Collective Dynamics

Comparison of Pedestrian Data of Single File Movement Collected from Controlled Pedestrian Experiment and from Field in Mass Religious Gathering

Siddhartha Gulhare[1] · Ashish Verma[2] · Partha Chakroborty[3]

[1] Department of Civil Engineering, Indian Institute of Science, Bangalore, India,
E-mail: siddharthagulhare89@gmail.com

[2] Department of Civil Engineering and Robert Bosch Centre for Cyber Physical Systems,
Indian Institute of Science, Bangalore, India,
E-mail: ashishv@iisc.ac.in

[3] Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India,
E-mail: partha@iitk.ac.in

Received: 31 October 2017 / Accepted: 4 May 2018
DOI: 10.17815/CD.2018.16

Abstract Managing and controlling crowd during mass religious gathering is a challenge for organizers. With good computational capabilities, it is possible to create tools to simulate crowd in real time to aid crowd management. These tools need to be first calibrated and validated with pedestrian empirical data. The empirical data collection from field is difficult and therefore, data collection through controlled pedestrian experiments have become a convenient substitute. However, the ability of experiment data to reproduce actual crowd behavior needs to be examined. This study compared the experiment data with field data collected from mass religious gathering named Kumbh Mela held in India, 2016. The single file movement (pedestrians moving along a single line; SFM) experiment was conducted and its results were compared with the field SFM results. The speed in the field was found to be generally higher than in the experiment for a given density. The results clearly indicate that the pedestrians in the field are motivated to achieve a purpose but participants in the experiments lack the motivation. The pedestrian dynamics of the experiment was found to be different from the field. Hence, the results of pedestrian experiments should not be extrapolated to understand panic, crowd risk situations.

Keywords Single file movement · mass religious gathering · controlled pedestrian experiments

1 Introduction

Planning and designing of pedestrian facilities for safe and efficient movement of crowd in mass religious gatherings is a challenge to managers and planners. The traditional way of designing such facilities and managing very large crowd, is generally based on experience and therefore, a rule of thumb. There is a need to develop methods and algorithms to manage such mass religious gatherings. Research on understanding pedestrian crowd dynamics mainly include empirical and theoretical approach. A conceptual classification of pedestrian crowd study is explained through a tree diagram in [1]. Many pedestrian simulation models have been developed; they can mainly be classified as macroscopic [2,3], microscopic [4–6] and mesoscopic [7]. With improvements in computational capabilities, it is possible to take live feed from CCTV cameras, drones, mobile GPS etc. and perform real time simulation to predict crowd dynamics for next few minutes or so. Like all models, pedestrian simulation models must also be calibrated and validated. Many empirical studies on pedestrian flow behavior in urban settings have been done in past. However, pedestrian data collection in field conditions in events such as mass religious gatherings is very challenging, due to many reasons such as getting required permission for data collection, associated bureaucratic hurdle, presence of multiple layers of security, difficulty in positioning the camera in ideal location to collect required data etc. Additionally there are challenges such as adverse weather, logistics, inability to capture a particular pedestrian flow phenomenon that is deemed relevant, etc. To overcome these problems, many researchers have shifted from field data collection to pedestrian experiments in controlled laboratory setup. The controlled experiments have the advantage of flexibility in controlling the influence variables and thus gives an opportunity to study the impact of one causal factor over another by keeping all other factors neutral. In the past decade, there has been a significant increase in the empirical data collection through controlled experiments to understand pedestrian behavior; at bottleneck [8–14], in single file movement [15–21], during evacuation [22–24], during counter flow [25]. However, during experimental studies, participants have to perform very limited amount of physical work for the assigned task and hence, they fail to imitate the physical exertion of the crowd in the field. Further, for most studies, the emotional situation of the participants is relaxed, so real effects are not shown [26]. It should also be taken into account that any variation in the instructions (given before the start of experiment) has potential to alter results significantly. These studies are conducted with participants (students/researchers) and hence, do not completely account for heterogeneity in crowd. The experiments are mostly performed indoor in comfortable environment and hence, do not incorporate external conditions like weather, which play a significant role in the field conditions. Finally, the participants in a controlled experiment lack purpose; they move because they have been asked to, not because they have a goal to reach. It can be argued that the motivation and stress level of participants can be slightly increased by reward system [27–29]. But very less is known about how much stress can be induced through rewards. Therefore, how well experimental studies reproduce crowd behavior in real mass gatherings need to be examined. The study compares, mutatis mutandis, the pedestrian behavior implied by data from controlled experiment and the behavior implied by field data from mass religious gathering. For this purpose, the simplest system of pedestrian movement, single file movement (SFM) was chosen. The field data is taken from the Mahakaleshwar temple during the Kumbh Mela-2016 in Ujjain. The Kumbh Mela is a religious fest and is considered to be the largest peaceful human gathering in the world. It is held, on an average, once in every three years with site rotating between four pilgrimage places in India: Haridwar, Allahabad, Nashik and Ujjain. Estimated 75 million people attended the Kumbh Mela held in Ujjain in 2016. A very large number of people from various backgrounds (urban, rural, foreign, holy men) visit the Kumbh Mela, bringing high level of heterogeneity in crowd. Such crowd brings mix of different pedestrian psychology with varying level of aggression, patience, etc.

