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Crowd Dynamics of a Rural Group in a Mass Religious Gathering: A Case Study of Kumbh Mela – 2016, India

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Abstract

Personal, societal, cultural or religious obligations and interests of many individuals combine to call for occasions where large number of people come together at a particular location for a specific purpose, resulting in a mass gathering. In such mass gatherings in general, numerous instances of stampede have been witnessed and many lives have been lost till date. Speaking from crowd's characterial standpoint, it is seen that there are two features of a crowd that stand out; first, group visitors are the predominant population when compared to single visitors in such mass gatherings and second, people taking part in such gatherings come from varying socio-demographic backgrounds. While trying to model the evolution of crowd for planning, design and assessment of facilities, major focus has been on simulating such scenarios by modelling individual behavior whereas group behavior has been overlooked to a large extent and effect of cultural differences on aggregate crowd behavior has been least explored. This study thus focusses on understanding the group behavior of people coming from a rural base to understand its behavioral characteristics as a group over space and time in a dense setup like *Kumbh Mela* in India, which is considered as the largest mass gathering in the world. Data collection was optimized by using qualitative as well as quantitative method for documenting spatial formation of walking groups to characterize it with respect to group size and explain some of the behavioral attributes of group at microscopic level in response to changing macroscopic characteristics of crowd. Rural and non-rural groups were both observed and data was used to infer understanding of diversity in group behavior. The spatial formation of the groups and its area occupancy was looked upon to draw inference on representative spatial formation for different group sizes and varying personal space of individuals. From the study, it was observed that for all group sizes, the group's cohesion and its shape varies with respect to the prevailing density conditions and proximity-to-destination. This study presents the inferences drawn from this unique empirical data and paves way for further work, which by utilizing the results of this study, proposes to test a constructed simulation against a synthetic simulation (based on default walking behavior parameters) by incorporating behavioral attributes of crowd in the model.

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*Keywords:*Mass gathering; Crowd dynamics; Pedestrian simulation; Group behavior; Cultural differences;Rural group; Spatial formation

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1. Introduction

Increasing number of mass gatherings around the world and with it, increasing cases of crowd accidents in recent past are now drawing attention to the lack of effective crowd management solutions . Questions have been raised over event-planners' ability to have crowd management systems which can ensure an incident-free mass gathering. For any crowd management system to be effective at the first place, it is important to first have a good understanding of crowd. This study, within the overarching goal of developing crowd management solutions, aims to understand the group behaviour in pedestrian crowds and how it may evolve over time. It focusses on empirical observation and data collection during the mass religious gathering for Kumbh Mela-2016, held in Ujjain, India, to understand various facets of crowd behavior. This study, in its attempt to understand crowd dynamics of a large-scale event, focusses on Kumbh Mela; which is known to be the largest gathering of mankind. Kumbh Mela is a religious pilgrimage, where Hindus from across the world come together to perform the sacred ritual of taking a dip in the holy river/ confluence of rivers. Legend has it that taking a dip during the course of this Kumbh Mela cleanses a person of all sins. This religious gathering is held every three years at one of the following places in India on a rotational basis: Haridwar, Allahabad, Nashik and Ujjain. Kumbh Mela – 2016, held in Ujjain was estimated by authorities to have attracted 75 million people over a course of one month. Throughout India's history, religion has been a key part of the culture. In a country of 1.25 billion, where almost 80% (79.2) of the population follows Hinduism by faith (Chandramouli and General, 2011), millions congregating for a religious gathering is not a surprising sight. What is surprising indeed is the number of lives that have been lost in such mass gatherings and the minimal attention that it has drawn over the years. There have been very few studies conducted in the past in any of such mass gatherings in order to understand the crowd dynamics and evolution of crowd in such setup. From that standpoint, this study in contrast, has tried to explore pedestrian behaviour in a mass gathering.

Though there have been large number of studies conducted on pedestrian dynamic characteristics, ranging from high to low density conditions and controlled to uncontrolled setups; it is noteworthy to mention that most of these have focused on people in regular urban setup on a smaller scale and microscopic characteristics of crowd like-group behaviour and cultural differences has been largely overlooked. To ensure fidelity of pedestrian simulation models, it is essential to consider the behavioural complexities into the model by probing microscopic behavioural characteristics of crowd. In India, approximately 69% (Chandramouli and General, 2011) of the population resides in rural areas and in a religious mass gathering like Kumbh Mela, majority of the population comes from a rural base. In a country like India, the interface between urban and rural India is quite significant in terms of social and cultural environment, and is reflected in their behavioural traits. The set of values, practices, traditions or beliefs a rural group shares differs from an urban group. Thus, it is important to explore these cultural differences while developing large scale simulation models. (Gayathri et al., 2017), underlines the uniqueness of the Kumbh Mela event and speaks in detail about the heterogeneity of crowd in detail. This study, keeping cultural differences and group behaviour as its need-for-study, tries to understand group dynamics in a mass gathering like Kumbh Mela. To understand the crowd dynamics within the Kumbh Mela, where rural population accounts for significant percentage of the population, it was important to capture and understand the rural crowd's dynamics. A mixed methods approach (Creswell, 2013) was adopted as the basis which combines qualitative and quantitative methods to provide a broader understanding. Qualitative methods aimed at identifying pattern(s) in crowd behaviour and acted as support for formulation of quantitative structure for further data collection.

