has become an integral part of the transportation sector. Different soft computing approaches such as tree-based methods (random forest, gradient boosting machine, decision trees, etc.) and neural networks (artificial neural network and deep neural network) have found significant importance in addition to traditional methods such as regression modeling. These methods use different hyper-parameters to tune the best fit model to predict the training and testing data. The evaluation metrics commonly used are mean absolute percentage error (MAPE), root mean squared error (RMSE), and mean absolute error (MAE). Table 5.6 shows the different studies which have been conducted using soft computing approaches. Although the application of soft computing in the field of vehicular traffic is widely explored, however, its application in pedestrian-based research is limited.

Table 5.6 Application of soft computing approaches in pedestrian-related studies

Soft computing technique used	Author	Type of study	Evaluation metric used
ANN	Yuen et al. (2014)	Intelligent based route choice modeling	–
ANN	Das et al. (2015)	Interrelationships between flow parameters	MAE, RMSE
CNN	Dong et al. (2016)	Automatic age estimation	–
ANN	Cohen and Dalyot (2019)	Pedestrian traffic flow prediction	–
ANN	Chakraborty et al. (2019)	Crash prediction modeling	MAE, RMSE, R^2
GLM, GBM, RF	Banerjee et al. (2020)	Overpass utilization modeling	AUC, MSE, Accuracy

Note ANN—Artificial Neural Network, CNN—Convolution Neural Network, GLM—Generalized Linear Model, GBM—Gradient Boosting Machine, RF—Random Forest, MAE—Mean Absolute Error, RMSE—Root Mean Squared Error, R2—Coefficient of Determination, AUC—Area Under Curve, and MSE—Mean Squared Error

5.8   Concluding Remarks and Way Forward

The current study tried to present an overview of pedestrian facilities, flow characteristics, techniques for data collection, different modeling approaches, level of service, and application of soft computing techniques. The major findings of the study are as follows:

- Across the globe, researchers majorly used qualitative or quantitative data collection techniques. Wherever data collection from the field was cumbersome, the researchers used controlled experiments across different geometries.
- Majority of the studies developed linear/exponential relationships between speed and density for different at-grade and grade-separated facilities.
- The most common parameters related to pedestrian flow characteristics which were considered across different studies, were macroscopic: speed and flow rate; and microscopic: gender, age, and luggage condition.
- In the case of parameters related to pedestrian infrastructure, the most common factors considered were width, surface, safety–security, and comfort.
- Majority of the studies either used perception survey or videography survey techniques to develop LOS standards.
- Macroscopic parameters (flow rate, density, speed, and space) and perception score were important measures of effectiveness while developing LOS using perception and videography techniques, respectively.
- Dynamic modeling only represents the pedestrians' interaction at the macroscopic level. However, continuous (social force model) and discrete (cellular automate) models could replicate the microscopic interactions.
- Self-organizing phenomena such as back-stepping, collective phenomenon, pushing behavior, clogging, and lane formation could be observed under normal/evacuation scenarios.
- Soft computing techniques have not been well explored for pedestrian-related studies. The majority of the studies used ANN to predict the flow characteristics and crash prediction.

Some important challenges for the future research direction are as follows:

- Applying both qualitative and quantitative techniques for data collection, which might provide information on both the actual ground condition as well as the perception of the pedestrians. This can be useful for the development of LOS standards for different facilities as well.
- Apart from linear/exponential speed–density models, other relationships can also be explored.
- While studying microscopic parameters, the size of the group, use of handheld devices, direction of movement, and disability need to be considered to have a better understanding.
- Grade-separated facilities need to be studied in more detail under the Indian scenario.

- Model development should focus on studying pedestrian interactions at microscopic levels to predict the self-organizing phenomenon.
- Application of well-calibrated and validated simulation models can be explored to evaluate the crowd management strategies during large gatherings.
- The development and application of soft computing approaches should be encouraged for different pedestrian studies.

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