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Understanding pedestrian crowd panic: a review on model organisms approach

Nirajan Shiwakoti *, Majid Sarvi [1]

Institute of Transport Studies, Department of Civil Engineering, Monash University, Building 60, Victoria 3800, Australia

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ABSTRACT

Understanding how crowds behave during collective displacement is at the heart of both pedestrian traffic engineering and 'movement ecology'. Perhaps the most critical reason for studying collective human dynamics under emergency/panic conditions is the lack of complementary data to develop and validate an explanatory model. A little used alternative is to study non-human model organisms. In this paper, we review experiences in using non-human organisms to study crowd panic in the literature. We then highlight the potential contribution that research with biological entities could make to understand the complex pedestrian behaviour and the enhancement of pedestrian safety during emergency/panic conditions. We also emphasise that understanding of behavioural similarities and dissimilarities between humans and animals is required for developing a good experimental design aimed to study collective behaviour. A generic model that could describe the common underlying mechanisms of crowd behaviour among organisms of different body sizes is identified as future challenge.

1. Introduction

Organisms that live in groups often move together and create traffic. Ant trails, wildebeest migrations, locust swarms, and pedestrian crowds on city footpaths are examples of such traffic. Understanding how crowds behave during collective displacement is at the heart of both 'movement ecology' (Holden, 2006) and pedestrian traffic engineering (Helbing et al., 2000). Although most collective movements are routine, survival and fitness may be strongly affected by occasional but potentially perilous crowd panics, such as escape from predators, evacuations of nests in the face of flooding, or flight of people from burning buildings. Human crowds have been studied during evacuations as long ago as the 1930s (Kholshevnikov and Samoshin, 2008), but the complex interactions between escaping individuals and their social and physical environments have made it difficult to obtain a full theoretical understanding of the phenomenon, and the practical problem of enhancing safety under emergency conditions still exists (Helbing et al., 2000; Shiwakoti et al., 2011). Numerous incidents have been reported (Still, 2011) in which overcrowding has resulted in injuries and death during emergency situations. Modelling and empirical study of pedestrian behaviour under emergency conditions is imperative to assist planners and managers of emergency response to analyse and assess safety precautions for those situations.

The use of term panic and emergencies in this study refer to situations in which individuals have limited information and vision (due to high crowd density and short time for egress), and which result in physical competition and pushing behaviour. This is different than the orderly evacuation. There have been many instances in the past where people have displayed physical competition and pushing behaviour during emergency evacuation, as well as instances where people behaved in much calmer way. The focus on the former issue is more critical.

To study and represent the complex phenomena of crowd movement, investigations have been carried out by researchers using different approaches. Fig. 1 shows a classification of the existing research which highlights a higher order grouping depending on whether studies have used mathematical modelling and simulation (Okazaki and Matsushita, 1993; Still, 2000; Helbing et al., 2000; Hoogendoorn and Bovy, 2002; Schadschneider, 2002; Klüpfel, 2003; Hughes, 2003; Kretz, 2007; Asano et al., 2009; Shiwakoti et al., 2011), experimental studies (Galea and Galparsoro, 1994; Proulx, 1995; Daamen and Hoogendoorn, 2003; Ko et al., 2007) or drawn on socio-psychology approaches (Quarantelli, 1957; Kelley et al., 1965; Mawson, 2007). Mathematical modelling and simulation can be further classified as microscopic, mesoscopic and macroscopic depending on the level of detail. It is to be noted that discrete models (microscopic) may not be analytically tractable while continuum models (macroscopic) may sometimes be analytically tractable (Hughes, 2003). The experimental studies have been carried out mostly with human subjects, while few studies have focussed on non-human organisms (Altshuler et al., 2005; Shiwakoti et al., 2011) to study collective dynamics. Crowd studies from a socio-psychological (sociology) perspective have been carried out

* Corresponding author. Tel.: +61 3 9905 5580; fax: +61 3 99054944.
E-mail addresses: Nirajan.Shiwakoti@monash.edu (N. Shiwakoti), Majid.Sarvi@monash.edu (M. Sarvi).
[1] Tel.: +61 3 99059696; fax: +61 3 99054944.

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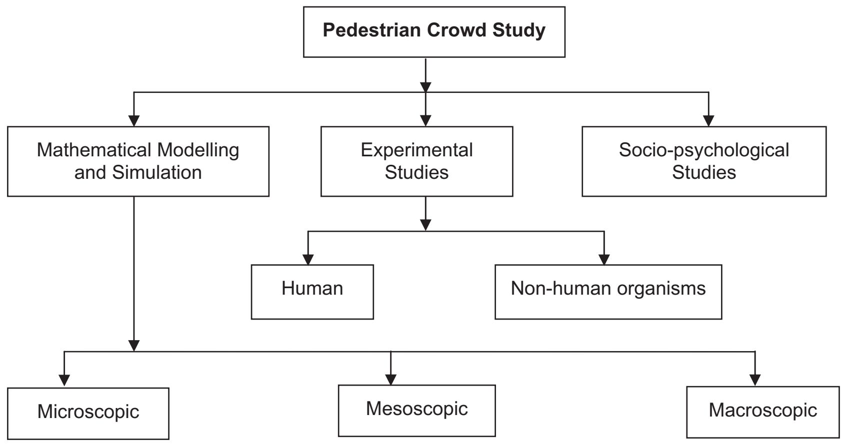

