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OPTIMIZATION OF PARAMETERS FOR PEDESTRIAN SIMULATION SOFTWARE: A CASE STUDY OF EMERGENCY EVACUATION EXPERIMENTS

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Resume

This research study provides a new framework to optimize pedestrian simulation parameters required to replicate emergency evacuation conditions specifically observed in high rise buildings, passenger vehicles and transport terminals. The simulation experiments are performed with generalised social force model in VISWALK simulation environment. The data required for optimization are obtained by conducting several evacuation experiments. The results indicate that pedestrian behavioural aspects, such as the relaxation time, distance from the other pedestrian and force exerted by closest pedestrians, have a significant impact on total evacuation time. The outcomes are in consistence with field observations and the calibrated parameters would help in simulating future scenarios including building level simulations and further simulating emergency evacuation of passengers from transport terminals and vehicles.

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1 Background

Evacuation of pedestrians from a building in emergency situation without any loss of life is always a challenging task. In emergency conditions, several reasons, such as physical obstruction, wrong selection of emergency exits, overcrowding, pushing and crushing, may result in injury or death of pedestrians. In addition, evacuation in closed or restricted environments is affected by several major and minor factors, such as age, gender, presence of groups, number of exits and so on. Several researchers attempted to understand the effect of pedestrian and room characteristics on evacuation behaviour using simulation and experimental methods [1-4]. Pedestrian simulation models are ordinarily used to study the evacuation characteristics of pedestrians under many circumstances. In another study [5], classroom evacuation scenarios are simulated with two exits in which a modified Cellular Automata (CA) simulation evacuation model was considered with occupant density of the exit. The study states that the phenomenon of people's hesitation and oscillation between different exits occurs in simulation when

occupant density around exits was considered. Zhao and Gao [6] made an attempt to present a generalized floor field model to characterize the exit choice behaviour in rooms, which have multiple exits. Aik [7] carried out evacuation experiments and simulations in a room with two exits. To understand the evacuation process through exits the study used a modified CA evacuation model incorporating neural network decision-making for intelligent exit selection. The study results show that the exit selection behaviour of occupants depends on the density around the exits. Chen and Han [8] in their study composed a multi grid model by introducing the force concept of social force model in the lattice gas model. They used finer lattice to enable pedestrians to occupy multiple grids in place of a single grid and studied the behaviour of the pedestrians while evacuating from a single door of a big room. The results revealed that with increase in the width of the door, the time of evacuation decreases but it is not linear. Li et al. [9] studied the escape panic of a classroom evacuation in real-life 2013 Ya'an earthquake in China using the social force model. The model parameters are calibrated and optimized using differential evolution

algorithm to reproduce the non-linear evacuation speed, which is consistent with observed video data. Results show that the trained evacuation leader and number of available exits have tremendous impact on evacuation process. Gu et al [10] studied the evacuation behaviour of school students in normal and emergency conditions through regression modelling. From the analysis it is observed that students' cumulative departures in normal conditions is a linear function, while in emergency it is a convex function and further students' reaction time increases substantially in emergency conditions.

It is a great challenge to conduct practical evacuation experiments without risking the lives of the people participating in the experiments. Therefore, evacuation modelling using the simulation technique is a great alternative to conducting evacuation experiments. Evacuation modelling is a branch of science concerned with simulating human behaviour in an emergency condition. Even though the empirical data is compulsory for setting up a simulation model, it has an advantage when it comes to creating various alternative scenarios. Simulations with good calibrated parameters help in more accurate forecasting. The simulation methodology not only produce accurate results but also saves money.

Transport security and passenger safety during evacuation from vehicles and terminals can be addressed using the simulation software. In transportation domain, computer-based simulation models with suitable parameters replicate passenger behaviour from passenger terminals and transport vehicles. They are used for economical way of evaluating in various conditions. Simulation models have been developed for assessing passengers boarding and alighting behaviours, evacuation behaviours using various methods. Najmanová et al. [11] explored the impact of various factors on passengers' evacuation from the rail coach to a station platform during emergency. In total, 15 evacuation experiments were conducted in a double decker train in Czech Republic and 91 passengers were called for the experiments that were conducted under various scenarios by varying widths, exit types and exit methods. Wang [12] studied the evacuation of passengers from the two floor metro station subway and station hall using pathfinder simulation model. In another study [13], an agent-based simulation model is used to handle the evacuation procedure in transit stations for various scenarios. They explored the impact of different factors on total evacuation time of passengers from the transit station.

The present study aims to evaluate the classroom evacuation scenarios in emergency conditions, using the VISWALK (PTV) simulation tool [14], which particularly suits the simulation for the fatal build-up of pressure observed during the emergency evacuations. To represent the real-world behaviour of the pedestrians, the model parameters need to be calibrated and validated. Therefore, the suitable empirical data is to be collected, either from the real world observations, or

from experimental studies. As availability of observed pedestrian data is difficult, researchers mainly relied on experimental studies [15-19]. These studies are useful in collecting pedestrian behavioural information, such as choice of route selection, individual travel times, individual speeds, trajectories and so on.

So far very few studies [20-21] attempted to validate the social force model parameters in VISSIM and VISWALK simulation environment. Kretz et al. [20] validated the social force model parameters in VISSIM simulation framework using the experimental data. In this study, pedestrian flow through bottlenecks in normal conditions have been simulated and found that default parameters given in VISSIM manual is sufficient to simulate the normal behaviour of pedestrians. Marten and Henningsson [21] in their study verified and validated the VISWALK pedestrian simulation model for the use as a building evacuation model. In the validation, results from VISWALK are compared to four real life experiments, including a corridor, classroom, theatre lobby and a staircase. The results confirmed that, with default parameter settings, speeds and travel times of the occupants are totally deviating from the actual results. This study suggests that model predictions will be close to experimental results if user has a good estimation of the occupant demographics and is aware of the limitations of the model. However, the literature review confirmed that the detailed discussion on influential parameter sets for emergency evacuations and their optimization procedure is nearly non-existent. Thus, the present study is an attempt to fill this gap.

The paper is organised as follows: section 2 discusses the concept of generalised social force model and the important VISWALK parameters. Section 3 introduces the methodology adopted for this study. Sections 4 and 5 cover the sensitivity analysis and calibration procedures respectively. Section 6 is about validation of parameters and some predictions. Finally, section 7 concludes the paper.

