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Understanding Group Behavior in Pedestrian Crowds- A Comparative Study of Groups in Mass Gatherings and a Regular Urban Setup

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Abstract

` Over time, many studies have been conducted on pedestrian behaviour to improve the fidelity of pedestrian models. Most of these have looked into this behaviour considering pedestrians as individual entities. On the contrary, when looking at mass gatherings, participation of groups is much higher than individuals, which calls for studies focussing on understanding group behaviour in a crowd. This study attempts to strengthen this understanding by studying pedestrian groups in a mass religious gathering and in an urban setup and later comparing both to draw inferences. GPS data is collected in Kumbh Mela representing mass gathering and video data in Open day at Indian Institute of Science campus representing urban setup. Trajectory extraction is done for the walking groups from data obtained using videography. The spatial formation of different group sizes along a corridor is plotted and their emergent patterns are generalized. The area occupancy of groups with respect to group sizes and their average walking speeds is calculated. Further, comparison is made between the results obtained from both the data sets. This study will help bring out interesting results on walking patterns of groups in crowd. This will also uncover how the walking behavior in mass gatherings is different from a regular urban setup.

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Keywords: Crowd dynamics; Group behaviour; Spatial formation; Mass gathering; India

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1. Introduction

Graphical simulation helps in proper assessment, planning and designing of mass gathering and other urban spaces, providing optimal architectural solutions for crowded facilities to ensure spatial effectiveness in terms of services and safety. But before these pedestrian simulations can support decision-making, it is important to calibrate and validate these computational models against empirical observations. Numerous studies have been conducted to understand pedestrian behavior in crowd. All of these studies aimed at understanding pedestrian behavior in crowd to improve the fidelity of pedestrian simulation models. Majority of the work focuses on understanding pedestrian behavior by considering pedestrians as individual entities. But speaking from crowd's characterial standpoint, it is seen that group visitors are the predominant population when compared to single visitors in any type of mass gatherings and as participation of groups is much higher than individuals, it calls for studies focusing on understanding group behavior in a crowd and its impact on overall flow of crowd.

As presence of groups among crowd was observed, lot of work followed on exploration of group behavior in pedestrian crowd. A study conducted at 18 different locations observed that one third of the population came in at least groups of two members (Coleman & James, 1961). Another study conducted in football event revealed that three quarter of people came in groups (Aveni 1977). In the case of Kumbh Mela (Largest mass gathering), a questionnaire survey revealed that 95% of surveyed people came in groups (Gayathri et al, 2017). (Singh et al 2009; Cheng et al 2014), assert that the percentage of people who come in groups in a crowd ranges from 40% to 70% and it majorly depends on the location and the environment. Many authors have compared the walking speeds with the size of groups. (Moussaid et al, 2010; Schultz et al, 2010), observed that increase in size of group negatively affects the group's speed. (Gorrini et al 2015), stated that presence of groups in crowd influences the capacity severely. (Duives et al, 2014), observed that at lower densities, flow breakdown is likely to occur due to presence of groups. (Strogatz et al, 2005), observed that pedestrians start walking in synchronized steps when density exceeds the critical value. It was also observed that while at low densities, smaller pedestrian groups of size- three, walk in a linear formation but as the density gets higher, group attains a 'V'-like formation where the pedestrian in the middle tends to stay back. Pedestrian groups are known to generally develop patterns and (Miguel, 2015) reinforces this by stating that a pedestrian group develops patterns while moving from one point to another, if it is free to evolve over time.

It can be seen that many studies have tried to stress upon understanding the impact of pedestrian groups on crowd dynamics. To have an accurate simulation of pedestrian movement, it is important to incorporate all the macroscopic and microscopic characteristics of crowd to firstly calibrate and validate the model using the empirical data. It attempts to address the gaps in understanding of group behaviour in pedestrian crowds by focusing on following research questions:

- Group size proportion in mass gatherings vs regular urban setup.
- Spatial formation of walking groups over time and space.
- Area occupancy of individuals with respect to varying group sizes.
- Average walking speed of groups with respect to varying group sizes.

Thus, this study attempts to strengthen the understanding walking groups among crowd in different geographical setup and draws inferences on spatial formation, area occupancy and average speeds of walking groups.