2 Controlled Single File Movement

Crowd dynamics is a complex phenomenon, which is affected by factors like passing maneuvers, self-organization, self-ordering (zipper effect), internal friction etc. [19]. To get an improved and simplified sight to the problem, a simple system of single file movement with reduced degree of freedom was chosen. In recent years, many experimental studies have been done to understand pedestrian single file movement. [19] observed a linear relationship between the space headway and speed. Comparison of fundamental diagrams between Indian and German culture was studied in [20] to understand how culture affects the walking behavior. [21, 30] carried out SFM experiment in China to investigate the characteristics of pedestrians. The experiments have not just been limited to the pedestrians, [31] compared the fundamental diagram of bicycle traffic with that of pedestrian and car traffic in closed loop circuit. The next section discusses the experimental setup for a SFM study.

2.1 Experimental Setup

The same corridor setup for the SFM as adopted in [19, 20], was chosen as shown in Fig. 1. The length of the corridor (close loop) is $l_p = 17.3\ m$ and that of the measured section is $l_m = 2\ m$. The width of the straight portion is 0.8 m, which is believed to be sufficient for SFM. The width of the curved section was increased to a maximum 1.2 m through elliptical transition curve. Two cameras were set up to capture the movement of the participants as shown in Fig. 1. Camera 1 was placed along the perpendicular bisector of the measured section at a distance of 10 m to avoid parallax error. Camera 2 was placed in the adjacent building to cover top view of corridor. For this study, data was collected manually from camera 1.

The controlled experiment was conducted in October 2016 at Indian Institute of Science Bangalore, India, which involved 40 participants belonging to the age group of 25-50

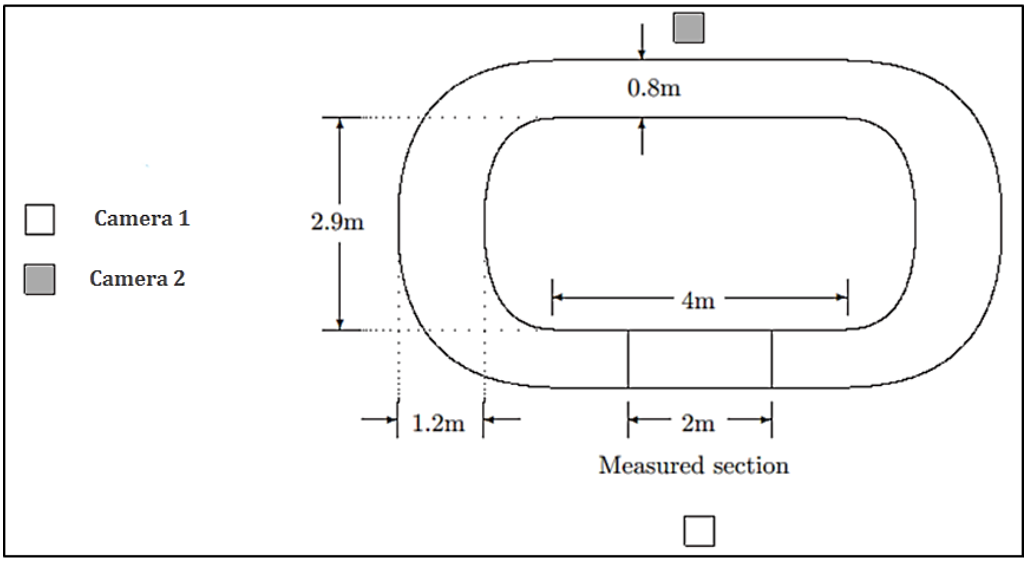

Figure 1 Sketch of the experimental setup

Figure 2 Snapshot of the experiment taken for the run with N = 40 Indian Institute of Science Bangalore, India.

years. The temperature and humidity during the experiment was about 27°C and 40%. Most of the participants who were a part of the experiment were not familiar with one another. In addition, participants were placed randomly in the closed loop setup and were asked to distribute uniformly. They were instructed to walk (in clockwise direction) as they would walk in normal circumstances and not to overtake as shown in Fig. 2. To obtain speed at different densities, experiment was executed in cycles with different number of participants (N) as mentioned in Tab. 1.