2. Background and Motivation

Accuracy of pedestrian simulation with respect to reality is an important aspect when considering it as a decision support system. Thus, it is important that simulation generates behavior similar to that observed in the field. There have been many studies on pedestrian dynamics that aim to capture the human behavior so as to build accurate models of crowds.

2.1. Group behavior

It is a common phenomenon to see pedestrians walking in groups, but very limited attention has been given to group behavior when developing pedestrian flow models (Cheng et al., 2014). There have been few studies in past which have highlighted the importance of collective behavior of group in crowd. Group, in sociological sense (Hare, 1962), is referring to individuals who have social ties and intentionally walk together, such as friends or family members. Many studies have investigated crowd as an assembly of isolated individuals and looked upon pedestrian dynamics taking individual behavior into account whereas collective behavior of group has not attracted much attention into crowd modelling and simulation. Previously, (Moussaïd et al., 2010) conducted studies on data obtained from pedestrian sidewalks and found out that up to 70% of the people in a crowd are actually moving in groups and showed that typical group walking patterns are generated because of social interactions among group members that in turn influences crowd dynamics. From observations, it can be deduced that the purpose of walk trip and social relationship of group members could be one reason affecting social interaction within the group. Leisure walk trips are likelier to have more social interaction compared to non-leisure walk trips. (Coleman and James, 1961; Aveni, 1977; James, 1953), underline the importance of groups in pedestrians and support the consideration of group behavior in further studies of pedestrian dynamics by examining the collective behavior and size distribution of freely-forming groups. (Do et al., 2016), studied crowd dynamics to analyze differences in walking behavior between groups and individuals.

It was observed that individuals change more trajectories than groups and groups usually split into subgroups over time. (Costa, 2010), found that walking speed of male was highest for male groups, intermediate for mix and lowest for female groups for dyads (group of 2) and triads (group of 3) but gender difference disappeared in larger groups. Splitting of groups into subgroups is commonplace in walking groups but in case of Kumbh Mela, it was not seen on this particular study stretch probably because this mass gathering is infamous for number of people getting separated from their group, hence the tendency is to maintain cohesion at all times irrespective of the size of group. (Wei et al., 2015), conducted study in passageway of a University and found that group members have closer interpersonal distance and diversity in group movement exists due to group size, gender and social relationship.

2.2. Cultural Differences

Though the models relate micro-level characteristics like- personal space and walking speed to macro-level charcterisctics i.e. density and flow, the parameter of cultural differences has been left unexplored at micro-level. When we talk about cultural differences in terms of pedestrian dynamics, previous works have talked about cultural parameters: personal space, base walking speed and group formations (In particular, Shape and Size). (Fridman et al 2011; Fridman et al, 2013), inspect the impact of cultural differences on crowd dynamics and explore the impact of cultural parameters of each individual agent (micro-level) on macro level crowd behavior. It also introduces cultural individual-level parameters into the simulations, and then examine the effects of these parameters on dawning crowd dynamics. (Chattaraj et al, 2009), compared the pedestrian characteristics like- free flow speed, speed-density, and speed-headway between India & Germany and found differences which were reflected statistically. In further similar work, (Morrall et al, 1991) carried out studies in Central Business District area and compared pedestrian characteristics of Canada with Srilanka. Differences were found, which were consequential of cultural differences.

2.3. Modelling and Simulation Techniques

For simulation of large scale crowd in Mecca, (Narain et al., 2009), combined Lagrangian representation of individuals with a coarser Eulerian model, thus capturing both the discrete motion of each agent and macroscopic flow of crowd. The system though is modeled on a aggregate level, treating its motion as similar to flow of single aggregate system. (Helbing et al., 2000) developed a continuous pedestrian simulation model to model the collective phenomenon of pedestrians in escape panic. (Bayazit et al, 2003), demonstrate generation of complex group behaviors using a roadmap providing global environment information. The behavior rules are embedded in the roadmaps which allow the agents to modify their actions based on location.

2.4. Summary

Overall, a brief summary of the relevant studies on pedestrian behaviour shows that a lot of studies have been done to understand the crowd dynamics. Though previous work in this area is commendable, there is still room for studying microscopic characteristics, particularly- group behavior and cultural differences which could help improve model's accuracy. Many studies have focused primarily on evacuation dynamics trying to model evacuation situation in a closed environment. Very few studies have tried to understand walking behaviour in a mass gathering-like setup. The crowd evolution in a mass gathering involves more complexities in an open environment and thus being difficult to model than an indoor situation. The present study contributes to literature on crowd dynamics by presenting a case study from a mass religious gathering in India and aims to provide inputs to modelling tool for realistic and accurate simulation of large-scale crowds. The paper reports the findings on group size, group's spatial formation and per person area occupancy with .respect to group size.

