Exitus: Agent-Based Evacuation Simulation for Individuals with Disabilities in a Densely Populated Sports Arena

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ABSTRACT

Emergency evacuation of critical infrastructure assets such as sports arenas is an important consideration given the continuing threat of terrorist attacks which inordinately affect them. In this paper, the authors present an agent-based evacuation model which may be used to support private sector organizations with capabilities-based planning efforts surrounding likely terrorist attack scenarios. The model is distinguished by its explicit consideration of individuals with disabilities in respect to the characteristics influencing their ability to negotiate surroundings. The results of an experiment simulating the truck bombing of an intermountain west sports arena reveal special areas of concern for arena managers and identify those who are most at risk or individuals with lower stamina. Ultimately, the model can be used to inform policymakers of more effective, evidence-based evacuation planning methods based on a better understanding of the behavior of heterogeneous populations during emergency situations.

Keywords: Agent-Based Modeling, Decision Support System, Emergency Evacuation, Individuals with Disabilities, Simulation

1. INTRODUCTION

Evacuation planning efforts within the last decade have been overwhelmingly focused on the role of public sector organizations. However, private sector organizations own 85% of the nation’s critical infrastructure, provide employment for the vast majority of people, and produce essential goods and services such as food, water, transportation and power (Kean et al., 2004). As a result, there is a compelling need for such organizations to protect themselves against the human and economic costs resulting from large scale disasters. Organizations owning critical infrastructure assets such as sports arenas are especially vulnerable. In July 2002 the U.S. Federal Bureau of Investigation issued a warning that individuals associated with terrorist groups were downloading stadium images from the internet (Estell, 2002). In May 2010, ten people were killed and 120 others injured after a bomb was detonated in a football stadium in northern Iraq (“Deadly bombing hits Iraqi stadium,” 2010).

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Evacuation procedures which consider the needs of all persons, including those with disabilities, constitute a key part of effective disaster response plans. Individuals with disabilities comprise 16% of the U.S. population and have been shown to be disproportionately affected by changes in the physical environment (U.S. Fire Administration, 1999). Yet emergency evacuation research has largely overlooked this relationship (Christensen, Collins, Holt, & Phillips, 2006). As a result, studies examining evacuations of individuals with disabilities from critical infrastructure assets like sports arenas are needed to help ensure their safety and mitigate the risk faced by private sector owners.

Unfortunately, the traditional evacuation-drill approach used to prepare for emergency situations presents several practical and financial challenges at this scale and magnitude. Consequently, simulation is often employed to create a realistic environment in which the social dynamics between virtual evacuees can be fully expressed. Agent-based Modeling (ABM) is a specific simulation technique which has already been used to successfully represent a variety of social dynamic systems such as wholesale electricity (Sueyoshi & Tadiparthi, 2008) and stock markets (Luo, Liu, & Davis, 2002). In this study, ABM is used in conjunction with geographical data to create a decision support system (DSS) capable of assessing the evacuation performance of sports arenas from several different analytical dimensions.

The remainder of the paper is organized as follows. We first review the literature surrounding evacuation simulation with an emphasis on the underlying theory of ABM. We then present our system’s architecture including its organization, implementation, and underlying assumptions. This is followed by a presentation of the results of an evacuation experiment designed to simulate the sports arena truck bombing scenario described in the National Planning Scenarios Executive Summary (U.S. Department of Homeland Security, 2005). We then discuss the managerial implications for those charged with protecting individuals with disabilities and conclude by reviewing the limitations of the study and possible directions for future research.

2. LITERATURE REVIEW

Evacuation simulation models can be broadly categorized according to the specificity of the human component. From this perspective, three general approaches are evident from the literature, macroscopic, microscopic, and mesoscopic. Macroscopic modeling is characterized as a top-down approach in which collective pedestrian dynamics such as spatial density or average velocity are related to model parameters through a closed-form formula (Lovas, 1994). Microscopic modeling is characterized as a bottom-up approach in which pedestrians are modeled as individual entities; formulae encapsulating spatial transition probabilities are repeatedly applied leading to temporal changes in state or behavior (Burstedde, Klauck, Schadschneider, & Zittartz, 2001). Mesoscopic modeling is a combination of both macro and micro techniques. Though agent movement is individually specified it is still dependent on aggregate flow conditions rather than interactions with other agents (Hoogendoorn & Bovy, 2000).

While macroscopic and mesoscopic models are very good at reproducing the general density-flow profiles observed in evacuating crowds (Colombo & Rosini, 2005; Helbing, Johansson, & Al-Abideen, 2007) they are unable to explain empirically observed emergent crowd phenomena. Emergence refers to the process of global pattern-formation based on interactions at lower levels naturally without influence from external signals or conventions. For example, lane formation occurs when opposite traveling flows dynamically form distinct symmetries such that conflicts with opposing individuals are reduced (Helbing & Molnar, 1995). Microscopic models, on the other hand, have been shown to successfully reproduce a wide variety of such phenomena including lane formation, clogging, oscillating flows, and others (Helbing & Molnar, 1995; Helbing, Buzna, Johanssen, & Werner,
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