Table 1 Description of number of run for different number of participants

No of participants	5	10	15	20	30	40
Cycles	6	6	6	6	4	3

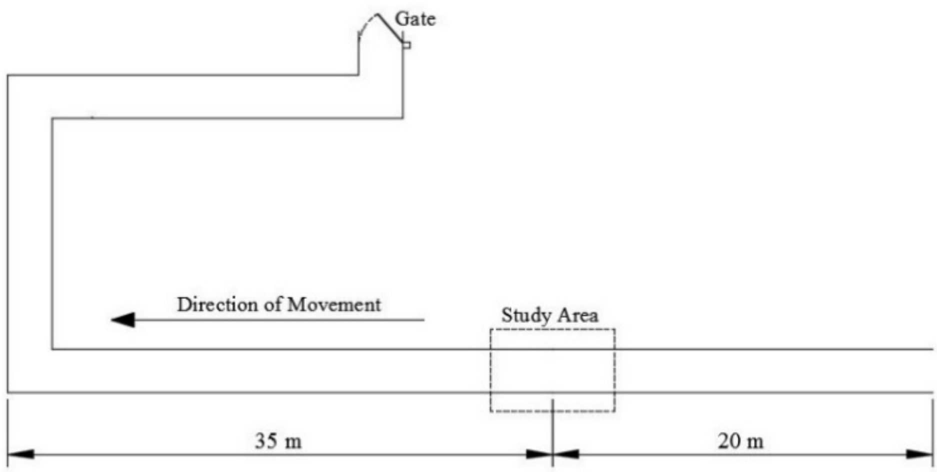

Figure 3 Schematic diagram of the Mahakaleshwar temple (field) SFM Setup

Figure 4 Screenshot of SFM in the Mahakaleshwar temple (field). Second corridor from left (enclosed in dotted line) is studied

3 Field Setup – Mahakaleshwar Temple

The Mahakaleshwar temple is a very important temple in the city of Ujjain, India and was one of the most important attractions during the Kumbh Mela-2016. It was visited by almost all pilgrims visiting the Kumbh Mela during its period from 22nd April to 21st May 2016. Outside the entrance of temple, straight corridors were installed to allow SFM towards the temple. Pedestrians had to walk through these corridors for approximately 90 m before entering into the temple premises from gate as schematically illustrated in Fig. 3. Though the corridors were well delineated, they seemed to have a lot of impact from the sides (since, the corridors folded over one another) as shown in Fig. 4. A CCTV camera (capturing top view of movement) was installed at approximately 20 m from the beginning of SFM. Among the four corridors, the second from the left with a width of 0.8 m (same as width of experimental setup) was chosen for study. The length of study area in video footage was 2.8 m. The field setup was different from experimental setup in some aspects such as presence of strong railings of height 0.9 m separating corridors (shown in Fig. 4). Pedestrians had to pass through the corridor only once to enter the temple and had to exit from the other side, unlike experimental setup where participants had to walk in endless loop. The temperature and humidity of field was about 40° and 30%, however the corridor was covered from top. The video duration of 2 hours and 50 minutes was analyzed in which 6929 pedestrians passed through the measured study section.

4 Data Collection

Vertical lines were annotated in the video to record the entry and exit time of each pedestrian. The entry and exit time provides the time taken to pass the measured section, which helps in calculating the speed of individuals. Since, there can be only (1-6) participants inside the measured area in the experiment, the classical density can take only very limited discrete values and hence, the enhanced linear density as calculated using equation 1 of [19]. Further area density was calculated by dividing linear density by width. Similar approach was used in the field data. The entry-exit time of each pedestrian was recorded from video footage by taking head of the pedestrian as the reference. The height of each pedestrian was recorded as short, medium and tall. In addition, appropriate correction for varying height was applied in entry and exit time.

5 Data Analysis and Comparison of Results

The difference in the style of walking in both the setup is illustrated in Fig. 5. In both the systems, pedestrians were free to use full provided space. In the field, small proportion of overtaking was observed, however, pedestrians were asked not to overtake in the experimental setup. The movement of pedestrians in the field was observed to be more unordered.