2 Social force model and VISWALK parameters

In the present study, PTV VISWALK-7.0 is used to simulate the emergency evacuation of pedestrians. The simulation tool is built on the concept of Generalised Social Force Model (GSFM) [22], which permits to investigate the distinctive degrees of panic. Moreover, the GSFM is able to predict the collective phenomenon of escape panic in the framework of self-driven many particle systems. Further, it is also good at representing the typical human behaviour in emergency conditions, such as arching, jamming and overcrowding. Simulation models, developed based on the social force model, have helped in developing several emergency evacuation strategies for different types of facilities in natural and human made disasters for instance earthquakes, fire, bottleneck conditions and so on [9, 14, 22]. The

Table 1 Description about VISWALK parameters [14]

No	VISWALK Parameter	Description	Range	Remarks
1	Tau (τ)	Represents the relaxation time of pedestrian. Its value is inversely proportional to force between pedestrians	0-1	Default Value is 0.4. if $\tau < 0.4$ then the pedestrian will be aggressive and similarly if $\tau > 0.4$ then pedestrian will be relaxed.
2	Lambda (λ)	The parameter in the model judges how people at one's back will behave	0-1	Default Value is 0.176. If λ increases, pushing from other pedestrians also increases.
3	Grid size (D)	Conveys the meaning that the maximum distance at which pedestrians have an effect upon each other	≥ 0	Default value is 5. If D decreases, it increases the influence on the other pedestrian. Units are meters.
4	Noise	The greater this parameter value, the stronger the random force that is added to the systematically calculated forces	0-2	With noise is equivalent to zero, the so called pedestrian „arches“ will form and remain stable. If the noise value lies within the range of 0.8 to 1.4, one of the pedestrians will step back after a while and another one will pass through.
5	React to N	During the calculation of total force for a pedestrian, only the influence exerted by the n closest pedestrians was taken into account	≥ 0	Default value is 8. React to N is inversely proportional to density.
6	VD	This parameter defines how individual will response to group in counter flow.	≥ 0	Default value VD is 3.0. It means there is less avoidance from opposite flow.

acceleration equation of generalised social force model is as follows.

$$m_i \frac{dv_i}{dt} = m_i \frac{v_i^0(t)e_i^0(t) - v_i(t)}{\tau_i} + \sum_{j \neq i} f_{ij} + \sum_W f_{iW}. \quad (1)$$

Here, pedestrian i of mass m_i wishes to attain his or her desired speed v_i^0 in a certain direction e_i^0 and actual velocity v_i with a relaxation time τ_i . Simultaneously, each pedestrian tries to maintain velocity dependent distance from other pedestrian's j and walls W . Corresponding interaction forces are f_{ij} and f_{iW} respectively. For detailed information on „interaction forces“ refer to [22]. Table 1 describes VISWALK pedestrian simulation parameters with their default values [14].

3 Methodology

Unlike other studies, simulation model development for emergency evacuation is a complicated one, where evacuation times for different classroom sizes with different door widths have to be predicted accurately using a specific parameter set. Therefore, a new methodological approach is proposed to obtain those values. Step by step procedure involved in this methodology is discussed below.

3.1 Experiments

The very first step in simulation model development is the collection of suitable input data from suitable

experiments. In this study, fifteen experiments have been carried out in a classroom environment for different age groups and varying door widths. In total of fifteen experiments, fourteen experiments data is used for calibration of parameters and one experiment data is used for validation of optimized parameter set. To consider different age groups of pedestrians (Post-graduate, Under-graduate and higher secondary school) with all the possible scenarios, data was collected at two different places, such as university classroom and public-school classroom, Delhi, India. Table 2 describes different characteristics of classrooms, whereas sketches of the classrooms are depicted in Figure 1 and Figure 2.

The first set of experiments were conducted at a Lancers convent public school, in which 43 students of the 6th grade participated, with 86% class occupancy and an average age of 11.14 years. The classroom consists of movable tables and chairs on a leveled floor. There was only one exit provided at the entrance of the classroom. The second set of experiments were conducted in the same school and in a similar kind of classroom in which 36 students of the 9th grade had participated, with 75% class occupancy and an average age of 14.56 years. The experiments conducted in the school classrooms consider different scenarios as shown in Table 3. The third set of experiments were conducted in the lecture hall complex in Indian Institute of Technology (IIT), Delhi in which 38 students had participated, with 63% class occupancy. The classroom consists of arrangement of movable tables and chairs on a leveled floor with two exits. The forth set of experiments were also conducted in the lecture hall complex of IIT Delhi in which 12 students had participated (LH-605), with 40% class occupancy. The experimental scenarios considered for the study are

Table 2 Characteristics of classrooms

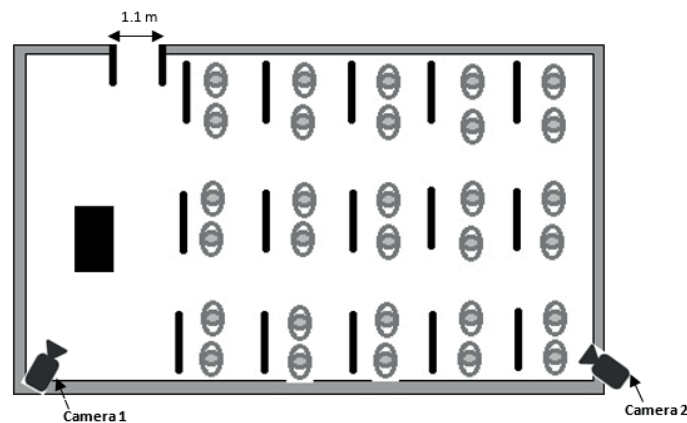
Description	Lancers Convent Public School, Delhi		Lecture Hall Complex, IIT Delhi	
	6 th grade	9 th grade	Undergraduate (UG) LH - 611	Post-Graduate (PG) LH - 605
Area of classroom (m ²)	46.65	46.2	87.86	38.97
Classroom Capacity	50	48	60	30
No of Exits	1	1	2	2
Placement of exits	Front	Front	Front	Back
Desk and chair arrangement	Movable	Movable	Movable	Movable

