Collective Dynamics

Characteristics of Stop and Go Wave in One Dimensional Interrupted Pedestrian Flow Through Narrow Channel

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Abstract Pedestrian microscopic simulation models can aid crowd management only if they can reproduce the crowd behavior correctly. To calibrate and validate the model, it is important to understand crowd movement during various activities involved in mass gathering events. A common practice in such gathering is to hold attendees in waiting area in near corridors separated by crowd barriers before the event and release in small batches to avoid overcrowding inside. This can make crowd aggressive during such entries. Crowd flow characteristics due to such behavior is difficult to recreate in pedestrian experimental studies in laboratory setting. This paper studied interrupted flow of such crowd through a narrow corridor, made of strong railing channel inside a temple. Interrupted flow lead to formation of one dimensional stop and go waves. These stop and go waves were studied from the trajectory data. The average speed of waves propagating over longer distance were also estimated. The quantitative output from this study can be used to calibrate and validate simulation models of such activity during mass gathering events.

Keywords Religious mass gathering · stop and go waves · pedestrian dynamics · India

1 Introduction

Mass gatherings can be music concerts, religious observance, sport events, rallies etc. In such gatherings, concentration of large crowd in small space pose potential crowd risk situations. It is always a challenge for event managers/organizers to manage such large crowd and plan their smooth and safe movement prior to such gatherings. Various guidelines have also been prepared to supplement crowd management. But, with advances in science and technology, it is possible to use microscopic pedestrian simulation models [1–6] to evaluate various crowd management plans prior to the event and they can also be used to run real time simulation to predict any crowd risk during the event. These tools can provide aid to crowd management only if they can re-enact every aspect of crowd behavior accurately. Therefore, along with the advancements in simulation tools, it is also very important to conduct detailed empirical study to understand different aspects of crowd flow characteristics at such events, which can be used to calibrate and validate the simulation models later.

A common practice at many events (concerts, religious events, shows, sale, etc.) is to not allow crowd to enter the premises before designated time and to allow only in batches. Attendees are made to wait in queues in narrow corridors (created using crowd control barriers to avoid people cutting in line) at the designated waiting areas (Fig. 1). Later they are allowed to enter premises in smaller batches to avoid any chaos inside. Once the previous batch is processed, next batch of attendees are released from the waiting area. However, excitement, long waiting hours, competitive behavior to get inside earlier and perception of unfair treatment by guards/volunteers can make crowd aggressive at the entrance. Other factors such as hunger, thirst, unfavorable weather (in case of open waiting area) makes the situation more vulnerable to crowd risk. It is difficult to measure behavior of crowd, but it is possible to measure the crowd flow characteristics for such interrupted flow, which is assumed to implicitly account for the behavior.

This study contributes to the existing empirical knowledge by observing the One-Dimensional movement of crowd entering in batches inside the main premise of a temple (using data from Mahakaleshwar Temple in Ujjain, India) after long waiting hours to witness important religious rituals during early morning hours. The formation of stop and go waves are studied for the interrupted flow using trajectory data. The results from this study can be used to calibrate and validate models to simulate the entry of crowd into such venues, which is a component of overall crowd management plan.

2 Review of Literature

Lot of macroscopic pedestrian studies have been conducted on real crowd in past. However, there are few microscopic studies based on field data because of challenges of field data collection and difficulties in accurate data extraction. The various field challenges includes, difficulty in installing camera at desired position/angle, inability to capture a flow phenomenon that is deemed relevant, etc. Because of these challenges, many researchers in recent years have shifted their focus from field data collection to pedestrian experiments because of the freedom to control the conditions (lighting, camera position, experimental setup, crowd composition etc.) for automatic microscopic data extraction. Pedestrian dynamics is a very complex phenomenon [7] and these pedestrian experiments give opportunity to control other influencing variables, which can potentially lead to crowd risk situations. Experimental studies on single file movement [7–10], evacuation [11–13], bot-

Figure 1 Crowd waiting outside in narrow channels created using crowd control barrier. Left image: line of people waiting for the iPhone 3G outside of the Apple Store in Newyork (Source: Apple Store, 5th Ave., NYC, 7/12/08 - 13 of 19 https://www.flickr.com/photos/goodrob13/2664214748). Right image: Pilgrims in Ujjain, India waiting in zig-zag narrow channels built at waiting hall in Mahakaleshwar temple to attend early morning rituals (Source: CCTV footage from Mahakaleshwar temple)

tleneck [14–17] have been conducted in the past. [17–21] have investigated stop and go waves in single file movement experiments. [22] have experimentally studied the propagation speed of starting waves of pedestrians.

