STM JOURNALS

Trends in Transport Engineering and Applications

Volume 1, Issue 1
www.stmjournals.com

Review of Simulation Techniques for Microscopic Mobility of Pedestrian Movement

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Abstract
Simulation techniques are very useful for developing models or systems over time to represent the real-world scenarios. The model represents the key characteristics or behaviors/functions of the selected physical or abstract system or process. Simulation techniques are useful when the real system cannot be engaged, because of inaccessibility, or dangerous or is unacceptable to engage or does not exist. Microscopic characteristics of pedestrian traffic consider speeds, walking directions, distances between pedestrians, relative positions, passing behavior and group behavior. In microscopic approach individual pedestrians are evaluated in the study which is required for detailed design of pedestrian infrastructure. In this study various microsimulation models, tools and microscopic data collection techniques have been discussed briefly to encourage designers, policy planners to implement pedestrian facilities considering the microscopic approach. Level of service criterion and guidance for capacity manual can be implemented by including microscopic characteristics of pedestrians. Microscopic simulation models are broadly divided into five categories named cellular-based model, physical force-based model, behavioral modeling, queuing network model and agent-based model. Various simulation tools are basically based on these four models. Nowadays a new model combining cellular automata and social-force model has been proposed. This study is required to update designers or planners about various microscopic approaches and helpful for designing real situation with details of pedestrian movement to improve pedestrian traffic facilities.

Keywords*: Pedestrian flow, microscopic simulation, social force, cellular automata, magnetic force*

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INTRODUCTION

Computer simulation is an efficient tool for analysis of real situation and also it is useful to test various conditions those are not possible to be observed in field, difficult to observe and expensive or hazardous for experimentation. "Simulation is the imitation of the operation of a real-world process or system over time" [1]. Microsimulation was started in mid-1980s with the rapid progress of computer technology. In microscopic simulation individual behavior of a person can be observed with interaction between various persons. Each pedestrian occupies certain space in time as an individual agent in the microscopic model. In macroscopic pedestrian simulation only behavior of a group can be observed but interaction between pedestrians cannot be considered. For detailed design purpose, there is a need to consider macroscopic pedestrian simulation such as lane changing behavior of pedestrians. In this study a review of past studies in this field has been covered. The study has been done on various microscopic simulation models and software. More realistic performance of pedestrian movement can be described using microscopic pedestrian simulation model. Simulation technique can be used to develop an optimal approach in design before implementation of any policy in pedestrian infrastructure.

Walking has benefits on health, environment and economy. Safety and security, convenience and government policy should be formulated to encourage pedestrians. The provisions of pedestrian capacity in HCM 2012 are principally guided by macroscopic approach and there is a definite possibility that microscopic modeling can further fine-tune the results.

Past Studies on Pedestrian Microsimulation

Microscopic pedestrian simulation depicts the process of creating a virtual model of pedestrian infrastructure to simulate the interactions and other microscopic detail. This involves treating each pedestrian in the model as a unique entity with its own goals and behavioral characteristics; each possessing the ability to interact with other entities in the model. It has two branches, simulation model and simulation software. Microscopic pedestrian simulation using computer started since the mid-1980s [2]. An analytical approach for microscopic pedestrian model was proposed by Henderson in 1974 [3]. Gipps and Murksjo in 1985 proposed a microsimulation model for interactions between pedestrians considering existence of repulsive forces between pedestrians [4]. In 1987, Reynolds studied microscopic-pedestrian-simulation-model (MPSM) from computer games and animations [5]. Two classes of parameters were produced, first class parameters (mean speed and flows of the various classes of pedestrian) which were set by the user to characterize the situation being simulated and second class of parameters were transparent to the user and consist of the pattern of scores and maintain a straight-line movement when approaching another pedestrian too closely. Graphical computer simulation was used in this study. A model was proposed by Okazaki and Matsushita in 1993 to simulate pedestrian movement with evacuation and queuing considering the motion of a magnetized object in a magnetic field [6]. EVACSIM simulation tool was performed a process-oriented, discrete-event simulation to model pedestrian as a queuing network customer and the pedestrian movement as the queuing network process by Lovas in 1994 [7]. Helbing and Molnar in 1997 demonstrated the detailed design and pedestrian interaction using microscopic pedestrian simulation to determine the flow performance of pedestrians [8]. Helbing *et al.* described microscopic simulations of pedestrian streams based on a behavioral force model [9]. Teknomo *et al.* in 2000 reviewed various microscopic simulation models [10]. A two dimensional cellular automaton model was proposed by Burstedde *et al.* in 2001 [11] to simulate pedestrian behavior considering particle attraction and repulsion between identical and different particles respectively and lane formation. Teknomo proposed a new microscopic data collection system considering αTXY database, used as a bridge between microscopic pedestrian simulation models, video data collection and microscopic pedestrian characteristics in 2002 [12]. He proposed the design of pedestrian facilities not merely a space allocation but other forms of flow controls in space, time and direction in the microscopic level when pedestrian interaction is considered. Microscopic simulation of evacuation processes for pedestrian dynamics was done in 2002 using cellular automata by Kirchner and Schadschneider [13].

Pedestrian flow has been simulated by Hoogendoorn and Bovy considering optimal control and differential games to observe pedestrian walking behavior [14]. NOMAD microsimulation tool was introduced by Hoogendoorn [15]. Run-time parameters, network topology, parameters describing walking behavior, Activity scheduling and route choice parameters, times and parameters describing emergency conditions and location of virtual detector loops were considered as input parameters in the simulation model. NOMAD is based on activity area, route choice (tactical level) and walking behavior (operational level). A cellular automata model was proposed by Jian *et al.* to simulate bi-direction pedestrian movement considering the human flexibility and intelligence as well as the virtual ‘‘force’’ among pedestrians [16]. Pedestrian movement mechanism was studied using the proposed model. Teknomo described possible application of the microscopic pedestrian model [17]. A new model was developed to improve the quality of pedestrian movement by considering their interaction in a microscopic level. Three microscopic simulation scenarios were considered to validate the model. Progress in simulation studies for pedestrian traffic has been described by Zhang *et al.* [2].