Table 3 Different experiment scenarios in Lancers Convent Public School

No.	Door Width (m)	6 th grade	9 th grade
1	0.8	S1 (big door)	S1 (big door)
2	1.1	S2 (both door)	S2 (both door)
3	0.3	S3 (small door)	S3 (small door)
4	0.8	Govt. Guidelines	Govt Guidelines

Table 4 Different experiment scenarios in lecture hall complex, IIT Delhi

No.	Door Width (m)	UG class	PG class
1	1.2	S1 (2 small door open)	S1 (2 small door open)
2	1.8	S2 (2 big doors open)	S2 (2 big doors open)
3	1.5	S3 (1 big and 1 small)	S3 (1 big and 1 small)
4	1.5	S4 (only 1 exit)	S4 (only 1 exit)
5	3	S5 (both doors open)	S5 (both doors open)

**Figure 1** Sketch of a classroom experimental scenario in Lancers Convent Public School, Delhi

given in Table 4. In all these experiments, students were instructed to evacuate the room from the shortest path to the exit. The evacuees are informed about the evacuation procedure before conducting the study and asked them to behave as if they are in emergency situation.

The data collection for the study was performed using the video graphic technique. As shown in Figure 1, videos were recorded from convenient vantage points and then data was extracted using MATLAB® based tool [23]. Data analysis was carried out using Microsoft

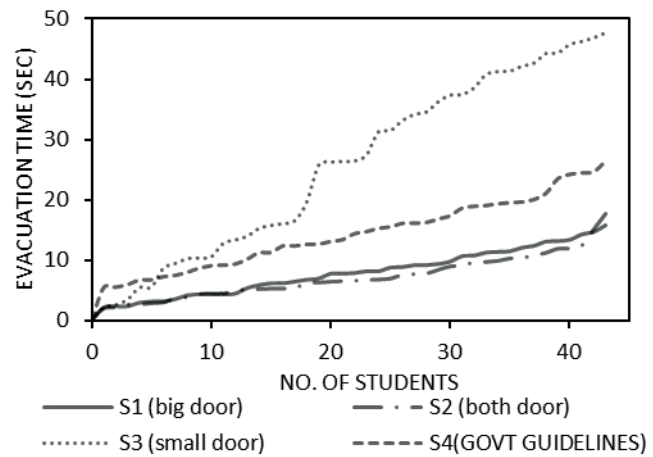
Excel and R statistical tool [24]. Snapshots of evacuation experiment and evacuation time details of the 6th grade classroom and undergraduate classroom is depicted in Figure 3. The data obtained from the evacuation experiments, such as flow, composition, individual travel times, individual speeds and total evacuation times, were obtained and used in simulation model development, parameters calibration and validation. The details of evacuation experiments are given in Table 5. More details on data collection procedure and development of evacuation models can be found in [2].



Figure 2 Sketch of a classroom experimental scenario in Lecture Hall Complex, IIT Delhi
(here Corridor width 1800mm, between benches (from left to right 720mm, 450mm and 630mm respectively)



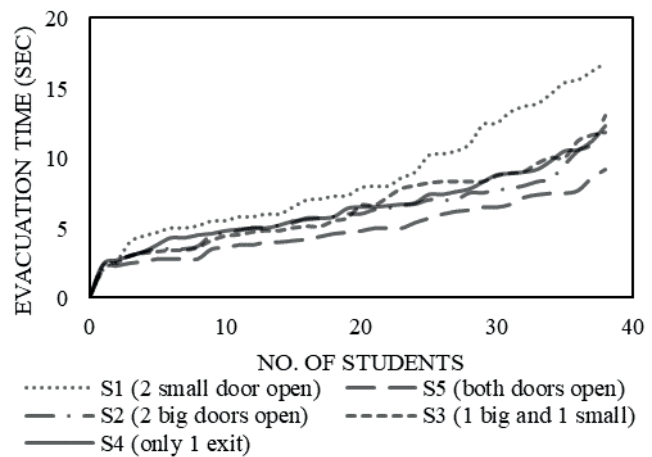
(a)



(b)



(c)

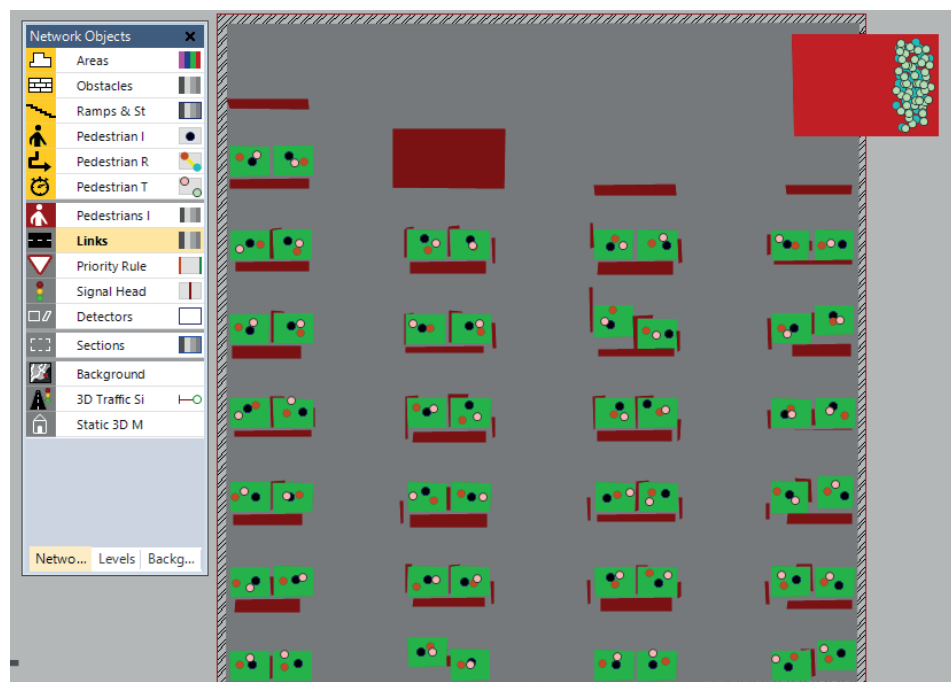


(d)