However, it can be argued that the emotional situation of the participants in such studies is relaxed, and therefore the real effects are not shown [23]. Heterogeneity, exertion, excitement, genuine stress to stay together in their groups, possible perception of unfair treatment by authorities, etc. are some of the traits of real crowd, which are difficult to reproduce in experimental setups. Gulhare et al. [24] had found field and experiment data for single file movement to be significantly different and suggested that data collected from field should be used for model calibration. [25] performed the macroscopic field study of shock wave at upstream of bottleneck for uninterrupted flow. There have been very less focus to understand stop and go waves in pedestrians for interrupted flow, which is prevalent at the entrance of many mass gathering events. This paper attempts to study microscopic flow for interrupted pedestrian flow from a real field data in mass gathering.

3 Data Collection

Shivrathri festival is widely celebrated in India during February and pilgrims from various places visit Mahakaleshwar temple, in Ujjain, India, during this time. Videography data using GoPro cameras was collected during this festival time inside the temple in Februrary 2017. A special ritual is performed at the main hall in the temple every morning from 4:30AM called Bhasma Arthi. The word Bhasma means ash and Arthi means offering to God. It is a kind of ritual that is performed in the temple using the ash made with cow dung. Unlike the localites, the pilgrims who visit during Shivrathri festival exhibit a sense of urgency to experience the special occasion as they consider this as a rare opportunity to observe the rituals. Therefore, this sense of urgency to be there in prime locations inside the ritual hall triggers their mind psychologically. The admission for the event is limited and devotees have to make advance booking. Hundreds of devotees visit every day to attend the event. They are allowed to enter and wait at the waiting hall from 12AM. The devotees try to come early to get front positions in the zig-zag constrained corridors of the waiting hall (Fig. 2). The corridors are separated by strong steel railings of approximately 0.9 m height. The entry to main hall is allowed from 4AM and devotees are released from waiting area in batches in some time intervals, they walk at free flow speed for approximately 100m to enter the main hall, which is two floors below and connected via ramps. The stop and go waves were created with the release of batch of people, which are captured using two cameras (frame rate: 30 frames per second) installed perpendicular to the direction of movement (Fig. 2). Both cameras capture the same long corridor at two different sections for 35 minutes duration. The videos were later synchronized in time with the help of flashlight illuminated at the area visible in both cameras. The corridor had few 2m long benches with 35cm of seat depth. Since, the camera only captured the 1-D motion of devotees, the effect of chair on crowd dynamics was ignored and can be treated as a limitation of the study. In the later parts of paper term pedestrians is used to denote devotees.