Zacharias *et al.* predicted pedestrian volume along corridors in a shopping environment which was based on the several simple pedestrian-centered heuristics [18]. These heuristics for the computer models are random walk, distance-limited walk, connectivity walk and connectivity walk. Discrete choice model was proposed by various researchers to determine direction and speed of pedestrians at each time interval [19–21]. A numerical model was proposed by Yamamoto *et al.* in 2007 to simulate pedestrian dynamics based on Real Coded Lattice Gas model [22]. A generic approach was proposed by Hoogendoorn and Daamen to identify parameters for microscopic models and particular for walker models [23]. Xianqiang *et al.* studied group behavior of pedestrians based on psychophysiology and behavior science [24]. Asano *et al.* proposed a microscopic movement model to describe the decision-making process of pedestrians trying to minimize their travel times while avoiding collisions using a multi-player game theory [25]. A calibration methodology was proposed for microscopic pedestrian models using pedestrian trajectory data by Hoogendoorn and Daamen [26]. All kinds of statistical tests, t-test for parameters significance and likelihood-ratio test was considered in this methodology. A microscopic pedestrian simulation model consisting of an operational model which describes pedestrians' avoidance behavior and a tactical model, describes pedestrians' route choices has been proposed by Asano *et al.* [27]. A simulation model has been proposed for pedestrian collective behavior by Zhang and Han considering follow effect, deterrent effect and rejection effect to influence pedestrian decisions [28]. Level of Service scheme was proposed by Kretz considering density of pedestrians, speed constant and crowd pressure over the square of a second speed constant for microscopic simulation of pedestrians [29]. A model was developed using social force model and cellular automata model to determine movement method for different groups of pedestrians by Kormanova [30].

Overview on Microscopic Pedestrian Simulation Models

Microscopic simulation models studied in past are described in this section. Microscopic simulation models are broadly divided into four categories, cellular-based, physical force-based, queuing network and agent-based model. Various microscopic simulation models, benefit cost cellular model, cellular automata model, magnetic force model, social force model, behavioral model, queuing network model (CA-Ped model, floor field model) and agent-based models are described here.

Cellular-Based Model

Benefit Cost Cellular Model [5]

This model was proposed by Gipps and Marksjo in 1985 considering pedestrian as a particle in a cell. Area of a cell was considered as 0.5 × 0.5 m^2. They proposed a cell can be occupied by only one pedestrian at a time and score will be assigned based on proximity to pedestrians considering repulsive effect of the nearby pedestrians. The score in each cell is the sum of the score generated by pedestrian individually when the field of two pedestrians overlaps. Pedestrian movement is based on the net benefit. The score was calculated considering eight-cell neighbor of the pedestrian.

Score was assigned to each cell based on its proximity to pedestrians. Repulsive effects of nearby pedestrians with the balanced against the gains that is the subject moving towards his destination represent by the obtained score of a cell individually. Gipps and Marksjo define "scores in the surrounding cells are approximately inversely proportional to the square of the separation of pedestrians in the two cells." Movement of each pedestrian obtained by net-benefit**[S-$P(\sigma_i)$]** value which was obtained by subtracting the cost of moving closer to other pedestrians (as measured by the score in the cell) from the gain the subject obtains by moving closer to his destination. $\mathrm{P}(\sigma_\mathrm{i})$ can be estimated using Eq. (1) or Eq. (3) and using Eq. (2) $\mathrm{Cos}\ \sigma_\mathrm{i}$ will be evaluated.

$$P(\sigma_i) = K \cos\sigma_i \, |Cos\ \sigma_i| \quad (1)$$

where,

K = A constant of proportionality to enable the gain of moving in a straight-line to be balanced against the costs of approaching other pedestrians too closely.

σ_i = Angle by which the pedestrian deviates from a straight-line to his immediate destination when moving to cell i.

$$Cos\sigma_i = \frac{(x_i - S)(d - S)}{|x_i - S||d - S|} \quad (2)$$

where,
x = location of the target cell,
S = location of the subject
D = location of the destination

$$P(\sigma_i) = \frac{k(x_i - S)(d - S)|x_i - S||d - S|}{|x_i - S|^2|d - S|^2} \quad (3)$$

Cost score of cell was calculated by considering Eq. (4),

$$S = \frac{1}{(\Delta - \alpha^2) + \beta} \quad (4)$$

Cellular Automata (CA) Model **[31–35]**

Cellular Automata is a discrete choice model for microscopic simulation. A cellular automaton consists of a regular grid of cells, each in one of a possible finite number of states, updation in discrete time steps with local, identical interaction rules. There are two types of cellular automata – stochastic cellular automaton and asynchronous cellular automaton based on the updating properties. Evaluation of each cell is based on the neighborhood of each cell in lattice. In one-dimensional lattice, the neighborhood consists of the cell itself plus its adjacent cells. There are $2^3 = 8$ possible combinations of cell values in the neighborhood. There are three types of neighborhoods used for two-dimensional cellular automata – von Neumann neighborhood, Moore neighborhood and extended Moore neighborhood.

Cellular automata model was proposed by Neumann and Ulam in early 1950. Cellular automata are mathematical models for systems to produce complicated patterns of behavior. These models are discrete in space, time and state variable. It consists of a regular grid of cells with a finite number of k possible states and updation of model is based on local interaction rules. Conway's (1970) "Game of Life" is an application of cellular automata microscopic simulation in two-dimensional concept [36]. Wolfram (since 1983) worked in this field. He worked on classification of CA models as mathematical models for self-organizing statistical systems and application of CA in various fields like biology, sociology, mathematics, physics, art and technology. Nagel and Schrekenberg have done simulation for freeway traffic using cellular automata model [37]. A study was done by Packard and Wolfram on two-dimensional cellular automata with values of 0 and 1 at each side considering k = 2. Quantitative characterization of global properties of two-dimensional cellular automata was discussed by them [38]. Evolution of each cell can be determined considering neighborhood for each cell. Blue and Adler worked on CA to simulate fundamental pedestrian flows considering unidirectional movement [39]. Blue and Adler proposed a microsimulation model, CA-Ped model for modeling bi-directional pedestrian walkways considering three modes of bi-directional pedestrian flow flows in directionally separated lanes, interspersed flow and dynamic multi-lane (DML) flow [40]. A bionics approach to describe the interaction between the pedestrians in evacuation process was described by Kirhner and Schadshneider using cellular automata [13]. Two-dimensional cellular automaton model for the simulation of pedestrian dynamics was proposed by Schadschneider to simulate large crowds faster than real time considering nearest-neighbor interactions and floor-field model was introduced [41]. A new tool Real Coded Cellular Automata invented by Yamamoto *et al.* to describe pedestrian dynamics considering Moore neighborhood for movement of pedestrians [22]. Effect of back stepping and phase transition of the bi-direction pedestrian movement was studied using cellular automata by Fang *et al.* [42].The impact of the sensitivity parameters k_S and k_D quantitatively during evacuation processes described by Kirhner *et al.* using stochastic cellular automaton [43]. The two-dimension pedestrian movement in corridor, the phase transition phenomenon of pedestrian movement was simulated by Jian *et al.* considering exchange position between face-to-face pedestrians [16]. The considerable probability of position-exchange is about 0.20 in this study. Various cellular automata rules were simulated using Matlab by Athanassopoulos *et al.* to provide an excellent platform for performing complex computations with the help of only local information [44]. Other languages like C, C++, and FORTRAN can be used for cellular automata simulation.

