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An agent-based simulation system for concert venue crowd evacuation modeling in the presence of a fire disaster

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ABSTRACT

A key activity in emergency management is planning and preparation for disaster. If the right safety measures are implemented beforehand, harmful effects can be significantly mitigated. However, evaluation and selection of effective measures is difficult due to the numerous scenarios that exist in most emergency environments coupled with the high associated cost of testing such scenarios. An agent-based system employs a computational model of autonomous interacting agents in an environment with the purpose of assessing the emergent behavior of the group. This paper presents a prototype of a computer simulation and decision support system that uses agent-based modeling to simulate crowd evacuation in the presence of a fire disaster and provides for testing of multiple disaster scenarios at virtually no cost. The prototype is unique in the current literature as it is specifically designed to simulate a concert venue setting such as a stadium or auditorium and is highly configurable allowing for user definition of concert venues with any arrangement of seats, pathways, stages, exits, and people as well as the definition of multiple fires with fire and smoke dynamics included.

1. Introduction

Of paramount importance to emergency managers is the question of how to prepare for as yet unseen disasters. Proper safety measures can literally mean the difference between life and death for large groups of affected people. However, emergency situations and their associated safety measures are highly specific to the environment in which they exist and there are generally numerous scenarios that must be considered. The cost of testing these multiple scenarios is oftentimes prohibitive (Jain & McLean, 2008). Thus, evaluation and selection of effective safety measures for emergency preparedness is quite difficult and is often left to the subjective judgment of an emergency manager.

Computer modeling and simulation seeks to remedy this problem by allowing for testing of multiple environment-specific scenarios at low cost. Agent-based systems use a computational model of autonomous agents that move and interact with each other and their environment. Such systems use a *bottom-up* modeling approach in which system control is decentralized and governed only by the behavior of the agents (Borshchev & Filippov, 2004). Agent-based modeling is the preferable technique for simulation of systems with a large number of active objects (e.g., people, business units, animals, etc.) that are dependent on the order/timing of events for the following reasons: (1) it allows for the capture of highly complex dynamics, (2) it can be implemented with little or no knowledge of the global interdependencies and/or aggregate effects of the system, and (3) it is easier to build upon as model changes generally require local not global adjustments (Borshchev & Filippov, 2004). The development of agent-based systems for emergency planning and preparedness remains an open research area as there exist a multitude of disaster environments that have yet to be addressed (Jain & McLean, 2008).

This paper presents a prototype of an Agent-based Decision Support System (ABS) for the simulation of crowd evacuation in the presence of a fire disaster for venues that are specifically intended for mass gatherings such as stadiums and auditoriums. The goal of the system is to allow for multiple scenario testing and decision support for the planning and preparedness phase of emergency management with regards to fire disasters at concert venues. The system is designed for emergency managers, police, and any administrators who are charged with fire disaster mitigation planning for concert venues. Users of the system can benefit by evaluating the effects of potential safety measures such as restrictions on the maximum number of people, wider pathways, additional exits, and fewer seats on crowd evacuation dynamics. The system is unique as it is specifically designed to simulate evacuation of a concert venue setting rather than an urban roadways or building evacuation setting as is prevalent in the literature. High

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densities of people and relatively limited exit routes and exit points are common characteristics of concert venues and their combination make such venues a significant concern for emergency managers. Additionally, the ABS system is highly configurable allowing for user definition of a concert venue with any number and arrangement of seats and bleachers, aisles and path ways, stages and playing fields, exits, and people and also allows for the definition of multiple fires with dynamics of fire spreading and smoke production included. The contribution of this study is twofold:

1. It provides an agent-based system that is specifically designed for crowd evacuation simulation of concert venues during a fire disaster.
2. The system is built for customization and provides to the user the ability to define the layout and structure of the concert venue to be simulated. This allows the user to replicate the venue of concern and provides decision support for the planning and preparedness phases of emergency management.

The rest of this paper is organized as follows: Section 2 provides a brief survey of the current research on agent-based systems for crowd evacuation modeling, Section 3 gives a description of the prototype ABS system, Section 4 details experiments conducted using the system to simulate disaster scenarios for simulated replicas of actual concert venues, and Section 5 discusses future work necessary to enhance and transition this prototype system into a viable commercial software system.

2. Review of current research

Recent advances in computational speed have made the construction of complex simulation systems more feasible. Several recent studies involving agent-based models for crowd evacuation simulation exist in the current literature. These studies generally fall into one of three categories: (1) crowd evacuation of buildings, (2) crowd evacuation for urban roadways, and (3) crowd behavior during evacuation.