2. Study Area and Data Collection

The pedestrian movement data was collected for two different locations, i.e. Kumbh Mela area and IISc (Indian Institute of Science), Bangalore Campus. Data collection was done in Kumbh mela held in Ujjain, India, during 22nd April to 21st May 2016. Kumbh Mela is one of the largest religious gathering held in India, in which an estimated 100 million people gather once in three years and it is held at four different locations rotation on a rotational basis. Pedestrian groups were identified by authors and portable GPS devices were handed over to each member of the group. The highly accurate GPS device records location coordinate and speed of the individual with time stamp. For this study, GPS data was collected for 26 groups of size three, four and five. Fig. 1 shows the typical trace of a group of four traversing across the Kumbh mela region.

Fig. 1. GPS trace of a group of four persons

Another dataset representing controlled- setup was collected on open day event held at Indian Institute of Science in Bangalore, India in 2018. Institute open day is a yearly event held to showcase and share the ongoing research in the Institute with the outside world. The event held in 2018 attracted 30 thousand visitors to the campus in one day. To capture this pedestrian movement within campus, video data was collected. Cameras were placed on lampposts spaced at a distance of 30m along a straight corridor. Two cameras were placed on each lamppost in order to capture top-down and angular view.

3. Methodology

The flow diagram in figure 2 depicts the schematic representation of methodology. To capture the pedestrian movement, data was collected using videography and portable GPS devices for two different locations. From the raw database, credible data was then filtered out and trajectory extraction of walking groups was done for data obtained from both, GPS and video. Data for both the locations was analyzed for proportion of different group sizes, groups' spatial formation over time and its area occupancy with respect to group size. Further, two different datasets were compared and patterns/ differences were identified and presented.