CA-Ped Model **[40, 45, 46]**
Model was proposed by Blue and Adler considering emergent behavior for bi-directional pedestrian walkways. Three modes of bi-directional pedestrian flow modeling flows in directionally separated lanes, interspersed flow and dynamic multi-lane (DML) flow were considered. Simulation results were able to capture fundamental properties of pedestrian movement. Sidestepping, forward movement and conflict mitigation were considered as fundamental elements of pedestrian movements in bi-directional microscopic pedestrian flow modeling. CA rule set was applied with two parallel update stages according to local rules for each pedestrian. This parallel update procedure was used by Rickert with other researchers and is also used by Simon and Gutowitz [46] for vehicular traffic.

A circular lattice of size 1000*10 with square cells at 0.457 m per side was used (occupying a minimum area of 0.21 m^2) as input parameters for simulation. 19 different densities ranging from 5 to 95% lattice occupancy in intervals of 5% was considered in experiment to observe fundamental parameters of pedestrian flow. Speed distribution was done based on three different types of walkers (fast, standard, and slow). Six different directional splits were considered for experiments, varied from uni-directional flow to balanced flow.

In speed-density relationship linear Greenshields model aligned with the beginning and end-points of the CA-Ped-based unidirectional curve divides the two halves of the S-curve into two arcs positioned on either side of the Greenshields line. In this model, interspersed flow and DML bi-directional curves differ from the unidirectional and bi-directional separated flow S-curve. CA-Ped model considers integer arithmetic calculations. Maximum flow occurs within 0.2 to 0.5 density ranges in this model. In lane changing condition, mode locking occurs at low-density range and at high-density range effects hinder overall flow and sidestepping affect the shape of the S-curve for speed-density. The inclusion of place exchange allows the model to avoid deadlocks.

Floor Field Model **[47]**
Floor field model is a cellular automaton model for studying evacuation dynamics. The static floor field describes the shortest distance to an exit door and the dynamic floor field is a virtual trace left by the pedestrians. Floor field model was extended for modeling panic behavior of people evacuating from a room by Nishinari and others. Lane formation in a corridor, herding and oscillation at a bottleneck was simulated in the extended model. The coupling to the static field and dynamic field characterizes, friction parameter, constants control diffusion and decay of the dynamic floor field and maximum distance from the wall or obstruction are used input parameters in this study. In this paper to calculate the visibility graph and Dijkstra's algorithm were used and the effect of the static floor field was modified by a factor pw (consider Eq. (5)) the wall effect is restricted up to the distance D_{max} from the walls,

$$pw = \exp(k_W \min(D_{max}, d)) \qquad (5)$$

where, d = Minimum distance from all the walls,
k_W = A sensitivity parameter.

Spatial adapted parameters were introduced in intelligent floor field cellular automation model by Kirik *et al.* to simulate different types of pedestrian movement, from regular to panic [48]. Pedestrian evacuation in rooms with internal obstacles and multiple exits was simulated by modified floor field model by Huang *et al.* considering logit-based discrete choice principle [49]. A modified floor field cellular automata model for simulating the pedestrian evacuation was proposed by Guo and Huang considering a high-density crowd is asymmetric, accumulative and transferable [50]. The space for evacuation was discretized into smaller cells; each pedestrian was allowed to occupy multiple cells considering the interaction among pedestrians as characterized by their own inertia.

Physical Force-Based Model

***Magnetic Force Model* [51, 6]**

Magnetic *Force Model* was developed by Okazaki (1979–93). Movement of each pedestrian was simulated considering the motion of a magnetized object in a magnetic field. Magnetic forces were estimated considering Coulomb's law, depending on intensity of magnetic load of a pedestrian and distance between pedestrians. Another force collision between pedestrians and pedestrian with obstacles was also included in this model. In this model each pedestrian in the system had given a positive charge and destinations such as doorways or service counters considered as negative charge. This magnetic effect means that pedestrians exert a repulsive force upon each other.

This model was developed by Okazaki to study pedestrian behavior during evacuation in real architectural space using two kinds of magnetic poles. A model was simulated by Okazaki and Matsushita considering two cases, evacuation from an office building and movement of pedestrians in queue spaces. Location of the starting point, walking velocity, time to start walking, orientation, destination and method to walk (indicated route, shortest route, way finding) data were collected for each pedestrian and location of walls, openings, columns, exits, and queue spaces data were observed for the plan of study location as input for the model simulation.

Magnetic forces were calculated according to Coulomb's law (Eq. (6)):

$$F = \frac{kq_1q_2}{r^3} \times x \qquad (6)$$

where,

F = Magnetic force (vector)

k = Constant value

q_1 = Intensity of magnetic load of a pedestrian

q_2 = Intensity of a magnetic pole

x = Vector from a pedestrian to a magnetic pole

r = Length of r

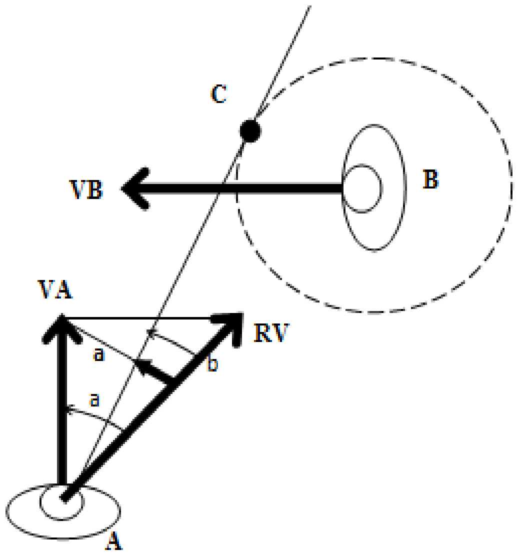

Fig. 1: *Acceleration Is an Act to Avoid Collision with Others.*

Acceleration (**a**) to avoid collision with other pedestrians was calculated by Eq. (7) and presented in Figure 1:

$$a = V_A. \cos(\alpha).\tan(\beta) \qquad (7)$$

where,

a = Acceleration acts on pedestrian A to modify the direction of RV to the direction of line AC,

α = Angle between RV and V_A

β = Angle between RV and AC

V_A = Velocity of pedestrian A

V_B = Velocity of pedestrian B

RV = Relative velocity of pedestrian A to pedestrian B

AC = Contacting line from the position of pedestrian A to the circle around pedestrian B.