The rest of the paper is organized as follows. Section3 provides a brief introduction of the study area and data collection processes and the techniques used. Results and discussions are presented in section 4. Final section focusses on summarizing the research and concludes the paper with an overview of future research.

3. Study Design and Data Collection

To collect spatial formation of a walking group over a length of corridor, techniques adopted could be either videography of the entire section or by tracing the group's shape at each time-step by giving each member of the group an accurate GPS module or proximity sensing device. The site conditions were a typical uncontrolled setup spread over large scale where ideal videography of the full study corridor is an in-executable task due to following constraints

- Unavailability of infrastructure to position cameras along the full length of study corridor
- Restricted field of view for cameras; weather protection canopies at some places acting as barriers to from-the-top videography.

Whereas, in the latter case, the concern was that it would be obtrusive in nature to assign each and every member of the group, a GPS or proximity sensing device and thus, intruding their personal space and mindset of spiritual experience, the pilgrims are there for. Besides that, recovery of devices once the study is over, would be another challenge in such dense setup like Kumbh Mela.

3.1. Study Area

As seen in Figure 1, two segments were chosen as study corridors for this work. The direction of crowd movement is shown with directional arrows. The rationale behind choosing these two locations was that the end point or destination of both the corridors were major activity points of the Kumbh Mela area. Corridor 1 leads to riverside area (*Ghat*) where people arrive to take the holy bath. Corridor 2 leads to the *Mahakal* temple, which

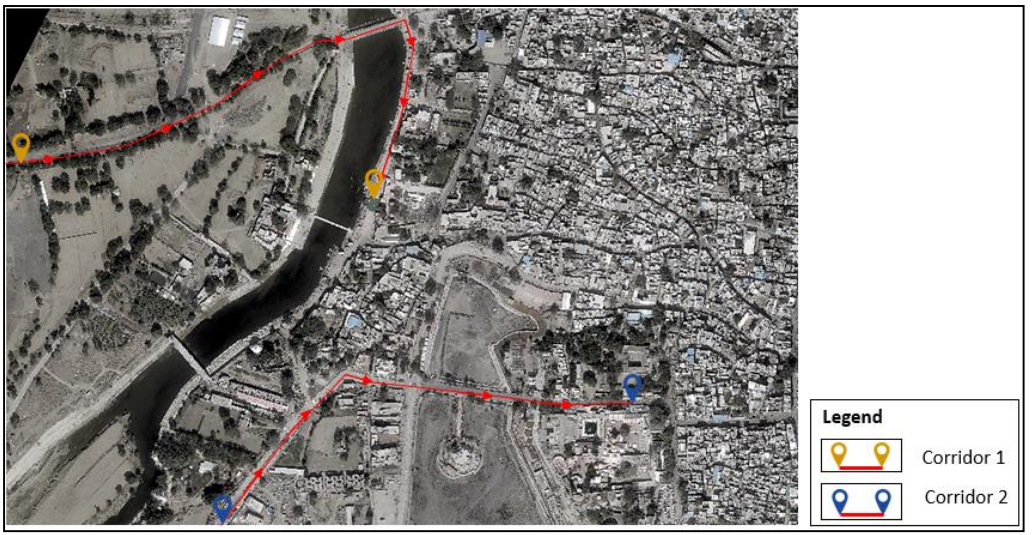

Fig. 1. Study Bed.

people visit to offer prayers. These locations were chosen as they are major activity centers of the the Kumbh Mela region.

3.2. Data Collection

The data collection technique was such that the spatial formation of group would be collected by enumerators walking alongside the subject group and documenting the relevant data. The longitudinal and lateral spread of the subject group was to be collected over time and space. The subject group would be first identified at the beginning of the study corridor and would be followed up to the activity center's proximity. The enumerators were also provided with portable GPS devices which recorded speed and coordinates data every 10 seconds and was also used to cross-verify the documentation later. Identification and selection of potential subject group at the starting point of the study corridor was an integral part of the data collection process. In a setup like the one in Kumbh Mela, the distinction between rural and non-rural group is very clear and one only had to back their common sense and judgment to identify a rural group at the upstream of study section. In addition, the two factors which distinguish rural group in the crowd are listed below;

- The attire they are wearing would be a typical rural attire, which the enumerators and authors are familiar with. Rural people in the region have a different clothing style than the urban people and use of conventional veils and turbans helped enumerators differentiate easily
- The manner in which the luggage is being carried. Rural people, largely prefer to carry duffle-bag-sized bags placed on their heads in contrary to urbans who always carry them in their hands.

These two criteria to a great extent helped an enumerator decide whether or not, a group is a rural-subject-group. A schematic representation of subject group's movement and the data collection scenario for different time steps is reflected in Figure 2. The encircled area consisting of pink and blue dots represents the females and males respectively of the subject group. The black dots represent the crowd and yellow dots represent the enumerators walking alongside group.