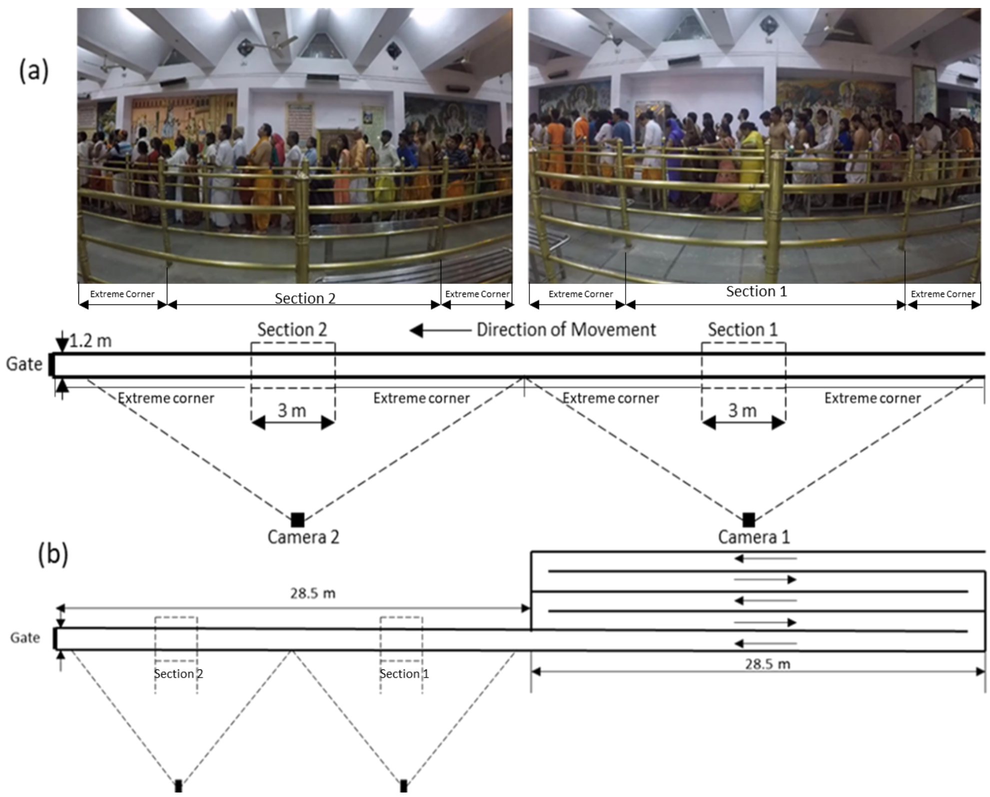


Figure 2 (a) Schematic diagram of corridor with screenshots of videos. The study section is confined to 3 meters in center (sections) to avoid parallax error and angular distortion. (b) Schematic representation of hall and location of study sections and camera positions

4 Data Analysis

4.1 Data Extraction

The pixel coordinates of position of each pedestrian was manually extracted at 2 fps by clicking on the same body part (generally shoulder) using Traffic Data Extraction tool [26]. Each pedestrian was manually traced from right side to left side of the video for approximately 6m ignoring the extreme corners considering only the middle portion i.e. section 1 and section 2 (Fig. 2(a)), to avoid parallax error and angular distortion. Extreme corners are the portions that are not used for analysis but are captured. The pedestrians may arrange themselves in 2-Dimension utilizing the full width of corridor. Careful approximations were made in determining the position whenever pedestrians were not completely visible. However, it would have led to some errors in trajectory data. Total 592 pedestrian trajectories were extracted from camera 1 and 615 trajectories were extracted from camera 2 by clicking more than 158,000 times in span of multiple weeks. Information like pedestrian ID (vehicle number in the TDE), time stamp and x-pixel coordinates (1-D motion) were used for further analysis.

4.2 Camera Calibration

The long corridor railing was marked at regular interval of 57cm with blue colored adhesive tape. The x-pixel coordinates (p_x) of these markings were collected and plotted against real distance along X direction (x in meters) (Fig. 3). The third order polynomial regression (Eq. 1 and 2) were derived to find relation between real coordinate system and pixel coordinate system.

For section 1,

$$x = -4.932 \times 10^{(-9)} {p_x}^3 + 9.631 \times 10^{(-6)} {p_x}^2 - 0.0117 p_x + 9.069; (R^2 = 0.999) \quad (1)$$

For section 2,

$$x = 9.69 + (-4.932 \times 10^{(-9)} {p_x}^3 + 9.631 \times 10^{(-6)} {p_x}^2 - 0.0117 p_x + 9.069); (R^2 = 0.999) \quad (2)$$

Where, p_x is x-pixel coordinate and x is global real coordinate. The distance between two sections is 9.69 m and this is added to section 1 in order to get the global real coordinate in section 2 (Section 1 ranges from x=3m to x=6m and section 2 starts from x=12.5m to x=15.5m.)

4.3 Density and Trajectories

The process of releasing pedestrians in batches to the main hall started at 4 AM, providing sufficient time for pedestrians to comfortably reach and settle in the main hall. The restricted number of attendees and the constrained corridors in waiting hall were designed for comfortable single file movement. The timeline of density at both sections can give some estimate of urgency in the crowd. The density is calculated by dividing number of