Social Force Model [8, 9, 52–55]

The social force model was developed by Helbing, Molnar and Vicsek. Social force is a continuous model and is defined as vector describing acceleration or deceleration effects that are caused by social interactions rather than by physical interactions or fields. Social force model describes pedestrian behavior considering interaction with environment and other people and is explained by attractive and repulsive forces. Social forces measure internal motivations of individuals for movement. In this model, social, psychological and physical interactions of pedestrian-pedestrian and pedestrian-environment effects are considered to describe social force. Self-organizing phenomenon can be described using social force model.

A microscopic model similar to gas-kinetic and fluid dynamic equations was proposed by Helbing. Attractive and repulsive effects of pedestrians were observed for constant density, formation of groups, superposition of attractive and repulsive effects, break of symmetry for avoidance behavior by Helbing to model pedestrian behavior mathematically. A physical force is acting to reach a certain destination at a certain time. Optimal behavior of pedestrian movement was simulated by trial and error process to give better behavioral strategy in this model. Lewin's theory was followed to introduce psychic tension to act towards its destination.

Systematic temporal changes of the preferred velocity of a pedestrian were described by a vectorial quantity $\mathrm{F}_{\alpha}(\mathrm{t})$ interpreted as social force [55]. Social force describes concrete motivation to act. Social force model was described by Helbing and Molnar in 1995 to determine the motion of pedestrian α considering following effects. Desired direction of motion $\vec{e}_{\alpha}$ of pedestrian estimated and acceleration of pedestrian due to avoidance was estimated using Eqs. (8) and (9). A repulsive effect due to other pedestrians and borders was evaluated by Eqs. (10) and (11). Using Eq. (12), attractive effects were calculated for modeling. Total motivation for walking model considering all effects is presented in Eq. (13). Equation (14) represents social force model.

i) $\vec{r}_{\propto}^{0}$ is destination of a pedestrian α and desired direction of motion $\vec{e}_{\alpha}$ of pedestrian estimated using the following equation,

$$\vec{e}_{\alpha} = \frac{\vec{r}_{\alpha}^{k} - \vec{r}_{\alpha}(t)}{\|\vec{r}_{\alpha}^{k} - \vec{r}_{\alpha}(t)\|} \quad (8)$$

where,
$\vec{r}_{\alpha}(t) =$ Actual position of pedestrian α at time t.
$\vec{r}_{\alpha}^{k}$ = Goals of a pedestrian are usually rather gates or areas than points.

Acceleration due to avoidance processes was calculated by:

$$\vec{F}_{\alpha}^{0}(\vec{v}_{\alpha}, v_{\alpha}^{0}\vec{e}_{\alpha}) = \frac{1}{\tau_{\alpha}}(v_{\alpha}^{0}\vec{e}_{\alpha} - \vec{v}_{\alpha}) \quad (9)$$

where,
Actual velocity = $\vec{v}_{\alpha}$
Desired velocity = v_{α}^{0}
Deviated velocity = $v_{\alpha}^{0}\vec{e}_{\alpha}$
Relaxation time = τ_{α}

ii) Repulsive effects of other pedestrians **β** can be calculated by:

$$\vec{f}_{\alpha\beta}(\vec{r}_{\alpha\beta}) = -\nabla_{\vec{r}_{\alpha\beta}} V_{\alpha\beta}[b(\vec{r}_{\alpha\beta})] \quad (10)$$

where,
Repulsive potential = $V_{\alpha\beta}(b)$
$\vec{r}_{\alpha\beta} = r_{\propto} - \vec{r}_{B}^{\propto}$
$\vec{r}_{B}^{\propto}$ = Location of the border B that is nearest to pedestrian α

Repulsive effect from borders

$$\vec{F}_{\alpha B}(\vec{r}_{\alpha B}) = -\nabla_{\vec{r}_{\alpha B}} U_{\alpha B}(\|\vec{r}_{\alpha B}\|) \quad (11)$$

where,
Repulsive and monotonic decreasing potential = $U_{\alpha B}(\|\vec{r}_{\alpha B}\|)$

iii) Attractive effects $\vec{f}_{\alpha i}$ at places r_i can be modeled using the following formula:

$$\vec{f}_{\alpha i}(\|\vec{r}_{\alpha i}\|, t) = -\nabla_{\vec{r}_{\alpha i}} W_{\alpha i}(\|\vec{r}_{\alpha i}\|, t) \quad (12)$$

where,
Attractive, monotonic increasing potentials = $W_{\alpha i}(\|\vec{r}_{\alpha i}\|, t)$
$\vec{r}_{\alpha i} = r_{\propto} - r_i$

Repulsive affect and attractive effects on pedestrian behavior are summarized below:

$$\vec{F}_{\alpha\beta}(\vec{e}_{\alpha}, \vec{r}_{\alpha} - \vec{r}_{\beta}) := w(\vec{e}_{\alpha} - \vec{f}_{\alpha\beta})\vec{f}_{\alpha\beta}(\vec{r}_{\alpha} - \vec{r}_{\beta})$$

$$\vec{F}_{\alpha i}(\vec{e}_{\alpha}, \vec{r}_{\alpha} - \vec{r}_{i}, t) := w(\vec{e}_{\alpha} - \vec{f}_{\alpha i})\vec{f}_{\alpha i}(\vec{r}_{\alpha} - \vec{r}_{i}, t)$$

where,

$$w(\vec{e}, \vec{f}) := \begin{cases} 1 \text{ if } \vec{e}.\vec{f} \geq \|\vec{f}\| cos\varphi \\ c \text{ otherwise.} \end{cases}$$