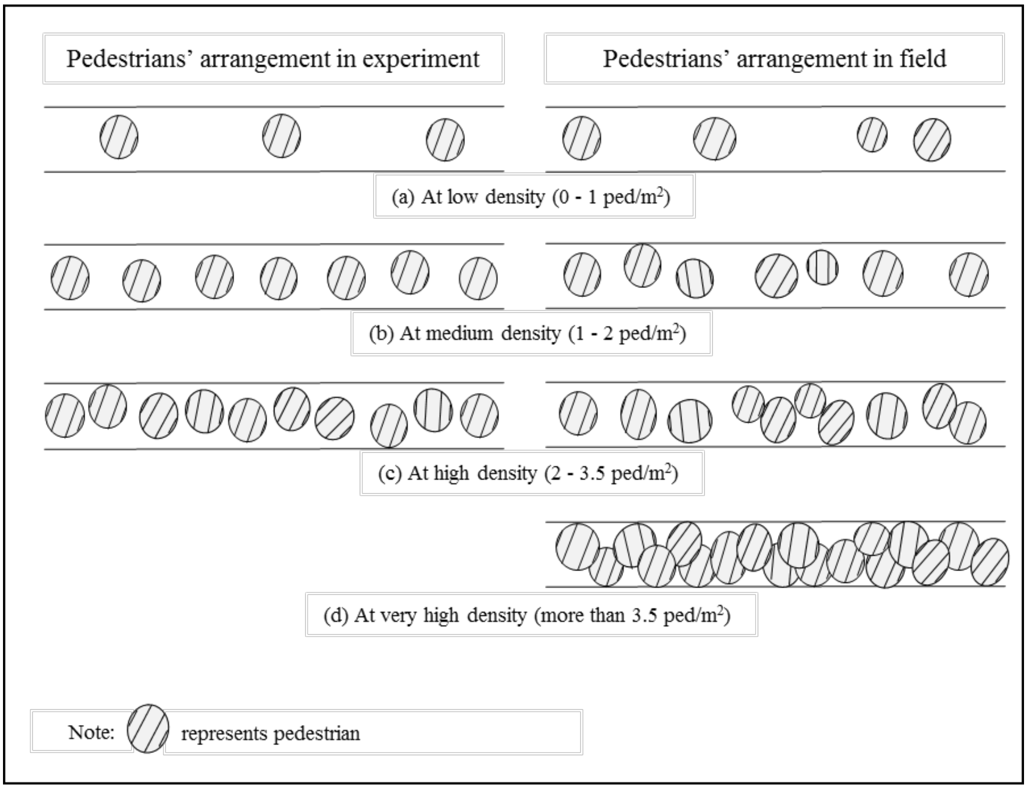

Figure 5 Illustration to show the difference in arrangement of pedestrians in SFM between experimental setup and field at the Mahakaleshwar temple

Table 2 Statistical measures for speed-area density relationship for experiment and field dataset

Data set	Intercept, γ	Slope, β	R^2	# data points
Experiment	$\gamma_E = 0.78$ ($S_{\gamma_E} = 0.019$) (t-stat=40.53)	$\beta_E = 1.07$ ($S_{\beta_E} = 0.010$) (t-stat=103.13)	0.91	1072
Field	$\gamma_F = 0.21$ ($S_{\gamma_F} = 0.010$) (t-stat=21.44)	$\beta_F = 0.42$ ($S_{\beta_F} = 0.004$) (t-stat=117.48)	0.61	8751

5.1 Speed vs. Density Relationship

The relationship between speed and density is used to quantitatively analyze the pedestrian facility. The interquartile graph of speed - area density for the field data and the experiment data are plotted in Fig. 6 (The behavior represented by the various interquartile graphs with different bin size and bin position were found to be similar.). The important subjective observation that can be made here is that relationship is not linear for both data set. It can be observed that speed is higher in field data than in experiment data for every density region (except for very low-density region). The rate of change of speed is