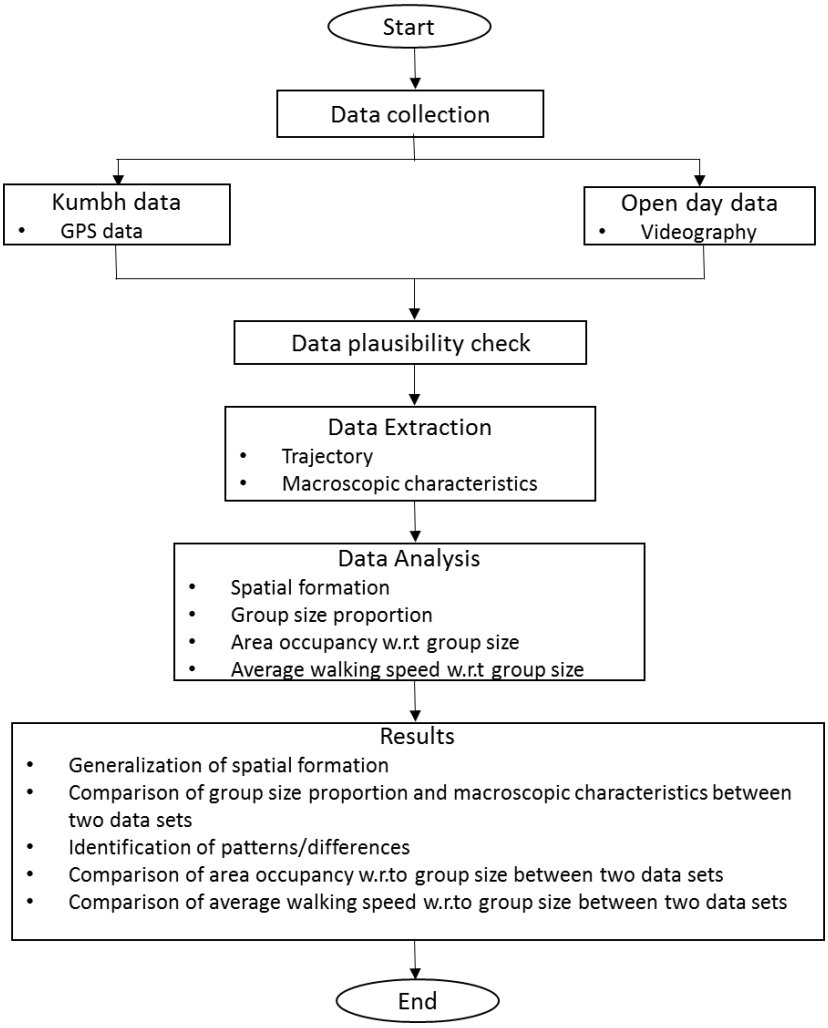

Fig. 2. Methodology

4. Data Extraction

2091 groups were identified from the videos of group sizes one to seven, considering individual pedestrians as group size one. Top-down videos were used for extracting pedestrian trajectories whereas angular videos were used to identify the group and verify them in all the cameras placed along the corridor. Data extraction was done for 30 groups of size three, four and five. Groups were identified based on their social interaction. This study assumes that pedestrians who stay in a close proximity, intentionally walk together and communicate among themselves form a group. Figure 3 shows screenshots from angular and top-down videos. Figure 4 shows a group of four captured in all three cameras placed along a straight corridor.

Fig. 3. (a) Group identification; (b) Trajectory extraction.

Fig. 4. (a) Pole 1; (b) Pole 2; (c) Pole 3

5. Data Analysis and Results

5.1 Group size proportion

The number of groups for each group size was manually counted for open day and Kumbh. A total of 1494 and 2098 groups ranging from group size 1 to 7 and greater than 7 were identified. The maximum number of people were found to be moving in groups of two. About 77% and 67% of people in open day and Kumbh respectively, came in groups. The plot between groups and group size peaks at group size two and declines gradually with increase in group size. This is evident from figure 5

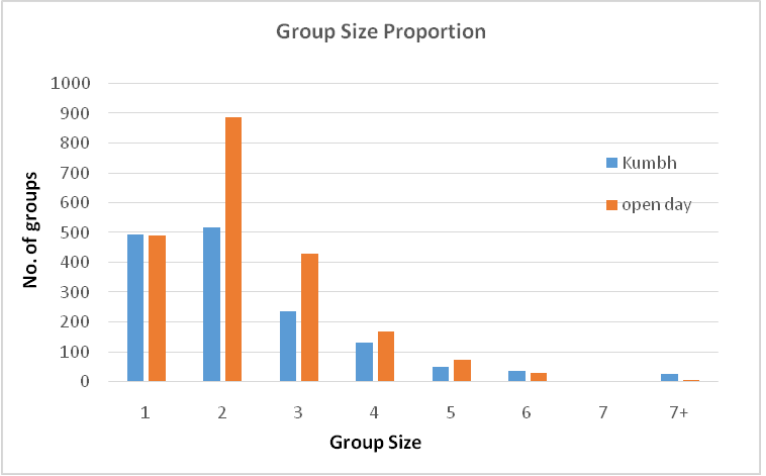

Fig.5. Group Size Proportion for kumbh and open day

5.2 Spatial formation

The emerging patterns that the groups take in order to walk in their comfortable positions, due to various reasons like supporting communication, being in close proximity with their group members etc, are studied. The patterns that group size 3, 4 and 5 form, along a straight corridor over a period for both open day and Kumbh data, are plotted using their coordinates. Figure 6, 7 and 8 shows the patterns that are predominantly seen in open day for group sizes 3, 4 and 5 respectively and Figure 9, 10 and 11 shows the patterns that are predominantly seen in Kumbh mela for group sizes 3, 4 and 5 respectively. It is evident from the figures that group size 3, in both cases, majorly form linear or V-pattern whereas group size 4 and 5 form asymmetric irregular polygons.