Effective angle 2φ of sight for effect of perception
Total Motivation considering all the effects,

$$\vec{F}_\alpha(t) = \vec{F}_\alpha^0(\vec{v}_\alpha, v_\alpha^0\vec{e}_\alpha) + \sum_\beta \vec{F}_{\alpha\beta}(\vec{e}_\alpha, \vec{r}_\alpha - \vec{r}_\beta) + \sum_B \vec{F}_{\alpha B}(\vec{e}_\alpha, \vec{r}_\alpha - \vec{r}_B^\alpha) + \sum_i \vec{F}_{\alpha i}(\vec{e}_\alpha, \vec{r}_\alpha - \vec{r}_i, t) \quad (13)$$

The social force model is now defined by:

$$\frac{d\vec{w}_\alpha}{dt} := \vec{F}_\alpha(t) + fluctuations \quad (14)$$

According to Lewin, behavioral changes can be guided by social forces [56]. The computer simulations assumed that the desired speeds are Gaussian distributed with mean 1.34 m/s and standard deviation 0.26 m/s by Helbing and Molnar. To model pedestrian behavior acceleration towards the desired velocity, distance from other pedestrians and obstructions and attractive effects were considered as movement parameters by Helbing and Molnar. “Computer simulations of crowds of interacting pedestrians show that the social force model is capable of describing the self-organization of several observed collective effects of pedestrian behavior very realistically”[8]. A model for crowd movement was proposed by Lakoba *et al.* [57] as Helbing, Farkas, and Vicsek in 2000 considered each pedestrian a Newtonian particle subject to both physical and social forces. Dynamics of the crowd behavior were captured by Mehran *et al.* using social force model [58]. A computer vision method was adopted in this study to detect and localize abnormal crowd behavior. A grid was placed over the image and moves them with the flow field and extracts interaction forces. Social Force model is used by various simulators SIMWALK, VISSIM, VISWALK.

(i) SIMWALK

SIMWALK is flexible pedestrian simulation software focused on evacuation, transportation and urban planning applications. It is decision support software for traffic engineers, transit planners, architects and urban planners. It provides a range of traffic-related analysis tools like LOS, density, speed, person counts or space utilization analysis. As a microsimulation software, SIMWALK models every pedestrian as a single person with its behaviors which results in a realistic modeling and simulation of pedestrians. It is based on the (microscopic) social force model (SFM), developed by Helbing which describes the walking behavior of pedestrians at an operational level. The impact of the model simplifications on the simulation results was investigated by Steiner *et al.* [59].

SIMWALK Pro and SIMWALK Transport are used widely. SIMWALK Pro is a flexible and very easy to use simulation software for improving pedestrian logistics and flow issues in urban planning, evacuation and traffic management. Effectiveness of the model can be measured by density, walking speed, person counts, travel time, space, pedestrian trail and level of service (LOS). SIMWALK is applicable to any complex environment where CAD plans or drawings are available: train stations, airports, complex buildings, streets and urban places. Based on CAD plans, SIMWALK allows simulating any kind of pedestrian scenario, depending on the desired number of pedestrians, walking speeds, behaviors, waiting times, etc. SIMWALK is agent-based simulation software where every agent simulates or acts as a pedestrian with specific goals, walking speeds, delays and avoidance of congestion.

SIMWALK Pro is used for safety evaluation of stations, airports, sports stadiums, buildings, etc., event management, urban planning, integration of pedestrian scenarios in normal traffic simulations (intersections) and evacuation studies.

SIMWALK Transport work on integrate timetables, simulation and analysis of passenger movements in train, metro and bus stations, design of stations and related objects like platforms, stairs, ticket counters etc. to optimize passenger safety and efficiency and optimize train time table, passenger transfer times and connections.

(ii) VISSIM

PTV VISSIM is a microscopic multi-modal traffic flow simulation software package developed by PTV Planung Transport Verkehr AG in Karlsruhe, Germany. VISSIM is a microscopic, time step and behavior-based simulation model developed to model urban traffic and public transport operations and flows of pedestrians. The movement of pedestrians is based on the social force model in VISSIM. The basic idea is to model the elementary impetus for motion with forces analogously to Newtonian mechanics. The forces which influence a pedestrian's motion are caused by his intention to reach his destination as well as by other pedestrians and obstacles. This simulation model was validated in a threefold way according to Helbing from ETH Zurich. Firstly, macroscopic parameters were calculated and compared to empirical data; secondly, it was ensured that microscopic effects like lane formation in counter flow situations and stripe formation in crossing flow situations are reproduced and thirdly, a realistic impression of resulting animations was in the focus. The social force model controls the operational level and parts of the tactical level, whereas the strategic level is defined by the user input. Two modes are used in VISSIM namely vehicle traffic mode and pedestrian traffic mode.

Parameters considered to define the BASE DATA menu are pedestrian types and pedestrian classes, walking behavior parameter sets, area behavior types, display types (of areas) and level properties for multi-story models. In the TRAFFIC menu pedestrian compositions should be defined as a set of default data (types of pedestrians, classes of pedestrians, compositions of flows of pedestrians) will be generated if VISSIM installation includes the pedestrian's component. Sahaleh *et al.* studied adjustment of various parameters having direct impact on the driving force in VISSIM (social force model) for model calibration [60].

(iii) VISWALK

VISWALK simulates and analyzes walking behavior whether in free space, inside buildings or in connection with mass gathering environments. PTV VISWALK enables you to simulate and model the human walking behavior. Planners use this software tool whenever pedestrian flows need to be simulated and analyzed. Space optimization, capacity planning, evacuation analysis, plan and optimize mass attendee events, routing and queuing analysis are various applications of VISWALK.

NOMAD Model (Normative Pedestrian Behavior Theory) [15, 61]

A microscopic pedestrian flow simulation model NOMAD developed by Serge Hoogendoorn in the project of "Collective walking behavior of pedestrians in public areas," financed the Netherlands Organization of Scientific Research (NWO), Delft University of Technology. Input parameters for this model are description of the walking infrastructure, parameters describing behavior of the different pedestrian types, activity and location activity areas, description of the demand for each activity pattern and the composition of this demand into pedestrian types, location of detectors, and run-time parameters.

