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Human and social behavior in computational modeling and analysis of egress

Xiaoshan Pan [a,*], Charles S. Han [b], Ken Dauber [c], Kincho H. Law [d]

[a] *Department of Civil and Environmental Engineering, 416 Escondido Mall, Bldg. 550, Rm. 556N, Stanford, CA 94305, United States*
[b] *Department of Civil and Environmental Engineering, 416 Escondido Mall, Bldg. 550, Rm. 556K, Stanford, CA 94305, United States*
[c] *Stanford Center for Innovations and Learning, Wallenberg Hall, 450 Serra Mall, Bldg. 160, Stanford, CA 94305, United States*
[d] *Department of Civil and Environmental Engineering, Terman Engineering Center, Rm. 242, Stanford, CA 94305, United States*

Abstract

Safe egress is one of the key design issues identified by facility planners, manager and inspectors. Computational tools are now available for the simulation and design of emergency evacuation and egress. However, these tools rely heavily on assumptions about individual human and social behaviors, which have been found to be oversimplified, inconsistent and even incorrect. Furthermore, the behaviors are usually incorporated into the computational model in an ad hoc manner. This paper presents a framework for studying human and social behavior, from the perspectives of human decision-making and social interaction, and for incorporating such behavior systematically in a dynamic computational model suitable for emergency egress analysis.

Keywords: Human and social behavior; Decision-making; Egress; Emergency; Computational modeling; Multi-agent system

1. Introduction

Design of egress for places of public assembly is a formidable problem in facility and safety engineering. Although the regulatory provisions governing egress design are prescribed in code, the actual performance of the evacuation systems is difficult to assess. There have been numerous incidents reported regarding overcrowding and crushing during emergency situations. They occur in sport stadiums (e.g., the stampede incident in a soccer stadium that killed more than 120 people in Ghana, Africa in 2001), schools (e.g., the incident due to power outage that killed 21 children and injured 47 in Beijing, China in 2002), social gathering places (e.g., the incident at a nightclub in Chicago, IL in 2003 that killed 21 people) and other facilities. In addition to injuries and loss of lives, the accompanying post-disaster psychological suffering, financial loss and adverse publicity have long-term negative effects on the individuals and organizations, including the survivors, the victims' families, and the communities [1].

Studies to improve crowd safety in places of public assembly involve many disciplines including architectural design for safe egress [2–4], crowd planning and management [5], crowd simulations [6–20], emergency planning, leadership training and many others [21]. Even for well-planned events in well-designed facilities, an undeniable fact is that real danger lies within the crowds. In a crowded environment, it has been observed that most victims were injured or killed by the so-called "nonadaptive" behaviors of the crowd, rather than the actual cause (such as fire or explosion) of the disaster. For example, in the Iroquois Theatre fire (in 1903), the initial fire was brought under control quickly; however, 602 people were trampled to death in the end. Another example is the Hillsborough English FA Cup Stampede (in 1981); though there were no real cause for the emergency, 95 people were killed and more than 400 people were injured.

Nonadaptive crowd behaviors refer to the destructive actions that a crowd may experience in emergency situations, such as stampeding, pushing, knocking and trampling on

* Corresponding author. Tel.: +1 650 725 3814; fax: +1 650 723 4805.
E-mail address: xpan@stanford.edu (X. Pan).

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others, etc.; these actions are responsible for a large number of injuries and deaths in man-made and natural disasters. To study nonadaptive behavior in a crowded environment, we need to gain an understanding of human and social behavior in emergency situations from both psychological and sociological perspectives. On a microscopic level, individuals in a crowd act and make decisions differently than when they are alone or in a small group. On a macroscopic level, nonadaptive crowd behaviors are collective phenomena triggered by some external crises or emergencies (fire, smoke or explosion). Surprisingly, there have been very few studies focusing on nonadaptive crowd behaviors from a psychological and sociological perspective in the area of facility and safety engineering.

Building codes contain "means of egress" provisions designed to ensure the safety of a building [4]. However, these codes only provide basic guidelines, are not exhaustive and are often insufficient for many practical situations [19]. First, current codes and guidelines contain inconsistencies which may lead to misinterpretations. An effective computational tool can test whether a specific guideline is appropriate for a particular situation. Second, each building is unique, and compliance with design guidelines does not automatically ensure safety. Often, local geometries–shapes and sizes of spaces and obstacles–can have significant influence on egress, albeit in a subtle way. For instance, a widening in a corridor could actually exacerbate crowd flow, rather than allow people to move faster [12]. To date, very few studies can be found in existing literature that examine how environmental constraints and local geometries impact crowd behaviors and movements. This type of study is difficult since it often requires exposing real people to the actual, and possibly dangerous, environment. A good computational tool which takes human and social behavior of a crowd into consideration could serve as a viable alternative.

Computational tools are now commercially available for the simulation and design of emergency evacuation and egress. However, most current computational tools focus on the modeling of spaces and occupancies but rarely take crowd behavior into consideration. On the other hand, the usefulness of a simulation tool is preconditioned by its ability to model properly and correctly the crowd who will occupy the facility and their behavior. Understanding nonadaptive crowd behaviors is essential to the development of effective egress strategies and models for achieving safety. Current computational models are unable to cover the range of scenarios suitable for safety engineering purposes [19]. As noted by the Society of Fire Protection Engineers [23], "These (computational) models are attractive because they seem to more accurately simulate evacuations. However … they tend to rely heavily on assumptions and it is not possible to gauge with confidence their predictive accuracy."

In this paper, we present a framework to study nonadaptive crowd behaviors from the perspective of human behavior and social interactions, and to incorporate such behavior in a dynamic computational model suitable for safe egress analysis. By incorporating different behavior-based models, we can gain better insight into the design of egress and to assess the performance of evacuation systems. The computational tool can potentially serve as a means to study safety engineering, such as assessing building codes and designs, testing safety and evacuation procedures and crowd management.

2. Background

2.1. Human and social behavior and crowd dynamics

The study of the "crowd" has a long history in sociology. Traditionally, the crowd has been seen as a dangerous phenomenon, in which individual identities, motivations and rationalities dissolve into a collective mind. The modeling of crowd behavior using fluid dynamics and particle systems thus has a firm basis in sociological thinking about mass assemblies. In terms of the history of social theory, this is an echo of Durkheim's [24] identification of socially induced religious ecstasy as the material base of the experience of a phenomenon that transcends the individual. The secular analogy of religious ecstasy is panic, or the yielding of individual rationality to an overwhelming collective force, albeit fear rather than joy.

Over the last two decades, this view of the crowd as unitary and overwhelming to its individual constituents has been eroded by a contrary perspective that: (1) sees individuals as retaining their rationality (though perhaps in bounded form, in Herbert Simon's sense [25]); and (2) identifies social structures of interaction below the level of the crowd, including both pre-existing structures (such as family and friendship groups) and structures like queues, arcs and rings that serve a particular function in the context of the gathering [26]. If these features of crowds and other gatherings are operative in both "normal" events and those in which emergencies occur, then these propositions have some clear implications for modeling emergency egress.

Studies of collective action in crowds, including studies of collective locomotion, have demonstrated that preexisting social relationships play a very significant role in structuring behavior [27–29]. People who come together to a gathering tend to move in concert with each other, orient their action to each other and leave together. This means that gatherings have a "lumpy" quality; an event with a thousand people might be composed of several hundred constituent groups moving as internally self-regarding and coordinated units. This has some obvious modeling implications, for example: (1) flow through exits is likely to be smoother if the path through the exit can accommodate groups as a whole, rather than requiring the group to disperse or string out; (2) if group (for example, family)