Bonomi, Manzoni, Pisano, and Vizzari (2009), Braun, Bodmann, and Musse (2005), Camillen et al. (2009), Fangqin and Aizhu (2008), Filippoupolitis, Hey, Loukas, Gelenbe, and Timotheou (2008), Ha and Lykotrafitis (2012), He and Zhao (2010), Massaguer, Balasubramanian, Mehrotra, and Venkatasubramanian (2006), Okaya and Takahashi (2011), Pan, Han, Dauber, and Law (2006), Pelechano and Badler (2006), Shi, Ren, and Chen (2009), Tang and Ren (2008), Yamamoto (2013), Yang, Wang, and Liu (2011, 2012) apply agent-based modeling to simulate the evacuation of buildings. In Ha and Lykotrafitis (2012) an agent-based system is used to model panic effects during evacuation of a building. Filippoupolitis et al. (2008), Shi et al. (2009), Tang and Ren (2008), Yang et al. (2011) provide an agent-based model to simulate building evacuation during a fire disaster. Fangqin and Aizhu (2008) provides an agent-based simulation model for building evacuation during a fire disaster which uses computational fluid dynamics to model fire dynamics and spatial analysis of GIS data to model peoples' knowledge of the building structure. Okaya and Takahashi (2011) employs a Belief-Desire-Intention (BDI) model to model human relationships and investigate their effects on building evacuation dynamics. Pelechano and Badler (2006) developed a simulation model for building evacuation by crowds who might not know the structure's connectivity or who find routes accidentally blocked. Yamamoto (2013) provides an agent-based model to simulate building evacuations during earthquake and fire disasters. Yang et al. (2012) integrates multiple agent-based models at differing resolutions (i.e., macro resolution and micro resolution) to simulate building evacuation dynamics.

Anh, Daniel, Du, Drogoul, and An (2012), Handford and Rogers (2011), Lucas, Martinez, Sickinger, and Roginski (2007), Shendarkar, Vasudevan, Lee, and Son (2006), Balmer, Nagel, and Raney (2004) employ agent-based modeling to simulate crowd evacuation dynamics of urban roadways. Anh et al. (2012) provides a hybrid agent-based model for roadway evacuation simulation that combines macro and micro level simulations to increase overall simulation efficiency while capturing necessary low-level simulation details. In Lucas et al. (2007) and Shendarkar et al. (2006) emergency aspects of an urban roadway evacuation are modeled including fires, gunmen, and police personnel. In Handford and Rogers (2011) the interdependency of driver behaviors is modeled in the context of roadway evacuation.

Banerjee, Abukmail, and Kraemer (2009), Ben, Huang, Zhuang, Yan, and Xu (2013), Chu, Pan, and Law (2011), Heliövaara, Korhonen, Hostikka, and Ehtamo (2012), Laughery (2001), Lee, Son, and Jin (2010), Liang, Low, Lees, Cai, and Zhou (2010), Norling (2004), Pan, Han, Dauber, and Law (2007), Ren, Yang, and Jin (2009), Sharma and Lohgaonkar (2010), Tsai et al. (2011), Wang, Li, Liu, and Cui (2011), Yang, Ren, and Wu (2012) apply agent-based models to study crowd behavior during evacuation. Banerjee et al. (2009) employs a layered intelligence model to efficiently simulate agent-based crowd evacuation and demonstrate the model's scalability to larger numbers of agents. In Ben et al. (2013) the evacuation environment is modeled using a cellular automata model while an agent-based model governs the behavior of evacuees. The model is used to study evacuation dynamics in environments with and without obstacles. Chu et al. (2011) incorporates behavioral theories from social science concerning group affiliations, group influences, and intra-group roles to model crowd evacuation dynamics. Heliövaara et al. (2012) uses an agent-based model to study crowd behavior in counterflow situations, that is situations in which groups of agents have opposing directions of movement. Laughery (2001), Lee et al. (2010), Norling (2004) employ a BDI framework to model the decision-making process of individuals in crowd evacuation scenarios. Liang et al. (2010) investigates the use of embedding information into the evacuation environment in order to influence crowd behavior in an evacuation. Pan et al. (2007) uses a multi-agent model to simulate behavior during evacuation that exhibits competitive, queuing, and herding behaviors while Ren et al. (2009) uses an agent-based model to simulate evacuation during an explosion disaster. Sharma and Lohgaonkar (2010) provides an agent-based model that has a fuzzy logic component for simulating human behavior and decisioning in an evacuation. The model is used to capture both individual and group behaviors in an emergency evacuation scenario. Tsai et al. (2011) provides a multi-agent evacuation simulation tool called ESCAPES that is specific to the airport domain and incorporates varying agent types, emotional interactions, informational interactions, and behavioral interactions. Wang et al. (2011) employs an ant colony evacuation model that includes avoidance and preferential path selection behaviors. Yang et al. (2012) proposes a multi-resolution agent-based model to simulate pedestrian flow in an evacuation.

A few studies have focused on specialized applications of agent-based crowd evacuation models. Carroll, Owen, and Hussein (2012) applies an agent-based model to simulate evacuation from a foot bridge. Song et al. (2013) employs an agent-based model to simulate evacuation from a train station under a bioterrorism attack. Wei, Xiong, Zhang, and Chen (2011) uses a grid simulation framework to address simulation efficiency for large agent-based evacuation models. Chen, Wang, and Liu (2011) provides a study that incorporates GIS data into a multi-agent system to simulate non-emergency evacuation of a sports stadium.

Of all the recent studies described above, the model of Chen et al. (2011) is the one that is most comparable to the model