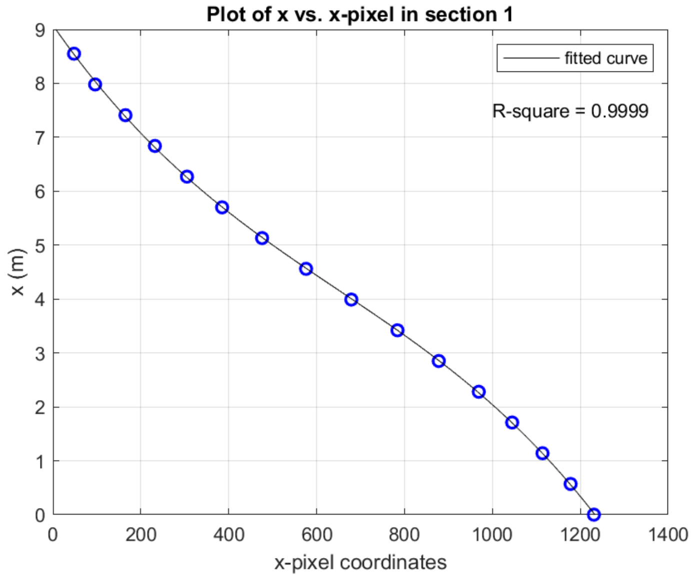


Figure 3 Regression curve fitted on scatter plot of real vs. pixel coordinates for camera calibration in section 1

pedestrians by the area of section. The moving average density is calculated for every 5 seconds using Eqn. 3. Similarly trajectory is also plotted from moving average of positions for every 5 seconds. The high density values in the study sections demonstrate the dense packing of crowd indicating the presence of urgency in the crowd (Fig. 4 and 5).

$$\bar{d_t} = 1/n \sum_{(j=t-n/2+1)}^{(t+n/2)} d_j \tag{3}$$

Density vs velocity graph is plotted for both the sections. It is observed that their relationship is linear. (Fig. 6)

4.4 Determination of Stop and Go Points

When the gates were opened to release a batch of pedestrians, the pedestrians in front moved which created space for other pedestrian behind to move and so on. This created a go wave. Once the gate was closed, all pedestrians came to halt one after another, which propagated a stop wave (or shockwave). The instantaneous speed was calculated from trajectory data and later moving average speed for 5 seconds was calculated from instantaneous speed to reduce noise. Since, the density was high, walking speeds were also low, therefore for the purpose of this study, the threshold speed was set to a very low value 5cm/s. When waiting pedestrians gained speed above 5cm/s, it was considered a go-point. Similarly, when speed of moving pedestrian reduced below 5cm/s, it was considered a stop-point. The determination of stop and go points for one of the pedestrians in section 1 is illustrated (Fig. 7). The locations of stop and go points in both sections are

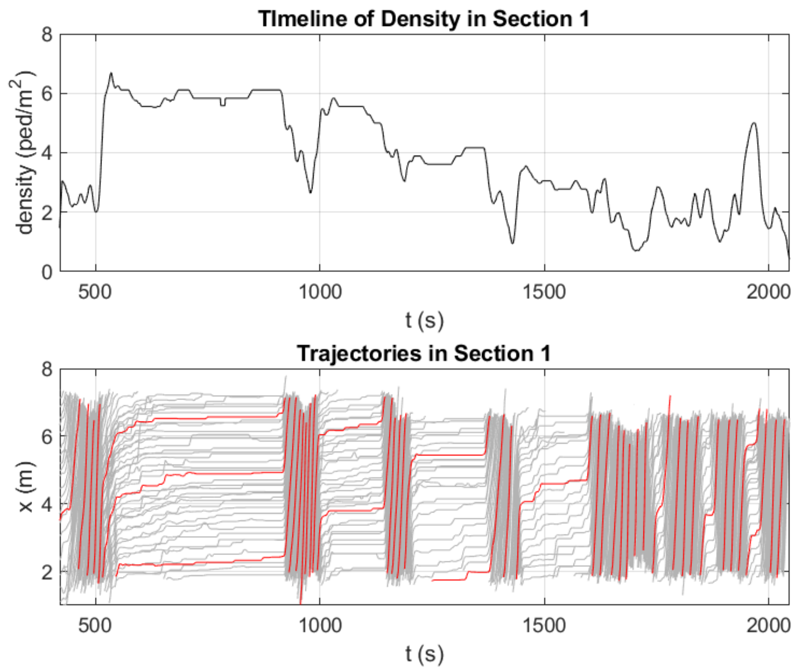


Figure 4 Top figure shows the timeline of density and bottom figure shows the trajectories in section 1. (Some trajectories are highlighted for better illustration)