Figure 3 (a) and (b) - Snapshot of the 6th grade and their cumulative evacuation times for different door widths respectively; (c) and (d) - Snapshot of the undergraduate class and their cumulative evacuation times for different door widths respectively (In Figure 2 (b): big door = 0.8m, both doors = 1.1m, small door = 0.3m, In Figure 2 (d): two small door = 1.2m, both doors = 3.0m, two big doors = 1.8m, 1 big and 1 small = 1.5m)

Table 5 Comprehensive view of evacuation experiments

No	Grade / class	Class occupancy (classroom capacity)	Door width (m)	Average age	Proportion of women	Classroom area (m ²)	Total Evacuation time (s)	Speed distribution (μ^* , σ^*)
1	6 th	43 (50)	0.8	11.14	41.80	46.65	15.70	0.93, 0.29
2	6 th	43 (50)	1.1	11.14	41.80	46.65	17.76	1.01, 0.27
3	6 th	43 (50)	0.3	11.14	41.80	46.65	47.60	0.36, 0.26
4	6 th	43 (50)	0.8	11.14	41.80	46.65	26.47	0.50, 0.15
5	9 th	36 (48)	1.1	14.56	41.66	46.2	14.21	0.99, 0.23
6	9 th	36 (48)	1.1	14.56	41.66	46.2	12.64	1.10, 0.32
7	9 th	36 (48)	0.3	14.56	41.66	46.2	33.03	0.51, 0.27
8	9 th	36 (48)	1.1	14.56	41.66	46.2	31.60	0.45, 0.16
9	UG*	38 (60)	1.2	23.80	10.50	87.86	16.80	0.93, 0.38
10	UG	38 (60)	1.8	23.80	10.50	87.86	13.00	1.26, 0.42
11	UG	38 (60)	1.5	23.80	10.50	87.86	11.80	1.23, 0.34
12	UG	38 (60)	1.5	23.80	10.50	87.86	12.30	1.43, 0.32
13	UG	38 (60)	3.0	23.80	10.50	87.86	9.20	1.53, 0.38
14	PG*	12 (30)	1.2	25.42	33.30	38.97	9.00	0.89, 0.25
15	PG	12 (30)	1.8	25.42	33.30	38.97	5.77	1.03, 0.20
16	PG	12 (30)	1.5	25.42	33.30	38.97	6.00	0.99, 0.22
17	PG	12 (30)	3.0	25.42	33.30	38.97	7.20	1.33, 0.66

**Figure 4** Snapshot of the VISWALK simulation model setup for the 6th grade

3.2 Simulation model development

In the next step, AutoCAD drawings (.dwg) of the classroom area chosen for the study is used as a background image to the VISWALK Simulation model (e.g. Figure 4 for Grade 6 classroom). Then, different pedestrian facilities are created (e.g. walking area, exit area, table and chairs etc.) and pedestrian inputs were given to prepare the simulation model. To evaluate the

model performance, Total Evacuation Time (TET) is chosen as a measure of performance (MOP); cumulative absolute residual error (CARE) and GEH1 statistics are chosen as goodness of fit (GOF) measures. Subsequently, the initial evaluation of VISWALK model was carried out using the default parameter set and the model performance is evaluated. It was found that the default parameter cannot satisfy the required criteria, where those parameters mainly meant for representing the

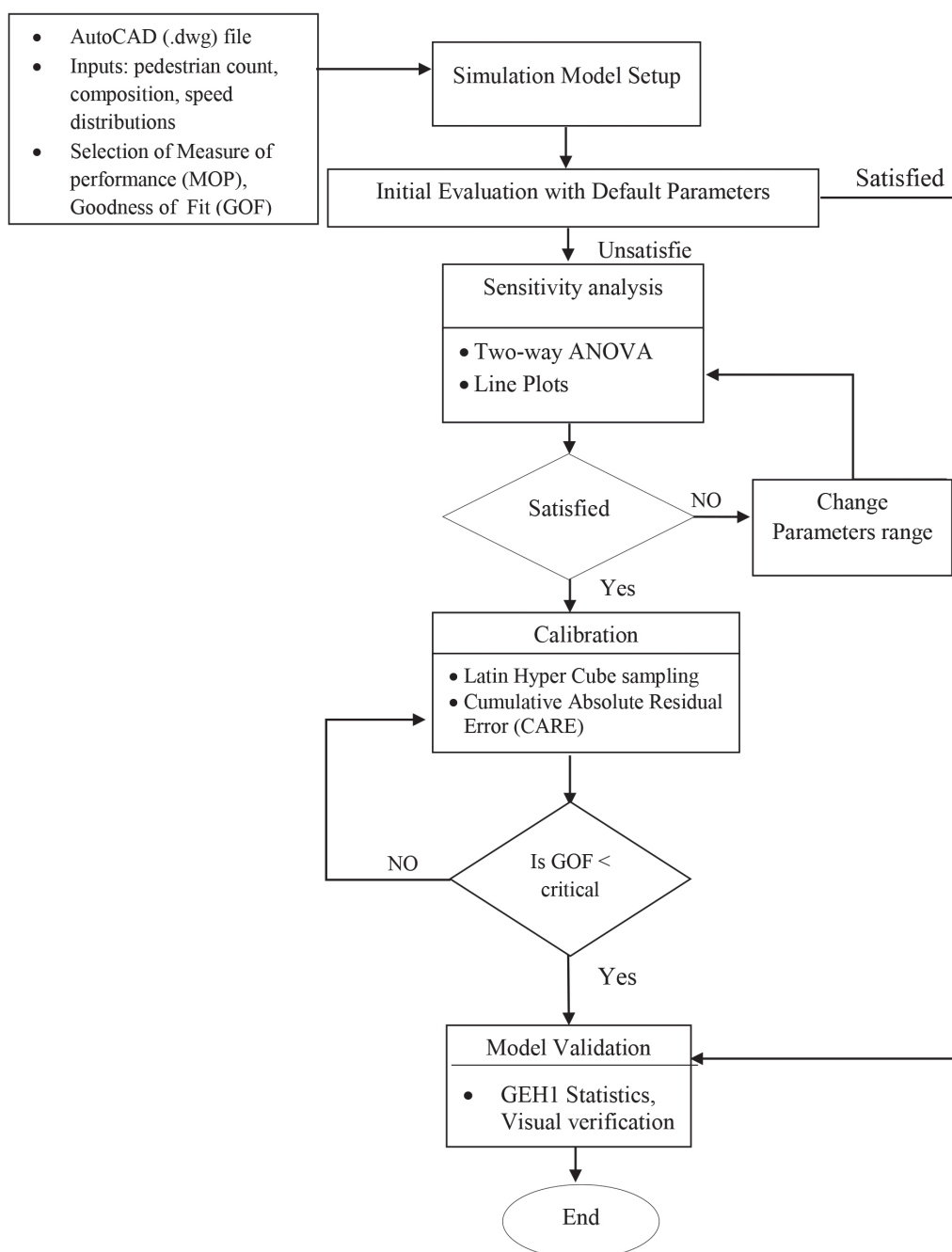


Figure 5 Methodology for calibration and validation of the VISWALK evacuation model