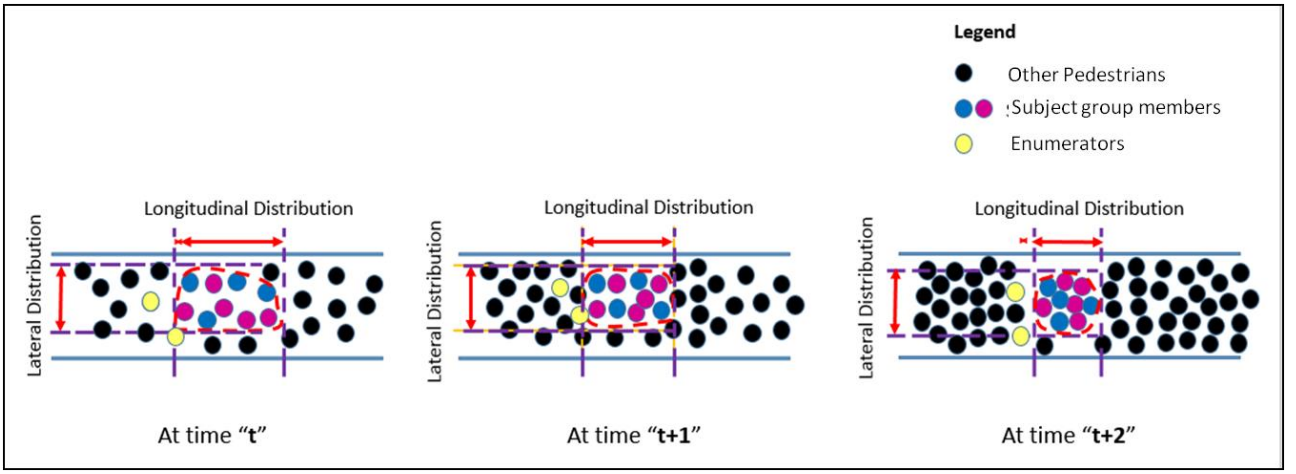

Fig. 2. Documenting group's spatial formation over time.

3.3. Enumerator Training

The idea was to document longitudinal and lateral spread over time. Primarily, every time there was a shape change, it was to be documented. Enumerators in yellow caps can be seen in Figure 3 following the subject groups with documentation form.

Fig. 3 Eumerators walking alonside subject group (a) Low Density; (b) Medium density.

To be able to judge the distance metrics while being in motion, it was essential to train and condition the enumerators in a manner such that reality is accurately reflected in the documentation and the dataset is not compromised. As a data collection strategy, enumerators were primed in a training drill. In this priming process, subject groups of size 6 to 10 were formed and were directed to stand attaining random shape(s). Enumerators then took the measure of lateral and longitudinal spread of these groups and gained an understanding of dimensions of a group. Post training, five enumerators were then directed to independently document lateral and longitudinal spread for fifteen different shapes of subject group. Simultaneously, the actual measurements were documented by authors for all 15 cases and was later compared with the enumerators' data. Three enumerators with highest accuracy i.e., least average error, were picked to assist the authors in data collection.

In order to reflect the error pattern of the three enumerators correctly in the actual field data, it was important to incorporate their error term in the field data which would be collected later. To rationally arrive upon the correction factor to be incorporated in field data, mean error for each three individual was looked at. T test was first conducted to check for difference in mean error of lateral and longitudinal spread. Results (Table 1) suggested that difference in the mean error was insignificant for all three enumerators. Since the error in documentation of lateral and longitudinal spread was insignificant, both values were clubbed for each individual.

Table 1: T Stat on mean error

Enumerator	T Value	Critical T	Result
1	0.22	2.04	Insignificant
2	0.11	2.04	Insignificant
3	0.22	2.04	Insignificant

Further, ANOVA test was then performed to check for differences in documentation between three enumerators. Results as mentioned in Table 2 reflected that there is no significant difference between the error means of three individual.

Table 2: ANOVA on mean error

Enumerator	F Value	Critical F	Result
All	0.15	3.1	Insignificant

As there was no significant difference, the error terms of all individuals for all the cases were then combined and assumed to be normally distributed which is shown in Figure 4. The Chi square value for goodness of fit ($p=0.05$), also indicated that the data would fit a normal distribution. Further, the mean, μ and standard deviation, σ of this fit were used to randomly generate error terms and these randomly generated error terms were then added to the actual field data as a correction factor.