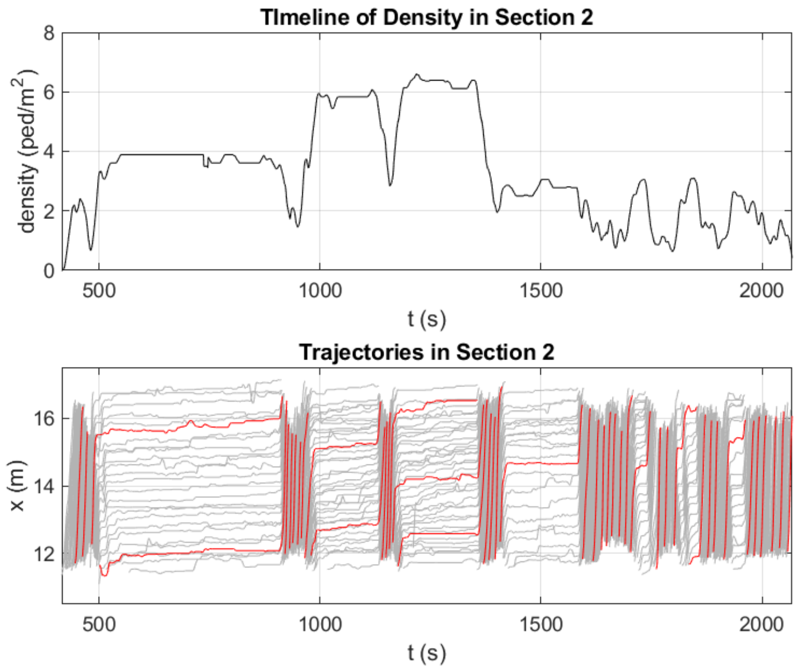
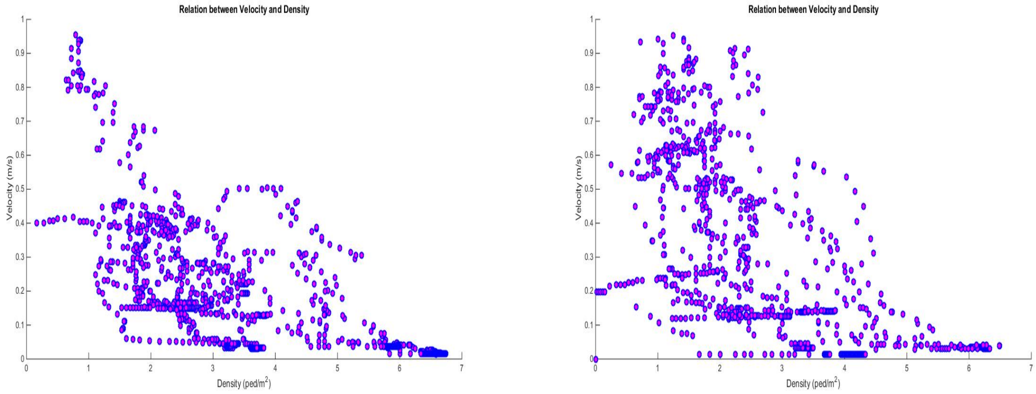


Figure 5 Top figure shows the timeline of density and bottom figure shows the trajectories in section 2. (Some trajectories are highlighted for better illustration)



(a) (b)

Figure 6 Relation between Velocity and Density in (a) Section 1 (b) Section 2

demonstrated (Fig. 8 and 9). The first go wave points formed at the starting when first batch of pedestrians were released was ignored in both sections.

