INTERSECTING AND MERGING PEDESTRIAN CROWD FLOWS UNDER PANIC CONDITIONS: INSIGHTS FROM BIOLOGICAL ENTITIES

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ABSTRACT

Planning public buildings for emergencies following natural or manmade disasters is a great challenge. Many different forms of complex pedestrian crowd behaviours that could be critical under panic conditions can be identified in major public infrastructures. Under normal conditions, researchers have observed moving patterns such as turning movements at the corners merging and crossing of different pedestrians' streams. Although previous crowd disasters in the past have highlighted that the interactions of these different movements is crucial in panic there are no comprehensive studies aimed at understanding and capturing these phenomena under panic conditions. Understanding these phenomena and being able to capture them in a robust model is a challenging task but is also a significant opportunity for research given the international demand for models of this type.

Recently some preliminary experiments were conducted at Monash University with ants to understand how crowds behave in complex situations, such as crossing and merging phenomena, under panic. In this paper we describe how those data from non-human biological can be used to study these complex manoeuvres. The experimental results show that intersecting and merging flows can impede the outflow of the individuals creating delays in the egress.

INTRODUCTION

Due to complex floor plans and interior designs at major infrastructures such as transfer stations, shopping malls, sport stadiums etc., complex human behaviours can be expected at those places. These pedestrian movements associated with complex floor plans or interior architectural features could be dangerous particularly under high crowd density and panic situations as described in some literature accounts of historical crowd disasters, such as Chertkoff and Kushigian (1999).

A chronological list of crowd disasters updated as recent as in 2012 can be found in Still's website (2011). As most of these incidents suggest, the problem of enhancing safety at mass gathering places under emergencies still exists and a great challenge. Thus, proper investigation and understanding complex pedestrian movements are very important for guaranteeing the safety of pedestrians, particularly under panic or emergency conditions following natural or man-made disasters.

Crossing and merging flows are basically two of complex pedestrian movements that can be frequently expected in those major infrastructures. Several previous researchers have theoretically as well as empirically or experimentally studied some of those complex movement patterns, under normal conditions. Crossing pedestrian flows has been studied basically under two categories, namely microscopic analyses and microscopic analyses. Macroscopic models evaluate the flow using 'fundamental diagrams', which are graphical representations of the relationship between macroscopic variables such as flow, density and average speed. For instance, Wong et al. (2010) macroscopically analysed intersecting flows considering four intersecting angles, i.e. 45°, 90°, 135° and 180°. From the experiments conducted with human, they observed that the average speed and crossing capacity are generally decreased with increase of crossing angle due to the interactions arisen from the conflicting streams.

Under microscopic approaches, interactions between individual pedestrian in crossing streams have been investigated by researchers like Daamen and Hoogendoorn (2003), Helbing et al. (2005), Guo et al. (2010), Asano et al. (2010). Under normal conditions, collision avoidance and give-way or cooperative behaviours have been explained with a game theory based approach by Asano et al. (2010) and with a logit-based probabilistic approach by Guo et al. (2010).

Not only these macroscopic and microscopic behaviours but various self-organized phenomena related with crossing flows have also been verified through experimental studies as well as with simulation models. Formation of temporary patterns such as unstable, temporary roundabout traffic has been described in by Helbing and Molnár (1997), Helbing and Vicsek (1999) and Helbing et al. (2005). These temporary roundabouts reduce necessary deceleration, stopping, and avoidance maneuvers considerably and therefore make pedestrian motion more efficient when two pedestrian streams cross each of those (Helbing and Molnár 1997). Formation of diagonal stripes is another phenomena associated with crossing pedestrian flows as described in Ando et al. (1988), Hoogendoorn and Daamen (2004), Helbing et al. (2005) and Bovy and Hoogendoorn (2006). Pedestrians move forward with the stripes and sideward within the stripes and therefore they can proceed their walking continuously without stopping. Thus, these stripes increase the efficiency of both of crossing flow streams.

Regarding merging flows, theoretical and experimental studies are very rare in the literature although merging is one of those unavoidable phenomena at crowd gathering places. Zhang et al. (2011) conducted a series of controlled experiments with humans for straight corridors and T-junctions and established that fundamental diagrams for different facilities (straight corridors and T-junctions) are not comparable. Tajima and Nagatani (2002) used a lattice-gas model of biased random walkers to simulate the pedestrian merging flows in a T-shaped channel and observed that the clogging can be occurred in main channel or branch channel or both, when input densities are larger than critical densities in those flow channels. However, this study was purely based on simulations and thus, validation might be required with real world or experimental data.

Likewise, several studies have addressed crossing flows and merging flows (very limited) and observed some self-organised phenomena majorly under normal conditions. However, there is

no guarantee that these theories are still valid for panic conditions since under panic people are reluctant to give way or to cooperate with others most of the times. Furthermore, under panic conditions, where people have limited information and vision and due to highly competing and pushing behaviours, theories and assumptions made for normal conditions might not be valid.