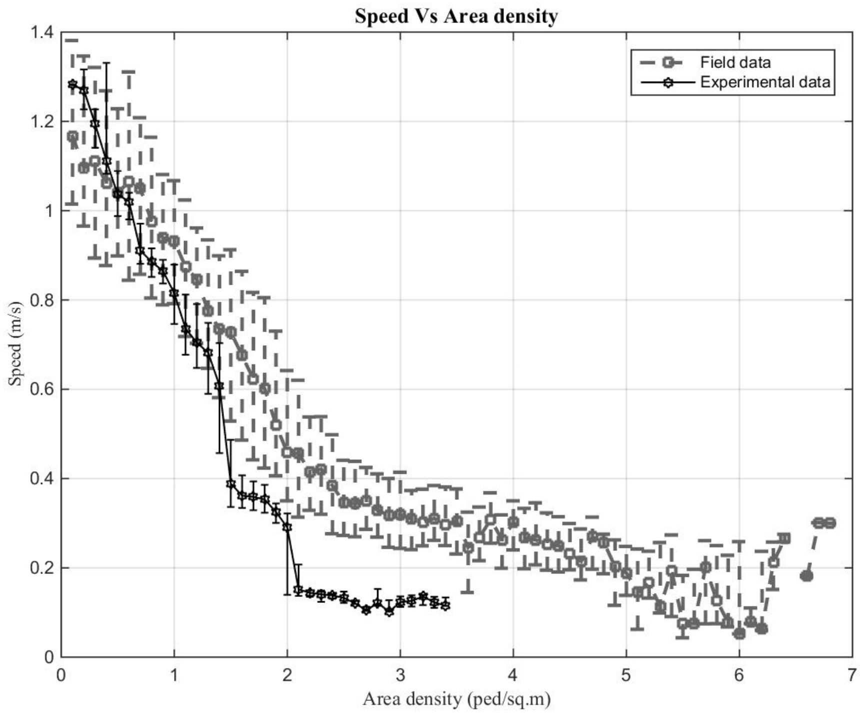

Figure 6 Speed-density data from field and experiment data

slightly higher in the experiment than in the field for density values less than $2\text{ped}/m^2$. For density values higher than $2\text{ped}/m^2$, participants have nearly seized to walk in the experiment, while pedestrians in the field continued to move forward. The exponential curve, $v = \alpha e^{-\beta d}$ is fitted on the data sets, where v is the speed, d is the density and β represents the decay rate, i.e. the rate of change of speed with respect to density is β times the current value of speed. In order to apply linear regression analysis, the equation is transformed to $\ln v = \gamma - \beta d$, where γ is natural log of α. The details of the parameters and test statistics are presented in Tab. 2.

As shown in Tab. 2, for experiment (β_E) is -1.07 and in field (β_F) is -0.42. The standard error values for β is $S_{\beta E} = 0.010$ for experiment and $S_{\beta F} = 0.004$ for field. The hypothesis that decay rate of speed (β) obtained from experiment and field are the same (Null hypothesis $H_0: \beta_F - \beta_E = 0$ and alternate hypothesis $H_1: \beta_F - \beta_E \neq 0$) was tested. Since number of data points are large

$$z = \frac{\beta_F - \beta_E}{\sqrt{S^2_{\beta F} + S^2_{\beta E}}} \quad (1)$$

is assumed to have normal distribution. From the above expression, z value calculated is 60.35, which is more than $z_{critical} = 1.96$ at 95% confidence interval for two tailed test and therefore null hypothesis has been rejected. The decay rate from experiment and field are significantly different. It can concluded that participants in the experiment lacks the motivation and had no reasons to go beyond their comfort limits. However, in the field, pedestrians have a goal to achieve and therefore despite impedance they continue to press forward (at reasonable speeds) even at higher densities.

5.2 Personal Space vs. Speed Relationship

The relationship between personal space (p) and speed (v) is not linear but close to parabolic in shape as shown in Fig. 7. Personal space, i.e. inverse of area density, was chosen because pedestrians were free to use full width in the setups. It was felt that in keeping with earlier analysis, where distance headway has been used and also realizing that longitudinal distance is more important to pedestrians, the analysis uses square root of personal space (p) as explained variable. One may think of $\sqrt{p}$ as longitudinal distance between pedestrians (assuming the personal space can be approximated as a square). It is proposed, for the sake of simplicity, that $\sqrt{p} = \eta + \theta v$, where η denotes the square root of personal space of pedestrian when stationary and θ denotes the rate of change of square root of personal space with respect to speed. To remove heteroscedasticity, weighted least square regression was performed. Details of parameters and test statistics are presented in Tab. 3.

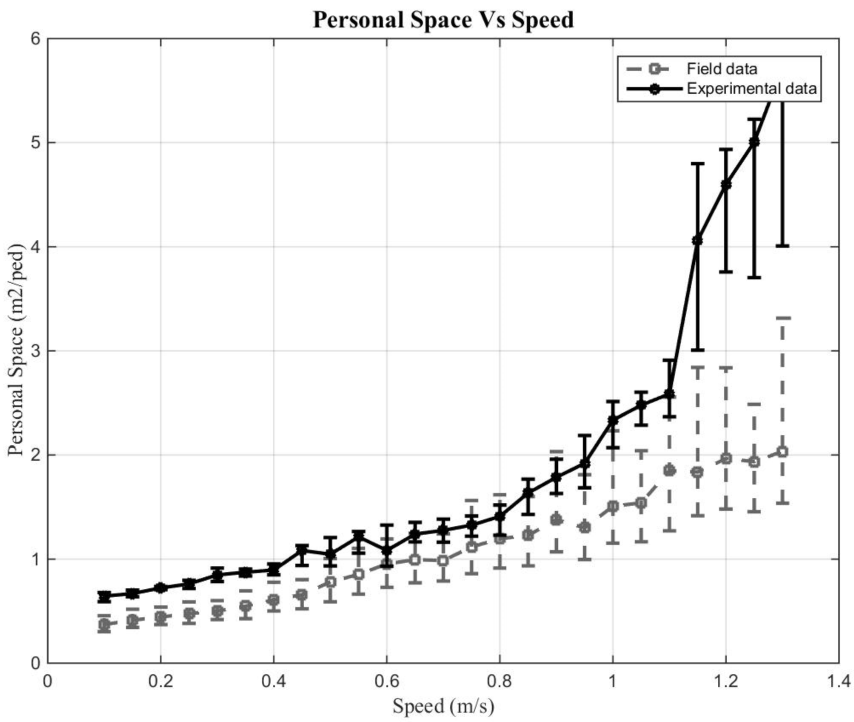

Figure 7 Speed-personal space relation for field and experiment data

The result of hypothesis testing (to test if parameters intercept and slope are same) are presented in Tab. 4, which indicates there is significant difference. The estimated personal space when stationary (η^2) for experiment is $0.31\ \mathrm{m^2/ped}$ and for field is