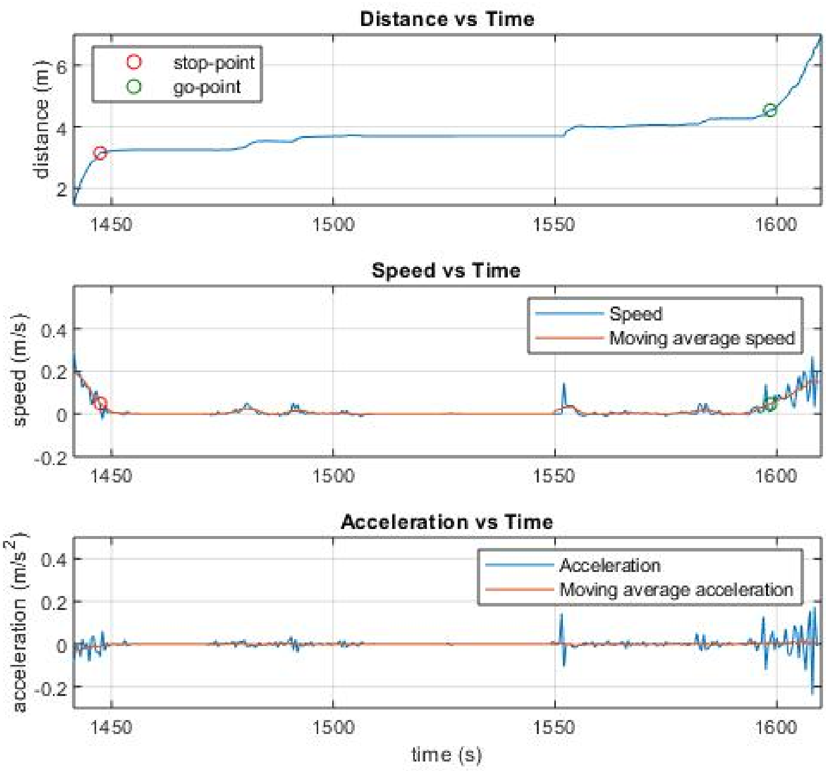


Figure 7 Illustration showing how stop and go points are determination for a sample pedestrian in section 1. (Moving average speed in middle plot is used for determination. Bottom plot of acceleration is not used in analysis and is given only for reference)