normal behaviour of pedestrians. Sensitivity analysis of walking behaviour parameters was done by the two-way analysis of variance (ANOVA) (without replications) and line plots to identify the most influential parameters of the model. The detailed analysis is given in section 4. If the output from the sensitivity analysis is in accordance with the observed data, then the analysis is moved to calibration level otherwise sensitivity analysis step will be repeated until the desired ranges are achieved.

In the calibration step, optimum set of model parameters are identified by minimizing the differences between simulated and observed values. To minimize the computational time, suitable parameter sets are generated using Latin Hypercube Sampling (LHS)

algorithm in which several sets of parameters are generated and the error value is estimated using the cumulative absolute residual error (CARE) and regression plots. The best parameter set will be the one, which produces the least error. More information on LHS and the outcomes are given in section 5. In the final stage, validation is carried out for the optimized parameter set to check its adoptability and to quantify the approximate error it is produced. Because the validated outcome is a single value, the GEH1 statistic was adopted to evaluate the model performance. Further, visual observations are also used to check the model accuracy in representing some of the pedestrian behaviour at bottlenecks in emergency conditions, such

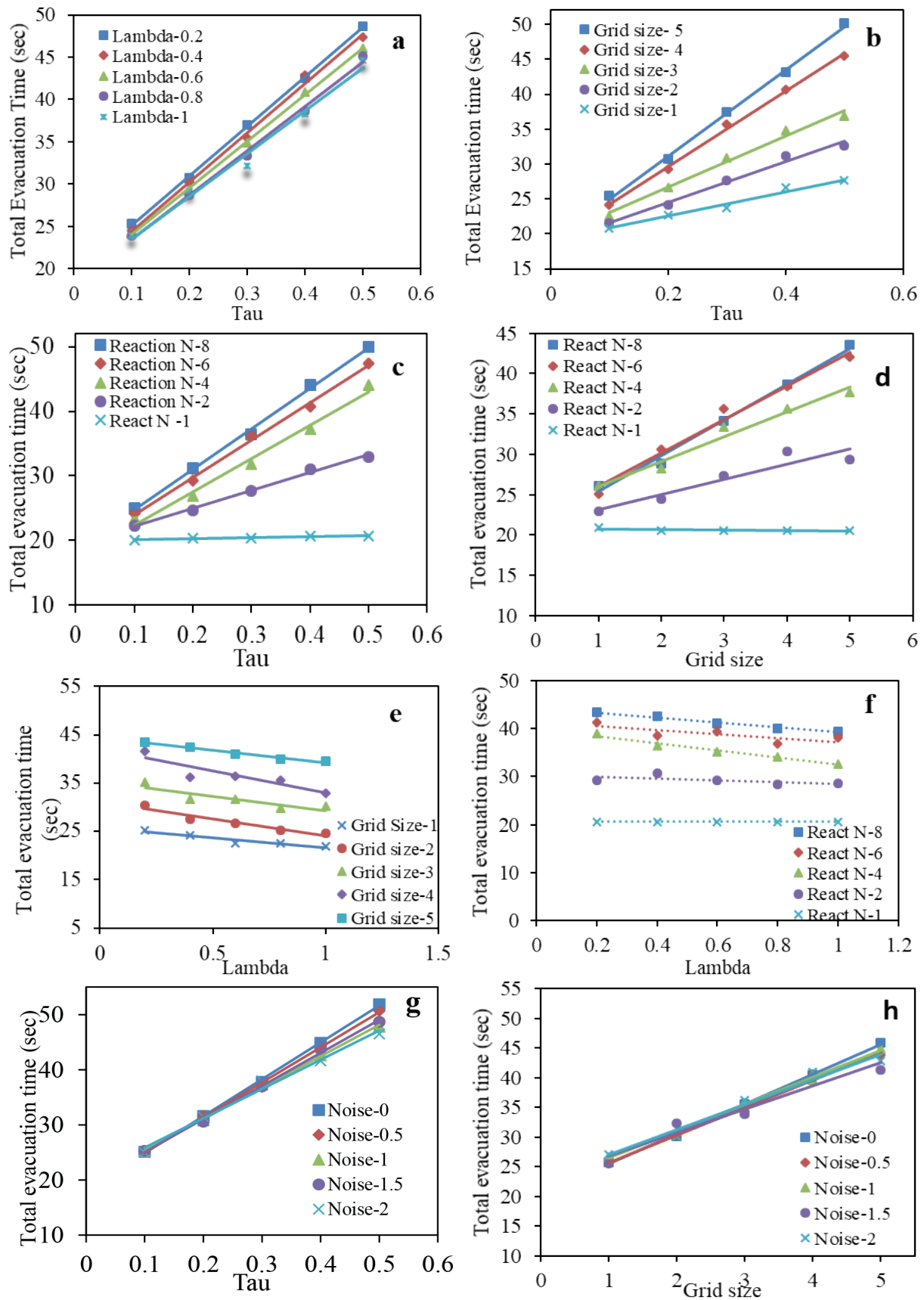


Figure 6 Estimated marginal means of the Total Evacuation Time between different pedestrian simulation parameters

as arching and clogging. The complete methodology flowchart used for calibration and validation is given in Figure 5.