The EmSim model developed at the Institute of Transport Studies at Monash University (Shiwakoti et al. 2011) successfully predicted the collective escape behaviour under panic for simplistic situations. Data collected from panicking ants was used to validate this model. This model could be modified to incorporate complex phenomena such as crossing and merging. Before modelling and simulating these movements and collective, self-organised patterns related with those movements, reliable empirical data must be collected for model calibration and validation purposes. However, collecting empirical data through real world observations and by conducting experiments with humans is extremely difficult and costly. In order to address this data issue, a series of experiments with panicking ants were conducted at Monash University. This paper describes those experiments with some initial results and how those results can be utilized to investigate the consequences of crossing and merging flows under panic conditions.

EXPERIMENTS WITH ANTS

Several experiments that use panicking Argentine ants were designed and conducted in order to understand crowd behaviours associated with crossing and merging phenomena, under panic conditions. This section describes details of those experiments and some initial observations.

Experiment scenarios

Schematic diagrams of the experiment setups for intersecting and merging flows with dimensions are shown in Figure 1. Depth of these chambers and corridors was around 3 millimetres, so that the number of ants climbing on walls, lids and go over each other could be minimized.
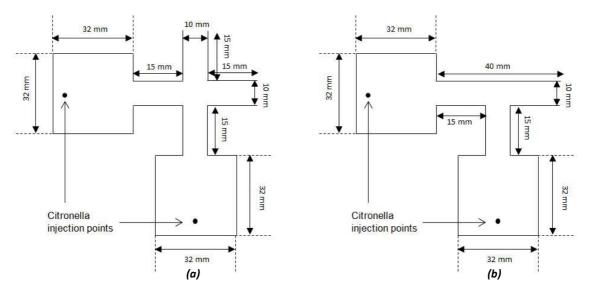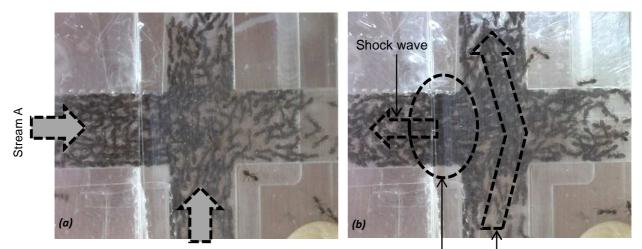

Figure 1: Schematic diagram for the experiment setups; (a) – right angled crossing flows, (b) – right angled merging flows.

Each moisturized chamber was covered with a transparent plastic lid with a small hole of approximately 1 mm diameter, which was used to inject citronella (a plant-derived insect repellent). Ants were allowed to nest naturally inside chambers and 10 µl of citronella was injected through those pin-halls at the same time after sufficient ants (300 – 400 ants to reflect high density conditions) had gathered. Ants were panicked and rushed through exit corridors as they detected the strong smell of citronella. During experiments care was taken to minimize the harm to ants. The experiments were video recorded with an overhead digital video camera.

Recorded videos were visually examined. Furthermore, an image sequence was obtained from those videos in order to determine two dimensional velocity distributions of intersecting or merging streams. Initial results of this analysis are described in the following sub sections.

Crossing flows

Snapshots obtained at two instances (after injecting citronella) during the merging flows experiment are shown in Figure 2.

. Figure 2 Occurrence of clogging; (a) – Approximately 3 seconds after starting the experiment, (b) – Approximately 4-5 seconds after starting the experiment.

One main observation of this experiment was shifting/transition of the clogging and shockwave between two streams, i.e. one stream is blocked while other stream is moving and then after some time the first stream started moving while the second stream is clogged. This is further verified with the velocity vector field diagram, shown in Figure 3.
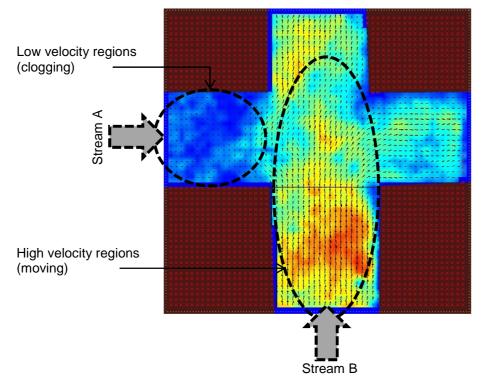

Figure 3: 2D mapping of velocity vector fields for intersecting flows.

In this figure, the areas with longer arrowheads correspond to high velocity regions, whereas regions with shorter arrowheads depict low velocity regions (as circled in the figure). Observing these velocity vector fields, it can be understood that during the experiment the average velocity of Stream B was higher whereas average velocity of Stream A was very low, which indicates that the clogging of Stream A while moving of Stream B.