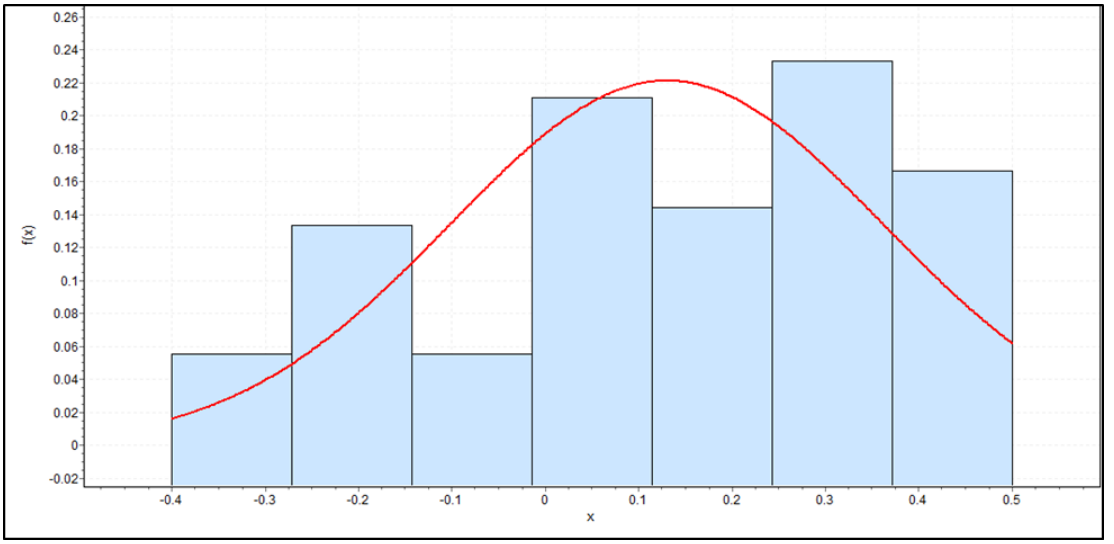

Fig. 4: Distribution of Error Term

3.4. Documentation Form

The documentation form was divided into two sections. The first section gathered information about group size and its gender make up. The second section contained both, micro and macroscopic-level aspects of crowd dynamics and the entries of spatial spread of the subject group.

4. Study Design and Data Collection

The data was collected for rural and non-rural groups along both the study corridors and inferences drawn from spatial formation are presented in this section along with interesting findings of relation between group's size and its shape formation.

4.1. Sample Characteristics

It was observed that percentage of women was more than men in case of rural groups and a reverse trend was seen in non-rural groups. In comparison to the non-rural groups, size of groups was observed to be much higher for rural groups. Different group sizes observed and their percentage share is represented in Table 3.

Table 3. Summary of socio-demographic and group size characteristics.

Factor	Percent
Rural Groups	
a. Gender	
Male	48
Female	52
b. Group Size	
4-6	30
7-9	34

> 9	36
Non-Rural Group	
a. Gender	
Male	54
Female	46
b. Group Size	
4	22
5	31
6	25
7, 8	22

4.2. Rural Group

The collected data had group sizes ranging from 4 to 13 persons. The group sizes were further categorized into three classes, i.e. Small, medium and large by assigning range 4-6, 7-9 and >9 respectively. The lateral and longitudinal spread accounted for each time-step, was aggregated into area and it was then used as the measure of group's cohesiveness over time.