Collective pedestrian flow phenomenon, lane formation, homogenous strips in crossing pedestrian flows, behavior at bottlenecks can be observed using NOMAD model. Optimal routes and locations where activities are performed, trajectories for each pedestrian in the walking area, passage times, speeds, and gaps of pedestrians passing the detectors and contour plots of speeds and densities are the output parameters of NOMAD model. There are two levels in NOMAD, viz., activity area and route choice level (tactical level) and walking behavior (operational level). It is based on activity and areas where activities are performed and the routes between them can be determined. In this model, route choice and activity area choice depends on the prevailing traffic conditions. Destination-route choice model and walker models are included in NOMAD model. Network topology, traffic demand per activity pattern, special/incident conditions, composition of pedestrian flow and walking parameters are the input parameters in this model. Theoretical assumptions and modeling issues for the pedestrian activity scheduling and route choice, as well as the walking behavior have been described by Hoogendoorn [15].

NOMAD model was implemented by Hoogendoorn and Bovy [14] and they proposed for NOMAD Walker model. The walking behavior of pedestrians can be described by walker model. The walker model can be described by Eqs (15) and (16).

$$\frac{d\vec{x}_p(t)}{dt} = \vec{v_p}(t) \quad (15)$$

$$\frac{d\vec{v}_p}{dt} = \vec{a_p}(t) \quad (16)$$

where, x_p= Location

v_p= Velocity

a_p= Acceleration

The acceleration model for the basic Nomad model can be described using Eq. (17):

$$\vec{a_p}(t) = \vec{s_p}(t) + \vec{r_p}(t) + \vec{o_p}(t) + \vec{p_p}(t) + \vec{\epsilon_p}(t) \quad (17)$$

where, s_p= Deviation from the pedestrian's destination

r_p= Avoidance of other pedestrians (Repulsion)

o_p= Avoidance of obstacles

p_p= The contact forces that arise when pedestrians are colliding

ϵ_p= A stochastic noise for population heterogeneity and unrepresented factor

A modified microscopic NOMAD Walker model was proposed by Campanella *et al.* [62]. Modification in the NOMAD model was done by improving pedestrian repulsion term (r_p) given in Eq. (18). Perceived lateral displacement of pedestrian q is shown in Figure 2.

$$a_p^{front-}(t) = -A_p^- \sum_{q \epsilon P_{front}^-} e^{-\frac{d_{pq}^*(t) * d_{pq}^{y^*}(t)}{R_p^-}} \quad (18)$$

where,

P_{front}^- = Set of pedestrians perceived by pedestrian p walking in the front part of the influence area and in opposing direction

A_p^- = Interaction factor for opposing pedestrians

$d_{pq}^{y^*}(t)$ = Perceived lateral distance from pedestrian p towards pedestrian q

$\frac{1}{R_p^-}$ = Spatial discount of pedestrian p for opposing pedestrians

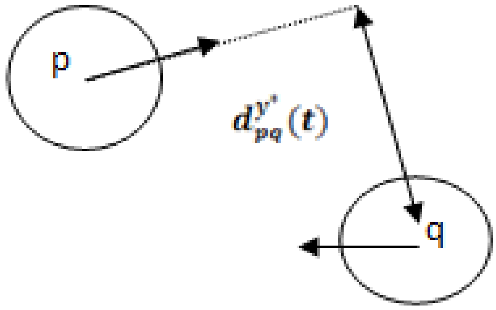

Fig. 2: *Perceived Lateral Displacement of Pedestrian q.*

Queuing Network Model

Queuing network models are basically applied to modeling pedestrian movement to simulate evacuation plan. This model approach is discrete event Monte Carlo simulation [12]. It represents graphically the routes for movement of objects through this network considering the optimizing path to reach destination. Connected points in a network are known as nodes and connections are known as links (Figure 3).

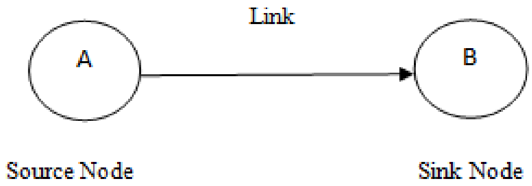

Fig. 3: *Diagram of a Network.*

Pedestrian flows can be described in terms of probability functions in queuing theory. The pedestrian's arrival in the queue, the service mechanism and the service are considered elements in a queuing system. Weighted-random choice was applied to choose a link and The FIFO (First in First Out) priority rule was the inherent rule in this model development. Emergency evacuation from a building was modeled by Chalmet *et al.* in 1982 to address occurring bottleneck using network optimization [63]. A state-depended queuing model was proposed by Smith to capture nonlinear effects of increased occupant traffic flow along emergency evacuation routes [64]. Pedestrian flow was modeled as a queuing network by Lovas *et al.* where each pedestrian was treated as a separate flow object, interacting with the other objects [7]. EVACSIM simulation model was used for evacuation in this study. Thompson and

Marchant used SIMULEX model to simulate escape movement from a large building [65]. Queuing network has been studied by Bolch *et al.* [66]. Mathematical expressions of the physical quantities for N-Parallel and N-Fork and probability density distribution of service time in N-Parallel and N-Fork was calibrated by Bolch *et al.* and also other concepts were used for other studies related to queuing network modeling [67]. The evacuation time is one of the performance measures. Simulation for evacuation of a large room with one door has been studied by Kirchner *et al.* considering clogging and stucking phenomena of pedestrians and as a result it was concluded that friction has not only quantitative effects but also qualitative changes [43]. A model was proposed by Pairisi and Dorso considering discrete nature of the pedestrian fluid allowing to set individual physical parameters to study microscopic dynamics of pedestrian evacuation [68]. The microscopic mechanism involved in the efficiency of the room evacuation process has been studied by Song *et al.* [69]. Yanagisawa *et al.* introduced the effect of delay for walking from the head of the queue to the service windows in the queuing theory, and the suitable type of queuing system under various conditions was obtained for each kind of people separately [70]. Yanagisawa *et al.* in 2010 improved efficiency of queuing systems using theoretical analysis and experiments by shortening the moving time in queue [71]. Also they have introduced in 2013 queuing model that means waiting time in parallel becomes shorter when both the arrival probability of pedestrians and the effect of walking distance are large considering simple distributions, geometric and exponential distributions [72].

(i) SIMULEX [65, 73]

SIMULEX is a computer model for evacuation of buildings. A series of tests were done by Thompson and Marchant in 1995 to model the large group of movements of people through different numbers of exists of different widths [65]. It can be used to model the effects of the invasion of personal space considering the movement of individual persons and represent a psychological modeling.