Merging flows

Snapshots obtained approximately at 2 seconds and approximately at 10 seconds after injecting citronella, of the merging flows experiment are shown in Figure 4.
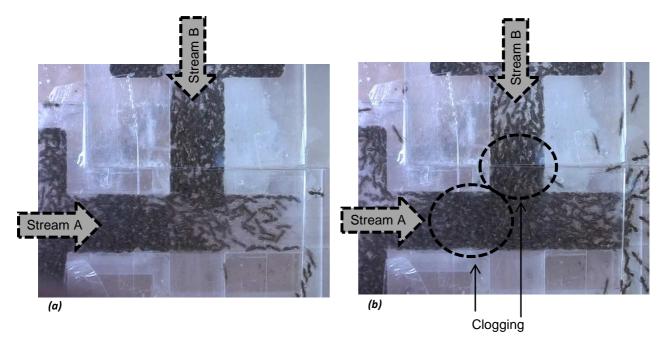

(a)

(b)

Clogging

Figure 4: Occurrence of clogging; (a) – Approximately 2 seconds after starting the experiment, (b) – Approximately 10 seconds after starting the experiment.

Quite similar to the observations made for crossing flow experiments, in this experiment a dominant flow was observed in one direction while other flow is blocked. However, in some cases, particularly when the densities are very high in both chambers, clogging was observed in both corridors, as depicted in Figure 4 and as verified with velocity vector field diagrams as shown in Figure 5.

Similar behaviour could be expected when humans are also in panic, due to highly non-cooperative and aggressive behaviours. Aggressive pedestrians try to squeeze through preceding pedestrians (Yu et al. 2005) and therefore, it is quite difficult for pedestrians in the intersecting stream to find a gap. Thus, for a while one stream is clogged while other is moving and this phenomenon is highlighted under high crowd densities and under panic situations (Chertkoff and Kushigian 1999). In extreme cases freezing by heating (Helbing et al. 2000) might also be occurred, which corresponds to the clogging of all streams and that can cause crushing.
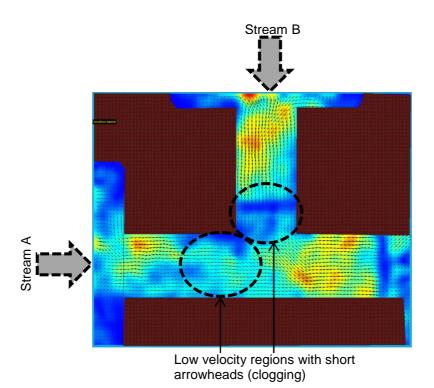
Stream B

Stream A

Low velocity regions with short
arrowheads (clogging)

Figure 5: 2D mapping of velocity vector fields for merging flows.

Analysing the recorded videos visually and analysing velocity vector field diagrams, the main qualitative observation made was the transition of clogging between streams, both for crossing and merging flows. This observation is quite consistent with the predictions made by Helbing et al. (2005) for human crowds under normal conditions, i.e. moving of dominant pedestrian flow while the perpendicular direction is waiting. However, according to Helbing et al. (2005), this phenomenon was temporary or short term for normal conditions. But, as observed in these experiments with ants, under panic this clogging could exist for a while and that duration might be sufficient to make a severe damage. For merging experiments, the occurrence of blockage of either stream or both streams is consistent with the simulation results by Tajima and Nagatani (2002) for human crowds under normal conditions.

More repetitions are needed and those experiments are in progress under different density level combinations for each chamber. Furthermore, quantitative analyses, such as densities in critical regions, outflow rates and clogging periods etc. will also be considered.

CONCLUSIONS AND FURTHER RESEARCH

Understanding collective pedestrian movements related with complex movements is important to assure safety and efficiency of pedestrian movements at mass gathering places. Complex movements such as crossing and merging could have significant impacts pedestrian movements particularly under high density and emergency conditions.

Under this study, several preliminary experiments were conducted utilizing panicking ants to understand crossing and merging phenomena under panic conditions. The main observation of both intersecting and merging experiments was the transition of clogging between two streams. Aggressive pedestrians tend to follow and squeeze through the preceding pedestrians and they are highly uncooperative to give way to the confronting pedestrians (confronting at a right angle in this case) resulting clogging in one stream while other stream is moving forward. In extreme cases, as verified with experiments, both streams could be clogged resulting trampling and crushing.

This paper described some initial results and more experiment replications are in progress. Furthermore, more complex scenarios such as different crossing angles, different merging scenarios, and different combinations of initial densities inside chambers will also be considered under further studies in order to obtain a more comprehensive understanding related with crossing and merging flows.

Modelling and simulation works will also be entailed and the data collected with these experiments will be used to calibrate those models and validate the predictions from those models.

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