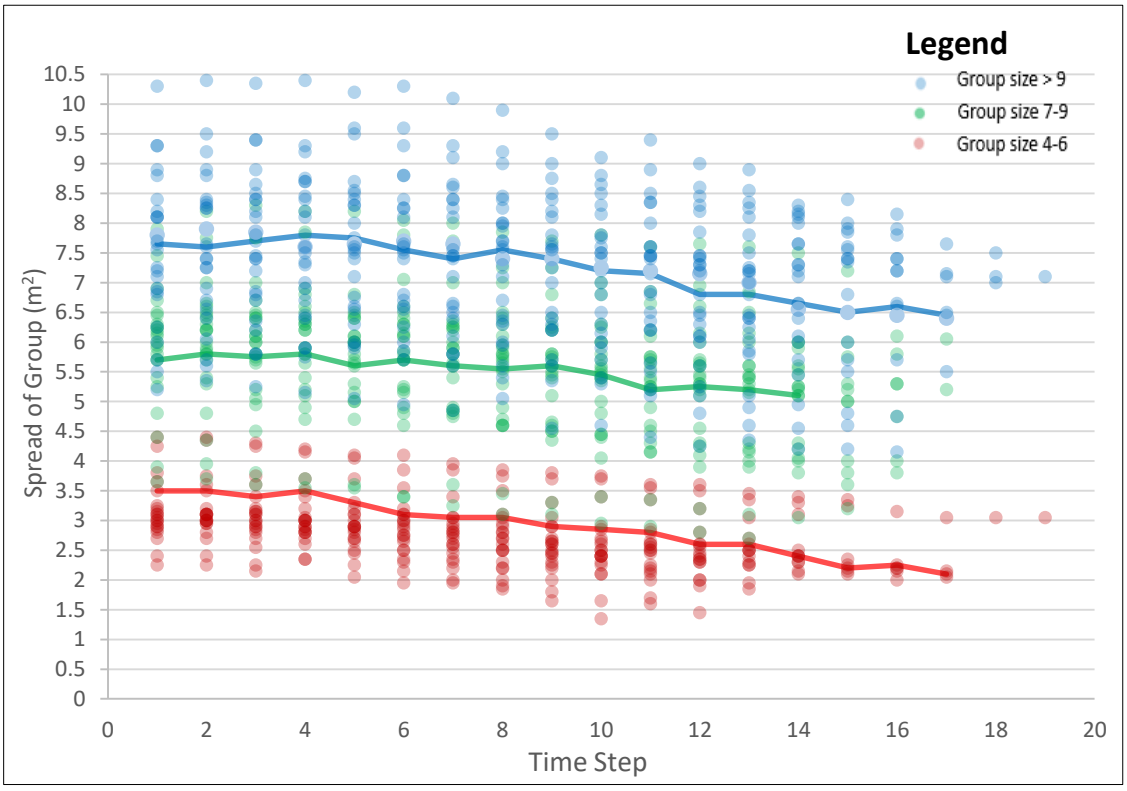

Fig 5: Group's cohesion over time

Figure 5 shows the plot of 'Area' of group versus time. Small, medium and large group sizes had 21, 24 and 25 number of cases respectively. Red dataset represents the group size of range 4-6; green represents the group size 7-9

and blue represents the plot of group size greater than 9. It is seen here that smaller the group size, smaller the lateral and longitudinal spread i.e. area, of the group. With time, as the group is moving closer to the activity center, there is decrease in area of the group. In almost all the cases, fall is reported in the groups' area over time. The rate of fall or slope of area plot is higher for large and medium group size and the smallest for small group size.

Table 4: Spread of "Area" mean for rural groups

Group Size	Standard Deviation	Mean area (m^2)
4-6	0.71	2.8
7-9	1.16	5.6
> 9	1.35	7.2

Table 4 shows the standard deviation of the spread for all the cases of all group sizes. It indicates that spread of group size 4-6 is lowest and spread for group size > 9 is the highest; indicating that as the group size is increasing, the average spread of the group is increasing. To be able to explore the impact of cultural difference, if any, it was important to also monitor non-rural groups to arrive upon any conclusions. Further section highlights the observations from non-rural group.

4.3. Non-Rural Group

The collected data had group sizes ranging from 4 to 8 persons. The smaller group size compared to the rural groups can be explained by the nuclear family size of non-rural population. It is seen in case of non-rural groups that the spread of group is relatively lower than rural groups. One reason could be higher interpersonal distance within rural groups as significant number are carrying head loads and walking at higher average speed, thus requiring more leeway which in turn increases the group spread. The plot of non-rural groups is shown in figure 6.

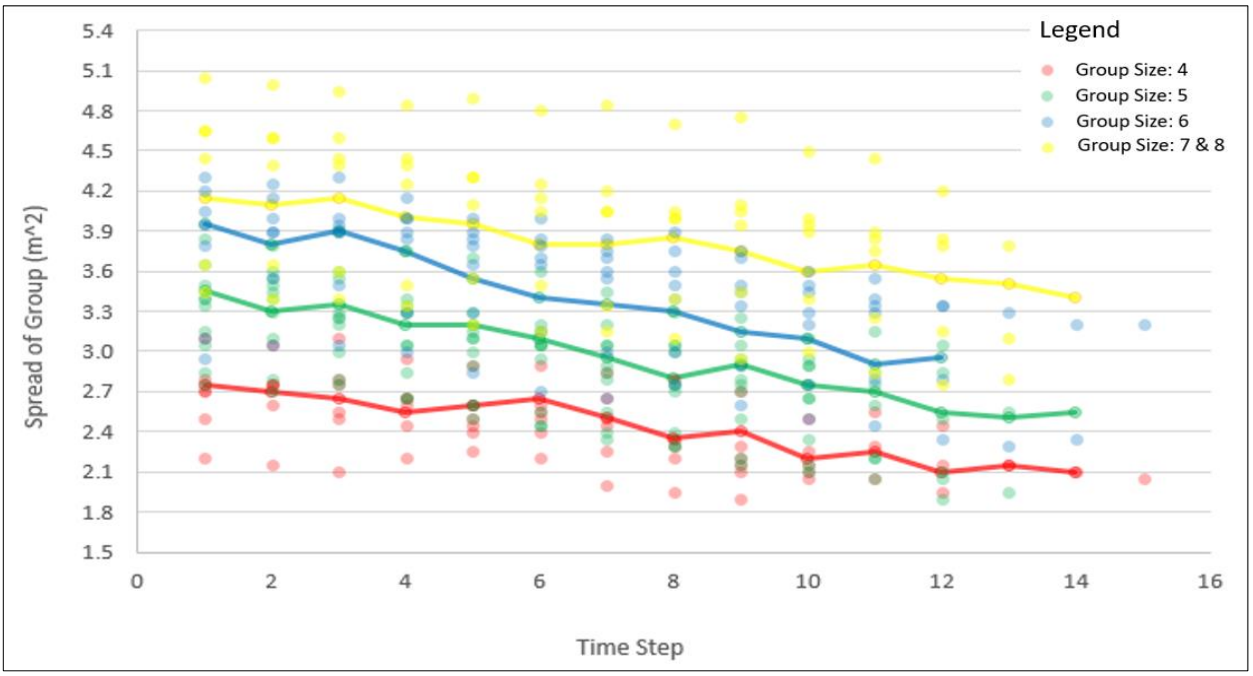

Fig 6: Nor-rural group's cohesion over time

It can also be seen from table 5 that standard deviation of the mean of group's spread is getting higher as the group size increases, which is same trend as in case of rural groups.