Table 3 Statistical measure for $\sqrt{p}$ vs.v relationship of experiment and field dataset

Data set	Intercept, η	Slope, θ	R^2	# data points
Experiment	0.56 ($S_{\eta_E} = 0.002$) (t-stat=269.5)	0.61 ($S_{\theta_E} = 0.009$) (t-stat=64.4)	0.80	1072
Field	0.43 ($S_{\eta_F} = 0.002$) (t-stat=208.2)	0.58 ($S_{\theta_F} = 0.006$) (t-stat=97.6)	0.52	8751

Table 4 Hypothesis testing for personal space vs speed parameters

Null Hypothesis	Alternative Hypothesis	z	Null Hypothesis is Accepted/Rejected
$\eta_F - \eta_E = 0$	$\eta_F - \eta_E \neq 0$	-45.96	Rejected at 95% level of confidence
$\theta_F - \theta_E = 0$	$\theta_F - \theta_E \neq 0$	-2.77	Rejected at 95% level of confidence

0.18 m^2/ped. The significant difference between personal space of field and experiment can be attributed to staggered arrangement of pedestrians, which possibly arise as pedestrians are eager to reach their goal and do not mind higher densities. It is visually affirmed from the video that pedestrians persistently moved towards the destination, which leads to staggered arrangement and consequent dense packing of pedestrians. The coefficient θ estimates the rate of change of square root of personal space with speed, which is significantly different for experiment and field as shown in Tab. 4. The significantly lesser value in the field reaffirms the belief that pedestrians in the field are less sensitive to changes in density.

6 Discussion and Conclusion

Crowd movement in large gatherings are often done through makeshift corridors. In order to understand pedestrian behavior in such corridors and to enquire into the dynamics of pedestrian flow researchers have conducted many controlled, typically closed-loop, experiments. These experiments have brought to light important features related to pedestrian movement. Often, they have been used as surrogates for the behavior that is to be expected in real-world scenarios, the assumption being that the behavior expected in real-world situations will be more or less the same as that observed in controlled experiments. This paper attempts to study the validity of such an assumption by comparing real-world pedestrian movement data with controlled experiment pedestrian movement data. The premise here is that movement of pedestrians in real-world scenarios may be different from those that can be created in a laboratory in two important ways:

i. In the real-world pedestrians move to reach a goal, this gives them motivation to move; while in the laboratory they move because they have been asked to. There are some scientific studies that have argued that this limitation of laboratory experiments can possibly be overcome by introducing very high incentives for the subjects, however, more studies are required to scientifically establish the same.

ii. feelings of excitement, apprehension, fatigue, etc. present in real-world situations are difficult, although not impossible, to inculcate in laboratory settings.

Data collected from a 2.8 m section of a few km long route leading to the Mahakaleshwar temple during the Kumbh Mela-2016, Ujjain, India (where estimated 75 million persons congregate over 30 days) is used as the real-world data. Data from 2 m long section of a controlled experiment on a 17.3 m long closed loop corridor in IISc Bangalore is used as the laboratory experiment data. Statistical analysis using these extensive data sets clearly indicate that there are significant differences in the pedestrian flow patterns.

This study brings up the need for more research on ascertaining effectiveness and applicability of controlled experiments in representing a real-world scenario. While the controlled experiments do give the analyst and planner an idea of the pedestrian behavior, its divergence from the actual behavior can be significant. Further, real-world scenarios also vary from controlled scenarios in few other ways. For example, the two scenarios differ in terms of (i) the crowd heterogeneity in religious gatherings (gender, age, socio-economic background, etc.), (ii) the fact that many travel in groups (and these groups are of different sizes), and (iii) the observations that often pedestrians, especially those from rural areas, carry headload. Although, one can argue that controlled experiments can be designed to account for these, however, so far it has not been reported in the literature. Even, the experiments carried out as part of this work could not include these, as it was found difficult to create such a heterogeneous mix with different group sizes and headloads. The urgency and stress level can be slightly enhanced by introducing reward system, which may improve the realism of experiment. However, this study did not incorporate the reward system because there is still not clear evidence as to what level of reward may be effective and whether induced stress or motivation to earn the offered reward during experiment can recreate real world scenarios (such as the excitement of pilgrims visiting holy place during very auspicious occasion or genuine fear of group members when they are separated or panic of crowd evacuating a burning building etc.). In addition, the experiment was conducted with an open boundary whereas the field setup had a closed boundary. This may have an influence on the results to some extent and is worth further research.