Fig. 1. Study of pedestrian crowd dynamics from different perspectives.

over many years and the focuses have been to study the crowd characteristics (collective behaviour) and their mental state in a given situation. It is not the focus of this paper to review all the approaches but rather to examine the use of non-human organisms in the study of pedestrian crowds under panic conditions. There is currently a lack of knowledge on how and to what extent the study of the collective dynamics of non-human biological organisms can be applied to the study of crowd panic. In this paper, we will examine the viability of performing experiments with non-human organisms to study pedestrian traffic under emergency conditions.

The paper is organised as follows. The next section reviews the empirical studies with biological entities and their relevance to human crowds. We then highlight the potential areas where such studies may provide insight into the crowd panic followed by limitation of animal models. The final section presents the conclusions and recommendations for future research.

2. Animal models and their relevance to pedestrian crowd

The bulk of the literature is restricted to the study of normal evacuation processes or normal (non-panic) pedestrian dynamics. Models of pedestrian behaviour in panic situations rarely have complementary empirical data to validate the model's prediction, so we may not want to rely entirely on mathematical models before scaling up to an applied, real world situation. Even the researchers responsible for developing the few existing models of crowd panic have identified the need for more rigorous modelling frameworks and the development of approaches to assess the reliability of model predictions (Helbing et al., 2000; Shiwakoti et al., 2011).

Most experiments with humans crowd (Daamen and Hoogendoorn, 2003; Helbing et al., 2005) aim to understand the behaviour and characteristics of pedestrian flow under non-panic conditions. Such experiments are of fundamental importance in understanding the behaviour of people under emergency conditions. For example, experiments with bottlenecks represent the congested part of buildings. However, comparisons with real life data are necessary to validate any model's prediction. To provide data for model validation, evacuation exercises have been carried out by some researchers. These trials have been conducted in public buildings (Proulx, 1995; Weckman et al., 1999; Olsson and Regan, 2001), industrial premises (Ko et al., 2007), and passenger vessels (Galea and Galparsoro, 1994). Usually evacuation times, response time of the occupants and movement of the occupants have been observed from such evacuation trials. There are however ethical and safety concerns that prevent creating a real panic. Researchers have to confine themselves to small numbers of participants with no control on the level of panic, which then may not represent the true scenario for pedestrian crowd behaviour. Although there is scope to use security videos to record the scenes of earthquakes or other disasters, still there are problems of accessibility (e.g. sensitive material, under investigation, etc.) or poor video quality (resolution, lens distortion, timing, etc.) and thus has attracted little attention to the researchers.

Animal models might provide a means of empirically testing and verifying human pedestrian models, particularly when human subjects cannot easily or ethically be employed. In the following sections, we identify the relevancy of the animal models pertaining to the study of pedestrian crowd.

2.1. Emergent systems

One of the interesting aspects of collective dynamics of various biological entities is that they are emergent systems. Order in emergent, self-organised systems arises at a global scale from simple interactions on a local scale and has been observed from various models (Camazine et al., 2001; Couzin and Krause, 2003). Such order has been observed in flocks, herds, schools, etc., where entities with limited intelligence interact locally, which in turn leads to the emergence of group behaviour on a global scale (Camazine et al., 2001; Couzin and Krause, 2003). How pedestrian crowds escape under emergency conditions is highly dependent on how the group goals and individual goals are constituted and coordinated in those situations. Models for pedestrian movement often predict that crowds act as an emergent system (Still, 2000; Helbing et al., 2002; Shiwakoti et al., 2011).

Based on an analysis of the traffic dynamics of leaf-cutting ants, Burd et al. (2002) suggested that mixed-direction traffic enhances total flow rates by breaking up clusters that would otherwise impede movement. This phenomenon has also been observed in pedestrian traffic where the self-organised bi-directional high-density crowds flow through each other with relative ease (also known as the finger effect) (Still, 2000; Helbing et al., 2002). Couzin and Franks (2003) have shown that ants' bidirectional traffic shares features with pedestrians traffic. An experiment of Dussutour et al. (2004) discovered the self-organised behaviour of foraging ants to cope with traffic control problems much as human beings do. Research at the University of Leeds revealed that humans flock like sheep (ScienceDaily, 2011). In a series of experiments, groups of people were asked to walk randomly around a large hall. Within the group, a few were informed in detail about where to walk. Participants were not allowed to talk or gesture to one another. The findings showed that in all cases, the 'informed individuals' were followed