Table 5: Spread of area mean for non-rural groups

Group Size	Standard Deviation	Mean area (m^2)
4	0.33	2.3
5	0.49	2.7
6	0.62	3.3
7,8	0.85	4.6

The highlight is that these deviations are smaller when compared to rural groups suggesting that apart from group size being large in case of rural groups, there is more heterogeneity in walking pattern of rural groups compared to non-rural groups.

4.4. Group Size and Shape

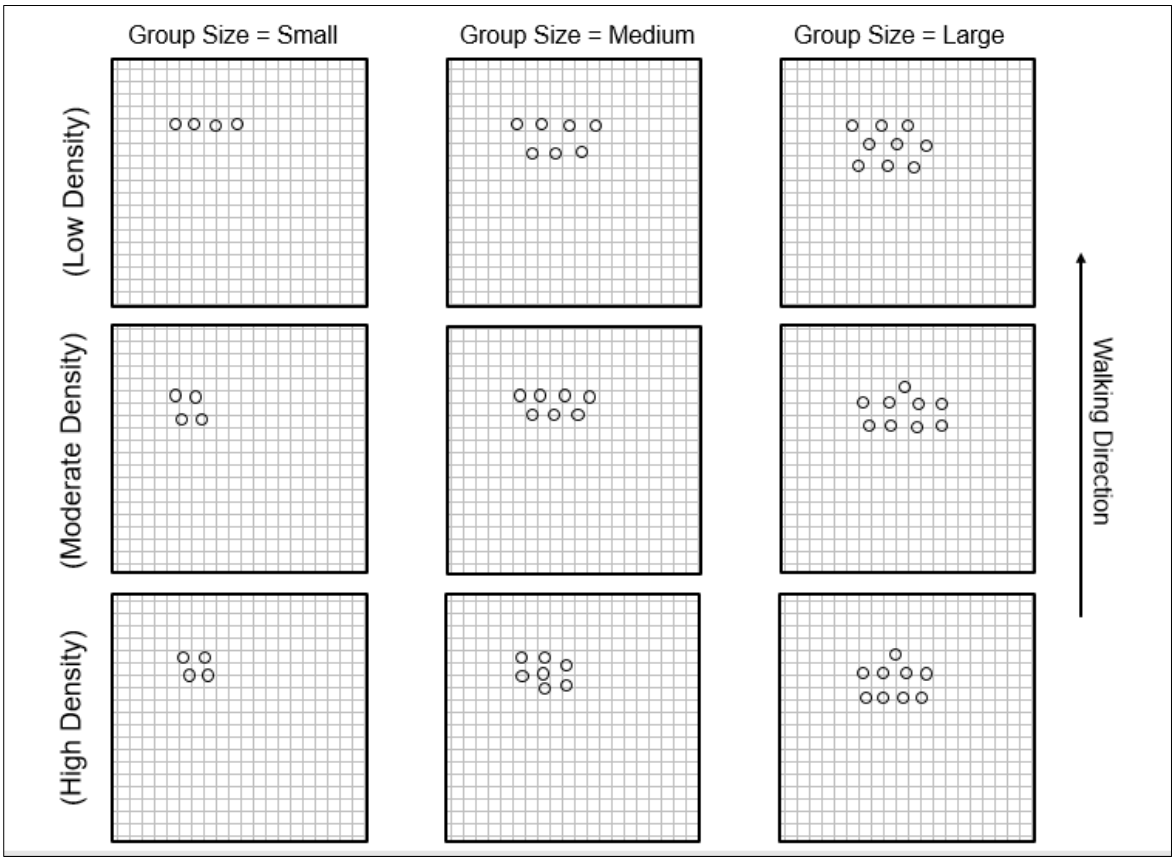

Fig 7: Generalized shape formation of groups

Group formation is also a complex characteristic, as it involves not just the size of its group but also its gender makeup. (Moussaïd et al, 2010), identified the groups in the collected video data and traced their spatial arrangement over space in low and moderate densities. The spatial arrangement of groups is traced for group size of two to four. Compared to the aforementioned study, the group sizes under observation in this study are larger; varying from 4 to