4 Sensitivity analysis

The sensitivity analysis plays a major role while handling a lot of variables in which few parameters are redundant. It helps in determining their relative importance and thus aids in identifying the variable(s) of interest. The sensitivity analysis for the VISWALK walking behavioural parameters is performed to know how, with a small change in the respective parameter values the individual results will behave [25]. In the present study, the two-way ANOVA method without replication is used to conduct pairwise sensitivity analysis. In this approach, simulations are carried out by varying selected two parameter values and keeping other parameters constant. Individual and combined effect of the two parameters on Total Evacuation Time (TET) was evaluated. Parameter VD value is taken as default as there is no opposite flow in experimental studies. The outcomes of the sensitivity analyses are presented in Figure 6 and Table 6.

Following conclusions can be drawn from the sensitivity analysis.

The results shows that τ and λ have individual and combined effect on simulation output i.e., TET. Here, the TET values increase with increasing τ and λ value. However, at lower values of τ , there is not much deviation in the output (Figure 6a). The two-way ANOVA results (Table 6) also proved the same. Figure 6b conveyed a meaning that there is a significant deviation in the TET values for different τ and D values. However, for small values of D there is not much change in the TET for varying τ values.

React to N and τ values have significant effect on TET, which can be concluded through Figure 6c. The ANOVA results also proved the above statement clearly (Table 6). However, for the lower React to N values there is no change in TET. It can be seen from Figure 6d that the parameter D with React to N has a significant relation with TET. The ANOVA results also proved it to be true (Table 6). However, for lower React to N values there is no change in TET. Figure 6e shows that parameters λ and D have a combined effect on simulation outcomes, however, the TET is not much affected while increasing λ value and keeping the parameter D constant. From the ANOVA results (Table 6) and Figure 6f can be seen that parameters λ and React to N show a significant impact on outcome, but there is no much difference in TET with increase in λ value when React to N is constant. From Figure 6g it is observed that with the increase in τ value, the TET is increased but Noise parameter does not have any influence on altering pedestrian behaviour. From Figure 6h is also shown that with increase in the D value the

TET increased but the Noise parameter does not have any effect on pedestrian behaviour and the same can be observed from the ANOVA results.

From the sensitivity analysis, it is observed that parameters, such as τ , D, React to N have significant impact on evacuation results. It may also suggest that those parameters are more influential in capturing pedestrian behaviour in emergency conditions. Further, it is also proved that λ has less influence and Noise parameter has no influence on simulation outcomes. Therefore, the noise parameter is considered to be constant in the calibration procedure.

5 Calibration

In calibration, the difference between simulated and observed variables are minimized by finding an optimum set of model parameters. In this study, a new approach has been adopted for the parameter calibration. In this approach, a large sets of walking parameters (sample sets are given in Table 7) were generated using the Latin Hypercube Sampling (LHS) algorithm using MATLAB® program. Then, each parameter set was supplied to the VISWALK model to simulate 14 evacuation scenarios simultaneously. The difference between estimated total evacuation time and observed evacuation time is considered as a measure of effectiveness. The parameter set, which produces the least error can be considered as effective one and will be used in further validation purpose and evaluating alternative scenarios. Several GOF measures, such as paired t-test, regression, MAPE etc. have been tested to estimate the error. However, none of them can suitably assess the model prediction accuracy. Therefore, the cumulative absolute residual error (CARE) was adopted as a goodness of fit measure (GOF). Calibration methodology adopted in this study is presented in Figure 7.

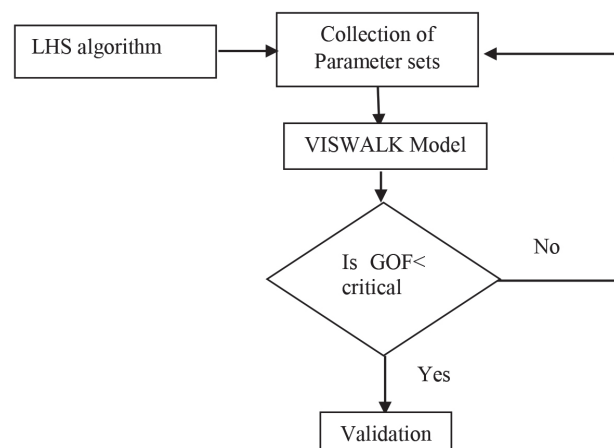
Latin hypercube sampling (LHS) is a stratified random sampling procedure that provides an efficient way of sampling variables from their multivariate distributions. It provides a full coverage of the range of each variable by maximally stratifying the marginal distribution. It was initially developed for the purpose of the Monte-Carlo simulation, where it is efficiently selecting input variables for computer models [26-27].

Table 8 shows twenty-three sample (including default parameter set) sets of parameters generated by the LHS, which were used to run simulations for different door widths and area of the classroom. Results given in Table 8 show that the R-square as an evaluation method is obsolete (high R^2 value can result in high residual error, e.g. set 23 in Table 8, while moderate R-square value scenario P-1 gives the least residual error). This study proposed Cumulative Absolute Residual Value (CARE) to identify the best parameter set from the analysis. Parameters are displayed in the table sorted on the basis of the error value in ascending order. The

Table 6 ANOVA without replication between different groups

No.	Source of Variation	SS	df	MS	F statistic	P-value	F critical
1	λ	37.25	4	9.31	15.74	0.00	3.00
	τ	1511.19	4	377.79	638.55	0.00	3.00
	Error	9.46	16	0.59			
	Total	1557.91	24				
2	D	575.10	4	143.77	17.16	0.00	3.01
	τ	796.09	4	199.02	23.75	0.00	3.01
	Error	134.04	16	8.37			
	Total	1505.24	24				
3	React to N	933.53	4	233.38	14.08	0.00	3.01
	τ	814.96	4	203.74	12.29	0.00	3.01
	Error	265.13	16	16.57			
	Total	2013.63	24				
4	React to N	693.03	4	173.25	19.05	0.00	3.01
	D	367.53	4	91.88	10.10	0.00	3.01
	Error	145.44	16	9.09			
	Total	1206.01	24				
5	D	1048.74	4	262.18	331.73	0.00	3.01
	λ	85.29	4	21.32	26.97	0.00	3.01
	Error	12.64	16	0.79			
	Total	1146.68	24				
6	React to N	1382.82	4	345.70	277.58	0.00	3.01
	λ	28.46	4	7.11	5.71	0.00	3.01
	Error	19.92	16	1.24			
	Total	1431.21	24				
7	Noise	10.25	4	2.56	2.34	0.09	3.00
	τ	1808.77	4	452.19	412.71	0.00	3.00
	Error	17.53	16	1.09			
	Total	1836.56	24				
8	Noise	3.20	4	0.80	0.65	0.63	3.00
	D	1011.21	4	252.80	207.41	0.00	3.00
	Error	19.50	16	1.21			
	Total	1033.91	24				