It is felt that theories of pedestrian motion that will ultimately lead to simulation tools for studying and predicting crowd dynamics need to be built, calibrated and validated using observations from real-world streams, to the extent possible. Controlled laboratory experiments can provide insights but whether they can replace real-world data is doubtful and needs further investigation.

Acknowledgements The work reported in this paper is part of the project titled “The Kumbh Mela Experiment: Measuring and Understanding the Dynamics of Mankinds largest crowd”, funded by the Ministry of Electronics and IT Ministry of Communication and Information Technology, Government of India (MITO-0105), Netherlands Organization for Scientific Research, NWO (Project No. 629.002.202), Department of Science and Technology, Russian Ministry of Education, and Robert Bosch Center for Cyber Physical Systems, Indian Institute of Science, Bangalore.

References

[1] Shi, X., Ye, Z., Shiwakoti, N., Li, Z.: A Review of Experimental Studies on Complex Pedestrian Movement Behaviors, pp. 1081–1096. Proc. of 15th COTA Int. Conf. of Transp. (2015). doi:10.1061/9780784479292.101

[2] Henderson, L.F.: The statistics of crowd fluids. Nature **229**(5284), 381–383 (1971)

[3] Helbing, D.: A fluid dynamic model for the movement of pedestrians. Complex Systems **6**, 391–415 (1992)

[4] Helbing, D., Molnár, P.: Social force model for pedestrian dynamics. Phys. Rev. E **51**, 4282–4286 (1995). doi:10.1103/PhysRevE.51.4282

[5] Blue, V., Adler, J.: Cellular automata microsimulation of bidirectional pedestrian flows. Transportation Research Record: Journal of the Transportation Research Board **1678**, 135–141 (1999). doi:10.3141/1678-17

[6] Okazaki, S., Matsushita, S.: A study of simulation model for pedestrian movement with evacuation and queuing. In: Smith, R.A., Dickie, J.F. (eds.) International Conference on Engineering for Crowd Safety, pp. 271–280 (1993)

[7] AlGadhi, S.A.H., Mahmassani, H.S.: Simulation of crowd behavior and movement: Fundamental relations and application. Transp. Res. Rec. **1320**, 260–268 (1991)

[8] Daamen, W., Hoogendoorn, S.: Experimental research of pedestrian walking behavior. Transportation Research Record: Journal of the Transportation Research Board **1828**, 20–30 (2003). doi:10.3141/1828-03

[9] Duives, D., Daamen, W., Hoogendoorn, S.: Anticipation behavior upstream of a bottleneck. Transportation Research Procedia **2**, 43–50 (2014). doi:https://doi.org/10.1016/j.trpro.2014.09.007. The Conference on Pedestrian and Evacuation Dynamics 2014 (PED 2014), 22-24 October 2014, Delft, The Netherlands

[10] Hoogendoorn, S.P., Daamen, W.: Pedestrian behavior at bottlenecks. Transportation Science **39**(2), 147–159 (2005). doi:10.1287/trsc.1040.0102

[11] Kretz, T., Grünebohm, A., Schreckenberg, M.: Experimental study of pedestrian flow through a bottleneck. Journal of Statistical Mechanics: Theory and Experiment **2006**(10), P10014 (2006)

[12] Seyfried, A., Steffen, B., Winkens, A., Rupprecht, T., Boltes, M., Klingsch, W.: Empirical data for pedestrian flow through bottlenecks. In: Appert-Rolland, C., Chevoir, F., Gondret, P., Lassarre, S., Lebacque, J.P., Schreckenberg, M. (eds.) Traffic and Granular Flow '07, pp. 189–199. Springer Berlin Heidelberg, Berlin, Heidelberg (2009)

[13] Seyfried, A., Boltes, M., Kähler, J., Klingsch, W., Portz, A., Rupprecht, T., Schadschneider, A., Steffen, B., Winkens, A.: Enhanced empirical data for the fundamental diagram and the flow through bottlenecks. In: Klingsch, W.W.F., Rogsch, C., Schadschneider, A., Schreckenberg, M. (eds.) Pedestrian and Evacuation Dynamics 2008, pp. 145–156. Springer Berlin Heidelberg, Berlin, Heidelberg (2010)