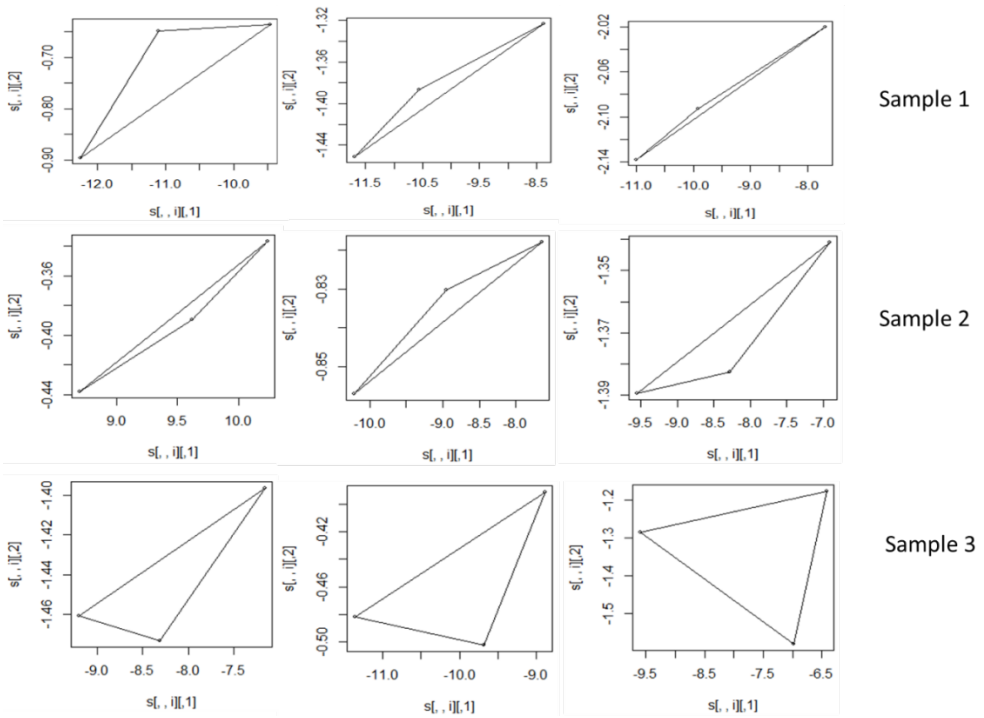

Fig. 6. Pattern predominantly seen in open day for group size 3

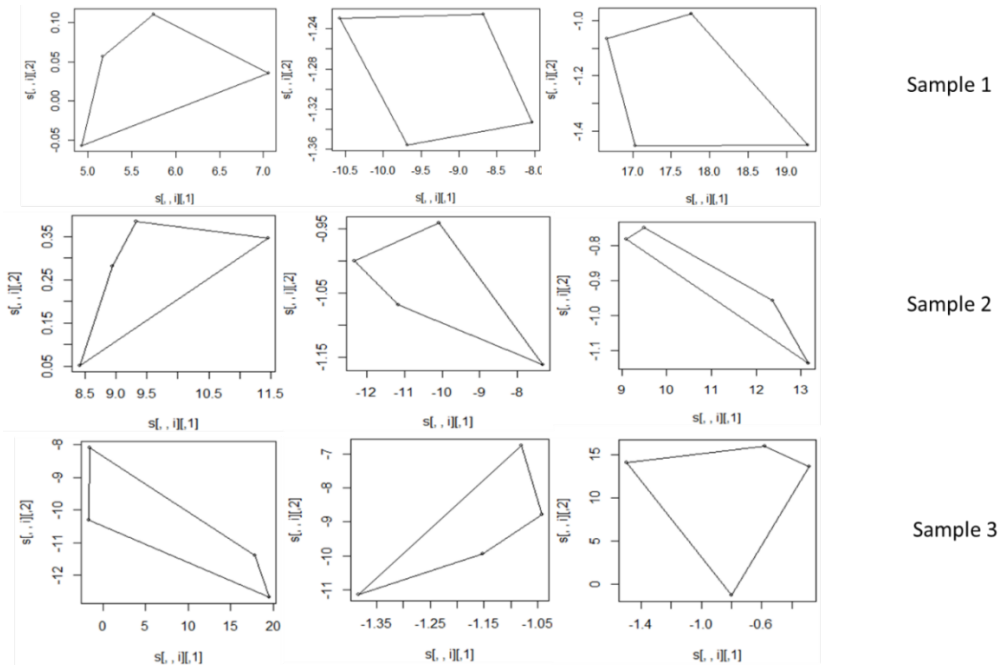

Fig. 7. Pattern predominantly seen in open day for group size 4

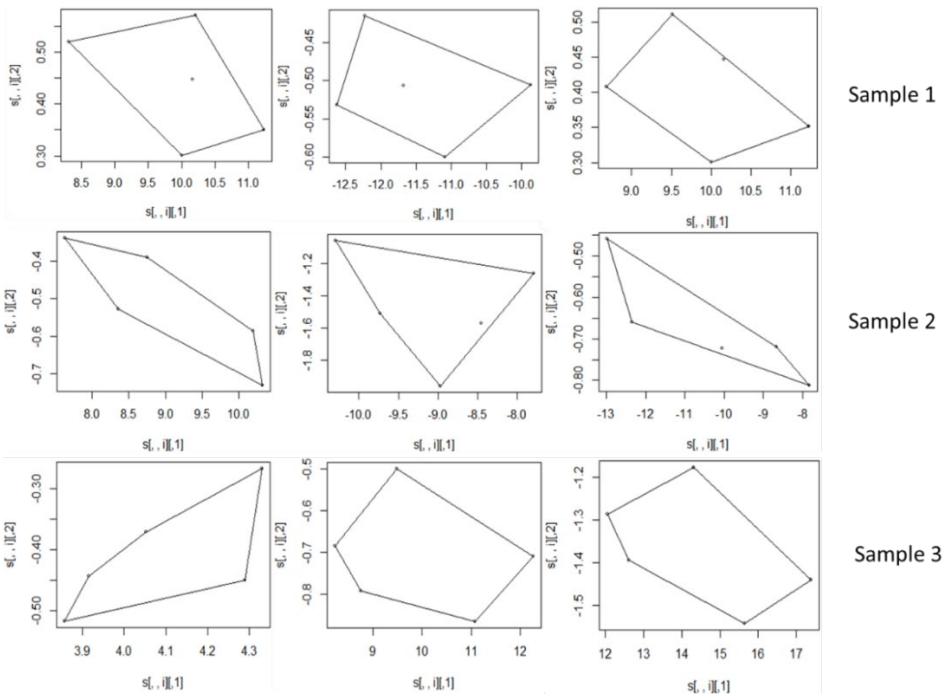

Fig. 8. Pattern predominantly seen in open day for group size 5

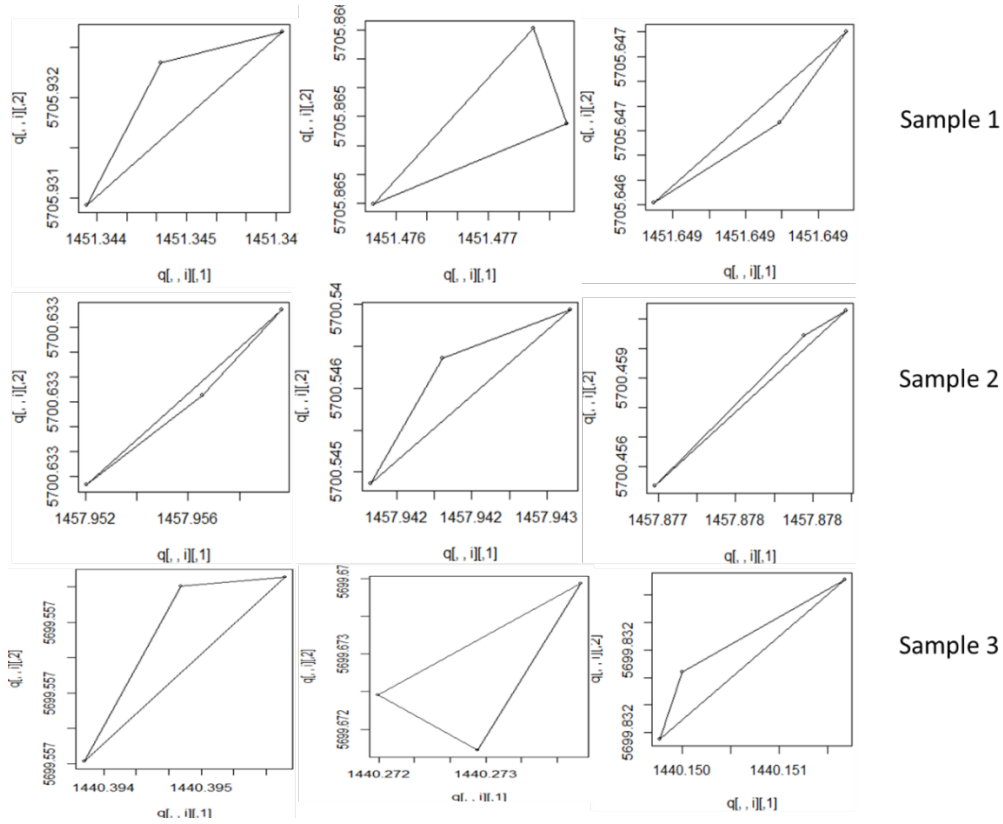

Fig. 9. Pattern predominantly seen in Kumbh mela for group size 3

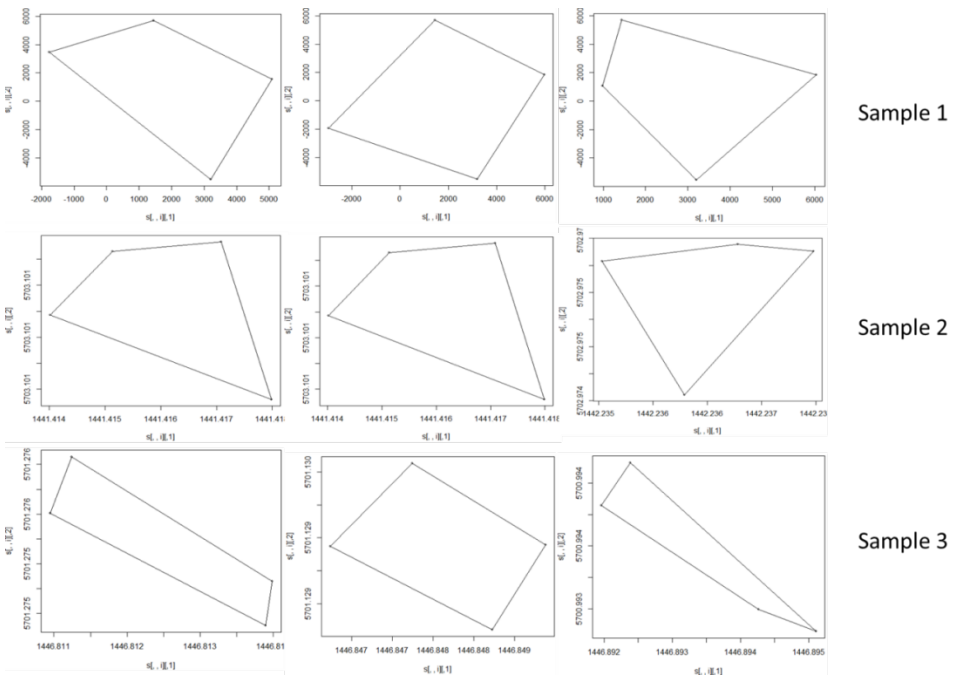

Fig. 10. Pattern predominantly seen in Kumbh mela for group size 4

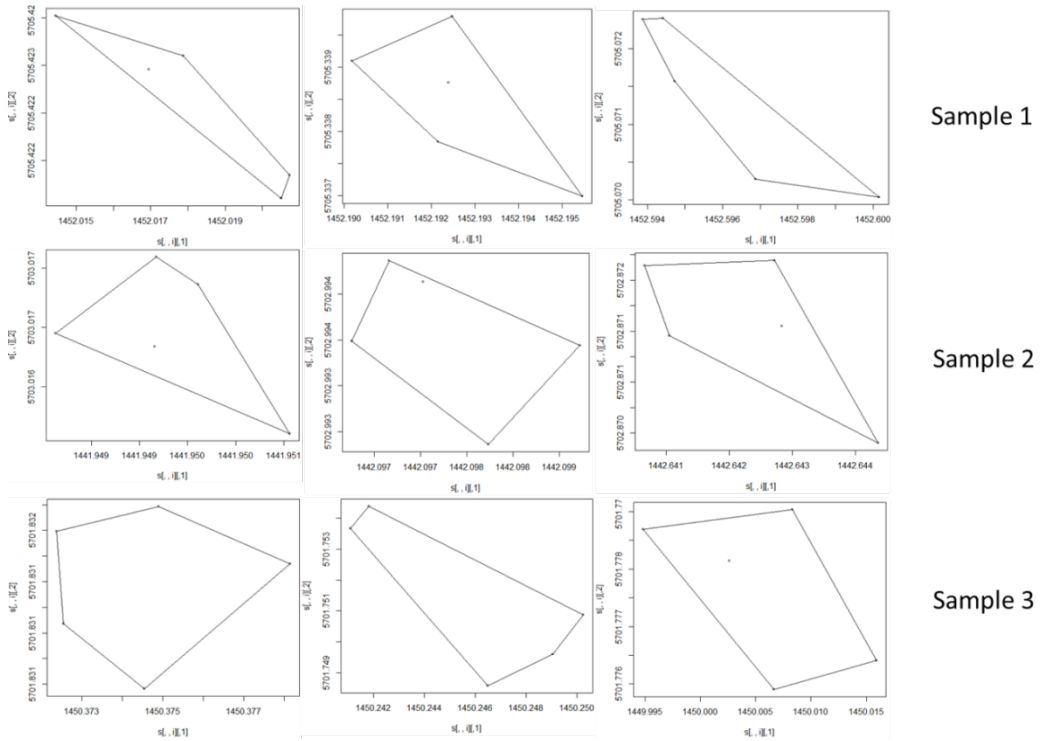

Fig. 11. Pattern predominantly seen in Kumbh mela for group size 5

5.3 Area occupancy

Table 1 represents the area occupancy of groups with respect to varying group size in open day and kumbh. It is clearly seen that as the group size increases, the area occupied by the groups also