SS = sum of squares, df = degree of freedom, MS = mean squares

**Figure 7** Flowchart for calibration procedure

best parameter set observed from the calibration is P1 and the same parameter set is used for the validation purpose. Results show that variables, such as door width and number of students, are crucial in representing evacuation time of the classroom. It is found that the relationship between the total evacuation time (TET) and door width is represented by a power function (Figure 8). This is in contrast to the findings of Liao et al. [28], which show that the relationship between the flow and a door width is linear. Results of this study can be best supported by the fact that TET is exponentially varying with the door width until a particular value and remains constant for further increase in door width, which is realistic in nature. As depicted in Figure 8, there is a good agreement between the total evacuation time values obtained from empirical and simulated values.

6 Validation

In the validation procedure simulation results are compared to the experimental values collected for undergraduate classroom with 38 number of students for the door width of 1.5m. The TET and visual confirmation, such as arching behaviour, are used as measure of performance. As the TET is a single value in this case, GEH1 (Equation (2)) statistics is used as

goodness of fit measure [25, 29], $GEH < 1$ indicates good fit. In present scenario, the GEH 1 statistic value is 0.27676 and it shows that there is no difference between actual and simulated values.

$$GEH1 = \sqrt{\frac{2(x_i - y_i)^2}{x_i + y_i}}, \quad (2)$$

where x_i is the observed value and y_i is the estimated value. If GEH value < 1 , it can conclude that there is no significant difference between the observed and simulated values.

Finally, using an optimized parameter set values, the future scenarios for the two classrooms in university environment are simulated considering full occupancy. It would be interesting to know how much time it will take to evacuate the rooms in any emergency situation. Total evacuation time values, obtained from the simulation runs, are shown in Table 9. These values are also compared to outputs from the regression model and they were found to be satisfactory.

7 Discussion

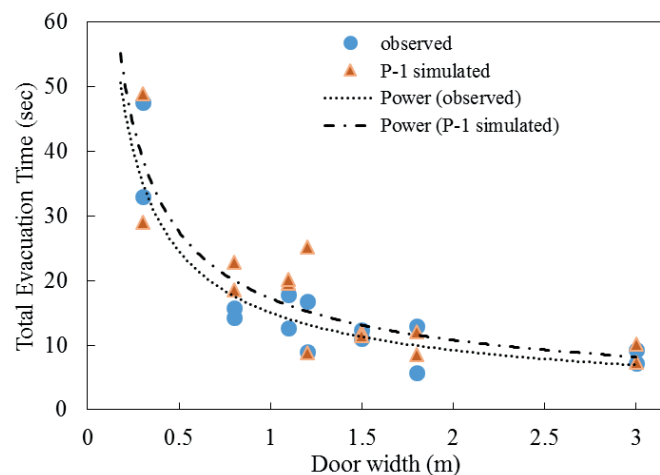
The impetus behind this research work is to develop a new framework to optimize the simulation model parameters and further to use the simulation model for suggesting solutions in an emergency. The

Table 7 Sample LHS Parameter set

No	τ	λ	D	React to N	Noise	VD
1	0.291	0.261	0.649	4	0.200	3
2	0.067	0.916	1.058	2	0.200	3
3	0.467	0.947	1.251	5	0.200	3
4	0.492	0.598	2.537	2	0.200	3
5	0.368	0.138	2.214	4	0.200	3
6	0.332	0.351	2.016	2	0.200	3
7	0.192	0.434	0.852	2	0.200	3
8	0.422	0.828	2.444	4	0.200	3
9	0.209	0.051	1.384	5	0.200	3
10	0.133	0.103	0.800	1	0.200	3
11	0.407	0.269	2.995	6	0.200	3
12	0.251	0.697	2.709	5	0.200	3
13	0.160	0.765	1.583	3	0.200	3
14	0.277	0.651	1.920	3	0.200	3
15	0.095	0.501	1.683	3	0.200	3
16	0.400	0.300	0.620	4	0.200	3
17	0.200	0.800	0.994	2	0.200	3
18	0.200	0.200	1.112	3	0.200	3
19	0.200	0.400	1.000	4	0.200	3
20	0.100	0.800	0.992	1	0.200	3
21	0.300	0.400	1.213	4	0.200	3
22	0.300	0.176	2.200	6	0.200	3

Table 8 Calibrated parameter sets

No.	Scenario	Parameter Set						R ²	Cumulative Absolute Residual Value (CARE)
		τ	λ	D	React to N	Noise	VD		
1	P1	0.400	0.300	0.620	4	0.200	3	0.8913	40.45
2	P2	0.200	0.800	0.994	2	0.200	3	0.7238	56.05
3	P3	0.100	0.800	0.992	1	0.200	3	0.6731	67.99
4	P4	0.200	0.200	1.112	3	0.200	3	0.8103	49.85
5	P5	0.300	0.400	1.213	4	0.200	3	0.8197	109.15
6	P6	0.300	0.176	2.200	6	0.200	3	0.8729	112.49
7	P7	0.200	0.400	1.000	4	0.200	3	0.8041	49.05
8	P8	0.291	0.261	0.649	4	0.200	3	0.5964	50.85
9	P9	0.067	0.916	1.058	2	0.200	3	0.6119	68.61
10	P10	0.467	0.947	1.251	5	0.200	3	0.6073	60.85
11	P11	0.492	0.598	2.537	2	0.200	3	0.5901	117.09
12	P12	0.368	0.138	2.214	4	0.200	3	0.7498	104.89
13	P13	0.332	0.351	2.016	2	0.200	3	0.7735	50.55
14	P14	0.192	0.434	0.852	2	0.200	3	0.6885	55.95
15	P15	0.422	0.828	2.444	4	0.200	3	0.7568	104.89
16	P16	0.209	0.051	1.384	5	0.200	3	0.7133	48.55
17	P17	0.133	0.103	0.800	1	0.200	3	0.5886	65.31
18	P18	0.407	0.269	2.995	6	0.200	3	0.4731	163.89
19	P19	0.251	0.697	2.709	5	0.200	3	0.7204	63.05
20	P20	0.160	0.765	1.583	3	0.200	3	0.6972	56.19
21	P21	0.277	0.651	1.920	3	0.200	3	0.7426	53.05
22	P22	0.095	0.501	1.683	3	0.200	3	0.6396	53.05
23	Default	0.400	0.176	5.000	8	0.200	3	0.9183	228.69