13. In a mass gathering like *Kumbh Mela*, people from far-off places arrived with family and friends; which explains the larger average group-size in this case. Generalized representation of shape formation of different group sizes over varying densities is reflected in figure 7, based on qualitative analysis. One grid size is considered to be of size 0.5m×0.5m and the circular shapes represent the persons in group. In case of small group size, it is seen that people are walking side by side, forming a linear shape perpendicular to walking direction. When the density increases, group splits in half and arranges themselves in two lines to accommodate for the reduced space. At high density, the group is compelled to do little adjustment to their arrangement by reducing their personal space. For medium-sized groups at low and medium densities, the arrangement is similar to those of low-sized groups and the only difference is number of people in the group. At high density, the group tends to arrange themselves in somewhat circular fashion where women or children are generally in the center and men position themselves at the peripheral boundary of this shape. The tendency of groups to maintain personal-space is such that the out-group space is more than the intra-group spacing for low and medium density conditions. Though as the density gets high near the activity center, the intra-group and out-group spacing between persons gets same and group behavior is dissolved. In case of large-sized groups, the behavior at low density was almost similar to small and medium-sized groups. Though as the density increases, it was observed that one person among the group tends to lead the group and other follow. In some groups, a leader was observed from low density onwards. The tendency is to maintain this arrangement is majorly due to overriding concern of not getting separated. The social interaction among group members was significant in large-sized groups compared to small and medium-sized groups where social interaction was much less suggesting that purpose of engaging in social interaction was predominantly to ensure group's cohesion than to engage in casual conversation or small talks. In *Kumbh Mela*, group's center of mass is the predominant factor in keeping the rural group's members together in contrast with other setups where social interaction is predominant factor in keeping the group together. In case of non-rural groups, it was observed that social interaction was much higher compared to rural groups. One observed reason for this appeared to be small group size of non-rurals and cohesive structure which made social interaction easier.

4. 5. Area Occupancy and Personal Space

It was observed that area occupancy of groups varied with group sizes. Area occupancy per person (Area occupied/ Group size) did not vary much apart from some random variation but a general trend was seen where per person occupancy in rural groups was seen to be higher than non-rural groups, as seen in table 6.

Table 6: Per Person occupancy for different group sizes

Group Size	4	5	6	7	8
Average area occupancy in a Rural Group (m^2/Person)	0.59	0.58	0.50	0.66	0.72
Average Area Occupancy in a Non-Rural Group (m^2/Person)	0.57	0.53	0.55	0.61	0.67

The average personal space for rural groups was found to be 0.60 m^2/person and 0.57 m^2/person for non-rural groups. Also, seeing the general trend, it could be deduced that inter-personal space required for rural groups is higher than non-rural groups. Presence of luggage and/ or higher walking speed could be attributed to that factor. In order to statistically test the significance of difference, a one tail t-test was conducted and was found insignificant at 95 % confidence interval but showed significance at lesser confidence interval. A larger sample could probably help highlight the difference that area occupancy per person is higher for rural groups when compared to non-rural groups.

Table 7: T Test for difference in Area occupancy per person

T Value	Critical T	Result
1.047	1.671	Insignificant (At 95 % CI)

5. Summary and Conclusions

The study proposes a dynamic-parameter model for walking behavior parameters of pedestrians. The parameters like- Population size of groups in crowd; Group Size distribution; Shape of groups at varying densities; Grid Size of pedestrian and his/her personal space; Number of pedestrians they are affected by, is varying over time and space. The simulation models adopting same parameters values throughout (constant-parameter models) will not account for constantly-changing microscopic characteristics of crowd and thus, could lead to unrealistic modelling. To be able to achieve reasonable model fidelity while modelling such dense crowd on a large scale, it is important to incorporate these constantly-changing microscopic behavior of crowd. Besides building on existing literature which investigates cultural differences and group behavior in human crowds, this study has investigated the behavior of rural crowd in a religious mass gathering through empirical observations made comparisons with non-rural groups. It paves way for further modifying the existing models for large-scale simulation of dense crowd by incorporating observed ranges of behavioral attributes into the model. It was also observed in both the cases that as pilgrim's group come closer to the place of activity, the group's cohesion increases. The prevailing density surrounding the group was major factor explaining the cohesion of group. From safety standpoint, it is important to neutralize the effect of increasing density in activity center's proximity by having good rigid boundary conditions which aid in effective crowd control.

6. Future Research Direction

In further addition to this study, group behaviour parameters will be tested and macroscopic observations made from the model will then be compared to realistic conditions. Upstream of the model would be treated as low-density zone and downstream as high-density zone. Dynamic-parameter values of microscopic behavioral complexities will be fed to the model and its effect on the aggregate behavior will be observed. In general, various models which do large-scale crowd simulation typically adopt continuum theory and show crowd characteristics in an aggregate manner and microscopic models on the other hand, because of their high level-of-detail, have very low scalability compared to macroscopic models. It is important to extensively explore the interface between these two models where one can test the model's scalability and execution efficiency while not compromising on complex behavioral attributes of crowd. Within further scope of this work, the aim is to test the scalability and efficiency of constructed simulation using Python-based framework by utilizing the results of this study and incorporating following attributes in the synthetic simulation.

- Group size distribution
- Assigning intra-group and out-group personal space distribution and;
- Defining shape of group based on prevailing density condition

Effect of these attributes can be seen by comparing synthetic simulation and constructed simulation while looking at aggregate behavior of crowd in both cases.

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