(ii) PEDROUTE

PEDROUTE is a computer simulation system which was originally developed by Gerry Wetson at London Underground Limited. The intellectual property rights were then sold to Halcrow Fox. PEDROUTE has been used extensively to model crowd parameters in underground networks around the world. It is actually the extension of Fruin’s level of service and relies on that data being an accurate representation of the crowd dynamics with respect to local geometry that appeared as limitation to the PEDROUTE system. To assess passenger movement, behavior and congestion level within the station, the PEDROUTE pedestrian simulation model is used. The various physical elements of the station (concourses, passageways, platforms, stairs, escalators, etc.) and the passenger demand for each element of the station are defined in PEDROUTE.

Agent-Based Model

Agent is an entity able to perform some activities autonomously and also a part of community. Pedestrian modeling concept using agent-based model was traced from flocking behavior of birds by considering individual agents or boids were modeled by Reynolds in 1987. Agent technologies are used in a wide variety of applications, from robotics to economic modeling [74]. This model approach discrete in space and in time considering the environment in which the simulation takes place is a lattice of cells. Agent-based models are general, flexible, modular and able to take advantage of distributed resources. This model is also known as multi-agent system (MAS), agent-based simulation (ABS), or individual-based modeling (IBM). This model also uses grid of cells as cellular automata invented simulating grids’ interactions with neighbors [75]. Batty studied spatial modeling changing to dynamic simulations of the individual and collective behavior of individual decision-making to observe randomness and geometry of local movement and spatial structures emerge from such actions [76]. Three experiments were done by him for modeling, first for local scale street scenes where congestion and flocking is all important, second for coarser scale shopping centers such as malls where economic preference interferes much more with local geometry, and finally for semi-organized street festivals where management and control by police and related authorities is integral to the way crowds move. Turner and Penn developed behavioral models considering movement rules from Gibson's principle of affordance [77]. Both theoretical issues such as ABM definition and architecture, and practical issues such as ABM applications and development platforms were studied by Chen [78]. The behavior and interactions of pedestrians were modeled as an agent-based system by using a combination of massively parallel processes simulating individual pedestrians, and a series of behaviors of these simulated pedestrians in the interactions with each other and their environment by Kerridge *et al.* [79]. Bandini *et al.* studied an agent-based approach encapsulating in the pedestrian's behavioral model effects, representing both proxemics and a simplified account of influences related to the presence of groups in the crowd [80]. Vizzari and Manenti have studied on an agent-based model of pedestrians considering groups as an influencing factor to the behavior of its members [81].

(i) PEDFLOW [82]

PEDFLOW model was developed in Java. This is a conceptual approach to represent pedestrian environments and behaviors. In this model, agents are represented as pedestrians and objects. PEDFLOW model has the ability to represent the microscopic details considering movement of individual pedestrian as a separate entity to produce a more realistic representation of reality. Service quality factors can be extracted directly from the model. Current position of every pedestrian, blockage, edge, and kerb were considered in modeling. PEDFLOW uses a hybrid simulation technique with a fixed-time step and space was considered using grid system. Rules are updated by parallel update system. An agent contains data about blockages, edges, and kerbs into the shared grid-based structure. Basic structure of the model from the point of view of a single pedestrian with grid size of 650 mm is given in Figure 4. At a more congested situation, six people per square meter (large crowd) can be considered in modeling.

Data collection for this model has been done by the authors' own hand-held, digital camcorders and city center CCTV cameras in accordance with formal ethical codes of conduct. Cameras will be mounted at vantage point to maximize the field of view; the current settings typically allow a viewing area of approximately 10–15 m length of individual pedestrian's trajectories and walking speeds, together with information about their gender, group size and approximate age data will be attracted from this study. Also aggregate measures of pedestrian activity such as flow and density will be calculated.

Five parameters were identified for decision-making process of the person namely static awareness (SA), preferred gap size (PGS), desired walking speed (DWS), personal space measure (PSM) and choice parameter. The results of the rule activation are the direction in which the pedestrian is to move and the speed of movement. Evaluation of rule depends on the entity value. Objective (behavior of the pedestrian is that which is directly observable and measurable) and subjective (unobservable aspects: perceptions, past experiences, and attitudes) aspects are represented by the model. This model allows determining practical uses of pavement or general pedestrian spaces and the individual differences that have an effect on behavior and the levels of service useful for planning purposes. The PEDFLOW model is able to provide urban designers and planners with the level of service and of measures of pedestrian behavior at individual and aggregate levels. The model also provides a systematic and consistent framework to assess the efficacy of street designs and traffic management measures for pedestrians. A detailed study was undertaken on multi-agent microsimulation system (PEDFLOW) designed by Kerridge *et al.* to represent conflicting pedestrian flows at a detailed level on a section of sidewalk, or in an open or enclosed space with obstructions [79].

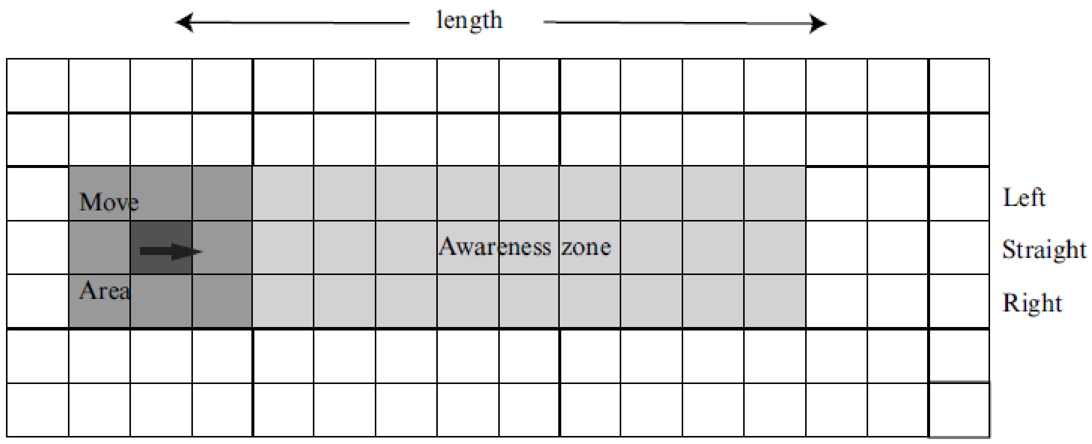

Fig. 4: *Basic Structure of the Model.*

(ii) SimPed [83]
SimPed has been developed by Delft University of Technology in cooperation with Movares. Winnie Daamen developed SimPed during his PhD research. The system can analyze pedestrian flow in high density area, shopping centers and football stadiums, or at major events. This system is essential for architects, planners, and managers to design pedestrian areas. SimPed simulates the infrastructure of public transport facilities or other public areas (city centers, shopping centers, stadiums). Levels-of-service for pedestrians, locations of congestion, and walking times for transferring passengers are output of this simulation technique. Modeling of interactions between passengers is included in this system.