increases in both cases. This is true because group size 3 predominantly forms linear or V-pattern which occupies less area when compared to group size 4 and 5 that predominantly forms irregular polygon which occupies more area.

Table.1. Area Occupancy of Groups w.r.t Varying Group Size

	Group size 3	Group size 4	Group size 5
Open day (in sq.m)	0.66	1.9	3
Kumbh (in sq.m)	0.8	1.8	2.05

5.4 Average Walking Speed

Table 2 represents the average walking speeds of groups with respect to varying group size in open day and kumbh. It is seen that the average walking speeds are almost same for all group sizes. The reason for same average walking speeds for all group sizes in kumbh may be due to the motivation and the urge to reach the destination as quick as possible which keeps then moving. This is owing to the spiritual gain that the people derive from the rare occasion. The reason for same average walking speeds for all group sizes in open day may be due to low density that is observed. The average walking speeds are log normally distributed with $\alpha = 0.01$. Figure 12 shows the log normal distribution for kumbh and open day.

Table.2. Average Walking Speed w.r.t. Varying Group Size

	Group size 3	Group size 4	Group size 5
Open day (in m/s)	0.45	0.44	0.47
Kumbh (in m/s)	0.96	0.99	1.03

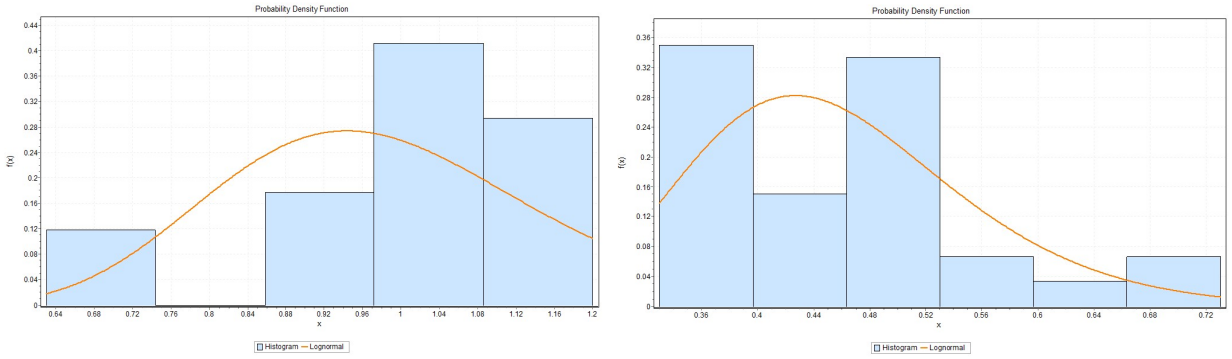

Fig.12. Average Walking Speed log normally distributed with Alpha = 0.01 for (a) Kumbh (b) Open day

6. Conclusion and Discussion

This study attempts to analyze to what extent the spatial formation of different group sizes is changing in a narrow corridor over time. In addition, this also tries to study the effect of group size on area occupancy of groups and average walking speeds in two scenarios of crowd. Even though the type of crowd is different, the results show that the area occupied by the groups increases as the group size increases. The average walking speed, irrespective of the group sizes, is same for kumbh due to the psychology of crowd. Motivation and urge to move forward to the destination keep people moving with constant high speeds. The average walking speed of groups in open day is same for all group sizes due to low density that was observed. Therefore understanding pedestrian group behaviour can help in decision-making by incorporating these empirical observations in pedestrian simulation model. This study is limited to groups of smaller sizes. Studying the behaviour of large groups can give more insights into their influence on crowd movements.

Acknowledgement

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