[14] Seyfried, A., Passon, O., Steffen, B., Boltes, M., Rupprecht, T., Klingsch, W.: New insights into pedestrian flow through bottlenecks. Transportation Science **43**(3), 395–406 (2009). doi:10.1287/trsc.1090.0263

[15] Cao, S., Zhang, J., Salden, D., Ma, J., Shi, C., Zhang, R.: Pedestrian dynamics in single-file movement of crowd with different age compositions. Phys. Rev. E **94**, 012312 (2016). doi:10.1103/PhysRevE.94.012312

[16] Fang, J., Qin, Z., Hu, H., Xu, Z., Li, H.: The fundamental diagram of pedestrian model with slow reaction. Physica A: Statistical Mechanics and its Applications **391**(23), 6112–6120 (2012). doi:https://doi.org/10.1016/j.physa.2012.07.005

[17] Fang, Z.M., Song, W.G., Liu, X., Lv, W., Ma, J., Xiao, X.: A continuous distance model (CDM) for the single-file pedestrian movement considering step frequency and length. Physica A: Statistical Mechanics and its Applications **391**(1), 307–316 (2012). doi:https://doi.org/10.1016/j.physa.2011.08.009

[18] Jelić, A., Appert-Rolland, C., Lemercier, S., Pettré, J.: Properties of pedestrians walking in line: Fundamental diagrams. Phys. Rev. E **85**, 036111 (2012). doi:10.1103/PhysRevE.85.036111

[19] Seyfried, A., Steffen, B., Klingsch, W., Boltes, M.: The fundamental diagram of pedestrian movement revisited. Journal of Statistical Mechanics: Theory and Experiment **2005**(10), P10002 (2005)

[20] Chattaraj, U., Seyfried, A., Chakroborty, P.: Comparison of pedestrian fundamental diagram across cultures. Advances in Complex Systems **12**(03), 393–405 (2009). doi:10.1142/S0219525909002209

[21] Liu, X., Song, W., Zhang, J.: Extraction and Quantitative analysis of Microscopic Evacuation Characteristics based on Digital Image Processing. Physica A: Statistical Mechanics and its Applications **388**(13), 2717–2726 (2009). doi:https://doi.org/10.1016/j.physa.2009.03.017

[22] Isobe, M., Helbing, D., Nagatani, T.: Experiment, theory, and simulation of the evacuation of a room without visibility. Phys. Rev. E **69**, 066132 (2004). doi:10.1103/PhysRevE.69.066132

[23] Schadschneider, A., Seyfried, A.: Validation of CA models of pedestrian dynamics with fundamental diagrams. Cybernetics and Systems **40**(5), 367–389 (2009). doi:10.1080/01969720902922400

[24] Zhang, J., Song, W., Xu, X.: Experiment and multi-grid modeling of evacuation from a classroom. Physica A: Statistical Mechanics and its Applications **387**(23), 5901–5909 (2008). doi:https://doi.org/10.1016/j.physa.2008.06.030

[25] Isobe, M., Adachi, T., Nagatani, T.: Experiment and simulation of pedestrian counter flow. Physica A: Statistical Mechanics and its Applications **336**(3), 638–650 (2004). doi:https://doi.org/10.1016/j.physa.2004.01.043

[26] Koshi, M., Iwasaki, M., Ohkura, I.: Some findings and an overview on vehicular flow characteristics. In: Proceedings of the 8th International Symposium on Transportation, pp. 403–426 (1983)

[27] Muir, H.C., Bottomley, D.M., Marrison, C.: Effects of motivation and cabin configuration on emergency aircraft evacuation behavior and rates of egress. The International Journal of Aviation Psychology **6**(1), 57–77 (1996). doi:10.1207/s15327108ijap0601_4

[28] Mintz, A.: Non-adaptive group behavior. The Journal of Abnormal and Social Psychology **46**(2), 150–159 (1951)

[29] Daamen, W., Hoogendoorn, S.: Capacity of doors during evacuation conditions. Procedia Engineering **3**, 53–66 (2010). doi:https://doi.org/10.1016/j.proeng.2010.07.007. First International Conference on Evacuation Modeling and Management

[30] Tian, W., Song, W., Ma, J., Fang, Z., Seyfried, A., Liddle, J.: Experimental study of pedestrian behaviors in a corridor based on digital image processing. Fire Safety Journal **47**, 8–15 (2012). doi:https://doi.org/10.1016/j.firesaf.2011.09.005

[31] Zhang, J., Mehner, W., Andresen, E., Holl, S., Boltes, M., Schadschneider, A., Seyfried, A.: Comparative analysis of pedestrian, bicycle and car traffic moving in circuits. Procedia - Social and Behavioral Sciences **104**, 1130–1138 (2013). doi:https://doi.org/10.1016/j.sbspro.2013.11.209. 2nd Conference of Transportation Research Group of India (2nd CTRG)