(iii) STREETS [84]
STREETS is a two-stage agent-based modeling considering GIS-based (geo-information system) socio-economic data (Pre-model) in the first stage to populate the second stage which is an agent-based dynamic model of pedestrian activity. Socio-economic data were used in this model considering a variety of agents with different behavior. The effects of configuration and attractors are integrated in STREET through their effects on agent behavior. Income and gender are considered as socioeconomic characteristics to create an activity schedule for the agent. Behavioral characteristics consider detailed behavior of agents including speed, visual range, and fixation. Second stage of STREETS model was developed completely within the Santa Fe Institute's SWARM simulation environment. SWARM offers a rich set of tools to develop and extract information from a model. Those tools will be used to collect statistics about agent movement, the popularity of different buildings under different configurations and so on.

(iv) The GA-Ped Model [80]
GA-Ped model is a reactive agent-based model which is characterized by an environment, discrete both in space and in time. The model employs floor fields to support pedestrian navigation in the environment. Space representation of the model was derived from the cellular automata (CA) theory. As per the theory of CA, space was discretized into small cells which may be empty or occupied by exactly one pedestrian. In this model, environment was defined as Env = (Space, Fields, Generators) where the space is a physical, bounded bi-dimensional area where pedestrians and objects are located; the size of the space is defined as a pair of values (x, y) specified by the user. Space was modeled as three-layered structure where each layer represents a particular aspect of the environment. First layer contains all the details about the geometry of the environment and the properties of each cell, second layer gives information about the values of the floor fields of each cell and the third layer stores the position of each pedestrian. Update rules are applied to all pedestrians considering shuffled sequential update. Pedestrians are modeled as simple reactive agents and each pedestrian is also endowed with a set of observation fans which is defined by the following formula:

Observation fan = < type, xsize, ysize, weight, xoffset ,yoffset >
Pedestrian = < pedID, groupID, schedule >

The behavior of a pedestrian was represented in four stages – sleep, context evaluation, movement evaluation and movement. Pedestrian movement was controlled by Moore neighborhood. Pedestrian movement, cell walkability floor field value, presence of pedestrians belonging to a given group, goal-driven component, group cohesion, geometrical repulsion, proxemic repulsion, and stochasticity were considered to explain behavior and transmission rules.

Data Collection Techniques for Microscopic Modeling

Cheung and Lam used time-lapse photography technique for data collection which provides microscopic analysis of flow characteristics [85, 86]. Time-lapse photography technique was used by Lam and Cheung to collect data and images were processed manually which was very labor-intensive [87]. Teknomo *et al.* have collected data using NTXY database to calculate the pedestrian traffic-flow characteristic (flow rate, speed and area module) [10]. Hoogendoorn *et al.* proposed an approach to automatically detect and track pedestrians from a sequence of high-quality video images [88]. Lens corrections for pin-cushion distortion and radiometric correction were combined with dedicated techniques to use the special features of the video data for successful application of automated detection and tracking of pedestrians. Data was collected by Willis *et al.* using either a standard hand-held digital camcorder mounted on a tripod, or CCTV cameras operated by collaborators within the local city councils for PEDFLOW model [89]. Video recordings were converted into digital format (.avi) using a standard videocapture card housed in a PC. Also in this study image analysis software was used to plot the frame-by-frame position of selected objects for the duration of the clip. Li *et al.* proposed a computer vision technique for the automated pedestrian data collection [90]. An efficient pedestrian tracking algorithm, the MMTrack, was used to detect and track pedestrians. A homography matrix was used to create a mapping from world coordinates to image plane coordinates. Walking speed measurements methodology and screen line counts methodology were used for automatic counting, tracking, and walking speed measurements.

Comparative Analysis of Microsimulation Models

Comparison of various microscopic pedestrian simulation models described in this section is made. Benefit cost cellular model and magnetic force model are completely based on arbitrary values of variables but magnetic force model is developed in heuristic approach. Social force model considers attraction and repulsion effects of pedestrians which has physical meaning. In social force model, "Physical interactions are combined with action of the social norm of keeping distance to unknown persons." Binary values are assigned in cellular automata model. Social force model and magnetic force model are continuous models where benefit cost cellular model and cellular automata model consider discreet movement of pedestrians. Macroscopic phenomena are explained in cellular automata model. Fundamental properties of pedestrian movements completely explained in cellular automata model. real understandable behavioral rules are considered to explain interaction between pedestrians and pedestrians with other obstacles. Mostly models are based on pedestrian moving toward the destination and makes repulsive effect toward other pedestrian or obstacles. Calibration and validation of parameters have not been done considering real pedestrian movement data.

CONCLUSIONS AND RECOMMENDATIONS

Various microscopic simulation models used to simulate pedestrian movement have been discussed in this paper. Brief descriptions of software for microscopic simulation models also have been discussed here. Benefit cost cellular model was proposed by Gipps and Marksjo in 1985. Social force model was developed by Helbing (1991, 1992, and 1993). Kormanova in 2012 proposed a model combining cellular automata model and social force model using agent-oriented architecture (ABAsim architecture) and designed scene infrastructure.

It can be concluded from this review that various studies have been done on microscopic simulation techniques for improving pedestrian facilities but they have not been applied in standard design guidelines to improve the pedestrian facilities. In microscopic approach, walking speeds, walking directions, distances between pedestrians, relative positions, passing behavior and group-forming characteristics are observed. Calibration and validation of various constant parameters used in pedestrian microscopic models should be implemented using real data. Microscopic approaches can be considered in HCM guidelines for LOS and capacity estimation for pedestrian facilities. This study will be helpful for designing of pedestrian infrastructure considering microscopic simulation techniques.

Various microscopic simulation tools were proposed considering different situations, these models are not studied in Indian conditions and also for other developing countries. These microscopic simulation models and tools are required to be experimented for developing country conditions.

ACKNOWLEDGMENT

The inputs received from MHRD fellowship at CTRANS and the research project “Indo HCM WP-7” sponsored by CSIR-CRRI are thankfully acknowledged in the presentation of this paper.

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