**Figure 8** Comparing observed results to simulation results**Table 9** Future Scenarios for full occupancy for door width 3.0m (University Scenario)

Condition: when class is fully occupied	Simulated TET (sec)
PG classroom	12.9
UG classroom	18
Parameter set for the simulation: $\tau = 0.4$, $\lambda = 0.3$, $D = 0.6$, React to N = 4, VD = 3, Noise = 0.2	

proposed methodology includes real world experiments in classrooms; identifying the suitable parameters, using sensitivity analysis; calibration and validation of selected parameters, using advanced techniques and finally testing of the model for future scenarios. Data availability is the major hurdle in fine tuning the simulation model and further it is extremely difficult to get the data from emergency evacuation incidents happened around the world in various conditions. As the first attempt in India, especially in classroom set-up, evacuation data was collected for different geometric configurations and involving students of diverse age groups. Before conducting the experiments, instructions were given to students in such a way that they behave as if they were in emergency situations.

In the next step, the sensitivity analyses were carried out to identify the most influential parameters, because these parameters mostly govern the outcome of the model. In the proposed method, the two-way ANOVA and two-dimensional line plots were involved in sensitivity analysis. Considering the problem at hand and the model parameters, fourteen classroom scenarios are simulated simultaneously using the parameter sets generated through the Latin Hypercube Sampling algorithm. The goodness of fit for the parameters is measured using cumulative residual error, which is an appropriate method to compare observed and empirical data. The validation of the optimized parameter set proved that they mimic the emergency conditions satisfactorily. The optimized parameters will help in simulating future scenarios including building level simulations.

From the simulation results it is found that the relationship between the total evacuation time and classroom door widths is non-linear. Initial observation shows that there is a little change in evacuation times with increasing door widths. However, there is a huge drop in evacuation time with a little increasing of door widths. Those results are commensurate with already published results, such as Chen and Han [8] and Gu et al. [10]. Results from Chen and Han [8] study show that with increase in the width of door, the time of evacuation decreases but it is not linear [8]. From the Gu et al. [10] study it is observed that students' cumulative departures in normal conditions is a linear function while in emergency it is a convex function and further students' reaction time increases substantially in emergency conditions. Similar studies are also observed in the transportation domain. For instance, Najmanova et al. [11] research study emphasizes on assessing the several characteristics of passengers by the means of laboratory based controlled experiments. Evacuation experiments were conducted in a double decker train in Czech Republic and the experiments were conducted under various scenarios by varying widths, exit types and exit methods. Results show that the evacuation time reduces with increasing door width, number of exits and their location. Passenger characteristics, like speeds

and exit flow rates as well as human behaviours were evaluated. In the other study by Kim et al. [30], a model suitable for the domestic environment is established, based on the data measured and tested in Korea and related formulas and variables are derived to predict the effect of reducing the boarding and alighting time when the door width is increased.

In addition to the existing knowledge, the present study provided the data about response of the students (i.e. the total evacuation time) of various categories with different characteristics for varying door widths in emergency; with simulations it is proved that door width has a tremendous impact on evacuation time. It is believed that the calibrated and validated parameters for VISWALK identified through a well-designed methodology, would help in developing solutions for various problems in infrastructure related domains, including the transportation.

8 Limitation of the study

In this study, evacuation data was collected for different geometric configuration and involving students of diverse age groups. Prior to conducting the experiments, instructions were given to students in such a way that they behave as if they were in emergency situations. It is difficult to obtain 100% accuracy in instil human responses during the emergency evacuation experiments. The factors, such as anxiety/fear and reaction times were captured partially in the present study. Using the basic data available from experiments, simulation models can be better calibrated and used for mimicking the real behaviour of evacuees by adjusting parameters and in the case of sensitivity analysis, to identify the most influential parameters, 15 combinations have to be verified. In this study authors explored only 8 combinations, considering the importance of the parameters in modelling. More research is possible in this direction.

9 Conclusions and future scope

This study is an attempt to establish the procedure for optimizing the simulation model parameters using the real-world data for emergency evacuation conditions. The proposed methodology is suitable for calibrating and validating any kind of pedestrian simulation model for normal and emergency scenarios. Conducting experiments on humans is arduous and perilous task and may leads to accidents as well. The authors have taken all the precautions to avoid incidents while conducting the experiment. Getting the data from recorded incidents is immensely useful and will further improve the quality of work. However, obtaining such data is hard and in most of the conditions it will not be available. In emergency evacuation, pedestrian behaviour plays a major role

and, in this study, pedestrian behavioural aspects, such as the relaxation time, distance from the other pedestrians and force exerted by the closest pedestrians, have a significant impact on total evacuation time from the classroom. Using the basic data available from experiments, simulation models can be better calibrated and used for mimicking the real behaviour of evacuees by adjusting parameters.

The methodology proposed in this study is very precise in considering all the necessary steps to optimize the pedestrian simulation parameters required to replicate emergency evacuation conditions, specifically in some practical applications, such as high-rise buildings, passenger vehicles and transport terminals. The proposed method assists in developing the suitable evacuation plans for emergency conditions and helps in improving the safety during the evacuations.

In line with the present study, in future, the authors would like to explore the application of the non-conventional optimization procedures, such as Genetic Algorithm (GA) or Differential Evolution (DA) in parameter estimation. In addition, number of doors

and door position influence on total evacuation time needs to be evaluated using the calibrated models. In the future, authors will extend this work to public transport vehicles and terminals where emergency evacuation of passengers from vehicles and terminals can be studied, using the simulation tools, such as VISWALK, PATHFIDNER and so on. From the experiments, it is observed that aggressiveness of the evacuees is the potential threat to the safety in panic conditions. Preparedness of the pedestrians for emergency situations is very important and continuous mock-drills for those conditions are mandatory.

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