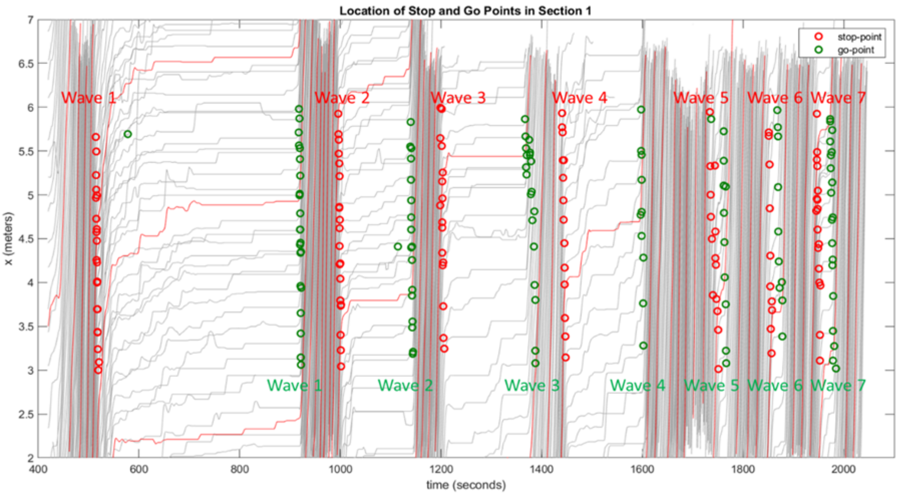


Figure 8 Stop and go points superimposed on trajectories of sections 1

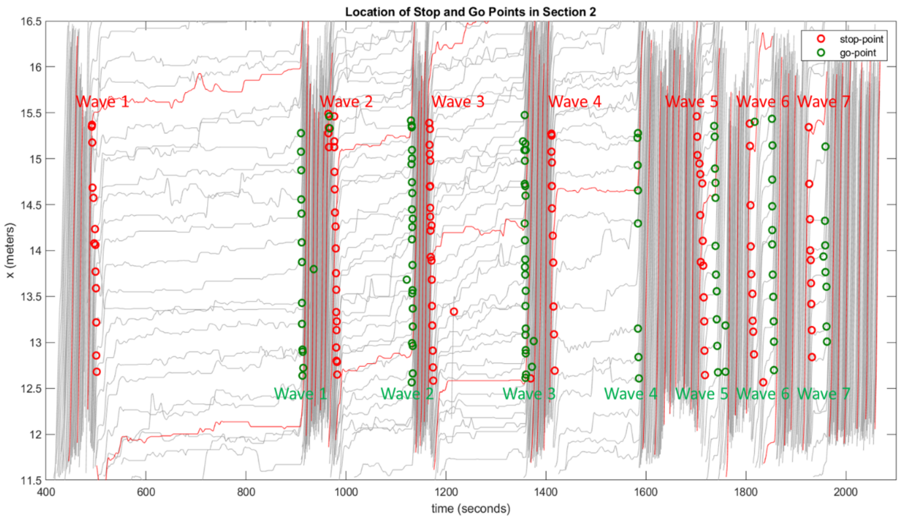


Figure 9 Stop and go points superimposed on trajectories of section 2

4.5 Speed of Local Stop and Go Waves

The stop and go points were clustered separately to form waves. First of all points lying within study sections (from 3m to 6m in section 1; from 12.5m to 15.5m in section 2) were only selected for analysis. The first criteria for clustering was that the adjacent point should be within 3 seconds and secondly it should be within 5 meter distance (in t-x plane). Points, which could not be clustered, were ignored. Seven stop waves and seven go waves were obtained for each section, which are consistent with Fig. 8 and Fig. 9. The speed of waves within the sections are tabulated (Tab. 1 and 2). The speed of waves were determined by fitting linear regression to each cluster. The stop-waves were more consistent in speed and R-square values as compared to go-waves. The speeds have

Table 1 Estimated Speed of Various Stop Waves in Both Sections

Wave no.	Section 1			Section 2		
	Speed (m/s)	R^2	Shock point nos.	Speed (m/s)	R^2	Shock point nos.
1	-0.45	0.83	22	-0.24	0.91	13
2	-0.49	0.91	20	-0.45	0.95	17
3	-0.29	0.61	16	-0.34	0.93	19
4	-0.39	0.93	14	-0.39	0.96	12
5	-0.11	0.65	14	-0.15	0.84	14
6	-0.36	0.81	10	-0.28	0.90	9
7	-0.26	0.75	17	-0.36	0.98	9

Table 2 Estimated Speed of Various Go Waves in Both Sections

Wave no.	Section 1			Section 2		
	Speed (m/s)	R^2	Shock point nos.	Speed (m/s)	R^2	Shock point nos.
1	-0.53	0.72	22	-0.63	0.89	13
2	-0.52	0.87	17	-0.61	0.38	21
3	-0.10	0.72	19	-0.43	0.35	22
4	-0.33	0.63	10	-0.98	0.68	8
5	-0.36	0.66	10	-0.39	0.94	11
6	-0.20	0.74	10	-0.51	0.79	11
7	-0.28	0.74	19	-0.16	0.26	8

negative values because both stop waves and go waves travel backwards. Shock point numbers are the number of points involved in a particular stop or go wave.

4.6 Average Propagation Speed of Stop and Go Waves

The purpose of using two cameras on the same corridor was to understand the characteristics of stop and go waves propagating over long distance. Wave numbers in Tab. 1 and 2 corresponds to the same waves propagating through both the sections. The average speed of the waves was determined by fitting linear regression into wave clusters having same wave number. The average speeds clearly indicates that Go waves on average travel faster than Stop waves (Tab. 3). This clearly shows that the sense of urgency to reach the main hall and to occupy prime locations to witness the rituals, triggers the pilgrims mind psychologically and hence when the queue is released, pilgrims try to rush to the main hall leading to high average speed of Go waves than stop waves.

Table 3 Estimated Average Speed of Stop and Go Waves Propagating in the Corridor

Wave no.	Section 1			Section 2		
	Speed (m/s)	R^2	Shock point nos.	Speed (m/s)	R^2	Shock point nos.
1	-0.48	0.98	35	-1.04	0.97	35
2	-0.48	0.99	37	-0.99	0.97	38
3	-0.29	0.99	35	-0.40	0.86	41
4	-0.31	0.99	26	-0.62	0.98	18
5	-0.29	0.96	28	-0.40	0.99	21
6	-0.22	0.99	19	-0.48	0.96	21
7	-0.46	0.99	26	-0.50	0.96	27

5 Conclusion and Discussion

This paper attempted to study the interrupted one dimensional pedestrian flow in constrained straight narrow channels. The flow characteristics estimated through this study implicitly incorporate the psychology of crowd who have been waiting for hours. Pedestrian dynamics is complex and is governed by many factors. The speeds of local Stop waves were more uniform than Go waves and had higher R-square values. The variability in speeds of local Go waves can be attributed to many factors such as group members trying to start together, presence of bench (some pedestrians resting on them), etc. However, the average speed of Go waves was higher than Stop waves due to induced motivation and the sense of urgency to reach their destination. These characteristics of crowd can be captured only from real field data. The results from this study can be used to calibrate and validate simulation models for interrupted crowd movements at the entrances of such events.

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